TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

AGENDA ITEM REQUEST

Consideration of 23 Total Maximum Daily Loads
for Public Comment

AGENDA REQUESTED: April 8, 2020

DATE OF REQUEST: March 20, 2020

INDIVIDUAL TO CONTACT REGARDING CHANGES TO THIS REQUEST, IF NEEDED: Andreea Vasile, Texas Register/Agenda Coordinator, (512) 239-1806

CAPTION: Docket No. 2019-1366-TML. Consideration for approval to publish and solicit public comment on 23 Draft Total Maximum Daily Loads for Indicator Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and associated tributaries in the Sabine River Basin, in Jasper, Newton, and Orange Counties. (Kerry Niemann, Stefanie Skogen) (Project No. 2020-004-TML-NR)

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Texas Commission on Environmental Quality
Interoffice Memorandum

To: Commissioners **Date:** March 20, 2020

Thru: Bridget C. Bohac, Chief Clerk
Toby Baker, Executive Director

From: L'Oreal W. Stepney, P.E., Deputy Director
Office of Water

Docket No: 2019-1366-TML

Subject: Proposal of 23 Draft TMDLs for Indicator Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and Associated Tributaries for Public Comment
Project No. 2020-004-TML-NR

Issue: Consideration for approval to publish and solicit public comment on 23 Draft Total Maximum Daily Loads (TMDLs) for indicator bacteria, dissolved oxygen (DO), and pH in Adams Bayou, Cow Bayou, and associated tributaries of the Sabine River Basin, in Jasper, Newton, and Orange Counties. The impaired segments and corresponding assessment units (AUs) are shown in Table 1:

Table 1. Impaired segments and AUs addressed by the proposed TMDLs ("x" marks noncompliance with the assessment criteria)

Segment Name	AU_ID	Bacteria	DO	pH
Adams Bayou Tidal	0508_01	x	x	
	0508_02	x	x	
	0508_03	x	x	
	0508_04	x	x	
Gum Gully	0508B_01	x		
Hudson Gully	0508C_01	x	x	
Cow Bayou Tidal	0511_01	x		
	0511_02		x	
	0511_03	x	x	
	0511_04	x	x	x
Cow Bayou Above Tidal	0511A_02		x	
Coon Bayou	0511B_01	x	x	
Cole Creek	0511C_01		x	
Terry Gully	0511E_01	x		
8 Segments	*14 AUs*	*23 AU TMDLs proposed*		

Assessment units are grouped by segment according to shading of rows in the table

Background and Current Practice: Twenty-three draft TMDLs have been prepared as required by the federal Clean Water Act, §303(d). TMDLs must be submitted to the United States Environmental Protection Agency (EPA) for approval as certified updates to the State of Texas Water Quality Management Plan (WQMP). The Water Quality Planning Division respectfully requests commission approval to propose the TMDLs for a formal public review and comment period. After the public comment period, staff may make changes to the draft TMDLs and will respond to public comments. Assuming approval for the proposal is granted by the commission, the next step would be to recommend that the commission consider adoption and certification of the final TMDLs as an update to the State of Texas WQMP. If approved, the TMDLs would then be forwarded to EPA for final action.

Problem Definition: The Texas Commission on Environmental Quality (TCEQ) adopted TMDLs for indicator bacteria, DO, and pH in Adams Bayou, Cow Bayou, and their associated tributaries on June 13, 2007, and EPA approved these TMDLs on August 28, 2007. Since the TMDLs were developed, there have been numerous changes in the watershed, including expansions of centralized wastewater collection and treatment. Additionally, the TMDL program uses the AU approach, load duration curve (LDC) analysis, and fully permitted loading scenarios in TMDLs that were not used in the 2007 TMDLs. For these reasons, TCEQ is updating the 2007 TMDLs that were adopted in the Adams Bayou and Cow Bayou watersheds.

Watershed Overview: This project addresses elevated levels of bacteria related to the primary contact recreation use, depressed DO related to the aquatic life use, and low pH related to the general use in freshwater and/or tidal stream segments in coastal southeast Texas. The total drainage area for the Adams Bayou watershed is approximately 46 square miles and the drainage area of the adjacent Cow Bayou watershed is approximately 199 square miles. The watersheds are located primarily within Orange County, with some areas of the watersheds incorporating portions of Jasper and Newton Counties.

Endpoint Identification: The endpoint for the TMDLs addressing impairments of the primary contact recreation use is to maintain a geometric mean of *Escherichia coli* (*E. coli*) below the geometric mean criterion of 126 colony forming units (cfu) per 100 milliliter (mL) in freshwater stream segments and a geometric mean of Enterococci below the criterion of 35 cfu/100 mL in tidal (saltwater) stream segments.

The endpoint for the TMDLs addressing impairments of the aquatic life use is to maintain a 24-hour average DO concentration of three milligrams (mg) per liter (L) in freshwater stream segments that are intermittent with perennial pools and four mg/L in tidal streams.

The endpoint for the TMDLs addressing impairment of the general use is to maintain a pH between six and 8.5 standard units in tidal stream segments. For these TMDLs, the primary oxygen demanding substances are considered to be carbonaceous biochemical oxygen demand, expressed as five-day carbonaceous biochemical oxygen demand ($CBOD_5$) and ammonia nitrogen (NH_3N).

Source Analysis: Potential sources of pollutants affecting the primary contact recreation, aquatic life, and general uses in the Adams Bayou and Cow Bayou watersheds include domestic and industrial wastewater treatment facilities (WWTFs), regulated stormwater runoff, sanitary sewer overflows, illicit discharges, failing on-site sewage facilities, and contributions from wildlife, unmanaged feral animals, and domesticated animals.

Linkage Analysis: The TMDLs addressing impairments of the primary contact recreation use were estimated using conventional LDC analysis for freshwater streams and a modified LDC approach for tidally influenced streams.

The TMDLs addressing impairments of the aquatic life and general uses were estimated using a combination of three deterministic models to simulate watershed, in-stream hydrodynamic, and water quality processes in Adams Bayou, Cow Bayou and their associated tributaries.

Margin of Safety: The TMDLs addressing the primary contact recreation use impairment incorporate an explicit margin of safety (MOS) of 5% of the total TMDL allocation. The TMDLs addressing the aquatic life and general use impairments incorporate an implicit MOS based on conservative assumptions made in the watershed, hydrodynamic, and water quality models used to estimate the TMDLs.

Wasteload Allocation: For the TMDLs addressing the primary contact recreation use impairment, existing Texas Pollutant Discharge Elimination System (TPDES) permitted WWTFs were allocated a daily wasteload allocation (WLA) calculated as their permitted discharge flow rate, multiplied by the instream geometric mean water quality criterion. For the TMDLs addressing the aquatic life and general use impairments, daily WLAs were estimated for current TPDES-permitted WWTFs that resulted in compliance with the 24-hour daily average DO and the pH criteria pertinent to the specific AUs affected by the discharges. A portion of the WLA in all TMDLs was also allocated, in aggregate, to regulated stormwater.

Load Allocation: For the TMDLs addressing the primary contact recreation use impairment, the load allocation (LA) components of the TMDLs correspond to direct nonpoint source pollution runoff and are the difference between the total load from stormwater runoff and the portion allocated to the WLA for regulated stormwater.

For the TMDLs addressing the aquatic life and general use impairments, the LA components of the TMDLs were estimated based on watershed and water quality simulation scenarios that resulted in compliance with the 24-hour daily average DO and pH criteria pertinent to the specific AUs affected by nonpoint source runoff within each stream segment.

Allowance for Future Growth: The TMDLs include allocations for future growth (FG). For the TMDLs addressing the primary contact recreation use impairments, FG was based on county and city population growth projections to 2070 for the Region I regional water planning group, published by the Texas Water Development Board.

In the case of the TMDLs addressing the aquatic life and general use impairments, FG allocations for pollutants affecting DO and pH were determined for AUs where additional assimilative capacity was indicated to be available by the models and was based on an explicit 10% potential increase from current permitted pollutant discharges. The additional assimilative capacity for pollutants contributing to the aquatic life use and general use impairments was limited to the lower portions of Cow Bayou Tidal and an unnamed tidal tributary of Cow Bayou.

TMDL Calculations: The final TMDL allocations needed to comply with the requirements of 40 Code of Federal Regulations §130.7 are presented in Tables 2 and 3. In these tables, the FG allowance has been added to the WLA term for WWTFs (WLA_{WWTF}).

Table 2 shows final TMDL allocations for the AUs with primary contact recreation use impairments in Adams Bayou, Cow Bayou, and associated tributaries. The allocations in Table 2 are based on the criteria for support of the primary contact recreation use in freshwater streams (*E. coli* geometric mean of 126 cfu/100 mL) and in tidal streams (Enterococci geometric mean of 35 cfu/100 mL).

Table 2. Final TMDL allocations to support contact recreation (loads are in billion cfu/day)

Water Body	AU	Indicator Bacteria	TMDL	WLA_{WWTF} †	WLA_{SW}	LA	MOS
Adams Bayou Tidal	0508_01	Enterococci	298.849	4.430	78.114	201.363	14.942
	0508_02	Enterococci	266.138	4.418	55.495	192.918	13.307
	0508_03	Enterococci	257.575	0.794	49.463	194.439	12.879
	0508_04	Enterococci	227.433	0.036	25.772	190.253	11.372
Gum Gully	0508B_01	*E. coli*	71.148	0.043	1.574	65.974	3.557
Hudson Gully	0508C_01	Enterococci	11.860	0.012	11.178	0.077	0.593
Cow Bayou Tidal	0511_01	Enterococci	1,275.887	6.279	95.500	1,110.314	63.794
	0511_03	Enterococci	947.924	0.727	48.859	850.942	47.396
	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
Terry Gully*	0511E_01	*E. coli*	832.940	0.043	145.590	645.660	41.647
		Enterococci	231.372	0.012	40.442	179.349	11.569

† WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities.

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e. freshwater or tidal), pollutant allocations for both *E. coli* and Enterococci were developed using the LDC method.

Table 3 shows final TMDL allocations for the AUs with aquatic life use and general use impairments in Adams Bayou, Cow Bayou, and associated tributaries. The allocations in Table 3 are based on water quality simulation scenarios that resulted in compliance with the instream DO and pH criteria pertinent to each impaired AU. The TMDL allocations in Table 3 are designed to support both aquatic life and general uses in the impaired water bodies.

Table 3. Final TMDL allocations to support aquatic life and general uses (loads are in pounds/day)

Water Body	AU	TMDL		WLA_{WWTF}		WLA_{SW}		LA		MOS
		$CBOD_5$	NH_3N	$CBOD_5$	NH_3N	$CBOD_5$	NH_3N	$CBOD_5$	NH_3N	
Adams Bayou Tidal	0508_01	177.29	14.53	0.00	0.00	106.14	8.70	71.15	5.83	Implicit
	0508_02	732.96	209.66	685.55	205.66	47.34	3.99	0.07	0.01	Implicit
	0508_03	126.04	19.62	41.70	12.51	84.34	7.11	0.00	0.00	Implicit
	0508_04	348.46	26.37	0.00	0.00	41.57	3.15	306.89	23.22	Implicit
Hudson Gully	0508C_01	21.10	1.74	0.00	0.00	20.96	1.73	0.14	0.01	Implicit
Cow Bayou Tidal	0511_02	449.79	42.90	90.09	14.82	32.44	2.53	327.26	25.55	Implicit
	0511_03	394.82	27.16	0.00	0.00	61.36	4.22	333.46	22.94	Implicit
	0511_04	198.92	14.21	7.51	1.50	7.79	0.52	183.62	12.19	Implicit
Cow Bayou Above Tidal	0511A_02	647.59	50.59	34.19	10.26	2.09	0.14	611.31	40.19	Implicit
Coon Bayou	0511B_01	71.69	6.04	1.58	0.48	19.54	1.55	50.57	4.01	Implicit
Cole Creek	0511C_01	148.72	10.05	0.00	0.00	2.42	0.16	146.30	9.89	Implicit

Seasonal Variation: Seasonality was examined by comparing indicator bacteria concentrations obtained from routine monitoring samples collected in Adams Bayou Tidal and Cow Bayou Tidal in the warmer months (May through September) against those collected during the cooler months (November through March). The analysis revealed that

indicator bacteria concentrations where generally higher during the cool season than during the warm season for Adams Bayou and Cow Bayou, as shown by a statistically significant comparison of geometric mean concentrations. It should be noted that the criteria used by TCEQ to assess recreational uses apply to water bodies during all seasons of the year. Therefore, seasonal variation is accounted for in the bacteria TMDLs presented in this document by virtue of the fact that these variations affect neither the calculation nor the implementation of bacteria TMDLs in Texas. The modeling system used to determine TMDLs addressing aquatic life and general uses implicitly considers inter-annual and seasonal variation by simulating an 11-year period of record, which includes over a decade of seasonal variation.

Public Participation: The Sabine River Authority provided coordination for public participation in this project, helping to create and maintain the Orange County TMDL Stakeholder Advisory Group (SAG). Between January 2003 and November 2006, the SAG conducted 15 public meetings to present and discuss information related to the TMDLs adopted by TCEQ in 2007. Stakeholders held five additional public meetings between May 2007 and August 2013 during the development of the TMDL Implementation Plan (I-Plan), which was approved by TCEQ on August 5, 2015. Two of those meetings, as well as a stakeholder meeting held in September 2016, included the presentation and discussion of information associated with the revisions of the TMDLs, which are currently being proposed for release for a formal public review and comment period.

Implementation and Reasonable Assurance: I-Plans for Texas TMDLs use an adaptive management approach that allows for refinement or addition of methods to achieve environmental goals. This adaptive approach reasonably assures that the necessary regulatory and voluntary activities to achieve pollutant reductions will be implemented. Periodic, repeated evaluations of the effectiveness of implementation methods ascertain whether progress is occurring and may show that the original distribution of loading among sources should be modified to increase efficiency. I-Plans will be adapted as necessary to reflect needs identified in the evaluation of progress. In September 2019, TCEQ worked with stakeholders in the Adams Bayou and Cow Bayou watersheds to compile a status update of the management measures and control action included in the Adams Bayou and Cow Bayou I-Plan.

Key Points in the TMDL Proposal Schedule:
Anticipated proposal date: April 8, 2020
Anticipated *Texas Register* publication date: April 24, 2020
Anticipated public meeting date: Expected to be held during the public comment period
Anticipated public comment period: April 24, 2020 – May 26, 2020

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Attachments:
None

cc: Chief Clerk, 7 copies

Draft for Public Comment, April 2020

Twenty-three Total Maximum Daily Loads for Indicator Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and Associated Tributaries

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

Assessment Units 0508_01, 0508_02, 0508_03, 0508_04, 0508B_01, 0508C_01, 0511_01, 0511_02, 0511_03, 0511_04, 0511A_02, 0511B_01, 0511C_01, 0511E_01

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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TMDL project reports are available on the TCEQ website at:
<www.tceq.texas.gov/waterquality/tmdl/>

The preparation of this report was financed in part through grants from the U.S. Environmental Protection Agency.

This TMDL report is based in large part on the two reports titled:

"Technical Support Document for Total Maximum Daily Loads for Dissolved Oxygen and pH in Adams Bayou, Cow Bayou, and Associated Tributaries"

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

prepared by the Texas Institute for Applied Environmental Research.

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Abbreviations

ALUAA	Aquatic Life Use Attainability Analysis
AU	assessment unit
BMP	best management practice
BOD	Biochemical Oxygen Demand
$CBOD_5$	five-day carbonaceous biochemical oxygen demand
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming units
DMR	Discharge Monitoring Report
DO	dissolved oxygen
DSLP	days since last precipitation
E. coli	*Escherichia coli*
ECHO	Enforcement & Compliance History Online
EPA	United States Environmental Protection Agency
FDC	flow duration curve
FG	future growth
g	gram
GUI	graphical user interface
HSPF	Hydrologic Simulation Program – FORTRAN
ICIS	Integrated Compliance Information System
I/I	inflow and infiltration
IH	interstate highway
I-Plan	implementation plan
lbs	pounds
L	liter
LA	load allocation
LDC	load duration curve
m^2	square meter
MCMs	minimum control measures
mg	milligrams
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NEIWPCC	New England Interstate Water Pollution Control Commission
NH_3N	ammonia nitrogen
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration

NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCS	Natural Resources Conservation Service
OrgN	organic nitrogen
OrgP	organic phosphorus
OSSF	on-site sewage facility
PCS	Permit Compliance System
PO_4P	orthophosphate phosphorus
QAPP	quality assurance project plan
R^2	coefficient of determination
RMA2	River Management Associates-2 simulation software
RMSE	root mean square error
SAG	stakeholder advisory group
s/d	seconds per day
SOD	sediment oxygen demand
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic Database
SU	standard units
SWMP	Storm Water Management Program
SWQM	surface water quality monitoring
TAC	Texas Administrative Code
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSS	total suspended solids
TSSWCB	Texas State Soil and Water Conservation Board
UA	urbanized area
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WASP	Water Quality Analysis Simulation Program
WLA	wasteload allocation
WQBEL	water quality-based effluent limits
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

Twenty-Three TMDLs for Indicator Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and Associated Tributaries

Executive Summary

This document describes total maximum daily loads (TMDLs) for bacteria, dissolved oxygen (DO), and pH in the tidally influenced portion of Adams Bayou (Segment 0508), tidally influenced and above tidal portions of Cow Bayou (Segments 0511 and 0511A), and in Gum Gully, Hudson Gully, Coon Bayou, Cole Creek, and Terry Gully (Segments 0508B, 0508C, 0511B, 0511C, and 0511E, respectively). The impairments first appeared on the State of Texas Clean Water Act Section 303(d) Lists between 1992 and 2002.

The Texas Commission on Environmental Quality (TCEQ) adopted TMDLs for indicator bacteria, DO, and pH in Adams Bayou, Cow Bayou, and their tributaries on June 13, 2007, and the United States Environmental Protection Agency (EPA) approved these TMDLs on August 28, 2007 (TCEQ, 2007). Since the TMDLs were developed, permitted discharges have expired or been withdrawn and there have been expansions in the availability of centralized wastewater collection and treatment. In 2006, TCEQ began using an approach that subdivides water quality segments into assessment units (AUs) for assessment of water quality. The AU approach is currently used in TMDL development, but it was not available in 2007. Therefore, the TMDL allocations by segment were used in the EPA-approved 2007 TMDLs for water bodies in the Adams Bayou and Cow Bayou watersheds. The 2007 TMDLs were also determined by model scenarios involving reductions from existing pollutant loadings, rather than from fully permitted loading scenarios, which is inconsistent with current practice. Bacteria TMDLs for freshwater and tidal streams are presently based on empirical load duration curve (LDC) analysis, rather than deterministic computer models. For these reasons, TCEQ has updated the 2007 TMDLs adopted in the Adams Bayou and Cow Bayou watersheds.

TCEQ first identified bacteria and DO impairments in water bodies in the Adams Bayou watershed in 1992 and in the Cow Bayou watershed in 1994. Following these listings, subsequent editions of the Texas Water Quality Inventory and 303(d) List (since 2010 called the Texas Integrated Report) listed additional water bodies in these watersheds through 2002.

Potential sources of pollutants affecting the contact recreation and aquatic life uses in the Adams Bayou and Cow Bayou watersheds include domestic and industrial wastewater treatment facilities (WWTFs), regulated stormwater runoff, sanitary sewer overflows, illicit discharges, on-site sewage facilities (OSSFs), and contributions from wildlife and domesticated animals.

Fifteen WWTFs are currently authorized to discharge treated effluent into water bodies in the Adams Bayou and Cow Bayou watersheds. Three of the facilities discharge in the Adams Bayou watershed and each of these treat domestic wastewater. Of the 12 facilities in the Cow Bayou watershed, six are domestic and six are industrial facilities. The wastewater effluent from five of the six industrial facilities contains a human waste component and all six facilities are authorized to discharge stormwater under their permits.

There are no Phase I municipal separate storm sewer system (MS4) permits in either watershed. However, a review of active authorizations under stormwater general permits identified seven local entities authorized to discharge urban stormwater under the State of Texas' Phase II MS4 general permit. The review of other general permits conducted in September 2019 also identified three concrete production facilities, seven active stormwater construction permits, and sixteen stormwater multi-sector general permit (MSGP) authorizations in the Adams Bayou and Cow Bayou watersheds.

The TMDLs addressing bacteria impairments were estimated using conventional LDC analysis for freshwater streams and a modified LDC approach for tidally influenced streams. Bacteria TMDLs for AUs in tidally influenced streams in the Adams Bayou watershed ranged from 11.9 billion colony forming units per day (cfu/day) to 298.8 billion cfu/day Enterococci. The bacteria TMDL for Gum Gully, a freshwater stream in the Adams Bayou watershed, was calculated at 71.1 billion cfu/day *Escherichia coli* (*E. coli*). Bacteria TMDLs for AUs in tidally influenced streams in the Cow Bayou watershed ranged from 37.3 billion cfu/day to 1,275.9 billion cfu/day Enterococci. The TMDL for Terry Gully, in the Cow Bayou watershed, was calculated at 832.9 billion cfu/day *E. coli* and 231.4 billion cfu/day Enterococci. The bacteria TMDL allocations include allocations for future growth (FG) based on county and city population growth projections and the existing full permitted discharge for each WWTF.

The TMDLs addressing DO impairments were estimated using a combination of three deterministic models, which were used to simulate watershed processes and in-stream hydrodynamic and water quality processes in Adams Bayou, Cow Bayou, and their associated tributaries. TMDLs for DO-impaired AUs in the Adams Bayou watershed ranged from 21.1 pounds per day (lbs/day) to 733.0 lbs/day of five-day carbonaceous biochemical oxygen demand ($CBOD_5$) and 1.7 lbs/day to 209.7 lbs/day ammonia nitrogen (NH_3N). TMDLs for DO-impaired AUs in the Cow Bayou watershed ranged from 71.7 lbs/day to 647.6 lbs/day $CBOD_5$

and 6.0 lbs/day to 50.6 lbs/day NH_3N. Pollutant allocations for FG were determined based on specific loading scenarios simulated using the calibrated TMDL modeling system. Due to the limited capacity of the streams in the Adams Bayou and Cow Bayou watersheds to assimilate oxygen demanding substances, FG allocations for these pollutants are only possible for the lower portions of Cow Bayou Tidal and an unnamed tidal tributary of Cow Bayou.

The TMDL estimates and load allocation (LA) calculations in this report will guide the determination of the assimilative capacity of each AU in each water body under changing conditions, including FG. WWTFs will be evaluated on a case by case basis.

Introduction

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

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

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

These TMDLs address impairments of the primary contact recreation use, due to exceedances of indicator bacteria, the aquatic life use, due to depressed DO, and the general use, due to low pH. TCEQ adopted TMDLs addressing these impairments on June 13, 2007, and the EPA approved these TMDLs on August 28, 2007 (TCEQ, 2007). TCEQ is revising TMDLs for 14 AUs in 8 segments that were included in the original TMDLs to update the TMDLs and associated load allocations for these AUs.

This TMDL document uses a watershed approach to address these impairments. While TMDL allocations were developed only for the impaired AUs identified in

this report, the entire Adams Bayou and Cow Bayou watersheds (Figure 1) and all WWTFs that discharge within these watersheds are included within the scope of these TMDLs.

The impaired AUs within the Adams Bayou and Cow Bayou watersheds and the associated primary contact recreation, aquatic life, and general uses are indicated in Table 1. Bacteria impairments are depicted in Figure 2. DO and pH impairments are depicted in Figure 3.

Section 303(d) of the Clean Water Act and the implementing regulations of the EPA in Title 40 of the Code of Federal Regulations (CFR), Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

TCEQ must consider certain elements in developing a TMDL. They are described in the following sections of this report:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Margin of Safety
- Pollutant Load Allocation
- Seasonal Variation
- Public Participation
- Implementation and Reasonable Assurance

The bacteria pollutant load allocations and the pollutant load allocations associated with depressed DO are presented separately. To accomplish this separation, the Linkage Analysis, Margin of Safety, Pollutant Load Allocation, and Seasonal Variation sections are provided, first, for the bacteria and, second, for the depressed DO. The pollutant load allocations associated with pH are discussed with depressed DO impairments, because of the interconnection of causes of depressed DO and low pH for Cow Bayou Tidal AU 0511_04.

Upon adoption of the TMDL report by the commission and subsequent EPA approval, these TMDLs will become an update to the state's Water Quality Management Plan (WQMP).

Table 1. Impairment by AU and use for Adams Bayou, Cow Bayou, and associated tributaries.

AU	Water Body	Primary Contact Recreation	Aquatic Life Use	General Use
0508_01	Adams Bayou Tidal	Impaired	Impaired	Unimpaired
0508_02	Adams Bayou Tidal	Impaired	Impaired	Unimpaired
0508_03	Adams Bayou Tidal	Impaired	Impaired	Unimpaired
0508_04	Adams Bayou Tidal	Impaired	Impaired	Unimpaired
0508A_01	Adams Bayou Above Tidal	Unimpaired	Impaired	Not Applicable*
0508B_01	Gum Gully	Impaired	Impaired	Not Applicable*
0508C_01	Hudson Gully	Impaired	Impaired	Not Applicable*
0511_01	Cow Bayou Tidal	Impaired	Unimpaired	Unimpaired
0511_02	Cow Bayou Tidal	Unimpaired	Impaired	Unimpaired
0511_03	Cow Bayou Tidal	Impaired	Impaired	Unimpaired
0511_04	Cow Bayou Tidal	Impaired	Impaired	Impaired
0511A_01	Cow Bayou Above Tidal	Unimpaired	Unimpaired	Not Applicable*
0511A_02	Cow Bayou Above Tidal	Unimpaired	Impaired	Not Applicable*
0511B_01	Coon Bayou	Impaired	Impaired	Not Applicable*
0511C_01	Cole Creek	Unimpaired	Impaired	Not Applicable*
0511D_01	Unnamed Tributary to Cow Bayou	Not Assessed	Not Assessed	Not Applicable*
0511E_01	Terry Gully	Impaired	Unimpaired	Not Applicable*

* Assessment of pH is not applicable to unclassified water bodies

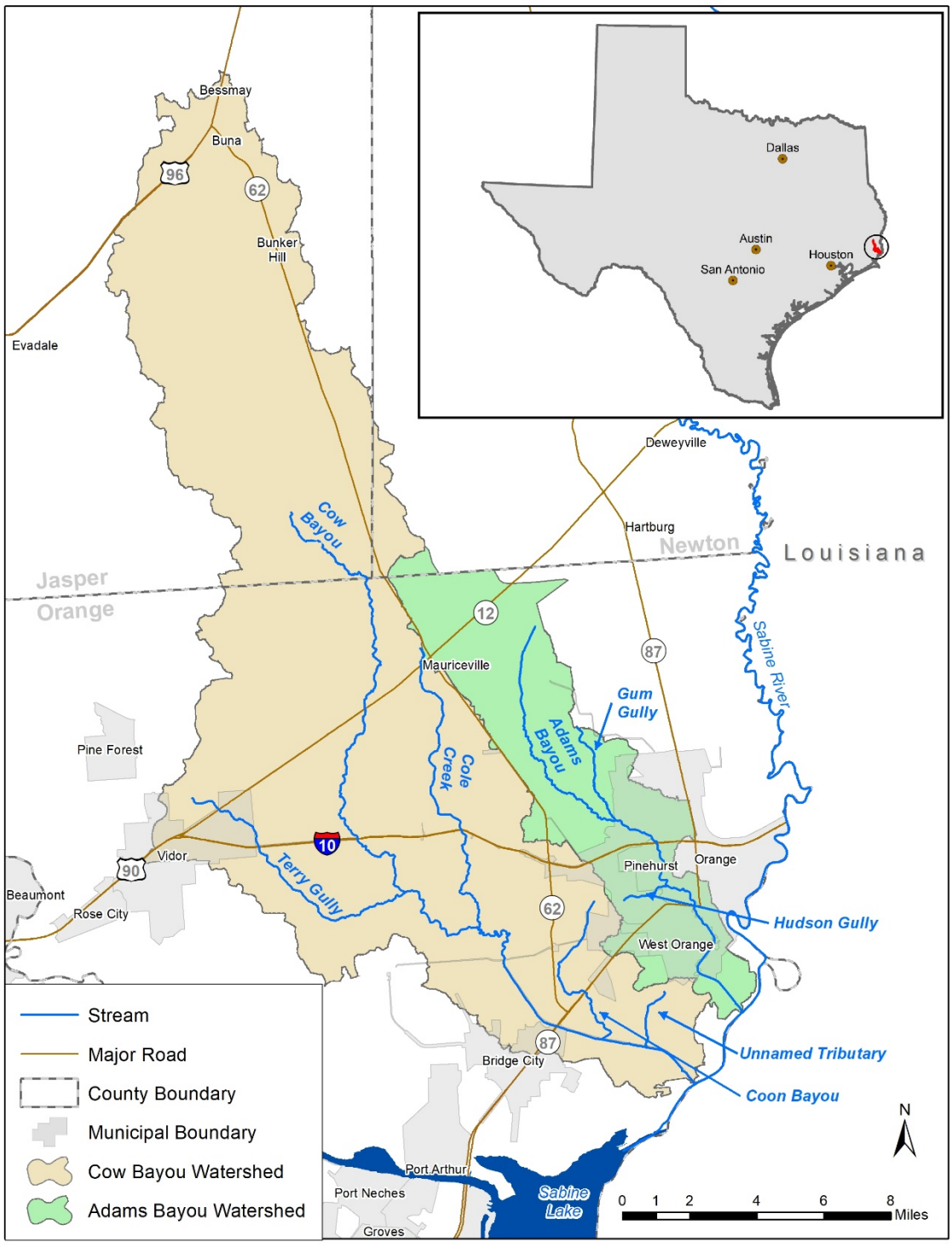

Figure 1. Overview map showing Adams Bayou and Cow Bayou watersheds.

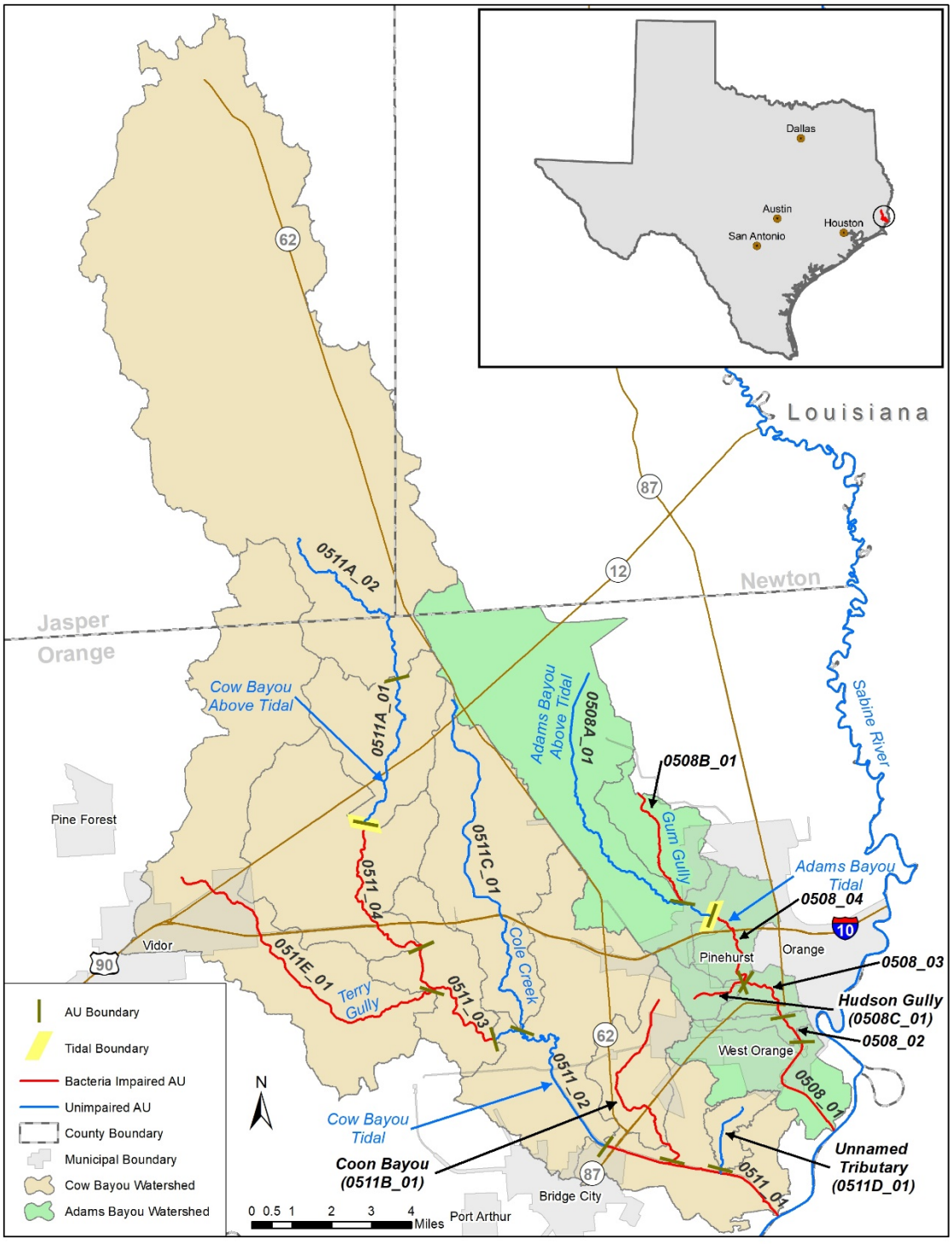

Figure 2. Impaired AUs for bacteria in the Adams Bayou and Cow Bayou watersheds.

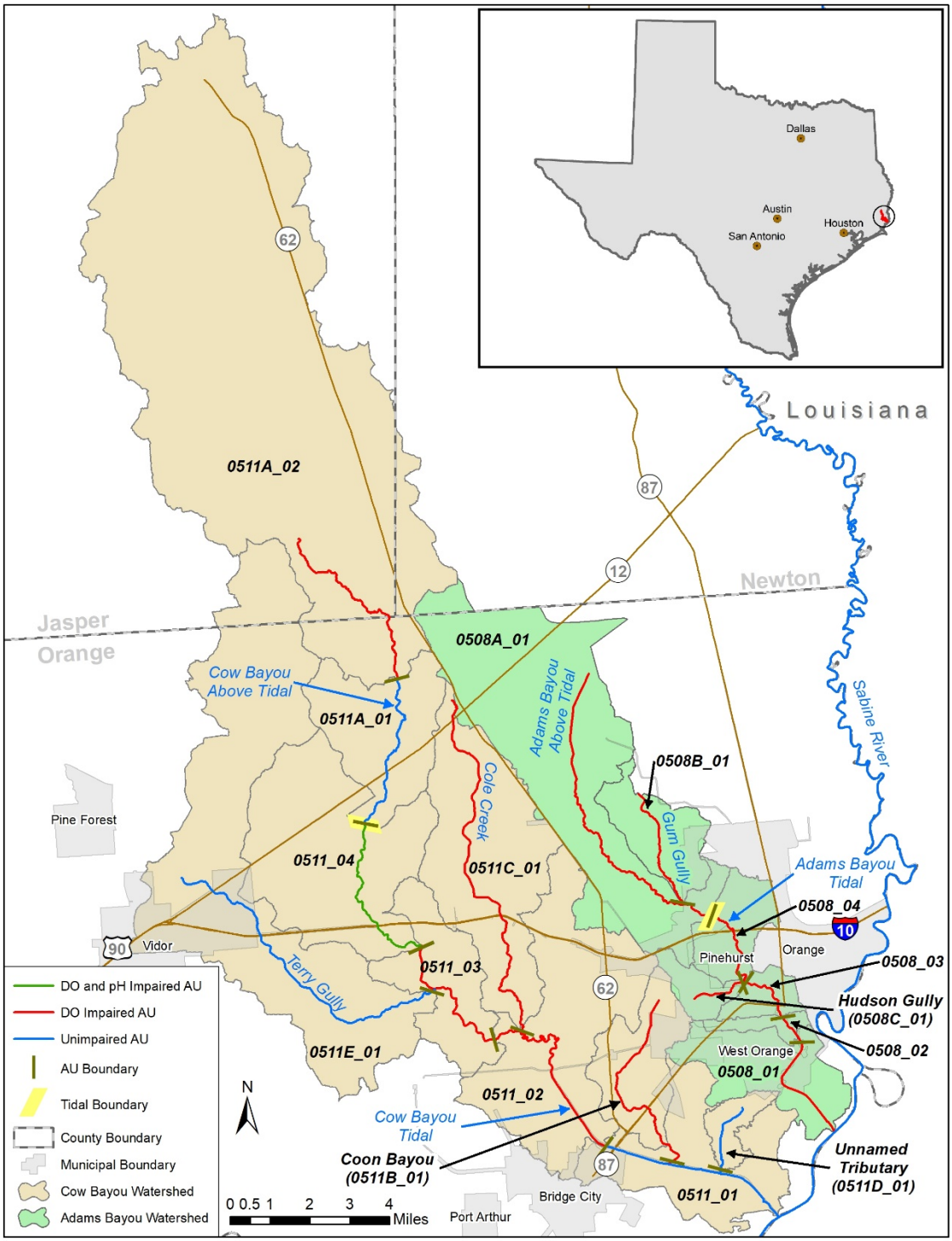

Figure 3. Impaired AUs for depressed DO and low pH in the Adams Bayou and Cow Bayou watersheds.

Problem Definition

TCEQ first identified impairments in Adams Bayou for bacteria and depressed DO in the *1992 State of Texas Clean Water Act Section 303(d) List*. TCEQ included the non-tidally influenced portion of Adams Bayou (Adams Bayou Above Tidal) and a tributary to Adams Bayou, Gum Gully, in the *2000 Texas Water Quality Inventory and 303(d) List,* also for bacteria and depressed DO impairments. A second tributary to Adams Bayou, Hudson Gully, was included in the *2002 Texas Water Quality Inventory and 303(d) List* for bacteria and depressed DO impairments.

The DO impairment in Cow Bayou was first identified in the 1994 State of Texas Clean Water Act Section 303(d) List. TCEQ included additional impairments to Cow Bayou in the *2000 Texas Water Quality Inventory and 303(d) List*, including bacteria and partial nonsupport of the general use due to low pH. The *2000 Texas Water Quality Inventory and 303(d) List* also included two tributaries to Cow Bayou, Coon Bayou and Cole Creek, for impairments due to bacteria and depressed DO. A third tributary to Cow Bayou, Terry Gully, was included in the *2002 Texas Water Quality Inventory and 303(d) List* for bacteria impairments.

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, during the assessment period, showed support of the contact recreation use in that water body. 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 impairment was based on exceedance of the fecal coliform single sample criterion, but not the geometric mean criterion, which became the sole-applicable criterion when EPA approved this change as part of the 2010 revisions to the Texas Surface Water Quality Standards.

Although TCEQ began assessing portions of stream segments separately in 2002, impaired segments were not listed by their individual AUs until the *2006 Texas Water Quality Inventory and 303(d) List*, at which time the definition of impairments was refined from segments to AUs. The complete list of water bodies grouped by impairment and combined segment and AU numbers are as follows.

Bacteria Impairments:

- Adams Bayou Tidal: 0508_01, 0508_02, 0508_03, 0508_04
- Gum Gully (unclassified water body): 0508B_01
- Hudson Gully (unclassified water body): 0508C_01
- Cow Bayou Tidal: 0511_01, 0511_03, 0511_04
- Coon Bayou (unclassified water body): 0511B_01

- Terry Gully (unclassified water body): 0511E_01

Depressed DO:

- Adams Bayou Tidal: 0508_01, 0508_02, 0508_03, 0508_04
- Adams Bayou Above Tidal: 0508A_01
- Gum Gully (unclassified water body): 0508B_01
- Hudson Gully (unclassified water body): 0508C_01
- Cow Bayou Tidal: 0511_02, 0511_03, 0511_04
- Cow Bayou Above Tidal (unclassified water body): 0511A_02
- Coon Bayou (unclassified water body): 0511B_01
- Cole Creek (unclassified water body): 0511C_01

Low pH:

- Cow Bayou Tidal: 0511_04

The indicator bacteria for freshwater are *E. coli* and, for saltwater, the indicator bacteria are Enterococci. Both *E. coli* and Enterococci are measured in units of cfu per 100 milliliter (mL/100 mL) or most probable number per 100 mL (MPN/100 mL). The units of cfu/100 mL and MPN/100 mL are considered equivalent for assessment purposes. For consistency, cfu/100 mL will be used exclusively in this report. Bacteria impairments listed prior to 2002 were assessed using fecal coliform data because the timing of the listings predates a change in indicator bacteria in the Texas Surface Water Quality Standards from fecal coliform to *E. coli* and Enterococci. DO is measured in milligrams per liter (mg/L), and pH is measured in standard units (SU). A summary of the water bodies and associated characteristics, water quality uses, and associated criteria for contact recreation, DO, and pH is provided in Table 2.

Ambient Indicator Bacteria Concentrations

A summary of the historical indicator bacteria (fecal coliform) data used to identify the contact recreation use impairments is provided in Table 3. The locations of the historical monitoring stations in the Adams Bayou and Cow Bayou watersheds are provided in Figure 4. The historical bacteria assessments were made using fecal coliform, which was the indicator bacteria at that time, with a geometric mean criterion of 200 cfu/100 mL and a single sample criterion of 400 cfu/100 mL.

Current surface water quality monitoring for bacteria in Adams Bayou and Cow Bayou occurs at TCEQ surface water quality monitoring (SWQM) Station 10441 on Adams Bayou Tidal (AU 0508_01) and Station 10449 on Cow Bayou Tidal (AU 0511_01).

The 2018 Texas Integrated Report (TCEQ, 2019a) for AU 0508_01 and 0511_01 indicated non-support of the primary contact recreation use because the geometric mean exceeded the criterion of 35 cfu/100 mL Enterococci at SWQM Stations 10441 and 10449, respectively. The *2006 Texas Water Quality Inventory and 303(d) List* for AU 0511_03 indicated non-support of the primary contact recreation use because the geometric mean exceeded the criterion of 35 cfu/100 mL Enterococci at Station 13781.

The endpoint for the bacteria TMDLs presented in this document is based on two different indicator bacteria. TMDLs addressing bacteria impairments in freshwater bodies are expressed in terms of *E. coli* and TMDLs addressing bacteria impairments in tidally influenced water bodies are expressed in terms Enterococci. The endpoint for the bacteria TMDL calculated for Terry Gully (AU 0511E_01) is presented using both *E. coli* and Enterococci, due to its complex hydrology.

Ambient DO and pH Concentrations

A summary of the historical DO data used to identify the aquatic life use impairments is provided in Table 4. The locations of the historical monitoring stations in the Adams Bayou and Cow Bayou watersheds are provided in Figure 4. Routine DO monitoring occurs at TCEQ SWQM Station 10441 on Adams Bayou Tidal (AU 0508_01) and Station 10449 on Cow Bayou Tidal (AU 0511_01).

Watershed Overview

Adams Bayou and Cow Bayou in southeast Texas are sluggish streams of the Sabine River Basin 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 and 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 10. The tidal portions of Adams Bayou and Cow Bayou extend approximately eight and 20 miles, respectively, above their confluences with the Sabine River. In the Texas Surface Water Quality Standards [Title 30, Texas Administrative Code (30 TAC 307.3)], 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

Table 2. Relevant water body characteristics, uses, and associated criteria for Adams Bayou, Cow Bayou, and associated tributaries.

Water Body	AU	Type	Indicator Bacteria for Contact Recreation Use	Primary Contact Recreation Geometric Mean Criterion (cfu/100 mL)	Aquatic Life Use	24-Hr AVG/MIN DO criteria (mg/L)	pH criteria under General Use (SU)
Adams Bayou Tidal	0508_01	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0508_02	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0508_03	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0508_04	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
Adams Bayou Above Tidal	0508A_01	Freshwater Intermittent with pools	*E. coli*	126	Limited	3/2	Not Applicable*
Gum Gully	0508B_01	Freshwater Intermittent with pools	*E. coli*	126	Limited	3/2	Not Applicable*
Hudson Gully	0508C_01	Tidal stream	Enterococci	35	High	4/3	Not Applicable*
Cow Bayou Tidal	0511_01	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0511_02	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0511_03	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
	0511_04	Tidal stream	Enterococci	35	High	4/3	6.0 – 8.5
Cow Bayou Above Tidal	0511A_01	Freshwater Intermittent with pools	*E. coli*	126	Limited	3/2	Not Applicable*
	0511A_02	Freshwater Intermittent with pools	*E. coli*	126	Limited	3/2	Not Applicable*
Coon Bayou	0511B_01	Tidal stream	Enterococci	35	High	4/3	Not Applicable*
Cole Creek	0511C_01	Tidal stream	Enterococci	35	High	4/3	Not Applicable*
Unnamed Tributary of Cow Bayou	0511D_01	Tidal stream	Enterococci	35	High	4/3	Not Applicable*
Terry Gully	0511E_01	Freshwater Intermittent with pools	*E. coli***	126	Limited	3/2	Not Applicable*

* Unclassified water bodies are not assessed for pH.

** TCEQ assesses Terry Gully as a freshwater stream; however, data collected as part of the 2003-2004 intensive surveys indicate a portion of the AU may be tidally influenced. Therefore, TMDLs for *E. coli* and Enterococci are presented in Table 18.

Table 3. Summary of historical assessment data for the bacteria impairments in the Adams Bayou and Cow Bayou watersheds.

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*
	0508_02	Fecal coliform	10442	06/01/1994 – 05/31/1999**	21	600	1992*
	0508_03	Fecal coliform	16059	06/01/1994 – 05/31/1999**	21	641	1992*
	0508_04	Fecal coliform	10443, 14990	06/01/1994 – 05/31/1999**	59	372	1992*
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
	0511_03	Fecal coliform	13781	06/01/1994 – 05/31/1999	45	135	2000
	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	1002	2000
Terry Gully	0511E_01	Fecal coliform	16040	03/01/1996 – 02/28/2001	26	363	2002

* The 1992 bacteria 303(d) listings were at the segment level using fecal coliform as the indicator bacteria. The 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.*

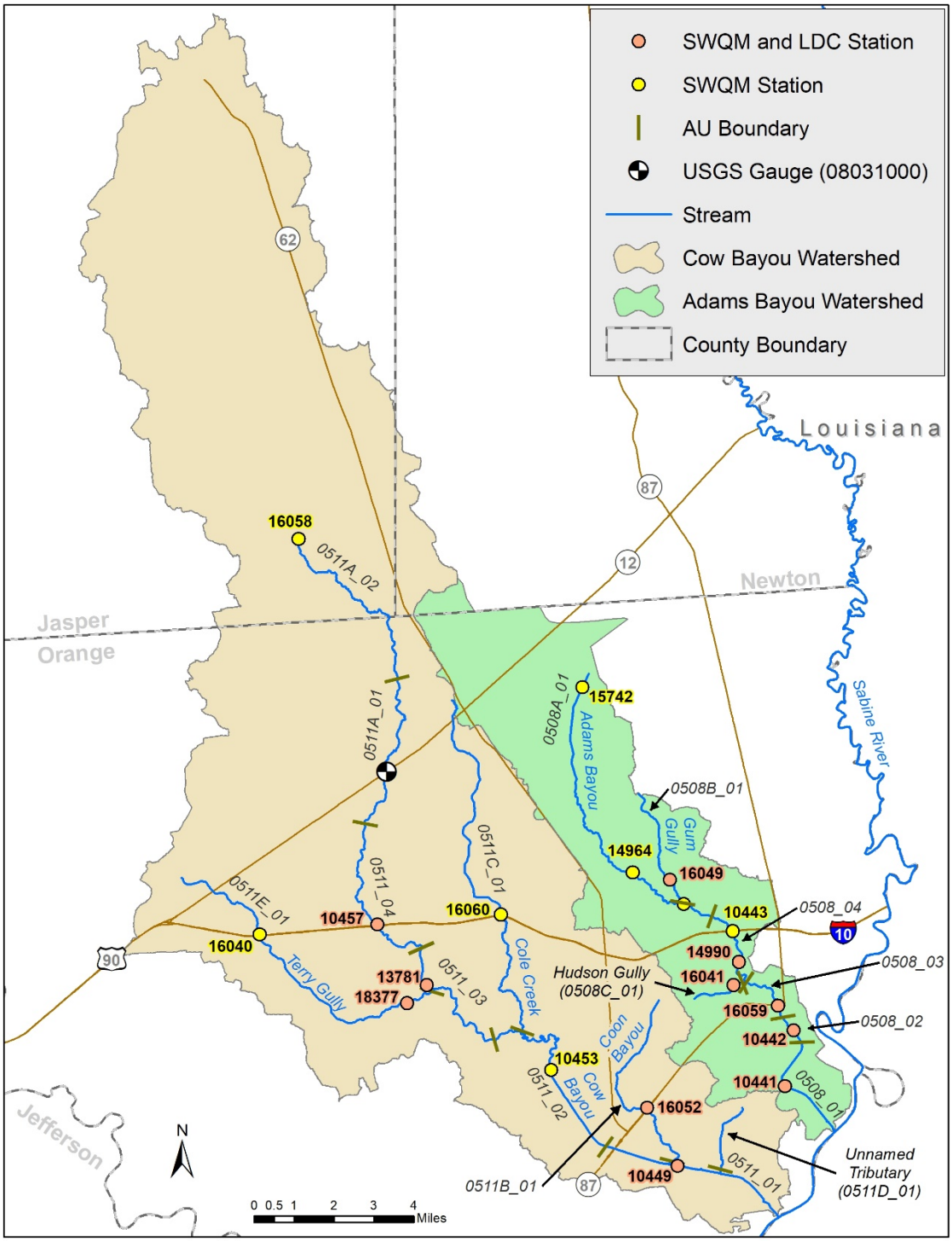

Figure 4. Location of TCEQ SWQM stations and LDC stations in the Adams Bayou and Cow Bayou watersheds.

Table 4. Summary of historical assessment data for the DO and pH impairments in the Adams Bayou and Cow Bayou watersheds.

Water Body	AU	Parameter	Station	Data Date Range	Number of Samples	Percent of samples below criterion	Year First Listed
Adams Bayou Tidal	0508_01	DO	10441	09/01/1987 – 08/31/1991	22	36	1992
	0508_02	DO	10442	06/01/1994 – 05/31/1999	21	81	1992*
	0508_03	DO	16059	06/01/1994 – 05/31/1999	21	90	1992*
	0508_04	DO	10443, 14990	06/01/1994 – 05/31/1999	62	77	1992*
Adams Bayou Above Tidal	0508A_01	DO	14964, 15742	06/01/1994 – 05/31/1999	38	39	2000
Gum Gully	0508B_01	DO	16049	06/01/1994 – 05/31/1999	20	40	2000
Hudson Gully	0508C_01	DO	16041	03/01/1996 – 02/28/2001	29	55	2002
Cow Bayou Tidal	0511_02	DO	10453	06/01/1994 – 05/31/1999*	65	29	1994**
	0511_03	DO	13781	06/01/1994 – 05/31/1999*	46	59	1994**
	0511_04	DO	10457	06/01/1994 – 05/31/1999*	23	52	1994**
	0511_04	pH	10457	06/01/1994 – 05/31/1999	23	22	2000
Cow Bayou Above Tidal	0511A_02	DO	16058	06/01/1994 – 05/31/1999	20	40	2000
Coon Bayou	0511B_01	DO	16052	06/01/1994 – 05/31/1999	21	76	2000
Cole Creek	0511C_01	DO	16060	06/01/1994 – 05/31/1999	21	19	2000

* The 1992 DO 303(d) listings were at the segment level. The Adams Bayou Tidal (Segment 0508) listing was based on data collected at Station 10441. Subsequent to the 1992 303(d) listing, additional DO data were collected at the AU level. The data reported for AUs 0508_02, 0508_03, 0508_04, 0511_02, 0511_03, and 0511_04 are from the *2000 Texas Water Quality Inventory* and 303(d) List

** The 1994 DO 303(d) listings for Cow Bayou Tidal (Segment 0511) were at the segment level. Subsequent to the 1994 303(d) listing, Segment 0511 was removed from Texas' 303(d) list and additional DO data were collected at the AU level. The Cow Bayou Tidal (Segment 0511) DO listing was based on data collected at Station 10449, which is in AU 0511_01. AU 0511_01 is not currently impaired for low DO and is therefore excluded from Table 4.

be saltwater. Classified tidal waters include all bays and estuaries with a segment number that begins with 24, all streams with the word tidal in the segment name, and the Gulf of Mexico." The portions of Adams Bayou and Cow Bayou upstream of tidal influence, as well as tributaries that are not tidally

influenced, are characterized in the Texas Integrated Report as being intermittent with pools.

The 2018 Texas Integrated Report (TCEQ, 2019a) provides the following Segment and AU descriptions for the water bodies considered in this document. Some segment lengths were estimated from geospatial analysis of TCEQ hydrography data layers. Watershed areas were calculated using information derived from USGS digital elevation models of this area of southeast Texas.

- 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 length of 8 miles). This Segment consists of four AUs:

  - 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).

- 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. This segment consists of one AU:

  - AU ID: 0508A_01 – Entire bayou above tidal (approximate length of 8.8 miles).

  The watershed area associated with AU 0508A_01 is 26.216 square miles (16,778 acres).

- 0508B Gum Gully
  From the confluence of Adams Bayou to the upstream perennial portion of the stream northwest of Orange in Orange County. This segment consists of one AU:

  - AU_ID: 0508B_01 – Entire creek (approximate length of 3.4 miles)

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

- 0508C Hudson Gully
  From the confluence with Adams Bayou to the headwaters near US 890 in Pinehurst in Orange County. This segment consists of one AU:

- AU_ID: 0508C_01 – Entire creek (approximate length of 1.5 miles)

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

- 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 (approximate length of 20 miles).

  - AU_ID: 0511_01 – Lower 5 miles
  - AU_ID: 0511_02 – 6-mile reach near FM 105
  - 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 four AUs is 53.364 square miles (34,153 acres).

- 0511A Cow Bayou Above Tidal

  From a point 4.8 km (3.0 mi) upstream of IH-10 in Orange County to the upstream perennial portion of the stream northeast of Vidor in Orange County (approximate length of 10.6 miles). This segment consists of two AUs:

  - AU_ID: 0511A_01 – Lower 5.3 miles of above-tidal reach
  - AU_ID: 0511A_02 – Upper 5.3 miles of above-tidal reach

  The combined watershed area for the two AUs is 86.094 square miles (55,100 acres).

- 0511B Coon Bayou

  From the confluence with Cow Bayou up to the extent of tidal limit in Orange County. This segment consists of one AU:

  - AU_ID: 0511B_01 – Entire tidal reach (approximate length of 5.2 miles)

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

- 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. This segment consists of one AU:

  - AU_ID: 0511C_01 – Entire tidal reach (approximate length of 10.6 miles)

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

- 0511D Unnamed Tributary of Cow Bayou
  From the confluence with Cow Bayou (north bank approximately 1.6 km from the Sabine River confluence) up to the extent of tidal limits. This segment consists of one AU:

  - AU_ID: 0511D_01 – Entire tidal reach (approximate length 1.7 miles)

  The watershed area associated with 0511D_01 is 1.805 square miles (1,155 acres).

- 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 (approximately 8.9 miles)

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

This document organizes the AUs into two main watersheds: the Adams Bayou watershed and the Cow Bayou watershed, each with their associated tributaries. Within each main watershed sub-watersheds are defined for each individual AU.

Watershed Climate

The Adams Bayou and Cow Bayou watersheds experience a subtropical humid climate. The average temperature varies from 50 ˚F in January to 83 ˚F 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 over the 30-year period 1986-2015. 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 5 for Port Arthur Airport, located immediately southeast of the Cow Bayou watershed (NOAA, 2016).

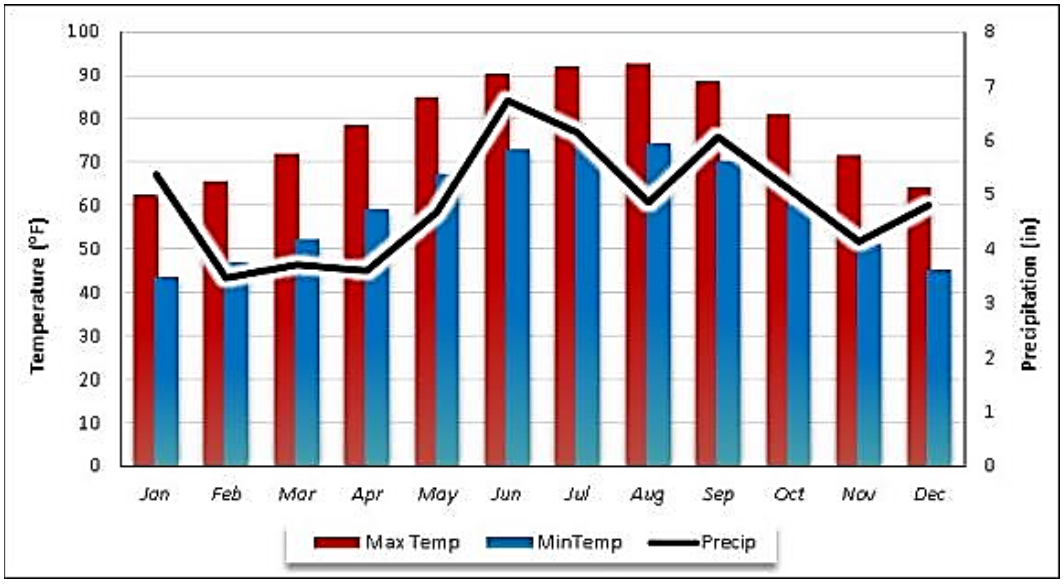

Figure 5. 30-year climatic average minimum and maximum air temperatures and precipitation by month at Port Arthur Airport (1986 – 2015).

Watershed Population and Population Projections

Population estimates were determined for the Adams Bayou watershed and Cow Bayou watershed using the 2010 U.S. Census information at the census block level (USCB, 2016a and 2016b). The 2020 population estimate for Adams Bayou watershed is 29,776 people, indicating an average population density of approximately 642 people per square mile. For the Cow Bayou watershed, the 2020 population estimate is 50,889 people, indicating an average population of approximately 256 people per square mile. Based on the Region I 2016 Regional Water Plan (Allan Plummer Assoc., et al., 2015) information, the largest cities partially or entirely in the Adams Bayou and/or Cow Bayou watersheds are Orange (estimated 2020 population of 19,616), Vidor (estimated 2020 population of 11,160), and Bridge City (estimated 2020 population of 8,271).

Based on information contained in the Region I 2016 Regional Water Plan, the decadal population projections for 2020 to 2070 are provided for counties and cities contained partially or completely within the Adams Bayou and Cow Bayou watersheds; the percent change in population from 2020 to 2070 is also provided (Table 5). The 2020 and 2070 population estimates, by AU subwatershed in the Adams Bayou and Cow Bayou watersheds, are provided in Table 6. To remain consistent with the Region I water planning process and their planning horizon, the same 2020 to 2070 period is used for the pollutant load development of the Adams Bayou and Cow Bayou watersheds.

Table 5. Population estimate and projections for 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 WSC	5,203	5,438	5,604	5,717	5,802	5,864	12.7

Source: Alan Plummer Assoc. et al., 2015.

Table 6. 2020 population estimate and 2020-2070 population projections for the subwatersheds of each AU associated with the Adams Bayou and Cow Bayou watersheds.

AU Watershed	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**	**12.6**

AU Watershed	Estimated 2020 Population	Estimated 2070 Population Projections	Percent Increase (2020 – 2070)
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 6 is detailed in Appendix B.

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 6. Tabular presentation of the land use/land cover data for the Adams Bayou watershed is provided in Table 7 and for the Cow Bayou watershed in Table 8.

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

- **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.
- **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.

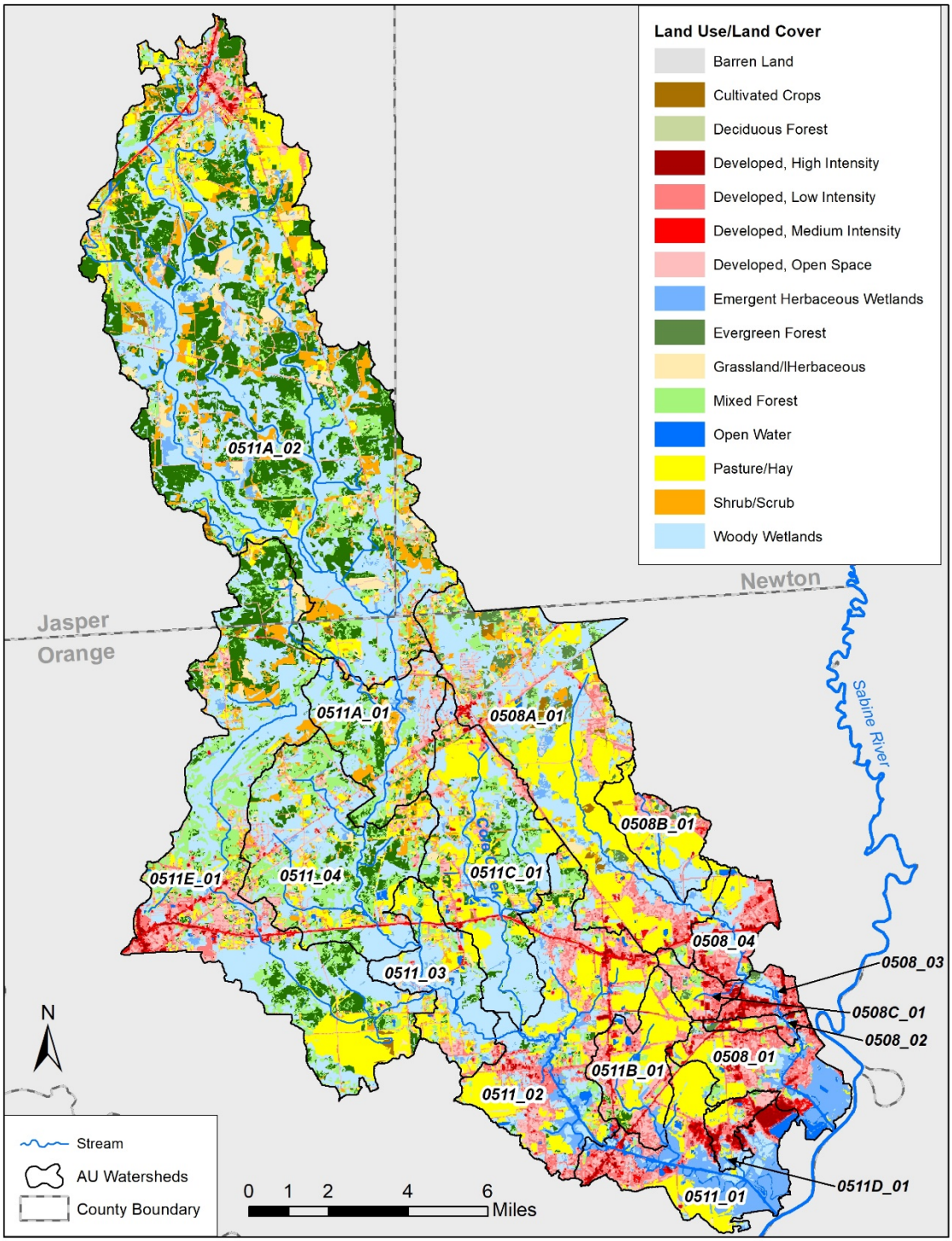

Figure 6. 2016 NLCD land use/ land cover for the Adams Bayou and Cow Bayou watersheds.

Table 7. 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**	**Percent of Total (%)**	**Acres**	**Percent of Total (%)**	**Acres**	**Percent 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**	**100δ**	**19,788**	**100δ**	**29,667**	**100δ**

† Adams Bayou Watershed Tidal portion includes the watersheds for AUs 0508_01, 0508_02, 0508_03, 0508_04 and 0508C_01.

* Adams Bayou Watershed Above Tidal portion includes the watersheds for AUs 0508A_01 and 0508B_01.

δ Due to rounding, the percentages by classification category may not add to exactly 100 percent.

Table 8. 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	Percent of Total (%)	Acres	Percent of Total (%)	Acres	Percent 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**	**100δ**	**55,100**	**100δ**	**127,210**	**100δ**

† Cow Bayou Watershed 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.

* Cow Bayou Watershed Above Tidal portion includes the watersheds for AUs 0511A_01 and 0511A_02.

δ Due to rounding, the percentages by classification category may not add to exactly 100 percent.

- **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.

Soils

Soils within the Adams Bayou and Cow Bayou watersheds were categorized by septic tank absorption field ratings. These data were obtained through the U.S.

Department of Agriculture Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (USDA-NRCS, 2016).

Soil properties and features such as saturated hydraulic conductivity, flooding, depth to bedrock, depth to cemented pan, ponding, rocks, fractured bedrock, subsidence, and excessive slope can affect septic tank effluent absorption, construction, and maintenance, along with public health (USDA-NRCS, 2016). The dominant soil condition within a septic drainage field can be used to identify soils that may prove problematic regarding septic system installation or performance and potentially lead to system failures such as effluent surfacing or downslope seepage.

Soils are rated based on the conditions affecting proper effluent drainage and filtering capacity. Soil conditions for septic tank drainage fields are expressed by the following rating terms and definitions (USDA-NRCS, 2016):

- **Not Limited** – Indicates that the soil has features that are very favorable for the specific use. Good performance and very low maintenance can be expected.
- **Somewhat Limited** – Indicates that the soil has one or more features that are moderately favorable for the specified use. The limitations can be overcome or minimized with special planning, design, and installation procedures. Fair performance and moderate maintenance can be expected.
- **Very Limited** – Indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.
- **Not Rated** – Indicates insufficient data exist for soil limitation interpretation.

Within the Adams Bayou and Cow Bayou watersheds, all rated soils are classified as “Very Limited” based on the dominant soil condition for septic drainage field installation and operation (Figure 7).

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for each TMDL. The TMDL endpoints also serve to focus the technical work to be accomplished and as criteria against which to evaluate future conditions.

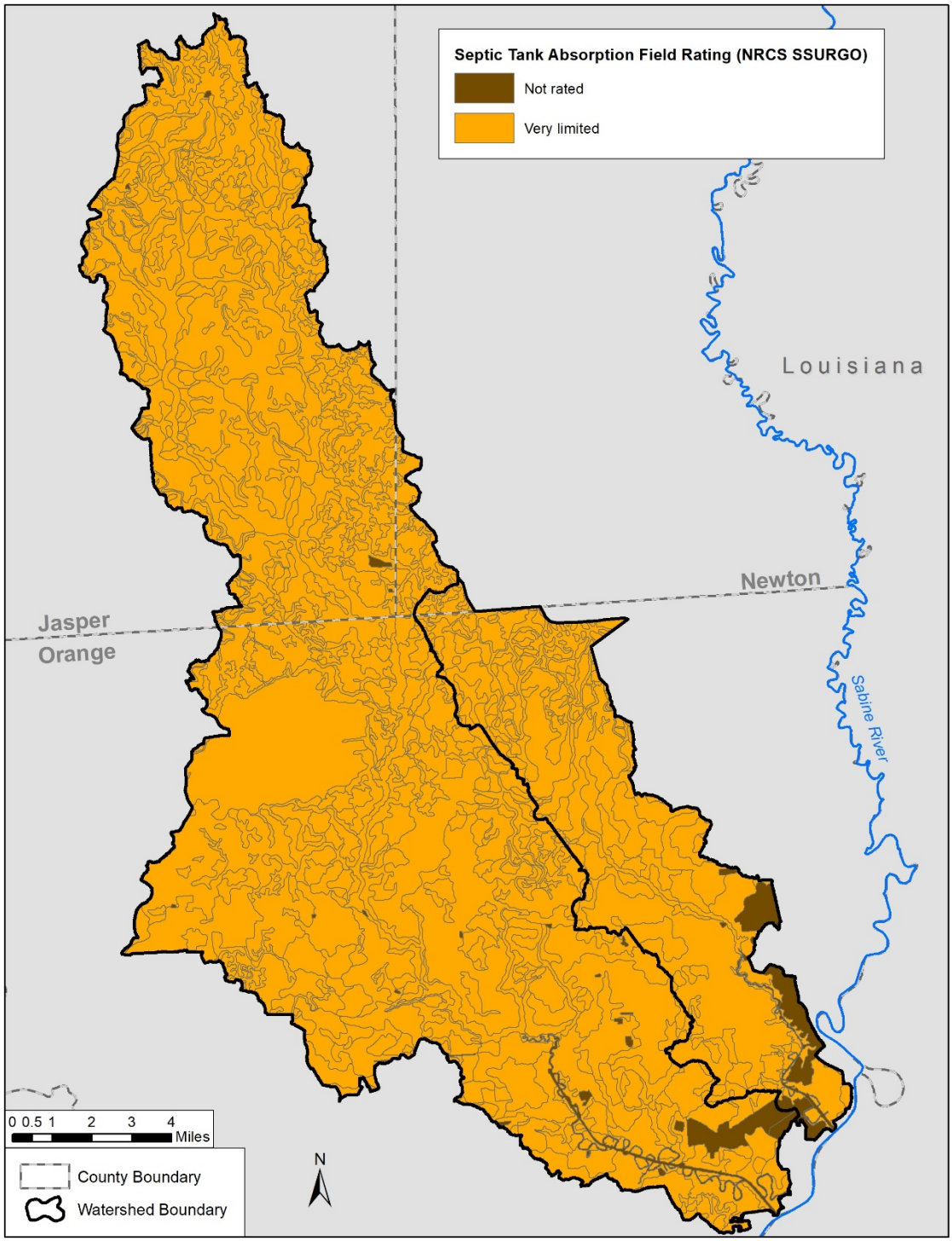

Figure 7. Septic tank absorption field limitation ratings for soils within the Adams Bayou and Cow Bayou watersheds.

Bacteria Endpoints

Adams Bayou, Cow Bayou, and associated tributaries have a designated or presumed use of primary contact recreation, which is measured against numeric criteria 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 primary contact recreation in freshwater consists of a geometric mean concentration not to exceed 126 cfu/100 mL (TCEQ, 2010a). The Enterococci criterion to protect primary contact recreation in saltwater consists of a geometric mean concentration not to exceed 35 cfu/100 mL (TSOS, 2018). These criteria form the basis for the endpoint of the TMDLs presented in this document.

DO Endpoints

Within the Adams Bayou and Cow Bayou watersheds, the tidal AUs have a high aquatic life use, and the water quality criteria require that daily 24-hour average DO be at least 4 mg/L, with a daily 24-hour minimum of at least 3 mg/L (TSOS, 2018). In order for water quality standards to be determined as fully supported, no more than 10 percent of daily average DO measurements (TCEQ, 2019b) can fall below the 4 mg/L daily average criterion.

The above tidal reaches in these systems are intermittent water bodies with perennial pools. A limited aquatic life use is presumed (based on flow type) for these water bodies, with a daily 24-hour average criterion of 3 mg/L DO and a daily 24-hour minimum criterion of 2 mg/L DO (TSOS, 2018). In order for water quality standards to be determined as fully supported, no more than 10 percent of daily average DO measurements can fall below the 3 mg/L daily 24-hour average DO criterion (TCEQ, 2019b).

pH Endpoint

The general use of water bodies in the Adams Bayou and Cow Bayou watersheds is protected by several water quality parameters including pH. Low pH is the source of impairment in AU 0511_04 of Cow Bayou Tidal, whereas all other AUs of classified segments included in this TMDL are fully supporting. The criterion for pH in Cow Bayou Tidal (Segment 0511) is for the pH measurements to range between 6.0 – 8.5 SU (TSOS, 2018).

Source Analysis

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) Program. WWTFs and stormwater discharges from industries, construction activities, and MS4s are considered point sources of pollution.

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

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

The pollutants of focus for these TMDLs include the indicator bacteria of *E. coli* and Enterococci, and $CBOD_5$ and NH_3N, as the primary oxygen demanding substances affecting DO and pH. Of secondary importance to DO dynamics are organic nitrogen and phosphorus (OrgN and OrgP), orthophosphate phosphorus (PO_4P), and total suspended solids (TSS).

Regulated Sources

The regulated sources in the TMDL watersheds include domestic and industrial WWTFs and stormwater discharges from industry, construction, MS4s and other activities covered under the stormwater multisector general permit.

Domestic and Industrial Wastewater Treatment Facilities

There are 15 domestic and industrial WWTFs authorized to discharge in the Adams Bayou and Cow Bayou watersheds (Figure 8; Tables 9 and 10). In Table 9 permit limits are provided for five-day biochemical oxygen demand (BOD_5), $CBOD_5$, NH_3N, and discharge. Three of the facilities discharge in the Adams Bayou watershed and each of these treat domestic wastewater. Of the 12 facilities in the Cow Bayou watershed, six are domestic WWTFs and six are industrial facilities. The wastewater effluent from five of the six industrial facilities contains a human waste (domestic) component. TCEQ reviewed each of the six permitted industrial discharges into the Cow Bayou watershed and determined how the domestic wastewater component should be considered for these bacteria TMDLs based on the attributes and information available for each permitted facility (Table 11).

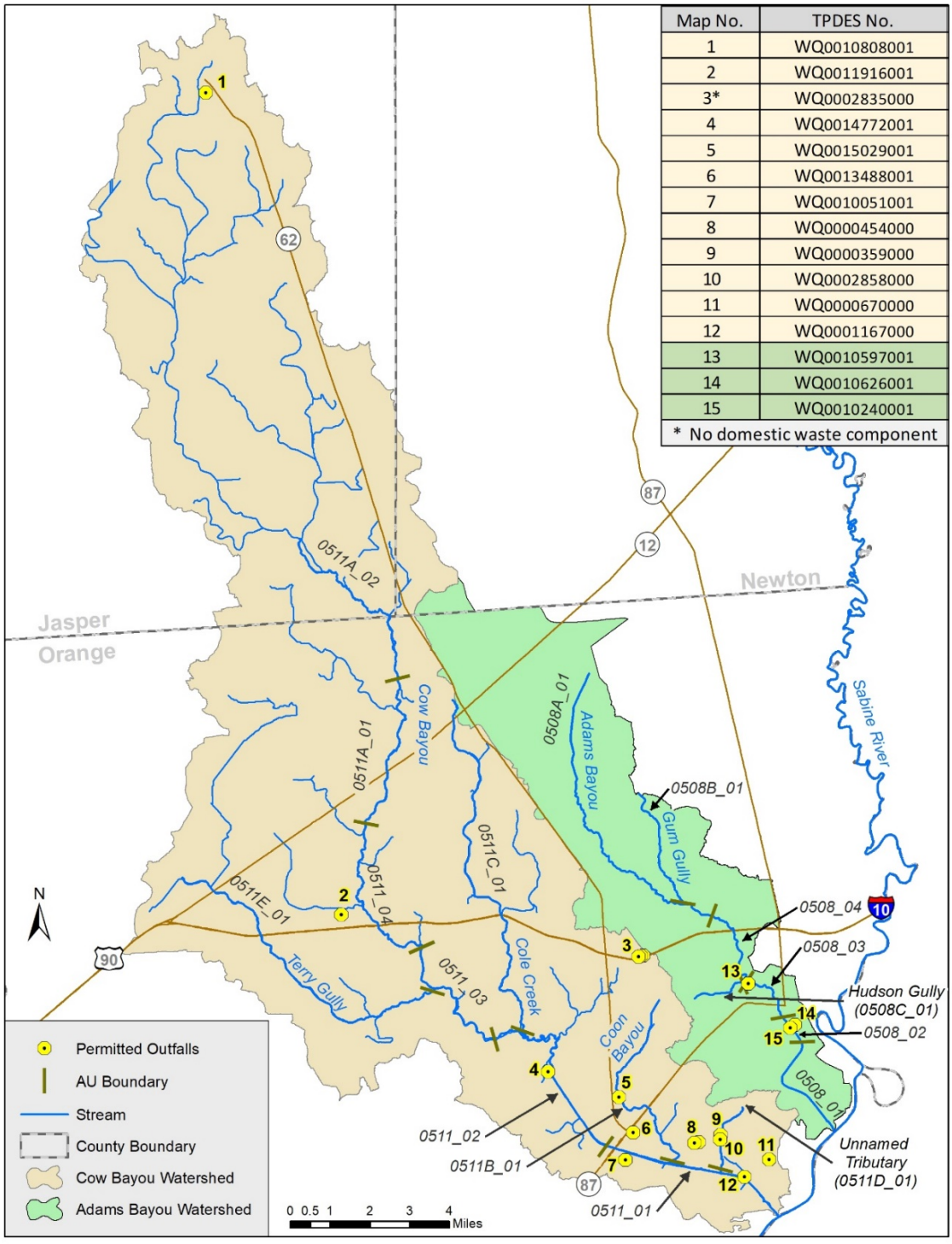

Figure 8. Adams Bayou and Cow Bayou watersheds showing TPDES permitted domestic and industrial regulated discharge facilities.

Table 9. Regulated domestic WWTFs in the Adams Bayou and Cow Bayou watersheds.

Figure 8 Map No.	Permittee	TPDES No. (NPDES No.)	AU	Outfall	Permitted Daily Average BOD_5 (mg/L)	Permitted Daily Average NH_3N (mg/L)	Permitted Daily Average Flow (MGD)	Recent Calculated Discharge[1] (MGD)
1	Jasper County Water Control and Improvement District (WCID) 1	WQ0010808001 (TX0021300)	0511A_02	001	30[2]	6	0.41	0.14
2	PCS Development Company	WQ0011916001 (TX0074250)	0511_04	001	20	Report[3]	0.09	0.0026
4	Orangefield Water Supply Corporation	WQ0014772001 (TX0129313)	0511_02	001	10[2]	2	0.75	0.20
5	Bayou Pines LLC	WQ0015029001[4] (TX0133418)	0511B_01	001	30[2]	8	0.009	NA
6	Gulflander Partners Group, L.P.	WQ0013488001 (TX0106437)	0511B_01	001	20	Report[3]	0.01	0.0044
7	City of Bridge City	WQ0010051001 (TX0025500)	0511_01	001	10	NK	1.6[5]	0.74
13	City of Pinehurst	WQ0010597001 (TX0024171)	0508_03	001	20	Report[3]	0.5	0.34
14	City of Orange[6]	WQ0010626001 (TX0073423)	0508_02	002	20	Report[3]	7.0[6]	1.36[6]
15	Orange County WCID 2	WQ0010240001 (TX0054810)	0508_02	001	10	Report[3]	1.22[5]	0.75

NPDES = National Pollutant Discharge Elimination System; NK = not known – no limit specified in permit; MGD = million gallons per day.

[1] The recent calculated discharge is the calculated average of the reported daily average discharge over the 5-year period of January 2014 through December 2018. This is based on information from discharge monitoring reports (DMRs).

[2] Permit limit is specified as $CBOD_5$

[3] Report – the permittee is required to report NH_3N, but there is no permit limit.

[4] Bayou Pines LLC operates an existing WWTF facility whose permit expired. WQ0015029001 is the permit number assigned to replace the expired permit.

[5] Permit limit is specified as the annual average flow in MGD.

[6] 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 daily discharge for those months of 1.36 MGD. Outfall 001 discharges to the Sabine River.

Table 10. Regulated industrial WWTFs in the Adams Bayou and Cow Bayou watersheds.

Figure 8 Map No.	Permittee	TPDES No. (NPDES No.)	AU	Outfall	Effluent Type [1]	Permitted Daily Average BOD_5 (mg/L)	Permitted Daily Average NH_3N (mg/L)	Permitted Daily Average Flow (MGD)	Recent Calculated Discharge [2] (MGD)
3	Miller Waste Mills, Inc. [3]	WQ0002835000 (TX0104710)	0511_02	001 002 003 [3]	SW IW, SW IW, SW	NK 26 [4] Report [5]	NK NK NK	Report [6] Report [6] Report [6]	0.0065 0.108 NK
8	Lion Elastomers Orange, LLC	WQ0000454000 (TX0002968)	0511_01	001 002	WW, IW, SW SW	11 NK	2 NK	1.202 NRR	0.69 NK
9	Chevron Phillips Chemical Company LP	WQ0000359000 (TX0004839)	0511D_01	001	WW, IW, SW	17.5	NK [7]	3.15	1.10
10	Printpack, Inc.	WQ0002858000 (TX0101192)	0511D_01	001 101	WW, IW, SW WW	NK 20	NK [7] NK	0.085 0.015	0.045 0.0068
11	Honeywell International Inc.	WQ0000670000 (TX0007897)	0511_01	001	WW, IW, SW	10	Report [8]	1.4	0.61
12	ARLANXEO USA LLC	WQ0001167000 (TX0003654)	0511_01	001	WW, IW, SW	3.5	Report [8]	6.0	3.62

NPDES = National Pollutant Discharge Elimination System; NK = not known – no limit specified in permit; NRR = no reporting requirement (stormwater only outfall); MGD = million gallons per day.

[1] Effluent types: WW = treated domestic wastewater; IW = industrial wastewater; SW = industrial stormwater.

[2] The recent calculated discharge is the calculated average of the reported daily average discharge over the five-year period of January 2014 through December 2018. This is based on information from DMRs.

[3] TCEQ received a request to amend permit WQ0002835000 to remove Outfall 003.

[4] No permitted daily average limit; limit is a daily maximum.

[5] Report – the permittee is required to report BOD_5, but there is no permit limit.

[6] Report – the permittee is required to report flow, but there is no permit limit.

[7] The permittee reported NH_3N until 2011 when the NH_3N report requirement expired. There is no permit limit.

[8] Report – the permittee is required to report NH_3N, but there is no permit limit.

Table 11. TCEQ consideration of domestic wastewater component of industrial permits in the Cow Bayou watershed.

Permittee	TPDES No.	NPDES No.	AU	Outfall	Flow (MGD)	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 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.

NPDES = National Pollutant Discharge Elimination System; 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 11.

All six industrial facilities have permitted outfalls for stormwater. Four of these industrial facilities are located entirely within regulated MS4 areas. Two facilities are located outside of regulated 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 their permitted stormwater outfalls.

TPDES/TCEQ Water Quality General Permits

In addition to the individual wastewater discharge permits listed in Tables 9 and 10, certain types of 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
- TXG500000 – quarries in John Graves Scenic Riverway
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations

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. Concrete production facilities are authorized to discharge stormwater and will be considered in the regulated stormwater section. There are two pesticide application authorizations in the watersheds for mosquito control. The pesticide authorizations are not expected to contribute indicator bacteria. No other active general permit facilities or operations were found.

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.

TCEQ maintains a Texas statewide database of SSO data reported by municipalities and industries. A search of the database for the 3-year period of 2016 through 2018 for TPDES permits with service areas included in the Adams Bayou and Cow Bayou watersheds indicated a total of 54 reported SSOs, of which 50 had reported SSO volumes. A summary of the SSO information is provided in Table 12.

Table 12. Summary of SSO incidences reported from 2016 through 2018 for the 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

TPDES-Regulated Stormwater

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

1. Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated MS4s, industrial facilities, and regulated construction activities.
2. Stormwater runoff not subject to regulation.

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

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and

implementing a Stormwater Management Program (SWMP). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the MS4. The permits require that the SWMPs specify the best management practices (BMPs) to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include:

- Public education, outreach, and involvement;
- Illicit discharge detection and elimination;
- Construction site stormwater runoff control;
- Post-construction stormwater management in new development and redevelopment;
- Pollution prevention and good housekeeping for municipal operations; 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 no permits of this nature are applicable to the watersheds of Adams Bayou and Cow Bayou. Discharges of stormwater from a Phase II MS4 area, commercial/industrial facilities, construction sites, or other facilities involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 – stormwater Phase II MS4 general permit for UAs
- TXR050000 – stormwater MSGP for commercial and 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 there were three active construction permits and nine MSGPs in the Adams Bayou watershed and four active construction permits and seven MSGPS in the Cow Bayou watershed. Also, some individual WWTFs are authorized to discharge stormwater under their TPDES individual permits. 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.

The entities regulated under MS4 permits for the watersheds of Adams Bayou and Cow Bayou are provided in Table 13. For the AU subwatersheds containing entities with Phase II general permits, the areas included under these MS4 permits (Figure 9) were used with other information to estimate the regulated stormwater areas for construction, industrial, and MS4 permits. The regulated areas for the Phase II permits were based on the 2010 UA 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. AU 0511C_01 only has three 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 the MS4 permitted area and the total developed land use area in each AU. 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 7 and 8. Estimated area under regulated stormwater industrial permits not within MS4 areas was 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 14 and is based on the 2010 UA. The estimate is based on the relationship of developed land use area to MS4 area, and the estimated regulated stormwater areas for industries located outside of MS4 areas.

Illicit Discharges

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

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (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.

Table 13. TPDES MS4 stormwater permits in the Adams Bayou and Cow Bayou watersheds.

Entity *	TPDES Permit	TPDES Authorization Number	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.

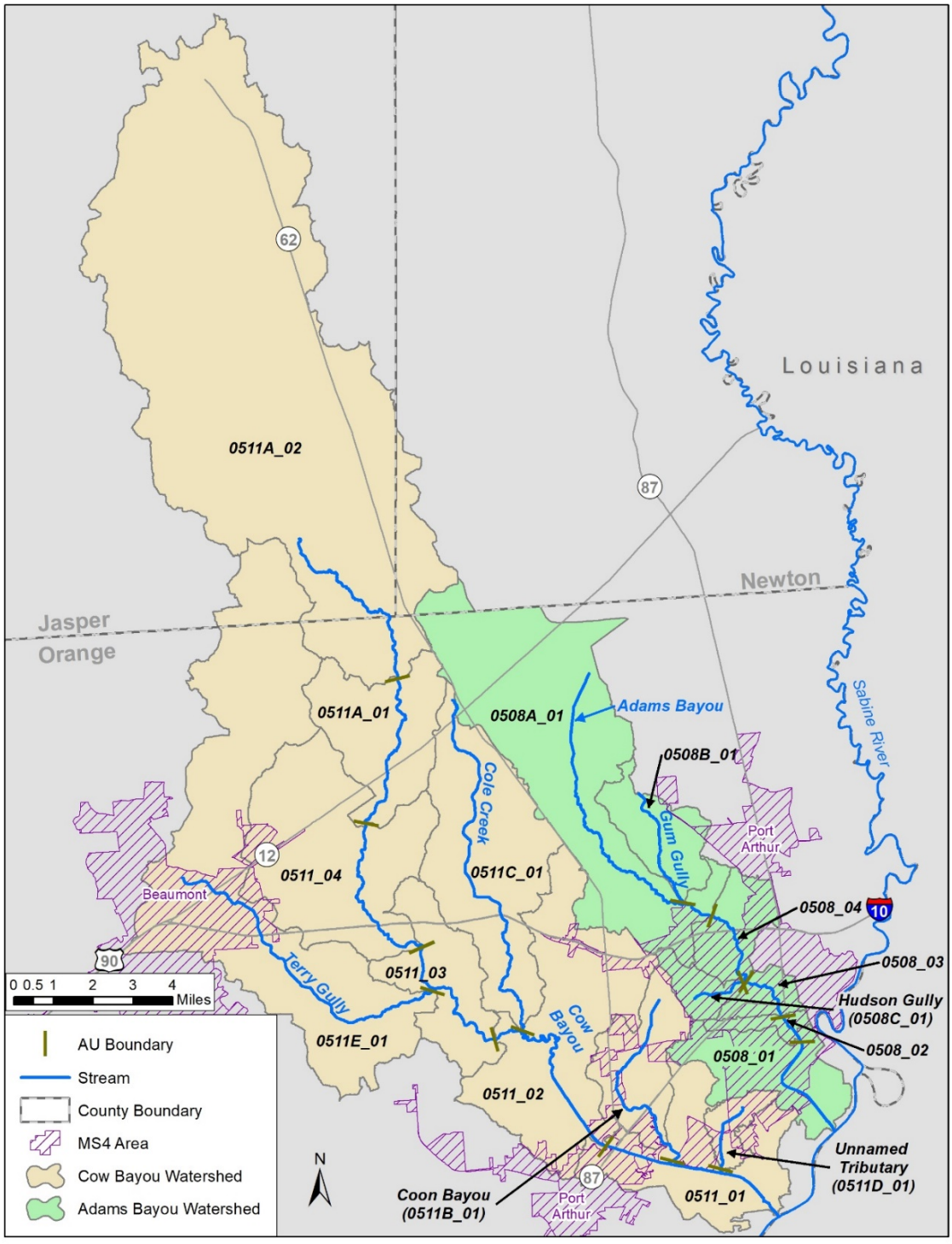

Figure 9. Regulated stormwater areas based on Phase II MS4 permits within the Adams Bayou and Cow Bayou watersheds.

Table 14. Estimated area under stormwater permit regulation for AUs of Adams Bayou and Cow Bayou.

Segment Name	AU	Estimated Stormwater Regulated Area 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 (%)
Adams Bayou Tidal	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
Adams Bayou Above Tidal	0508A_01	707	16,778	4.21	3.93
Gum Gully	0508B_01	70	3,010	2.33	2.33
Hudson Gully	0508C_01	1,170	1,178	99.32	99.32
Cow Bayou Tidal	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
Cow Bayou Above Tidal	0511A_01*	70	5,975	1.17	0.43
	0511A_02*	165	49,125	0.34	0.34
Coon Bayou	0511B_01	1,137	4,079	27.87	27.87
Cole Creek	0511C_01*	170	10,453	1.63	1.63
Unnamed Tributary to Cow Bayou Tidal	0511D_01	699	1,155	60.52	60.52
Terry Gully	0511E_01	4,098	22,273	18.40	18.40

* For these AUs dominated by rural land uses, regulated stormwater area was based on an empirical relationship developed between the MS4 permitted area and the total developed land use area in each AU, plus for 0511C_01, an estimated stormwater area for a small MSGP facility.

Unregulated Sources

Unregulated sources of pollutants entering surface water bodies are generally nonpoint. NPS pollutant loadings enter impaired segments through distributed, nonspecific locations, which may include urban runoff not covered by a permit.

Unregulated Agricultural Activities and Domesticated Animals

A number of agricultural activities that do not require permits can be potential sources of loadings of fecal bacteria, $CBOD_5$, and NH_3N, and other pollutants relevant to these TMDLs. 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 agricultural activities at the county level (USDA, 2019). In addition to hay and other forage, the other major crop in Orange County is rice, but this is primarily outside the watersheds of Adams Bayou and Cow Bayou. Cattle are the most abundant large livestock animal based on 2017 county-level data, which was used along with 2016 NLCD land use data to estimate livestock and domestic animal populations in the Adams Bayou and Cow Bayou watersheds (Table 15). Other abundant livestock include chickens, quail, goats, and horses. The estimated livestock and domestic animal populations were reviewed by Texas State Soil and Water Conservation Board (TSSWCB) staff.

Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute bacteria and oxygen demanding constituents 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.

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 loadings of bacteria and oxygen demanding substances.

Table 15. Estimated domesticated animal populations for the 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

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
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] Adams Bayou Watershed Tidal portion includes the watersheds for AUs 0508_01, 0508_02, 0508_03, 0508_04, and 0508C_01.

[2] Adams Bayou Watershed Above Tidal portion includes the watersheds for AUs 0508A_01 and 0508B_01.

[3] Cow Bayou Watershed 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.

[4] Cow Bayou Watershed Above Tidal portion includes the watersheds for 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

Table 16 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 loads of fecal bacteria and oxygen demanding substances from pets is unknown.

Table 16. Estimated households and pet populations for the Adams Bayou and Cow Bayou watersheds.

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

Wildlife and Unmanaged Animal Contributions

Fecal 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 the 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 they may be washed into nearby streams by rainfall runoff.

Fecal matter from wildlife is generally not considered as important a source of oxygen demanding substances. However, oxygen demanding substances (represented by $CBOD_5$) and NH_3N are present in their waste and can also be contributed to streams via direct deposition and deposition onto land surface with subsequent wash-off during rainfall runoff. 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.

However, population estimates for feral hogs and deer can be made from existing information for the Adams Bayou and Cow Bayou watershed. 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 2016 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.

On-Site Sewage Facilities

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

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01 percent 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 this question. 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 10). 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 have 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 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.

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.

Linkage Analysis for Bacteria

Establishing the relationship between instream water quality and the source of fecal bacteria loadings is an important component in developing bacteria TMDLs. It allows for the evaluation of management options that will help achieve the desired endpoint. This 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 these flows, the 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 regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff has the capacity to carry 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 stormwater runoff enters the receiving stream. Over time, the concentrations can decline because the sources of bacteria are reduced as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

LDCs were used to examine the relationship between instream water quality and the source of 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 allocations. 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.

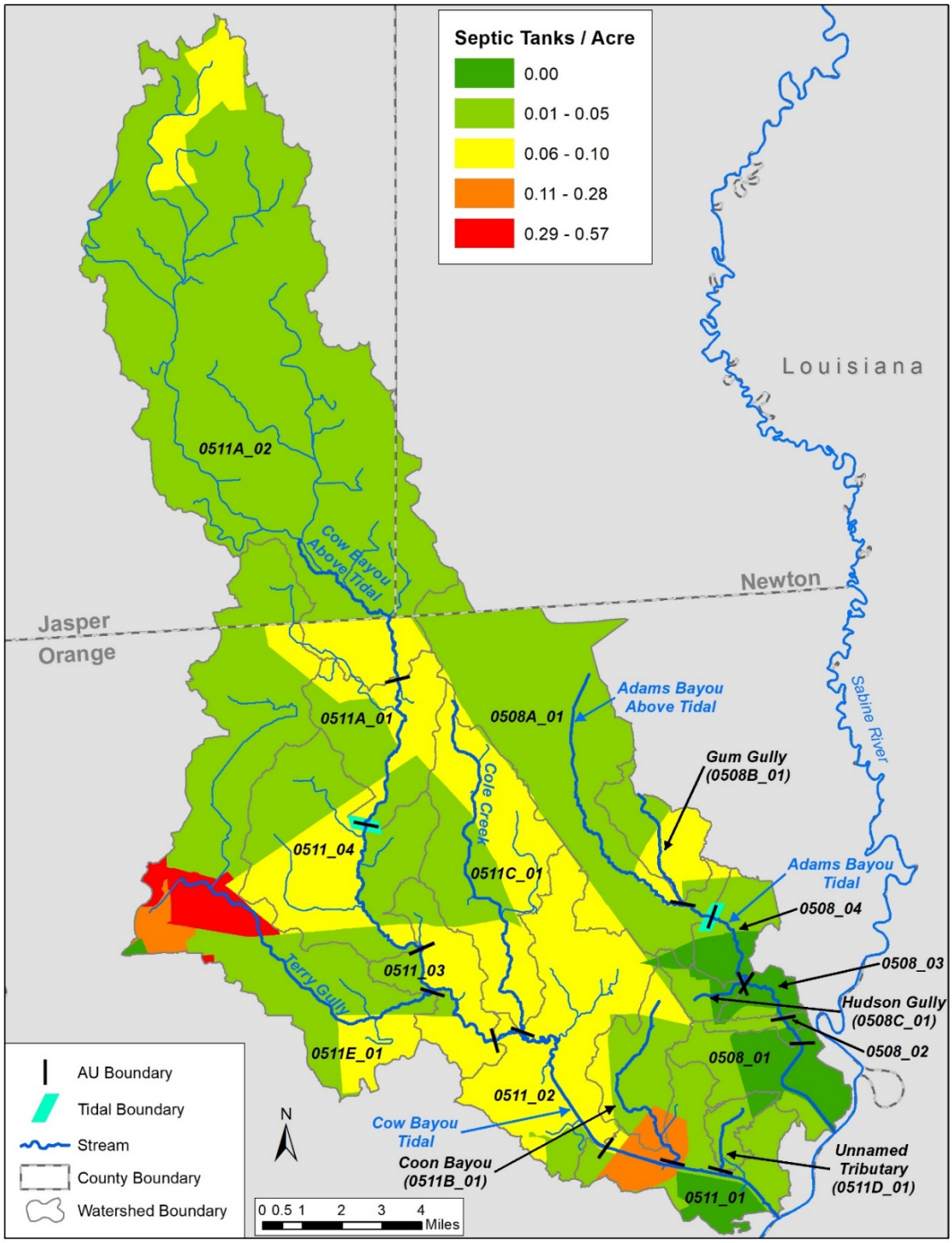

Figure 10. Septic tank densities within the Adams Bayou and Cow Bayou watersheds based on 1990 federal census data.

Deterministic 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 predominant 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, 2018a).

The LDC method has been selected for use in these TMDLs to provide greater consistency of the bacteria pollutant load allocation process for the impaired AUs of Adams Bayou and Cow Bayou, and their associated tributaries. As will be discussed 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.

Load Duration Curve Analysis

The standard LDC method was used for the impaired freshwater streams and the modified LDC method was used for the impaired tidal streams to examine the relationship between instream water quality and the broad sources of 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 simple statistical methods that provide a basic description of the water quality problem. These tools are easily developed and explained and use 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 LDC method, both standard and modified, 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 was 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 deterministic models. Further, the Bacteria Task Force appointed by TCEQ and TSSWCB 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 source and NPS.

The modified LDC method is based on the assumption that the combining of freshwater with saltwater increases the loading capacity in the tidal river because saltwater typically contains lower concentrations of enteric bacteria than freshwater (ODEQ, 2006). More details on the modified LDC method are provided later in this section and in Appendix A.

Data requirements for the LDC are minimal compared to the requirements for deterministic computer models. 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 duration curves (FDCs) and LDCs. In the modified LDC approach, salinity data provide a measure of the degree of mixing of saltwater 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, are used to define the drainage area of each station for which FDCs and LDCs were developed.

Hydrologic data in the form of daily streamflow records were available from the USGS (USGS, 2019), which operates the sole streamflow gauge in the study area on Cow Bayou in the above tidal AU 0511A_01 (Figure 4). This gauge serves as the primary source for streamflow records used in developing standard and modified FDCs and LDCs.

Self-reported data for each TPDES permitted facility, in the form of monthly discharge monitoring 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. The DMR data are used to estimate adjustments to streamflow resulting from WWTF discharges upstream of a location.

While ambient Enterococci and *E. coli* data were available for several stations in the watersheds of Adams Bayou and Cow Bayou, only station 10441 in Adams Bayou Tidal AU 0508_01 and station 10449 in Cow Bayou Tidal AU 0511_01 are

currently monitored (Figure 4). At these two stations, the indicator bacteria collected are Enterococci. The selection of other stations was based on 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 impaired 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 impaired AU as being a freshwater stream or a tidal stream, with the modified approach necessitated at tidal streams (Table 17).

The FDCs were generated by:

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

Table 17. List of bacteria impaired 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
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
18377	Terry Gully (Freshwater Stream)	0511E_01	*E. coli* / Enterococci *	Standard

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e. freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

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.

Bacteria LDCs were developed by multiplying each streamflow value along the FDCs by the Enterococci geometric mean criterion (35 cfu/100 mL) or *E. coli* geometric mean criterion (126 cfu/100 mL) and by the conversion factor to convert to loading in colonies per day. This effectively displays the LDC as the curve of maximum allowable loading:

> TMDL (billion cfu/day) = Criterion * Flow in cubic feet per second (cfs) * Conversion Factor

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

The resulting curve plots each bacteria load value (y-axis) against its exceedance value (x-axis). Exceedance values along the x-axis represent the percent of days that the bacteria load was at or above the allowable load on the y-axis.

LDCs were created for every bacteria-impaired AU in the Adams Bayou and Cow Bayou watersheds. The SWQM stations used to develop the LDCs are shown in Figure 4. For the LDCs developed for station 10441 in Adams Bayou AU 0508_01 and station 10449 in Cow Bayou AU 0511_01, historical Enterococci data were available from the TCEQ's Surface Water Quality Monitoring Information System (SWQMIS) database and were superimposed on the allowable bacteria LDCs. Each historical Enterococci measurement was associated with the flow on the day of measurement and converted to a bacteria load. For both stations, the associated flow for each bacteria loading was compared to the FDC data to determine its value for "percent days flow exceeded," which becomes the "percent of days load exceeded" value for purposes of plotting the Enterococci loading. Each load was then plotted on the LDC at its percent exceedance. This process was repeated for each Enterococci measurement. Points above the LDC curves represent exceedances of the bacteria geometric mean criterion and their associated loadings.

As a further refinement, the historical Enterococci points on the LDCs for stations 10441 and 10449 were symbolized according to whether the sampling event was considered to be a wet or non-wet weather event based on past

rainfall. A sample was determined to be influenced by a wet weather event based on the "days since last precipitation" (DSLP) 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 data users of the general climatic conditions. A wet weather event was defined as a sample collected on any date with DSLP of four days or less.

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of FDCs and LDCs. The hydrologic classification scheme utilized for the TMDL watersheds is as follows: 0-10 percent (highest flows); 10-60 percent (mid-range flows); and 60-100 percent (lowest flows). Additional information explaining the LDC method may be found in Cleland (2003) and Nevada Division of Environmental Protection (NDEP, 2003) for the standard LDC method and in Oregon Department of Environmental Quality (2006) for the modified LDC method.

The five percent exceedance or median loading of the highest flow regime (0–10 percent exceedance range) for the LDC representing the geometric mean criterion is used for the TMDL calculations of the impaired AU. The five percent exceedance is used for the TMDL calculations, because it represents the pollutant loading value at the critical high flow conditions.

An important observation is that under the highest flow regime used for the TMDL calculations, there was no saltwater volume computed as being present at any stations where the modified LDCs were developed. At the critical high flow conditions, saltwater is effectively pushed out of the creek by the freshwater inflows present under the "highest flow" regime. With an absence of saltwater at these high flows, the modified LDC results are effectively simplified to those of the LDC method without any adjustments to accommodate tidal influences.

More details on the methods used to develop the LDCs may be found in the *Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Adams Bayou, Cow Bayou, and Associated Tributaries* (Hauck and Adams, 2020), hereafter referred to as the TSD.

Load Duration Curve Results

All LDC curve results for bacteria-impaired AUs in the Adams Bayou and Cow Bayou watersheds can be found in the TSD. To demonstrate the LCD method, the following example is provided. The LDCs developed for station 10441 in Adams Bayou Tidal AU 0508_01 and station 10449 in Cow Bayou Tidal AU 0511_01 are provided in Figures 11 and 12. The two LDCs provide a means of identifying the streamflow conditions under which exceedances in Enterococci concentrations have occurred in the respective streams. For both LDCs, the wet

weather data points occurred, as expected, most frequently under the higher flow regimes and consistently exceeded the geometric mean criterion.

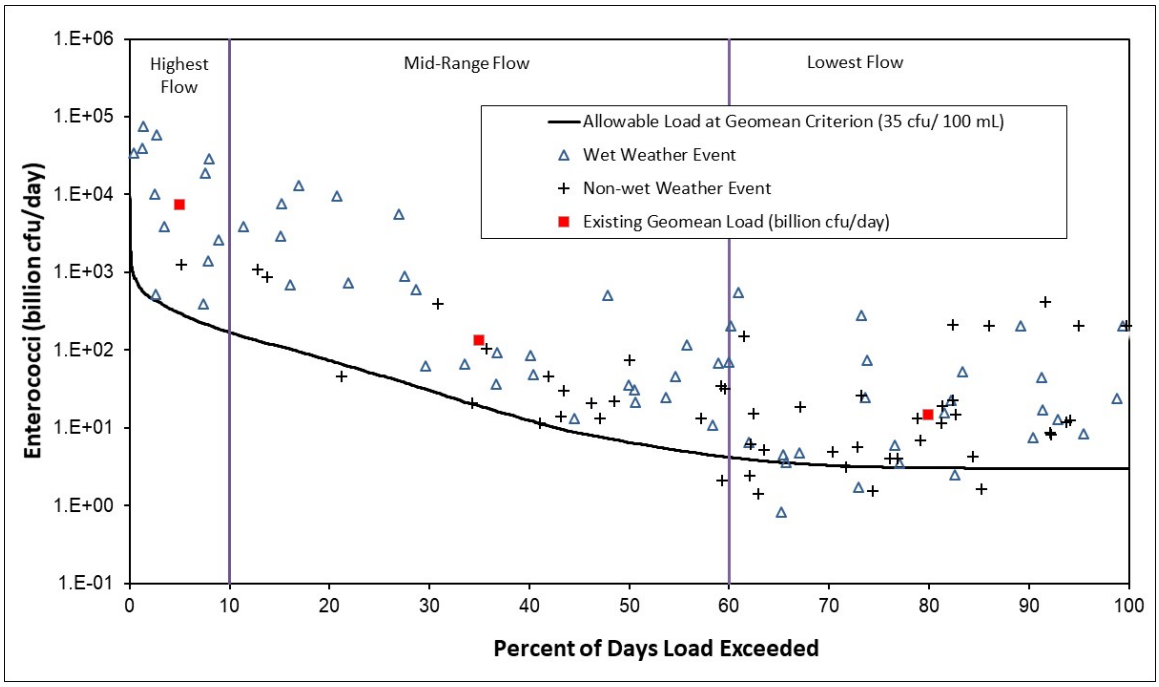

Figure 11. Load duration curve at Station 10441 on Adams Bayou Tidal (AU 0508_01) for the period of January 1, 2003 through December 31, 2018.

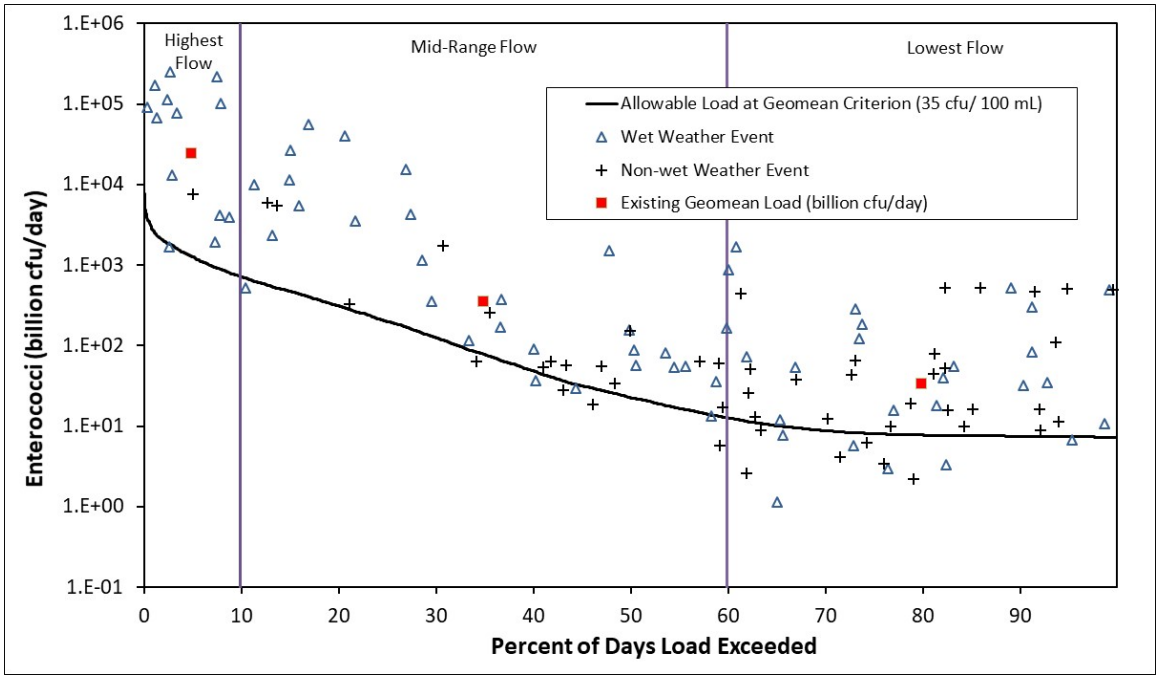

Figure 12. Load duration curve at Station 10449 on Cow Bayou Tidal (AU 0511_01) for the period of January 1, 2003 through December 31, 2018.

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 the geometric mean criterion 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 at the same level horizontally to one another. 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.

Margin of Safety for Bacteria

The margin of safety (MOS) is used to account for uncertainty in the analysis used to develop the TMDL and thus provide 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 an MOS.

The bacteria TMDLs covered by this report incorporate an explicit MOS of five percent of the total TMDL allocation.

Pollutant Load Allocation for Bacteria

The TMDL represents the maximum amount of a pollutant that the stream 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:

$$TMDL = WLA + LA + FG + MOS$$

Where:

TMDL = total maximum daily load

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

As stated in 40 CFR 130.2(i), 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.

The TMDL component for each impaired AU addressed in this report is derived using the median flow within the highest flow regime (or five percent exceedance flow) of the LDC developed for the selected SWQM station in each impaired AU (Table 17). The following sections will present an explanation of the TMDL component, followed by the results of the calculation for that component.

AU-Level TMDL Computations

The bacteria TMDLs for the six impaired AUs of the Adams Bayou watershed and five impaired AUs of the Cow Bayou watershed were developed as a pollutant load allocation based on information from LDCs developed in each AU. As discussed in more detail in the section of this document titled "Load Duration Curve Analysis," 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 five percent exceedance value (the median value of the highest-flow regime) is the TMDL:

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

Where:

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

Flow = the five 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 five percent load duration, the TMDL values are provided in Table 18.

Table 18. Summary of allowable loading calculations for the impaired AUs in Adams Bayou, Cow Bayou and associated tributaries.

Water Body	Station	AU	5% Exceedance Flow (cfs)	Indicator Bacteria	TMDL (Billion cfu/day)
Adams Bayou Tidal	10441	0508_01	349.0	Enterococci	298.849
	10442	0508_02	310.8	Enterococci	266.138
	16059	0508_03	300.8	Enterococci	257.575
	14990	0508_04	265.6	Enterococci	227.433
Gum Gully	16049	0508B_01	23.08	*E. coli*	71.148
Hudson Gully	16041	0508C_01	13.85	Enterococci	11.860
Cow Bayou Tidal	10449	0511_01	1,490	Enterococci	1,275.887
	13781	0511_03	1,107	Enterococci	947.924
	10457	0511_04	804.1	Enterococci	688.551
Coon Bayou	16052	0511B_01	43.54	Enterococci	37.283
Terry Gully	18377	0511E_01	270.2	*E. coli*	832.940
				Enterococci*	231.372

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e. freshwater or tidal), pollutant allocations for both *E. coli* and Enterococci were developed using the LDC method.

Margin of Safety for Bacteria TMDLs

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

MOS = 0.05 * TMDL

Where:

MOS = margin of safety load

TMDL = total maximum daily load

Since the MOS is based solely on the TMDL component of the equation, the calculation is straight forward (Table 19).

Table 19. MOS for impaired 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
	0508_02	Enterococci	266.138	13.307
	0508_03	Enterococci	257.575	12.879
	0508_04	Enterococci	227.433	11.372
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
	0511_03	Enterococci	947.924	47.396
	0511_04	Enterococci	688.551	34.428
Coon Bayou	0511B_01	Enterococci	37.283	1.864
Terry Gully	0511E_01	*E. coli*	832.94	41.647
		Enterococci*	231.372	11.569

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Wasteload Allocation for Bacteria

The WLA consists of two parts—the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW}$$

WWTFs

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

$$WLA_{WWTF} = \text{Criterion} * \text{Flow} * \text{Conversion Factor}$$

Where:

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

Flow = full permitted flow in million gallons per day (MGD)

Conversion Factor (to billion cfu/day) = 1.547 cfs/MGD *283.168 deciliters (100 mL)/cubic feet (ft^3) * 86,400 seconds per day (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 WWTF and added for the AU subwatershed.

Table 20 presents the WLAs for each individual WWTF located within its respective 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 six months of non-zero discharge reported for Outfall 002. The average discharge of those six 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 WLA within this TMDL because there is no human waste component associated with its discharge, therefore this facility is not included in Table 20.

Table 21 presents the wasteload allocation for WWTFs by AU considering all WWTFs located in an AU plus all upstream WWTFs.

Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of 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. The LA component of the TMDL corresponds to unregulated nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$$

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

To calculate the WLA_{SW} component of the TMDL, the FDA_{SWP} must be determined. The FDA_{SWP} was calculated based on the combined area under regulated stormwater permits (Table 14). In order to calculate WLA_{SW}, the FG term must be known. The calculation for the FG term is presented later, in a separate section of this report, but the results will be included in the following table (Table 22) for continuity. Table 22 provides the information needed to compute WLA_{SW}.

Once the WLA_{SW} and WLA_{WWTF} components are known, the WLA component can be calculated as the sum of the two parts, as shown in Table 23.

In urbanized areas currently regulated by an MS4 permit, development and/or re-development of land in urbanized areas must implement the control measures and programs outlined in an approved SWMP. Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in the TPDES permit and the SWMP.

An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality.

Table 20. Wasteload allocations for TPDES-permitted facilities in the Adams Bayou and Cow Bayou watersheds.

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

NA = Not Applicable.

[a] Permitted Daily Average Flow from Tables 9 and 10.

[b] 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 for those 6 months of 1.36 MGD which was used in Table 20. The flow of 1.36 MGD was assigned to this facility for pollutant load allocation purposes. Outfall 001 discharges to the Sabine River.

[c] WLAs for WWTFs discharging into AU 0511D_01 (Unnamed Tributary of Cow Bayou) are associated with the TMDL calculated for 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.

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

Table 21. Wasteload allocation for WWTFs (WLA_{WWTF}) of the impaired AUs of Adams Bayou, Cow Bayou, and associated tributaries.

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
	10442	0508_02	Enterococci	3.080	4.081
	16059	0508_03	Enterococci	0.500	0.662
	14990	0508_04	Enterococci	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
	13781	0511_03	Enterococci	0.500	0.662
	10457	0511_04	Enterococci	0.500	0.662
Coon Bayou	16052	0511B_01	Enterococci	0.019	0.025
Terry Gully	18377	0511E_01	*E. coli*	0.000	0.000
			Enterococci*	0.000	0.000

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

** Includes full permitted flow of WWTFs in impaired and unimpaired (or unassessed) AUs.

Table 22. Regulated stormwater calculations for impaired AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day.

Water Body	Station	Segment	Indicator Bacteria	TMDL	WLA_{WWTF}	FG	MOS	FDA_{SWP}	WLA_{SW}
Adams Bayou Tidal	10441	0508_01	Enterococci	298.849	4.081	0.349	14.942	0.2795	78.114
	10442	0508_02	Enterococci	266.138	4.081	0.337	13.307	0.2234	55.495
	16059	0508_03	Enterococci	257.575	0.662	0.132	12.879	0.2028	49.463
	14990	0508_04	Enterococci	227.433	0.000	0.036	11.372	0.1193	25.772
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
	13781	0511_03	Enterococci	947.924	0.662	0.065	47.396	0.0543	48.859
	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
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

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Table 23. Wasteload allocation calculations for impaired AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day.

Water Body	Station	Segment	Indicator Bacteria	WLA_{WWTF}	WLA_{SW}	WLA
Adams Bayou Tidal	10441	0508_01	Enterococci	4.081	78.114	82.195
	10442	0508_02	Enterococci	4.081	55.495	59.576
	16059	0508_03	Enterococci	0.662	49.463	50.125
	14990	0508_04	Enterococci	0.000	25.772	25.772
Gum Gully	16049	0508B_01	*E. coli*	0.000	1.574	1.574
Hudson Gully	16041	0508C_01	Enterococci	0.000	11.178	11.178
Cow Bayou Tidal	10449	0511_01	Enterococci	5.565	95.500	101.065
	13781	0511_03	Enterococci	0.662	48.859	49.521
	10457	0511_04	Enterococci	0.662	8.560	9.222
Coon Bayou	16052	0511B_01	Enterococci	0.025	9.861	9.886
Terry Gully	18377	0511E_01	*E. coli*	0.000	145.590	145.590
			Enterococci*	0.000	40.442	40.442

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Load Allocation

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

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$$

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 regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 24.

Allowance for Future Growth

The FG component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future.

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

The FG component of impaired AUs in the Adams Bayou and Cow Bayou watersheds was based on the projected percent population increase information between 2020 and 2070 (provided previously in Table 5) and the existing full permitted discharge for each WWTF within the watersheds (Tables 9, 10, and 20). 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 subwatershed of the AU or whenever the computed FG discharge for an AU, based on WWTFs within the immediate sub-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 20). While the FG allowance is computed using information from existing WWTF permits, it is not intended to restrict any future assignments of this allocation solely to expansions at these facilities. Rather, the FG allocation is purposed for any new facilities that may occur and expansions of existing facilities.

$$FG = Criterion * [\%POP_{2020\text{-}2070} * WWTF_{FP}] * Conversion\ Factor$$

Where:

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

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

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

Conversion Factor = 1.547 cfs/MGD *283.168 deciliters (100 mL)/cubic feet (ft^3) * 86,400 seconds per day (s/d) * 1.0E-09 billion = 0.03785412

The calculation results for the impaired and some unimpaired AU subwatersheds are shown in Table 25.

Table 24. Load allocation calculations for the impaired AUs of Adams Bayou, Cow Bayou and associated tributaries.

Load units expressed as billion cfu/day

Water Body	Station	AU	Indicator Bacteria	TMDL	WLA_{WWTF}	WLA_{SW}	FG	MOS	LA
Adams Bayou Tidal	10441	0508_01	Enterococci	298.849	4.081	78.114	0.349	14.942	201.363
	10442	0508_02	Enterococci	266.138	4.081	55.495	0.337	13.307	192.918
	16059	0508_03	Enterococci	257.575	0.662	49.463	0.132	12.879	194.439
	14990	0508_04	Enterococci	227.433	0.000	25.772	0.036	11.372	190.253
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
	13781	0511_03	Enterococci	947.924	0.662	48.859	0.065	47.396	850.942
	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
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

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Summary of TMDL Calculations for Bacteria

Table 26 summarizes the TMDL calculations for the six impaired AUs of the Adams Bayou watershed and the five impaired AUs of the Cow Bayou watershed. The TMDL was calculated based on the median load in the 0-10 percentile range (five percent exceedance, highest flow regime) for load 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 27) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Seasonal Variation in Indicator Bacteria

Seasonal variations (or seasonality) occurs 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.

For example, 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 Tidal and station 10449 on Cow Bayou Tidal. 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 (α=0.05, p=<0.01) and Cow Bayou (α=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 28). 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 28.

Table 25. FG calculations for the impaired 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
	10442	0508_02	Enterococci	0.2544	0.337
	16059	0508_03	Enterococci	0.0995	0.132
	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
	13781	0511_03	Enterococci	0.0491	0.065
	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: 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.

† AU 0511C_01 is not impaired for bacteria; it is included in Table 25 for the purpose of showing its flow contribution to FG in downstream AUs.

** TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Table 26. TMDL allocation summary for the impaired 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
	10442	0508_02	Enterococci	266.138	55.495	4.081	192.918	0.337	13.307
	16059	0508_03	Enterococci	257.575	49.463	0.662	194.439	0.132	12.879
	14990	0508_04	Enterococci	227.433	25.772	0.000	190.253	0.036	11.372
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
	13781	0511_03	Enterococci	947.924	48.859	0.662	850.942	0.065	47.396
	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
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 18.

[b] WLA_{SW} = from Table 22.

[c] WLA_{WWTF} = from Table 21.

[d] LA = from Table 24.

[e] FG = from Table 25.

[f] MOS = from Table 19.

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Table 27. Final TMDL allocations for the impaired 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
	0508_02	Enterococci	266.138	4.418	55.495	192.918	13.307
	0508_03	Enterococci	257.575	0.794	49.463	194.439	12.879
	0508_04	Enterococci	227.433	0.036	25.772	190.253	11.372
Gum Gully	0508B_01	*E. coli*	71.148	0.043	1.574	65.974	3.557
Hudson Gully	0508C_01	Enterococci	11.860	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
	0511_03	Enterococci	947.924	0.727	48.859	850.942	47.396
	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
Terry Gully	0511E_01	*E. coli*	832.940	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.

* TCEQ assesses Terry Gully (AU 0511E_01) as a freshwater stream using *E. coli* as the indicator bacteria. However, a portion of the AU may be tidally influenced. To anticipate any potential future changes in the characterization of Terry Gully (i.e., freshwater or tidal), pollutant load allocations for both *E. coli* and Enterococci were developed using the LDC method.

Table 28. 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

It should be noted that the criteria used by TCEQ to assess recreational uses apply to water bodies during all seasons of the year. Therefore, seasonal variation is accounted for in the bacteria TMDLs presented in this document by virtue of the fact that these variations affect neither the calculation nor the implementation of bacteria TMDLs in Texas.

Linkage Analysis for DO and pH

Establishing the relationship between instream water quality and the source of loads of oxygen demanding substances is an important component in developing DO TMDLs. It allows for the evaluation of management options that will achieve the desired endpoint. This relationship may be established through a variety of techniques.

For these TMDLs, the primary oxygen demanding substances are considered as CBOD, as represented by its common laboratory analysis of $CBOD_5$, and NH_3N. Both $CBOD_5$ and NH_3N are the common parameters given limits in TPDES permits for maintaining appropriate DO levels in receiving waters. The linkage analysis for the pH impairment in AU 0511_04 is discussed later in this document.

Prior to discussing the DO modeling system, further discussion of the two oxygen demanding substances of $CBOD_5$ and NH_3N are warranted. Biochemical oxygen demand (BOD) is comprised of carbonaceous and nitrogenous components. These two components comprise the primary oxygen demanding substances included in the DO TMDLs. Most TPDES municipal WWTF permits, for which NH_3N limits are not stipulated, have a limit for BOD_5, which requires laboratory analysis of effluent measuring carbonaceous and nitrogenous oxygen

demand over a five-day period. If a WWTF permit has an NH_3N limit, then a $CBOD_5$ permit limit is required, which necessitates that the five-day laboratory test be conducted using an inhibitor that reduces the nitrogenous oxygen demand being measured, and separate laboratory analysis for NH_3N. Additionally, $CBOD_5$ represents some fraction of the total CBOD that would result if the test were conducted for a longer period. Based on statistical analysis of CBOD data collected in Adams Bayou and Cow Bayou, a multiplier of 3.0 was used to convert $CBOD_5$ to ultimate CBOD in the development of the DO TMDLs.

DO Modeling System

The linkage analysis for the DO TMDLs was performed through the operation of a modeling system comprised of the following components:

- a hydrologic and water quality model of the watershed and above tidal reaches developed using the Hydrologic Simulation Program – FORTRAN (HSPF),
- an in-stream hydrodynamic model for the tidal reaches developed using the River Management Associates-2 (RMA2) simulation software,
- a water quality model for the tidal reaches, developed using the Water Quality Analysis Simulation Program (WASP) simulation software,
- accessory programs to link the three models, and
- a user interface to edit model inputs and review model outputs.

Figure 13 illustrates the basic structure of the modeling system used in the linkage analysis for the DO TMDLs. The HSPF model serves as the hydrologic and water quality model for the above tidal reaches of Adams and Cow Bayous and associated tributaries. HSPF does not have the capacity to simulate tidal flows and water quality. HSPF subbasins and reaches are split at the upper tidal boundary of each stream and major tributary, and similarly, the RMA2 and WASP models extend only up to this tidal boundary. At this tidal boundary, the HSPF-simulated instream flows serve as boundary flow conditions for the RMA2 hydrodynamic model. Similarly, the HSPF-simulated loads of water quality constituents serve as boundary input loads to the WASP water quality model.

The HSPF watershed model also simulates runoff flows and water quality constituents to portions of the watershed that run off directly to tidal reaches of Adams Bayou, Cow Bayou, and associated tributaries. The model linkages of HSPF output involve straightforward spatial and temporal aggregations, unit conversions, and data format modifications. The RMA2 linkage to WASP includes these, as well as conversions from water velocity to flow based on cross-sectional area. The linkages were created using utility programs. Modeling system applications were developed for the Adams Bayou watershed and its water bodies and the Cow Bayou watershed and its water bodies.

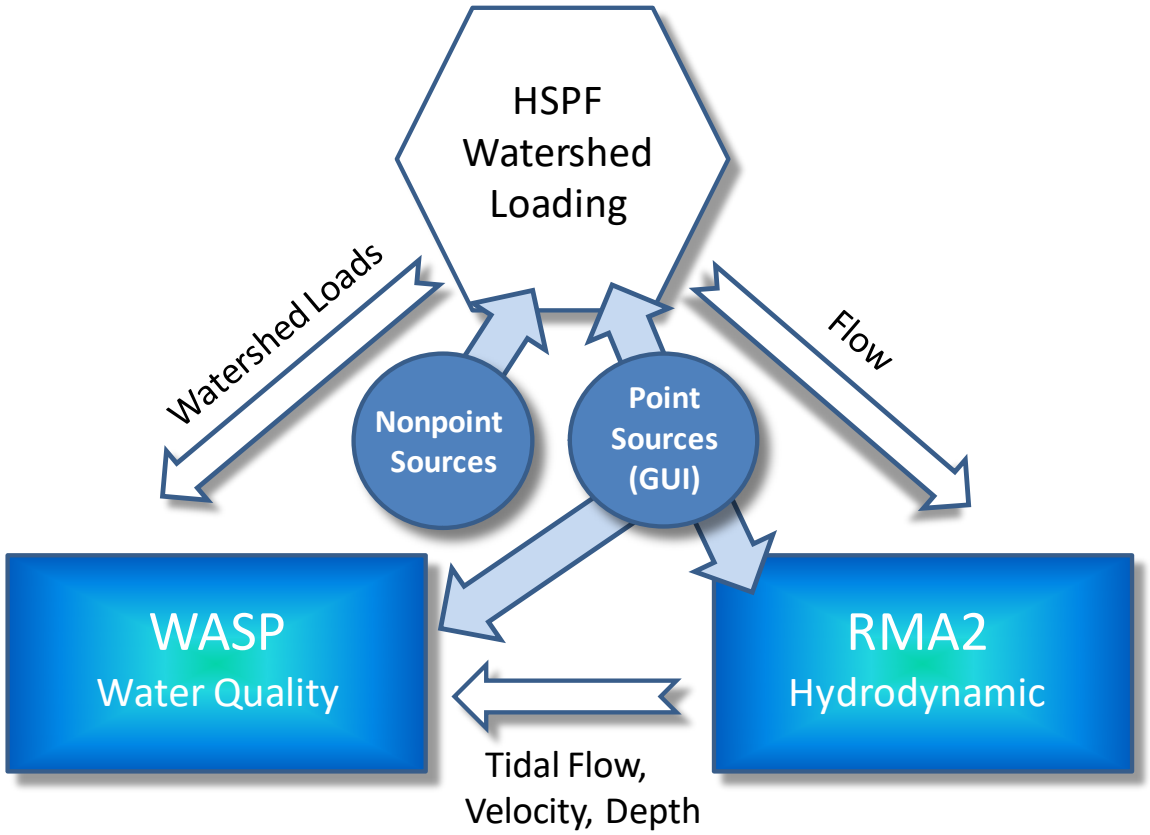

Figure 13. Schematic of modeling system.

Within the HSPF model, the Adams Bayou watershed was divided into 12 subbasins and the Cow Bayou watershed was divided into 18 subbasins. Within the WASP model, the Adams Bayou tidal stream network was divided into 118 model segments averaging 187 meters (614 feet) in length and the Cow Bayou tidal stream network was divided into 136 model segments averaging 360 meters (1,181 feet) in length. The RMA2 segmentation was designed with compatibility to the WASP segmentation to allow RMA2 simulated flows, depths, and water levels to readily be used as input into WASP.

More details on the modeling system, the calibration and validation of the modeling system, and its application for various scenarios may be found in the *Technical Support Document for Total Maximum Daily Loads for Dissolved Oxygen and pH in Adams Bayou, Cow Bayou, and Associated Tributaries* (Hauck et al., 2020).

Verification of the Modeling System Simulations

The simulations conducted using each of the component models of the modeling system required verification to ensure proper operation of HSPF, RMA2, and WASP. Model verification is a two-step process by which each model's pertinent predictions (i.e., flow and water quality for HSPF, flow for RMA2, and water quality for WASP) are first calibrated against measured data. In the second step, model predictions are independently validated against additional measured data. For the modeling system used for these TMDLs, the verification process begins with the HSPF models, which represent watershed conditions of the Adams Bayou watershed and the Cow Bayou watershed. The verified HSPF predictions of flow, as shown on Figure 13, are then used as inputs to RMA2. The RMA2 models of the tidal stream networks of Adams Bayou and Cow Bayou are then verified. Last in the sequence of verification is WASP, which uses watershed loads from HSPF and tidal flows, velocities, and depths from RMA2, as shown on Figure 13. All activities of the verification of these three models occurred under the coverage of annual renewals of a quality assurance project plan (QAPP) approved by TCEQ (TIAER, 2019).

The verification of flow for HSPF used the daily streamflow measurements from the USGS-operated flow gauging station on Cow Bayou (08031000) as shown in Figure 14. HSPF water quality verification was based predominantly on intensive surveys of water quality parameters measured at several locations on the Adams Bayou stream network during May 23-28, 2004 and June 28-July 1, 2004 and in the Cow Bayou stream network during July 17-22, 2004 and August 23-26, 2004. The station identifiers used for the locations monitored during these intensive surveys is provided in Figure 14. The verification of the RMA2 models of the tidal streams of the Adams Bayou watershed and of the Cow Bayou watershed relied on flows and water levels measured during the same intensive surveys as were used for the testing of the HSPF models. Finally, verification of the WASP models used measured water quality parameters from the same Adams Bayou watershed and Cow Bayou watershed intensive surveys at the same locations used to verify the RMA2 models.

During the calibration process of each model, the input parameters to which the model was most sensitive were adjusted, within literature-recommended ranges or as indicated from watershed specific data, to improve the model results. Improvement of model simulated results was measured through comparisons to measured data from the intensive surveys selected for calibration using statistical performance targets specified in the QAPP and through visual review of graphical presentations of the simulated and measured data. For the validation process, the input parameters optimized during the calibration

process were used to operate each model, and the simulated results were compared to the verification data from the intensive surveys.

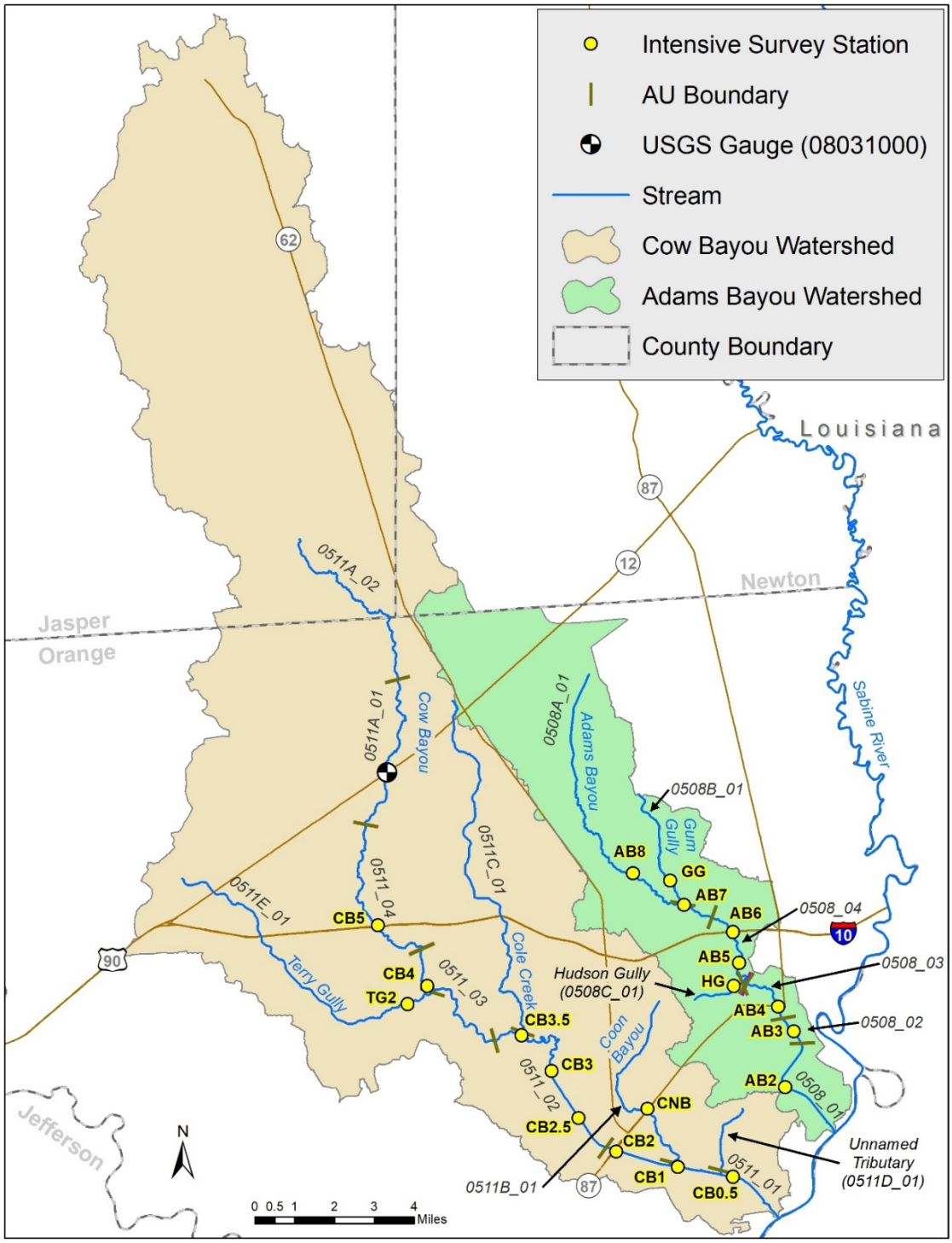

Figure 14. Intensive survey stations in Adams Bayou and Cow Bayou watersheds and the USGS stream gauge station on Cow Bayou.

The critical water quality parameter for purposes of the DO TMDLs is DO. The pertinent model performance target for DO is the root mean square error (RMSE) of predicted values with respect to observed values. RMSE is computed using model predictions and measured data collected at the same time and location. The RMSE of the modeling system met the performance target if its value was less than 1.5 mg/L for the combined DO data collected for the Adams Bayou watershed locations and for the Cow Bayou watershed locations.

The WASP model performed well in predicting water quality conditions in the tidal portion of Adams Bayou and its tidal tributaries. The WASP results met the DO target of RMSE less than 1.5 mg/L specified for the combination of all stations for the separate calibration and validation periods (Table 29). If this RMSE target is extended to the individual station level, the target is also met at all stations. A longitudinal representation of simulated and measured DO concentrations for the Adams Bayou stations is presented in Figure 15 for the survey periods used for calibration and validation.

Table 29. Model performance values for Adams Bayou monitored stations during the intensive surveys of 2004.

Period	Survey Station Identifier	SWQM Station Identifier	Measured Average (mg/L)	Modeled Average (mg/L)	RMSE (mg/L)
Calibration	All	All	2.04	1.85	0.69
Validation	All	All	3.60	3.29	0.48
Cal. and Val.	AB2	10441	1.84	1.75	0.38
Cal. and Val.	AB3	10442	1.66	1.51	0.52
Cal. and Val.	AB4	16059	1.84	1.50	0.77
Cal. and Val.	AB5	14990	2.26	2.00	0.44
Cal. and Val.	AB6	10443	2.84	2.79	0.46
Cal. and Val.	AB7	15107	3.85	3.58	0.93
Cal. and Val.	AB8	14964	3.65	3.58	0.37
Cal. and Val.	GG	16049	3.67	3.65	0.49
Cal. and Val.	HG	16041	3.79	2.78	1.28

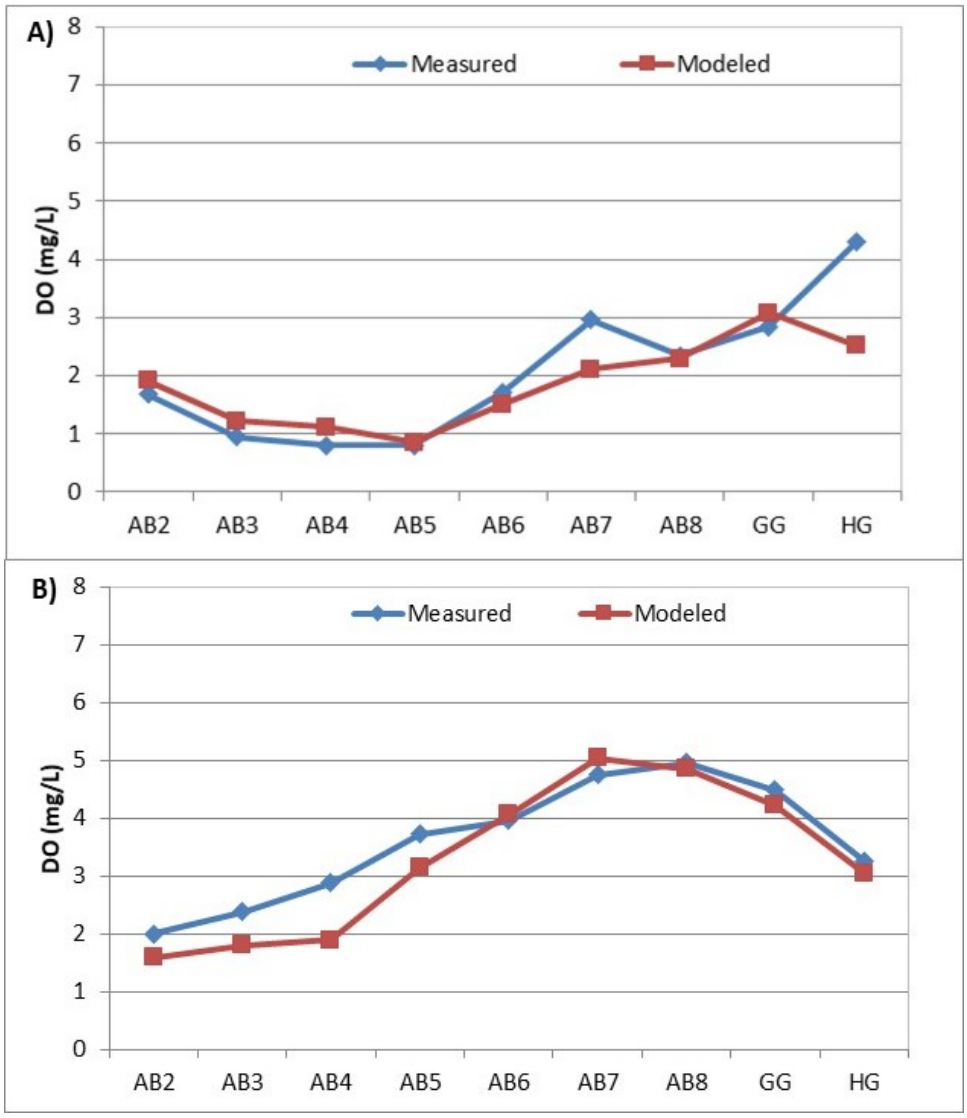

Figure 15. Longitudinal representation of simulated and measured daily average DO for Adams Bayou watershed stations for A) the calibration period and B) the validation period.

Though the Cow Bayou WASP simulation results did not match the measured DO values as well as those for Adams Bayou, the model performed well in predicting DO in the tidal portion of Cow Bayou and its tidal tributaries. Based on the DO performance target specified in the QAPP, the WASP results met the target for the combination of all stations for the separate calibration and validation periods (Table 30). If the RMSE target specified in the QAPP is extended to the individual station level, the target is not met at three stations: CB2.5, CB3, and TG2. Stations CB2.5 and CB3 are located in AU 0511_02 of Cow Bayou Tidal, which is impaired for depressed DO and is located between the unimpaired AU 0511_01, immediately downstream of AU 0511_02, and

impaired AUs 0511_03 and 0511_04, which are directly upstream of AU 0511_02. WASP results appear to be less robust in simulating the DO in this transition zone between depressed DO and acceptable DO. The third station with a missed DO performance target was station TG2, which is located in Terry Gully (0511E_01), an AU that is not impaired for depressed DO. A longitudinal representation of the simulated and measured DO concentrations for the Cow Bayou stations is provided in Figure 16.

Table 30. Model performance values for Cow Bayou monitored stations during the intensive surveys of 2004.

Any station not meeting the RMSE target of less than 1.5 mg/L is in **red bold** font

Period	Survey Station Identifier	SWQM Station Identifier	Measured Average (mg/L)	Modeled Average (mg/L)	RMSE (mg/L)
Calibration	All	All	3.01	3.74	1.34
Validation	All	All	4.00	3.25	0.89
Cal. and Val.	CB0.5	18374	5.43	5.12	0.43
Cal. and Val.	CB1	10449	4.88	4.87	0.69
Cal. and Val.	CB2	10451	4.55	4.83	1.27
Cal. and Val.	CB2.5	10452	4.58	4.73	**1.57**
Cal. and Val.	CB3	10453	3.95	4.36	**2.07**
Cal. and Val.	CB3.5	10454	1.86	2.41	0.81
Cal. and Val.	CB4	13781	1.84	1.76	0.51
Cal. and Val.	CB5	10457	1.46	1.49	0.95
Cal. and Val.	CNB	16052	3.54	3.56	1.34
Cal. and Val.	TG2	18377	2.96	1.78	**1.74**

Based on values of the various performance targets for HSPF, RMA2, and WASP model predictions for flow, water level, and water quality parameters compared to measured data, the modeling systems for both watersheds were considered adequately calibrated and validated for the purpose of development of the DO TMDLs.

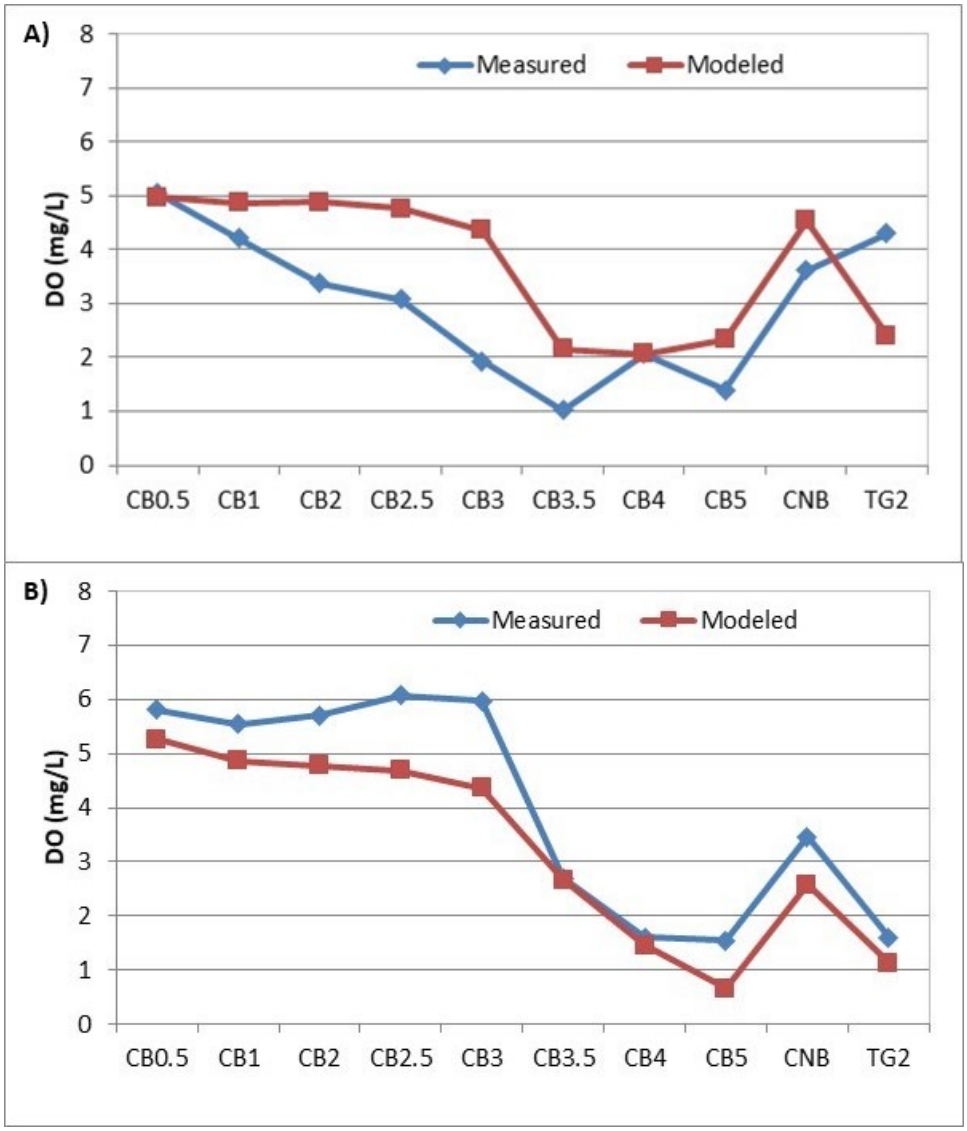

Figure 16. Longitudinal representation of simulated and measured daily average DO for Cow Bayou watershed stations for A) the calibration period and B) the validation period.

Water Quality Loading Linkage Analysis and Modeling Scenarios

A series of water quality loading scenarios were simulated using the calibrated modeling systems for water bodies in the Adams Bayou watershed and the Cow Bayou watershed to identify the impact on compliance with water quality standards for DO. It was assumed that reductions in loads of $CBOD_5$ would ultimately result in reductions in sediment oxygen demand (SOD), because SOD is derived from oxidation of settled organic matter. Similarly, reductions in the fluxes of NH_3N from sediments to the water column were assumed to result

from reductions in external loading of organic matter. Modeling scenarios involving changes in loading were conducted using a two-step process. In the first step, models were run with external load modifications of $CBOD_5$ and NH_3N. In the second step, the SOD and internal fluxes of NH_3N and PO_4P from sediments to the water column were modified by a percentage equal to the percent change in the dissolved $CBOD_5$ concentration. However, SOD was not reduced below a minimum level of 0.35 grams per square meter per day ($g/m^2/day$). The 0.35 $g/m^2/day$ value is an estimate of background SOD, based on a memorandum of understanding between EPA and TCEQ on water quality permitting practices (TCEQ, 2010c).

For each scenario, the modeling system was operated for the 11-year period of January 1, 2002 through December 31, 2012. The length of this simulation period ensures that inter-annual and seasonal variability is addressed adequately. Four scenarios representing various conditions were simulated with the modeling system for the purpose of informing the development of the pollutant load allocations for the Adams Bayou and Cow Bayou watersheds:

- Existing Pollutant Loads Scenario: HSPF modeled watershed loads and industrial and municipal WWTFs discharging at existing conditions based on their DMRs and other available information on the water quality of each discharge.

- Full Permitted Loads Scenario: HSPF modeled watershed loads and industrial and municipal WWTFs discharging at full permitted limits. The full permitted loads for TPDES facilities were based on limits in individual permits. In the absence of permit limits, default values used in TCEQ permit evaluations, values derived from DMR data, and outfall monitoring data included in permit renewal applications were used as point source loading inputs. The full permit loads for municipal WWTFs are provided in Table 31. Table 32 shows full permit loads for industrial WWTFs.

- No Load Scenario: All permitted point source loads and HSPF modeled watershed loads are set to zero. This scenario explores the physical factors constraining dissolved oxygen dynamics in the Adams Bayou and Cow Bayou stream systems. It does not represent a realistic condition but is useful for reference purposes.

- Pristine Condition Scenario: All permitted point sources loads are set to zero and all land uses in HSPF are set to “natural” conditions. For this, all developed land classes, cropland, pasture/hay, and septic fields were converted to the grassland/herbaceous land use category in HSPF subbasins occurring primarily below IH-10, and to mixed forest for subbasins occurring primarily north of IH-10. Thus, there were no anthropogenic pollutant loads,

but there were natural non-point source loads corresponding to a likely pre-settlement and pre-development condition.

The daily average DO criteria for support of the aquatic life use served as the instream target for assessing the modeling system DO prediction and, subsequently, the necessary pollutant load reductions required by TMDLs for the AUs of both watersheds. The daily minimum DO criteria was not evaluated because the WASP model was not set up or calibrated to predict diurnal fluctuation in DO, which is not expected to be simulated as accurately as daily average DO.

The results from the modeling systems for Adams Bayou and Cow Bayou watersheds were averaged to provide predicted daily average DO concentrations for each day of the 11-year simulated period at the subbasin level in HSPF and segment level in WASP. For each day of this period, the predicted daily average DO predictions for all WASP segments comprising each tidal AU were spatially averaged to develop a 11-year time series of daily average DO values for each AU. These time series of predicted daily average DO concentrations formed the basis for determining whether each tidal AU met the criterion used to assess support of the high aquatic life use, which requires that 24-hour daily average DO be at least 4 mg/L (TSOS, 2018). In order for water quality standards to be assessed as fully supported, no more than 10 percent of daily average DO measurements can fall below the 4 mg/L 24-hour daily average criterion (TCEQ, 2019b).

The above tidal AUs in Adams Bayou and Cow Bayou watershed have a 24-hour daily average criterion of 3 mg/L DO (TSOS, 2018). In order for the water quality standards to be assessed as fully supported, no more than 10 percent of daily average DO measurements must be below this 3 mg/L daily average DO criterion (TCEQ, 2019b). The AUs in Cow Bayou Above Tidal (0511A_01 and 0511A_02) were assessed using the daily average DO concentrations predicted by HSPF in an analogous manner to that employed for tidal AUs using WASP DO predictions. One HSPF subbasin represented 0511A_01, and the daily average DO predictions from HSPF for the 11-year period were used in the assessment process. For 0511A_02, two HSPF subbasins defined the AU, requiring the spatial averaging of the daily average DO predictions for each subbasin to provide the assessment dataset.

Table 31. Full permitted conditions for regulated domestic WWTFs in the Adams Bayou and Cow Bayou watersheds.

Permittee	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (mg/L)	Daily Average NH_3N (mg/L)	Minimum DO (mg/L) [1]
Jasper County WCID 1	WQ0010808001 (TX0021300)	0511A_02	001	0.41	30	6	4
PCS Development Company	WQ0011916001 (TX0074250)	0511_04	001	0.09	20	12[2]	2
Orangefield Water Supply Corporation	WQ0014772001 (TX0129313)	0511_02	001	0.75	10	2	4
Bayou Pines LLC	WQ0015029001 (TX0133418)	0511B_01	001	0.009	30	8	4
Gulflander Partners Group, L.P.	WQ0013488001 (TX0106437)	0511B_01	001	0.01	20	12[2]	2
City of Bridge City	WQ0010051001 (TX0025500)	0511_01	001	1.6[3]	10	12[2]	4
City of Pinehurst	WQ0010597001 (TX0024171)	0508_03	001	0.5	20	12[2]	3
City of Orange[4]	WQ0010626001 (TX0073423)	0508_02	002	7.0[4]	20	12[2]	2
Orange County WCID 2	WQ0010240001 (TX0054810)	0508_02	001	1.22[3]	10	12[2]	4

[1] Permit-specified minimum DO concentration used as input condition to modeling system.

[2] Default value based on TCEQ guidance and values assumed in TCEQ permit evaluations.

[3] Annual average flow in MGD.

[4] 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. Simulated as 7.0 MGD on all days of discharge indicated in the DMR data for the period of January 1, 2002 – December 31, 2012. Outfall 001 discharges to the Sabine River.

Table 32. Full permitted conditions for regulated industrial WWTFs in the Adams Bayou and Cow Bayou watersheds.

Permittee	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (mg/L)	Daily Average NH_3N (mg/L)	Minimum DO (mg/L)[1]
Miller Waste Mills, Inc.	WQ0002835000 (TX0104710)	0511_02	001[2] 002 003[3]	- 0.116[4] -	- 20[5] -	- 1[6] -	- 2 -
Lion Elastomers Orange, LLC	WQ0000454000 (TX0002968)	0511_01	001 002[2]	1.202 -	11 -	2 -	2 -
Chevron Phillips Chemical Company LP	WQ0000359000 (TX0004839)	0511D_01	001	3.15	17.5	0.8[7]	2
Printpack, Inc.	WQ0002858000 (TX0101192)	0511D_01	001 101[8]	0.085 -	10[6] -	3[7] -	2 -
Honeywell International Inc.	WQ0000670000 (TX0007897)	0511_01	001	1.4	10	1[7]	2
ARLANXEO USA LLC	WQ0001167000 (TX0003654)	0511_01	001	6.0	3.5	1[7]	2

[1] Default value based on TCEQ guidance and values assumed in TCEQ permit evaluations.

[2] Stormwater only outfall; not included as direct point source in modeling system; included through land use in HSPF model.

[3] Based on DMR data, discharge from Outfall 003 has not occurred; therefore, discharges have never been reported; outfall not included in modeling effort.

[4] Average of 2017 – 2018 DMR data.

[5] Permit has a daily maximum limit of 26 mg/L; daily average BOD_5 based on ratio of permit limits for daily average and daily maximum total organic carbon and the daily maximum BOD_5 limit.

[6] Estimate based on permit renewal information. No permit limit for BOD in outfall 001.

[7] Value determined based on evaluation of DMR data.

[8] Internal outfall that is included in Outfall 001.

All other above tidal AUs in the Adams Bayou and Cow Bayou watersheds were represented in the modeling system by one or more HSPF subbasins and in the more downstream portions of each above tidal AU by the RMA2 and WASP models due to observed tidal fluctuations in these AUs. For these AUs, the same averaging of daily DO data occurred by model (i.e., HSPF and WASP) output data, each averaged independently to develop two 11-year time series of daily DO concentrations. From these two time series, another time series of daily average DO concentrations was developed based on weighting the WASP DO output data by the percentage of the AU stream length represented in WASP and also weighting of the HSPF DO output data by the percentage of the stream length represented in HSPF.

HSPF and WASP DO predictions for each of the four scenarios were developed through operation of the modeling system for the conditions specific to each scenario. For all AUs in the Adams Bayou and Cow Bayou watersheds, whether impaired or unimpaired for depressed DO, an AU-level 11-year time series of predicted daily average DOs was developed. Each time series was then analyzed to determine the percentage of days that DO was below the allowed 24-hour daily average DO criterion of 4 mg/L for tidal streams and 3 mg/L for above tidal streams, presumed to be freshwater intermittent streams with perennial pools.

Results of the analysis of the modeling system DO predictions are provided in Table 33. The existing pollutant loads scenario results support the findings of historical water quality assessments, in that the water bodies considered impaired through analyses of measured data also exceeded the DO criteria based on simulation results (i.e., days not meeting DO criterion greater than 10 percent) for all impaired AUs of the Adams Bayou watershed and all impaired AUs of Cow Bayou watershed, except 0511A_02. The modeling system provides predictions that DO is depressed only 5 percent of the time in 0511A_02, though under the full permit loads scenario that percentage increases to 16 percent, which indicates an exceedance of the criteria. Further, the existing pollutant loads scenario results correctly indicate that AUs 0511_01, 0511D_01, and 0511E_01 meet the DO pertinent criterion. However, under the full permit loads scenarios, model results indicate AU 0511D_01 exceeds the DO criterion, with depressed DO predicted to occur 29 percent of the time.

The no load scenario provided the expected condition of low percentages of days not meeting the DO criterion, with the exception of 0511A_02 at 18 percent, which is a higher percentage than the full permitted loads scenario. Review of the daily average DO time series from HSPF output indicated that under the no load scenario, the occurrence of low flows greatly increased, and, under these low flows, predicted DO was depressed.

Table 33. Scenario assessment results for daily average DO for AUs of Adams Bayou and Cow Bayou watersheds.

AUs with predicted depressed DO have a value greater than 10 percent for days not meeting the average DO criterion.

Water Body Name	AU	24-hour Average DO criterion (mg/L)	Existing Loads Scenario Days Not Meeting DO Criterion (%)	Full Permitted Scenario Days Not Meeting DO Criterion (%)	No Load Scenario Days Not Meeting DO Criterion (%)	Pristine Condition Scenario Days Not Meeting DO Criterion (%)
Adams Bayou Tidal	0508_01	4	71	85%	0	3
	0508_02	4	91	97	0	0
	0508_03	4	91	95	0	0
	0508_04	4	89	90	0	1
Adams Bayou Above Tidal	0508A_01	3	57	59	0	19
Gum Gully	0508B_01	3	24	50	2	21
Hudson Gully	0508C_01	4	88	90	0	2
Cow Bayou Tidal	0511_01	4	1	5	0	0
	0511_02	4	27	32	0	2
	0511_03	4	40	42	0	2
	0511_04	4	37	41	0	1
Cow Bayou Above Tidal	0511A_01	3	0	0	0	0
	0511A_02	3	26	16	18	34
Coon Bayou	0511B_01	4	25	29	0	1
Cole Creek	0511C_01	4	30	32	3	2
Unnamed Tributary to Cow Bayou Tidal	0511D_01	4	0	27	0	0
Terry Gully	0511E_01	3	3	3	3	10

Under the pristine condition scenario, the HSPF prediction of greater number of days with low flow and commensurate depressed DO increased in every above tidal AU of the Adams Bayou and Cow Bayou watersheds, indicating a strong relationship between simulated flows and depressed DO. For the tidal AUs, the occurrences of depressed DO for the pristine condition scenario were similar to the no load scenario, though showing somewhat higher values, but with occurrences of days with depressed average DO still well below 10 percent. AUs with greater than 10 percent of days with depressed average DO under the

pristine condition scenario include 0508A_01 (Adams Bayou Above tidal), 0508B_01 (Gum Gully), and 0511A_02 (Cow Bayou Above Tidal).

Pollutant Load Allocations for DO TMDLs

To determine pollutant load allocations that result in compliance with the DO criteria, the application of the modeling systems was more narrowly focused than under the existing pollutant loads, full permitted load, no load, and pristine conditions scenarios. Those impaired AUs for which DO TMDLs are being revised were the main focus of the assessment of modeling results.

Consideration of Above Tidal AUs in the Adams Bayou Watershed

The TMDL modeling scenarios showed that reductions of $CBOD_5$ and NH_3N greater than 70 percent in Adams Bayou Above Tidal (0508A_01) and 75 percent in Gum Gully (0508B_01) were necessary to maintain daily average DO values in compliance with the 24-hour daily average DO criterion of 3 mg/L. The subwatersheds of AUs 0508A_01 and 0508B_01 have no WWTF outfalls and have very small areas of regulated stormwater (4.21 percent in Adams Bayou Above Tidal and 2.33 percent in Gum Gully); therefore, the largest share of pollutant reductions would need to come from unregulated sources. Notably, the number of days AUs 0508A_01 and 0508B_01 failed to meet the daily average DO criterion under simulated pristine conditions exceeded the 10 percent use support threshold by a considerable margin (19 percent in Adams Bayou Above Tidal and 21 percent in Gum Gully). This is not the case for another Adams Bayou tributary, Hudson Gully, which fails to meet the daily average DO criterion only 2 percent of the time under pristine conditions but requires a pollutant load reduction of 80 percent to meet the daily average DO criterion. Hudson Gully (0508C_01) is tidally influenced and has a regulated stormwater area that comprises 99.3 percent of its subwatershed.

Adams Bayou Above Tidal and Gum Gully are unclassified water bodies presumed to be freshwater intermittent streams with perennial pools. The limited aquatic life use assigned to these water bodies by TCEQ is a presumed use. An October 2002 report prepared for TCEQ as part of the 2007 TMDL effort provides a historical review of water quality information on Adams Bayou, Cow Bayou and associated tributaries (Parsons, 2002). The report describes the general lack of biological, habitat, and water quality data in water bodies in the Adams Bayou watershed and cites the usefulness of performing an Aquatic Life Use Attainability Analysis (ALUAA) on Adams Bayou to determine the proper aquatic life use designations for that water body and its tributaries. Indeed, uncertainty surrounding presumed aquatic life uses of freshwater bodies in the Cow Bayou watershed led to the completion in 2008 of an ALUAA for Cow Bayou. The analysis found that Cow Bayou Above Tidal had zero flow

approximately one third of the time but concluded that persistent pools remained in the stream during these periods of no flow (TPWD, 2008). The persistence of pools during periods of no flow in a freshwater intermittent stream is a requisite for the presumption of a limited aquatic life use designation for these water bodies. Some freshwater intermittent streams do not form persistent pools during periods of no flow, or the pools formed are not adequate to support significant aquatic life. In these cases, TCEQ assigns a "minimal" aquatic life use designation, which has an associated 24-hour daily average DO criterion of 2.0 mg/L.

The water body fact sheets included in the *2000 Texas Water Quality Inventory and 303(d) List* for Adams Bayou Above Tidal and Gum Gully mention that assessment of the relevant water quality standard and/or confirmation of the impairment should be considered as options for projects to address standards attainment issues in these water bodies. The fact sheets contain this language because, in addition to a lack of habitat and biological information needed to determine site-specific aquatic life uses for these water bodies, the aquatic life use impairments included in the *2000 Texas Water Quality Inventory* for Adams Bayou Above Tidal and Gum Gully were based on instantaneous (i.e., grab sample) DO data which are not well suited for comparison with the 24-hour DO criteria.

Currently, TCEQ's SWQMIS database shows five 24-hour (diel) DO measurements conducted in Adams Bayou Above Tidal. The measurements were conducted in 2001 and 2002. No diel DO data is available at all for Gum Gully. TCEQ's SWQMIS database also includes a total of nine flow measurements conducted in Adams Bayou Above Tidal and three flow measurements in Gum Gully. Over half of these flow measurements showed zero flow (five zero flow values in Adams Bayou Above Tidal and two in Gum Gully). In addition to flow duration and the quality and areal extent of persistent pools during periods of very low or no flow, the demarcation of the extent of tidal influence is an important consideration for the assignment of aquatic life uses. During the intensive surveys conducted as part of the TMDLs adopted in 2007, all Adams Bayou monitoring sites, including sites considered by TCEQ to be representative of Adams Bayou Above Tidal, exhibited tidal fluctuations in water surface elevation (Hauck et al., 2020), which is another indication of the need to conduct an ALUAA on Adams Bayou and its freshwater tributaries to, among other things, better define the farthest upstream extent of the tidal boundary.

Given the uncertainty associated with the aquatic life use currently presumed for Adams Bayou Above Tidal and Gum Gully, TCEQ is excluding AUs 0508A_01 and 0508B_01 from the TMDLs presented in this document, opting instead to recommend collecting additional habitat, biological, and water quality data in these AUs as part of an ALUAA. Results of ALUAAs can be used to assign or

confirm appropriate site-specific DO criteria for these water bodies. Additional diel water quality data may also be collected in these AUs to assess attainment of the aquatic life use determined through the ALUAA. If, after these efforts, AUs 0508A_01 and 0508B_01 fail to meet the pertinent DO criteria as determined by the ALUAA and additional monitoring, TCEQ will address these impairments through the TMDL process and will include DO TMDLs for Adams Bayou Above Tidal and Gum Gully in an update to Texas' WQMP. Table 34 shows the water bodies included in the 2007 EPA-approved TMDLs but excluded from the 2020 TMDL revisions.

Table 34. Water bodies included in the 2007 EPA-approved TMDLs, but excluded from the 2020 TMDL revisions.

Water Body Name	Segment ID	AU
Adams Bayou Above Tidal	0508A	0508A_01
Gum Gully	0508B	0508B_01

Although no TMDLs or pollutant load allocations are included in this document for Adams Bayou Above Tidal (AU 0508A_01) or Gum Gully (0508B_01), the subwatersheds of these AUs are considered part of the contributing watershed for AU 0508_04 (Adams Bayou Tidal), since both AUs are part of the drainage area of AU 0508_04 (Figure 3).

Consideration of Unimpaired AUs in the Cow Bayou Watershed

AUs 0511D_01 and 0511_01 of the Cow Bayou watershed are not listed as impaired for DO, though both AUs will be considered in the presentation of results to ensure that DO remains in compliance with the criteria in the pollutant load allocation scenario that will include future growth of WWTFs in these AUs. Additionally, 0511E_01 (Terry Gully), also not listed as impaired for DO, will be considered part of 0511_03, because Terry Gully flows directly into Cow Bayou Tidal 0511_03 (Figure 3).

AU 0511D_01 has not been assessed for support of aquatic life and is, therefore not considered impaired for this use. The results of the simulation for the existing permit loads scenario supports the categorization of AU 0511D_01 as unimpaired for DO. However, the full permitted loads scenario results indicate that 0511D_01 would exceed the DO criterion under those conditions (i.e., full-permitted pollutant loads). AU 0511D_01 will be discussed in more detail under the discussion of the Cow Bayou watershed pollutant load scenarios.

Pollutant Load Reduction Scenarios

For the pollutant load allocations in the Adams Bayou and Cow Bayou watersheds, a series of scenarios were performed to quantify the assimilative capacity of individual AUs while simultaneously demonstrating compliance with the pertinent DO criteria in the entire bayou system. The starting point for these scenarios was the full permitted load scenario. Fully permitted loads represent municipal and industrial discharge permit limits for flow (or discharge), NH_3N and $CBOD_5$ or, in the absence of direct permit limits, values derived from the evaluation of DMRs and permit renewal data or default concentrations used by TCEQ in permit evaluation modeling.

Loads of $CBOD_5$ and NH_3N to each AU were progressively reduced from full permitted values in the manner shown in Table 35, focusing on "hot spots" of low DO, in an iterative fashion until each AU reached attainment of the pertinent DO criteria. The nomenclature in Table 35 includes the term "runoff," which represents loads from the HSPF model without any point source contributions. Regulated and unregulated contributions comprise the water quantity and water quality runoff obtained from HSPF. The areal extent of regulated stormwater areas is defined in Table 14 at the AU level. The load reduction progression in Table 35 was implemented by keeping flows the same and reducing the concentration associated with the effluent flows.

Table 35. Load reduction progression for NPS and industrial and municipal point source reductions used in the simulation scenarios.

Runoff (NPS*) Reduction in NH_3N and $CBOD_5$	Industrial WWTF Reduction of NH_3N and $CBOD_5$	Domestic WWTF Treatment Effluent Concentration	
		NH_3N(mg/L)	$CBOD_5$ (mg/L)
0% Reduction	0% Reduction	12	20
20% Reduction	20% Reduction	12	10
40% Reduction	40% Reduction	3	10
60% Reduction	60% Reduction	2	10
70% Reduction	70% Reduction	2	7
80% Reduction	80% Reduction	2	7
90% Reduction	90% Reduction	2	5
95% Reduction	95% Reduction	1	5
100% Reduction	100% Reduction	No Discharge	No Discharge

* The term NPS is used here to represent pollutants from regulated and unregulated sources in rainfall runoff.

Additional explanations of the approach taken to reduce $CBOD_5$ and NH_3N loads in the scenario simulations of impaired AUs include the following:

- The reduction in industrial WWTF loadings was set equal to the reduction in runoff (NPS) loadings; for these cases, $CBOD_5$ and NH_3N loads in industrial WWTF effluents were reduced by the same percentage as the load of these parameters in runoff.
- The reductions in domestic WWTF loadings were applied according to the discrete effluent concentration hierarchy shown in Table 35.
- Domestic WWTF loadings were not relaxed from limits in existing permits. The input loads for the WWTFs were specified as the more stringent of (1) existing permit limits (or, in the absence of permit limits, values used to represent permit limits) or (2) the limits specified in Table 35.
- For domestic WWTF loadings, the level of required treatment did not increase until the next percent reduction level was reached in Table 35. For example, at runoff (NPS) and industrial WWTF reductions from 40 to 59 percent, the municipal permit limits are NH_3N equal to 3 mg/L and $CBOD_5$ equal to 10 mg/L and, for reductions between 60 and 69 percent, the limits are NH_3N equal to 2 mg/L and $CBOD_5$ equal to 10 mg/L;
- The minimum DO concentration specified in permits for industrial and domestic WWTFs were assumed to be increased to 5 mg/L if any load reduction was required in the AU in which the facility is located.

The runoff (NPS) from HSPF and industrial WWTF outfalls permitted for combined stormwater and industrial process wastewater results in duplicate representation of the stormwater component of these industrial TPDES permitted outfalls (Table 10) in the modeling system. Industrial outfalls that are only permitted for stormwater are represented in HSPF. Industrial outfalls that include stormwater and process wastewater are included in HSPF and specified as WWTF inputs into the modeling system. The inability to separate the flows from these industrial outfalls into distinct stormwater and process wastewater components makes this duplication unavoidable. The amount of land area actually contributing through these combined outfalls is estimated to be less than one percent of the 127,210 acres comprising the Cow Bayou watershed. There are no TPDES permitted industrial facilities in the Adams Bayou watershed. Further, the majority of the industrial facilities in the Cow Bayou watershed discharge into unimpaired AUs in the lower portion of Cow Bayou Tidal (Figure 8), where historical data indicate no DO impairments and where the modeling system scenarios give similar results of no DO impairments. Therefore, the duplication is not significantly impacting results and represents a conservative feature of the modeling effort.

Results of Pollutant Load Reduction Scenarios

The pollutant load reduction scenario for the Adams Bayou watershed required these conditions to comply with the DO criteria in the impaired AUs:

- Unregulated NPS and regulated stormwater load reductions of 45 percent for Adams Bayou Tidal AU 0508_01.
- Unregulated NPS and regulated stormwater load reductions of 40 percent for Adams Bayou Tidal AUs 0508_02 and 0508_03.
- Unregulated NPS and regulated stormwater load reductions of 60 percent for Adams Bayou Tidal AU 0508_04.
- Unregulated NPS and regulated stormwater load reductions of 80 percent for Hudson Gully AU 0508C_01.
- All TPDES municipal WWTFs with daily average effluent limits at 10 mg/L $CBOD_5$ and 3 mg/L NH_3N, and minimum DO at 5 mg/L based on the 40 percent runoff reduction required in AUs 0508_02 and 0508_03.
- No assimilative capacity afforded for future growth.

The predicted DO conditions for the Adams Bayou watershed under the pollutant load reduction scenario are provided in Table 36. The municipal WWTF permit limits for parameters most relevant to addressing the DO impairments are provided in Table 37.

The pollutant load reduction scenario for the Cow Bayou watershed required these conditions to comply with the DO criteria in the impaired AUs:

- Unregulated NPS and regulated stormwater load reductions of 0 percent for Cow Bayou Tidal AU 0511_02.
- Unregulated NPS and regulated stormwater load reductions of 50 percent for Cow Bayou Tidal AU 0511_03.
- Unregulated NPS and regulated stormwater load reductions of 60 percent for Cow Bayou Tidal AU 0511_04.
- Unregulated NPS and regulated stormwater load reductions of 50 percent for Cow Bayou Above Tidal AU 0511A_02.
- Unregulated NPS and regulated stormwater load reductions of 50 percent for Coon Bayou AU 0511B_01.
- Unregulated NPS and regulated stormwater load reductions of 50 percent for Cole Creek AU 0511C_01.

- Each TPDES municipal or industrial WWTFs effluent limit was based on the runoff percent reductions computed for the AU in which the facility is located as provided in Table 37, for municipal facilities, and Table 38, for industrial facilities. The exception was for the two industrial facilities located in 0511D_01 for which the simulation indicated that if the assumed DO in the effluent was 5 mg/L, instead of the 2 mg/L assumed in TCEQ modeling, then depressed DO was avoided in this water body. Therefore, for the two industrial facilities in 0511D_01, an effluent minimum DO of 5 mg/L was assigned to their permits for modeling purposes. $CBOD_5$ and NH_3N effluent limits assigned to these facilities, for modeling purposes, are based on current treatment requirements for these parameters.
- An assimilative capacity for future growth of 10 percent of existing loads was available for industrial and municipal facilities in AUs 0511_01, 0511_02, and 0511D_01.

Margin of Safety for DO Modeling

The MOS is used to account for uncertainty in the analysis used to develop TMDLs and thus provides a higher level of assurance that the goal of the TMDLs 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 margin of safety 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. Accounting for this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The DO TMDLs incorporate an implicit MOS based on conservative model assumptions. The conservative model assumptions include:

Table 36. Predicted DO from pollutant load reduction scenarios for DO impaired AUs of Adams Bayou and Cow Bayou watersheds.

AUs 0511_01 and 0511D_01 are not impaired for DO but are included in this table for the purpose of showing the implications of future growth on DO in these AUs.

Water Body Name	AU	Without Future Growth			With Future Growth		
		Average DO (mg/L)	10th Percentile DO (mg/L)	Days Not Meeting Average DO Criterion (%)	Average DO (mg/L)	10th Percentile DO (mg/L)	Days Not Meeting Average DO Criterion (%)
Adams Bayou Tidal	0508_01	5.6	4.0	9.2	NA	NA	NA
	0508_02	6.0	4.5	1.2	NA	NA	NA
	0508_03	6.2	4.7	1.0	NA	NA	NA
	0508_04	5.9	4.1	7.1	NA	NA	NA
Hudson Gully	0508C_01	5.8	4.2	6.9	NA	NA	NA
Cow Bayou Tidal	0511_01	6.1	4.5	0.1	6.0	4.4	1.0
	0511_02	6.3	4.2	4.5	6.2	4.0	7.7
	0511_03	6.9	4.1	7.9	6.9	4.0	9.9
	0511_04	7.3	4.1	8.2	7.3	4.1	9.1
Cow Bayou Above Tidal	0511A_02	7.1	3.4	8.4	7.1	3.4	8.4
Coon Bayou	0511B_01	6.2	4.1	8.4	6.1	4.0	9.7
Cole Creek	0511C_01	7.3	4.1	8.6	7.2	4.0	9.7
Unnamed Tributary to Cow Bayou Tidal	0511D_01	7.2	4.1	6.0	7.1	4.0	8.5

Table 37. Permit limits for existing regulated domestic WWTFs in the Adams Bayou and Cow Bayou watersheds based on TMDL load reduction scenarios.

Permit	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (mg/L)*	Daily Average NH_3N (mg/L)	Minimum DO (mg/L)
Jasper County WCID 1	WQ0010808001 (TX0021300)	0511A_02	001	0.41	10	3	5
PCS Development Company	WQ0011916001 (TX0074250)	0511_04	001	0.09	10	2	5
Orangefield Water Supply Corporation	WQ0014772001 (TX0129313)	0511_02	001	0.75	10	2	4
Bayou Pines LLC	WQ0015029001 (TX0133418)	0511B_01	001	0.009	10	3	5
Gulflander Partners Group, L.P.	WQ0013488001 (TX0106437)	0511B_01	001	0.01	10	3	5
City of Bridge City	WQ0010051001 (TX0025500)	0511_01	001	1.6[1]	10	12[2]	4
City of Pinehurst	WQ0010597001 (TX0024171)	0508_03	001	0.5	10	3	5
City of Orange[3]	WQ0010626001 (TX0073423)	0508_02	002	7.0[1]	10	3	5
Orange County WCID 2	WQ0010240001 (TX0054810)	0508_02	001	1.22[1]	10	3	5

*All BOD effluent values were modeled as $CBOD_5$ with commensurate NH_3-N input values.

[1] Annual average flow in MGD.

[2] Default value based on TCEQ guidance and values assumed in TCEQ permit evaluations.

[3] 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. Simulated as 7.0 MGD on all days of discharge indicated in the DMR data for the period of January 1, 2002 – December 31, 2012. Outfall 001 discharges to the Sabine River.

Table 38. Permit limits for existing regulated industrial WWTFs in the Adams Bayou and Cow Bayou watersheds based on TMDL load reduction scenarios.

Permit	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (mg/L)*	Daily Average NH_3N (mg/L)	Minimum DO (mg/L)
Miller Waste Mills, Inc.	WQ0002835000 (TX0104710)	0511_02	001 [1] 002 003 [2]	- 0.116 [3] -	- 20 -	- 1 -	- 2 -
Lion Elastomers Orange, LLC	WQ0000454000 (TX0002968)	0511_01	001 002 [1]	1.202 -	11 -	2 -	2 -
Chevron Phillips Chemical Company LP	WQ0000359000 (TX0004839)	0511D_01	001	3.15	17.5	0.8	5
Printpack, Inc.	WQ0002858000 (TX0101192)	0511D_01	001 101 [4]	0.085 -	10 -	3 -	5 -
Honeywell International Inc.	WQ0000670000 (TX0007897)	0511_01	001	1.4	10	1	2
ARLANXEO USA LLC	WQ0001167000 (TX0003654)	0511_01	001	6.0	3.5	1	2

*All BOD effluent values were modeled as $CBOD_5$ with commensurate NH_3-N model input values.

[1] Stormwater only outfall; not included as direct point source in modeling system; no new limits assigned in the pollutant load reduction scenario.

[2] Based on DMR data, discharge from Outfall 003 has not occurred; therefore, discharge has never been reported; no new limits assigned in the pollutant load reduction scenario.

[3] Average of 2017 – 2018 DMR data.

[4] Internal outfall that is included in Outfall 001; no new limits assigned in the pollutant load reduction scenario.

- The fact that the evaluation was performed under full permitted limits for point source discharges, which are seldom reached in practice;
- The models predict that DO levels are greater than required to meet water quality standards in most AUs. That is, in order to meet the criteria 90 percent of the time in several of the impaired AUs, the DO levels in adjacent AUs meet the criteria more than 90 percent of the time.
- A multiplier of 3.0 was used to convert $CBOD_5$ to ultimate carbonaceous biochemical oxygen demand for all TPDES municipal and industrial WWTFs inputs included in the modeling system. A default value of 2.3 is used as the multiplier in TCEQ permit evaluations. The multiplier of 3.0 was based on statistical analysis of simultaneously collected five, fifteen, and twenty-day carbonaceous biochemical oxygen demand in ambient water samples obtained during the intensive surveys used for verification of the modeling systems.

- Stormwater runoff loads for some industrial facilities are accounted for in both the HSPF and WASP models.

Pollutant Load Allocation for DO

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding water quality standards. The pollutant load allocations for the selected scenarios were calculated using the TMDL equation, repeated here for clarity:

$$TMDL = WLA + LA + FG + MOS$$

Where:

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

As stated in 40 CFR 130.2(i), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For DO impairments, TMDLs are expressed as pounds per day of pollutants affecting DO dynamics and represent the maximum one-day load the water body can assimilate while still attaining the DO criteria specified in the Texas Surface Water Quality Standards.

The TMDL component for each impaired AU covered in this report is derived using the daily average loads from the 11-year simulations of flow and water quality in the streams of Adams Bayou and Cow Bayou watersheds. The pollutant load reduction scenarios of each watershed, for which DO conditions are summarized in Table 36, provides the basis of the DO TMDLs. The following sections will present an explanation of each TMDL component first, followed by the TMDL results.

Wasteload Allocation for DO

As previously mentioned, the WLA consists of two parts—the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW}$$

WWTFs

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) in pounds per day (lbs/day) for $CBOD_5$ and NH_3N calculated as the full permitted discharge in MGD multiplied by the permit limit in mg/L determined from application of the TMDL modeling system for the pollutant load reduction scenarios. This is expressed in the following equation:

$$WLA_{WWTF} = Flow * Permit\ Limit * Conversion\ Factor$$

Where:

Flow (MGD) = full permitted flow

Permit limit for $CBOD_5$, NH_3N, or DO in mg/L

Conversion factor (to lbs/day) = 3.78541E6 (L/day)/MGD * 2.20462E-6 lbs/mg = 8.34 lbs/(mg/L)/MGD

Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of these TMDLs because the modeling system output for stormwater is at the HSPF subbasin level, which includes both regulated and unregulated land areas.

The determination of WLA_{SW} from the HSPF subbasin level simulations occurred through a two-step process. First, the stormwater load output from each HSPF subbasin is proportioned into the AUs represented in the subbasin based on the percentage of the AUs in each subbasin. The total stormwater load for each AU is computed as the sum of the component parts from each HSPF subbasin in which the AU was located. Second, the percentage of each AU watershed that is under the jurisdiction of stormwater permits (Table 14) is used to estimate the amount of the overall runoff load to be allocated as the regulated stormwater contribution in the WLA_{SW} component of the TMDL.

Load Allocation

As with the WLA_{SW} component, LA is computed at the AU level for the AUs impaired for depressed DO. The LA component of the TMDL corresponds to the unregulated portion of the direct nonpoint runoff and is the difference between the total load from stormwater runoff from HSPF simulations and the portion allocated to WLA_{SW}.

Allowance for Future Growth

The FG component of the TMDL equation addresses the necessity to explore for the effects of future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. Any allowance for future growth will result in protection of existing uses and conform to Texas's antidegradation policy.

In AUs that required load reductions as indicated by TMDL modeling system simulations, no allowance for FG was assigned. Nevertheless, in some of these AUs there is some room for future loading increases in localized areas. However, the amount of the permissible additional loading depends on the location of the discharge within the AU. Any proposed additional loading must be evaluated using the TMDL models to ensure that it will not result in non-compliance with water quality standards. Similarly, there is flexibility to modify the permitted loading of $CBOD_5$ or NH_3N, provided that either constituent's impacts on DO are balanced by reductions of one versus the other. These evaluations must be performed via model simulations.

In AUs for which no load reductions were required in the TMDL modeling system simulations, FG loads were added into the simulations. This was only the case for Cow Bayou watershed AUs 0511_01, 0511_02, and 0511D_01, where no load reductions were required in the simulations to meet the DO criterion. For the purposes of the TMDL, the flow of each municipal and industrial WWTF within these AUs was increased by 10 percent, representing a commensurate 10 percent increase in loading of $CBOD_5$ and NH_3N, as well as, DO. As noted above, any proposed additional loadings from either permit expansions or new permits must be evaluated using the modeling system to ensure that compliance with water quality standards is maintained. Nonetheless, for AUs 0511_01, 0511_02, and 0511D_01, an FG component is provided in the TMDL allocations. Also, the FG of 10 percent for existing TPDES permitted facilities is for illustrative purposes to demonstrate capacity and should not be interpreted as being assigned solely to each facility.

TMDL Calculations for DO

Based on the assigned permit limits for municipal and industrial WWTFs used as input into the pollutant load allocations (Tables 37 and 38), wasteload loadings can be assigned to each WWTF in lbs/day. The WLA_{WWTF} assigned to each facility, including $CBOD_5$ and NH_3N, as well as DO, are provided in Table 39 for municipal WWTFs and Table 40 for industrial WWTFs.

The regulated stormwater (WLA_{SW}) and unregulated stormwater (LA) components of the TMDL are provided in Table 41 based on the 11-year simulation results from the HSPF watershed models.

Summary of TMDL Calculations for DO

Table 42 summarizes the TMDL calculations for the five impaired AUs of the Adams Bayou watershed and the six impaired AUs of the Cow Bayou watershed. The TMDLs were calculated based on the application of the TMDL modeling system of the Adams Bayou watershed and the TMDL modeling system of the Cow Bayou watershed. The values are based on the reductions required to support a high aquatic life use for all tidal streams with a 24-hour daily average DO criterion of 4 mg/L and a limited aquatic life use for freshwater streams with a 24-hour daily average DO criterion of 3 mg/L. The summary of TMDL calculations includes AUs 0511_01 and 0511D_01 to illustrate the FG term for AU 0511_01 and because the TMDL modeling system showed exceedance of the DO criterion in 0511D_01 at the fully permitted loads scenario, requiring permitted DO effluent loadings for facilities discharging to this AU (0511D_01).

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 (Table 43) include the FG component within the WLA_{WWTF} and excludes Cow Bayou Tidal 0511_01, which is unimpaired for DO and in which the TMDL modeling system showed additional capacity to assimilate $CBOD_5$ and NH_3N loads while complying with the 24-hour daily average DO criterion.

Table 39. Wasteload allocations for regulated domestic WWTFs in the Adams Bayou and Cow Bayou watersheds.

Permit	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (lbs/day)	Daily Average NH_3N (lbs/day)	Minimum DO (lbs/day)
Jasper County WCID 1	WQ0010808001 (TX0021300)	0511A_02	001	0.41	34.19	10.26	17.10
Orangefield Water Supply Corporation	WQ0014772001 (TX0129313)	0511_02	001	0.75	62.55	12.51	25.02
PCS Development Company	WQ0011916001 (TX0074250)	0511_04	001	0.09	7.51	1.50	3.75
Bayou Pines LLC	WQ0015029001 (TX0133418)	0511B_01	001	0.009	0.75	0.23	0.38
Gulflander Partners Group, L.P.	WQ0013488001 (TX0106437)	0511B_01	001	0.01	0.83	0.25	0.42
City of Bridge City	WQ0010051001 (TX0025500)	0511_01	001	1.6[1]	133.44	160.13[2]	53.38
City of Pinehurst	WQ0010597001 (TX0024171)	0508_03	001	0.5	41.70	12.51	20.85
City of Orange [3]	WQ0010626001 (TX0073423)	0508_02	002	7.0[3]	583.80	175.14	291.90
Orange County WCID 2	WQ0010240001 (TX0054810)	0508_02	001	1.22[1]	101.75	30.52	50.87

[1] Annual average flow in MGD.

[2] Determined using a default value assumed in TCEQ permit evaluations.

[3] 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. Simulated as 7.0 MGD on all days of discharge indicated in the DMR data for the period of January 1, 2002 – December 31, 2012. Outfall 001 discharges to the Sabine River.

Table 40. Wasteload allocations for regulated industrial WWTFs in the Adams Bayou and Cow Bayou watersheds.

Permit	TPDES No. (NPDES No.)	AU	Outfall	Daily Average Flow (MGD)	Daily Average $CBOD_5$ (lbs/day)	Daily Average NH_3N (lbs/day)	Minimum DO (lbs/day)
Miller Waste Mills, Inc.	WQ0002835000 (TX0104710)	0511_02	001 [1] 002 003 [2]	- 0.116 [3] -	- 19.35 -	- 0.97 -	- 1.93 -
Lion Elastomers Orange, LLC	WQ0000454000 (TX0002968)	0511_01	001 002 [1]	1.202 -	110.27 -	20.05 -	20.05 -
Chevron Phillips Chemical Company LP	WQ0000359000 (TX0004839)	0511D_01	001	3.15	459.74	21.02	131.36
Printpack, Inc.	WQ0002858000 (TX0101192)	0511D_01	001 101 [4]	0.085 -	7.09 -	2.13 -	3.54 -
Honeywell International Inc.	WQ0000670000 (TX0007897)	0511_01	001	1.4	116.76	11.68	23.35
ARLANXEO USA LLC	WQ0001167000 (TX0003654)	0511_01	001	6.0	175.14	50.04	100.08

[1] Stormwater only outfall; not included as direct point source in modeling system; no new limits assigned in the pollutant load reduction scenario.

[2] Based on DMR data, discharge from Outfall 003 has not occurred; therefore, discharge has never been reported; no new limits assigned in the pollutant load reduction scenario.

[3] Average of 2017 – 2018 DMR data.

[4] Internal outfall that is included in Outfall 001; no new limits assigned in the pollutant load reduction scenario.

Table 41. Regulated and unregulated stormwater calculations for impaired AUs of Adams Bayou, Cow Bayou and associated tributaries.

All loads expressed in lbs/day.

AU	Total Runoff $CBOD_5$	Total Runoff NH_3N	Regulated Stormwater Area (%)	WLA_{SW} $CBOD_5$	WLA_{SW} NH_3N	LA $CBOD_5$	LA NH_3N
0508_01	177.29	14.53	59.87	106.14	8.7	71.15	5.83
0508_02	47.41	4.00	99.85	47.34	3.99	0.07	0.01
0508_03	84.34	7.11	100.00	84.34	7.11	0.00	0.00
0508_04	348.46	26.37	11.93	41.57	3.15	306.89	23.22
0508C_01	21.10	1.74	99.32	20.96	1.73	0.14	0.01
Adams Bayou Total	**678.60**	**53.75**	**NA[1]**	**300.35**	**24.68**	**378.25**	**29.07**
0511_01[2]	222.25	17.68	29.30	65.12	5.18	157.13	12.50
0511_02	359.70	28.08	9.02	32.44	2.53	327.26	25.55
0511_03	394.82	27.16	15.54	61.36	4.22	333.46	22.94
0511_04	191.41	12.71	4.07	7.79	0.52	183.62	12.19
0511A_02	613.40	40.33	0.34	2.09	0.14	611.31	40.19
0511B_01	70.11	5.56	27.87	19.54	1.55	50.57	4.01
0511C_01	148.72	10.05	1.63	2.42	0.16	146.30	9.89
0511D_01[2]	43.61	3.76	60.52	26.39	2.28	17.22	1.48
Cow Bayou Total	**2,044.02**	**145.32**	**NA[1]**	**217.15**	**16.58**	**1,826.87**	**128.75**

[1] N/A – not applicable. Adams Bayou and Cow Bayou watersheds are each represented by multiple sub-basins in HSPF with each sub-basin containing a unique composition of land uses that result in differing runoff loads of $CBOD_5$ and NH_3N by area. Also, the loads from each sub-basin are proportioned into WLA_{SW} and LA terms for individual AUs based on the percent of the sub-basin in each AU and the regulated stormwater area percent of each AU. The differing land uses comprising HSPF sub-basins and subsequent differing runoff loads by area result in spatial variability that does not allow a unique watershed-wide percent of regulated stormwater to be computed that is correct for both $CBOD_5$ and NH_3N loads.

[2] AUs 0511_01 and 0511D_01 are not impaired for DO and are included for purposes of showing implications of future growth on DO in these AUs.

Table 42. TMDL allocation summary for AUs of Adams Bayou, Cow Bayou and associated tributaries.

All loads expressed in lbs/day.

Columns for $CBOD_5$ and NH_3N MOS not included; implicit MOS based on conservative model system assumptions.

AU	TMDL $CBOD_5$	TMDL NH_3N	WLA_{WWTF} $CBOD_5$	WLA_{WWTF} NH_3N	WLA_{SW} $CBOD_5$	WLA_{SW} NH_3N	LA $CBOD_5$	LA NH_3N	FG $CBOD_5$	FG NH_3N
0508_01	177.29	14.53	0.00	0.00	106.14	8.70	71.15	5.83	0.00	0.00
0508_02	732.96	209.66	685.55	205.66	47.34	3.99	0.07	0.01	0.00	0.00
0508_03	126.04	19.62	41.70	12.51	84.34	7.11	0.00	0.00	0.00	0.00
0508_04	348.46	26.37	0.00	0.00	41.57	3.15	306.89	23.22	0.00	0.00
0508C_01	21.10	1.74	0.00	0.00	20.96	1.73	0.14	0.01	0.00	0.00
Adams Bayou Total	1,405.85	271.92	727.25	218.17	**300.35**	**24.68**	**378.25**	**29.07**	0.00	0.00
0511_01 [1]	811.40	283.75	535.61	241.90	65.12	5.18	157.13	12.50	53.54	24.17
0511_02	449.79	42.90	81.90	13.48	32.44	2.53	327.26	25.55	8.19	1.34
0511_03	394.82	27.16	0.00	0.00	61.36	4.22	333.46	22.94	0.00	0.00
0511_04	198.92	14.21	7.51	1.50	7.79	0.52	183.62	12.19	0.00	0.00
0511A_02	647.59	50.59	34.19	10.26	2.09	0.14	611.31	40.19	0.00	0.00
0511B_01	71.69	6.04	1.58	0.48	19.54	1.55	50.57	4.01	0.00	0.00
0511C_01	148.72	10.05	0.00	0.00	2.42	0.16	146.30	9.89	0.00	0.00
0511D_01 [1]	557.13	29.22	466.83	23.15	26.39	2.28	17.22	1.48	46.69	2.31
Cow Bayou Total	**3,280.06**	**463.92**	**1,127.62**	**290.77**	**217.15**	**16.58**	**1,826.87**	**128.75**	**108.42**	**27.82**

[1] AUs 0511_01 and 0511D_01 are not impaired for DO and are included for purposes of showing implications of future growth on DO in these AUs.

Table 43. Final TMDL allocations for impaired AUs of Adams Bayou, Cow Bayou and associated tributaries.

All loads expressed in lbs/day.

Columns for $CBOD_5$ and NH_3N MOS not included; implicit MOS based on conservative model system assumptions.

AU	TMDL $CBOD_5$	TMDL NH_3N	WLA_{WWTF} $CBOD_5$ [1]	WLA_{WWTF} NH_3N [1]	WLA_{SW} $CBOD_5$	WLA_{SW} NH_3N	LA $CBOD_5$	LA NH_3N
0508_01	177.29	14.53	0.00	0.00	106.14	8.70	71.15	5.83
0508_02	732.96	209.66	685.55	205.66	47.34	3.99	0.07	0.01
0508_03	126.04	19.62	41.70	12.51	84.34	7.11	0.00	0.00
0508_04	348.46	26.37	0.00	0.00	41.57	3.15	306.89	23.22
0508C_01	21.10	1.74	0.00	0.00	20.96	1.73	0.14	0.01
Adams Bayou Total	**1,405.85**	**271.92**	**727.25**	**218.17**	**300.35**	**24.68**	**378.25**	**29.07**
0511_02	449.79	42.90	90.09	14.82	32.44	2.53	327.26	25.55
0511_03	394.82	27.16	0.00	0.00	61.36	4.22	333.46	22.94
0511_04	198.92	14.21	7.51	1.50	7.79	0.52	183.62	12.19
0511A_02	647.59	50.59	34.19	10.26	2.09	0.14	611.31	40.19
0511B_01	71.69	6.04	1.58	0.48	19.54	1.55	50.57	4.01
0511C_01	148.72	10.05	0.00	0.00	2.42	0.16	146.30	9.89
Cow Bayou Total [2]	**1,911.53**	**150.95**	**133.37**	**27.06**	**125.64**	**9.12**	**1,652.52**	**114.77**

[1] WLA_{WWTF} includes the FG component.

[2] $CBOD_5$ and NH_3N loads for unimpaired AUs 0511_01 and 0511D_01 are excluded from this table, though these loads were provided in Table 41.

Pollutant Load Allocation for pH

As a measure of the hydrogen ion content (acidity) of water, pH is also an impairment in Cow Bayou Tidal AU 0511_04 requiring a TMDL. General water quality uses are not met due to observed pH levels below the acceptable range of water quality criteria (6.0–8.5) for AU 0511_04. Five of the 23 pH measurements (22 percent) taken in AU 0511_04 from 1994 to 1999 in the upper tidal reaches of Cow Bayou were lower than the minimum pH of 6.0 SU, resulting in the non-support listing (Table 4).

It is difficult to simulate pH through water quality modeling. A large number of natural processes affect pH levels—watershed soil and bedrock type, watershed vegetation type, loading of organic matter, wastewater effluent discharges, temperature, seasonality, photosynthesis by phytoplankton and other aquatic plants, and respiration of organic matter. Algal photosynthesis consumes hydrogen ions, raising the pH. Respiration reverses this process, releasing hydrogen ions and lowering pH. The pH parameter varies less as alkalinity (buffering capacity) increases, but these bayous have low levels of alkalinity. In particular, at approximately 22 kilometers upstream of the Sabine River, the median levels of total alkalinity are 20 mg/L as calcium carbonate. Further, the lower tidal portions of both bayous are more strongly buffered by the salts found in saltwater.

HSPF and more recent versions of WASP do simulate pH. To properly and accurately simulate pH, the modeling system would have needed to include not only pH as a state variable in both models, but also carbon dioxide, total inorganic carbon, and alkalinity. Including pH to simulation capabilities was not reasonable due to data constraints for proper model development. Instead an indirect approach based on well understood water-chemistry processes was applied to address the pH issues of Cow Bayou Tidal AU 0511_04.

The primary process responsible for lower pH in many systems is the respiration of organic matter. Primary production by aquatic plants, on the other hand, is the key process raising the pH level in many systems. Low pH levels tend to occur in poorly buffered systems where respiration exceeds primary production. Another potential source of low pH is un-neutralized point source discharges, though such a source is not known to occur in the area of impairment.

The modeling conducted as part of this TMDL exercise shows the source of low pH in Cow Bayou Tidal AU 0511_04 appears to be the degradation of organic matter, which is also the primary source of low DO levels. Figure 17 shows that the changes in average pH levels with distance downstream in Cow Bayou vary

inversely with the CBOD levels. Thus, the low pH values tend to occur where CBOD levels are highest, likely due to the degradation of the organic matter comprising CBOD. For this reason, it is reasonable to assume that the same measures intended to raise DO levels will also raise pH values to meet water quality standards.

Given that the DO criteria are not met in Cow Bayou far more frequently than the pH criteria, it follows logically that a TMDL involving sufficient reductions in oxygen demanding organic matter to meet water quality criteria for DO will also lead to attainment of the pH standard. Therefore, the TMDL for attainment of the pH criteria in Cow Bayou Tidal requires the same allocations for $CBOD_5$ and NH_3N as for attainment of the DO criteria (Table 43).

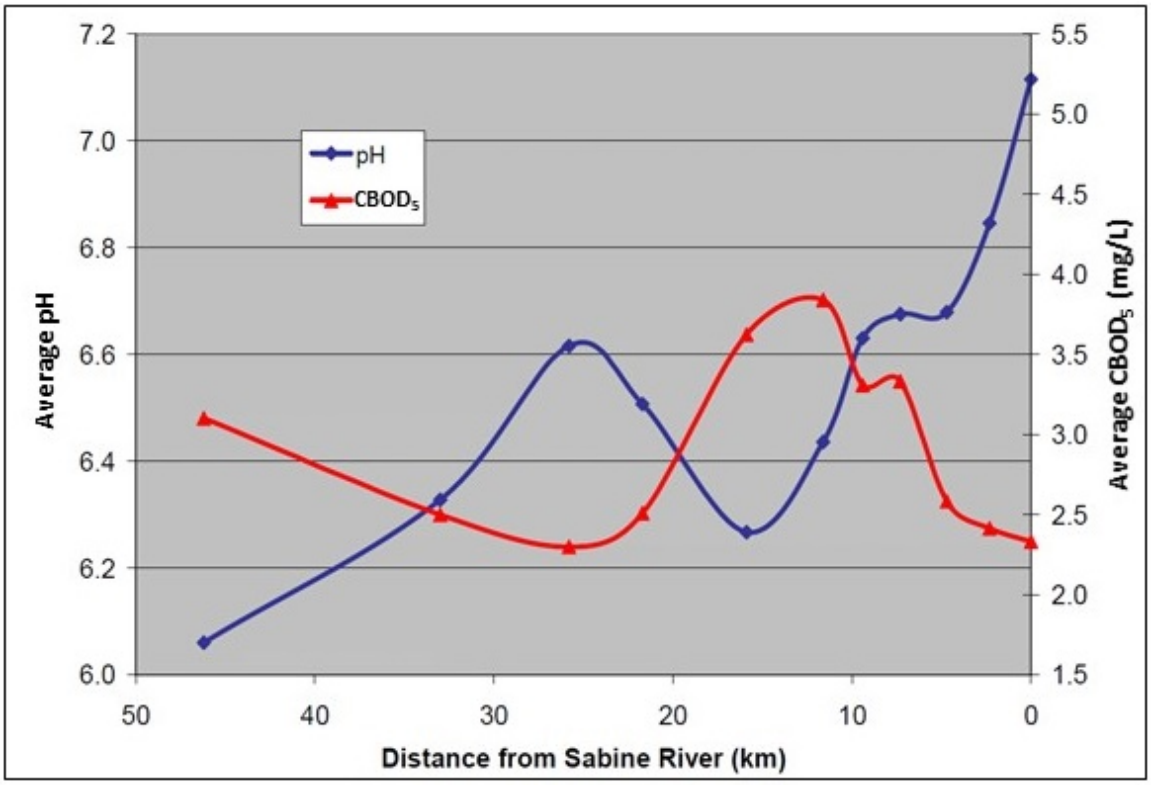

Figure 17. Average measured pH and $CBOD_5$ in Cow Bayou with distance upstream during the summer 2004 summer intensive surveys used for RMA2 and WASP validation.

Seasonal Variation in DO and pH

Previous studies conducted on Adams Bayou and Cow Bayou have examined seasonal variation in water quality parameters, including DO and pH. A 2002 historical review of water quality data collected on Adams Bayou, Cow Bayou and associated tributaries concluded that DO levels were lowest during the

summer season when water temperatures are higher and stream flows are lower (Parsons, 2002). The report, which looked at historical data from 1969 to 2002, also showed seasonal variation in pH, with the lowest pH values occurring in mid to late summer. In 2008, Contreras and Whisenant used Analysis of Similarity (ANOSIM), a nonparametric statistical test analogous to the parametric-based ANOVA test, to analyze seasonality in water quality data collected during the ALUAA conducted on Cow Bayou. Cow Bayou samples were different among seasons as revealed by the results of the ANOSIM test (Global R value was 0.234, *p* value was less than 0.001). The difference is driven primarily by the disparity between spring and summer samples, with the lowest DO and pH values occurring in summer samples when elevated water temperatures and higher specific conductance values are also most prevalent (TPWD, 2008).

The time period modeled by the Adams Bayou and Cow Bayou TMDL modeling system (January 1, 2002 through December 31, 2012) includes over a decade of seasonal variation. By simulating a complete 11-year period, the modeling system and TMDLs implicitly consider inter-annual and seasonal variation.

Implementation of WLAs

The TMDLs in this document will result in protection of existing uses and conform to Texas' antidegradation policy. The three-tiered antidegradation policy in the Texas Surface Water Quality Standards prohibits an increase in loading that would cause or contribute to degradation of an existing use. The Antidegradation Policy applies to point source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality.

TCEQ intends to implement the individual WLAs through the permitting process as monitoring requirements and/or effluent limitations as required by Title 30 Texas Administrative Code Chapter 319 (30 TAC Chapter 319), which became effective November 26, 2009. WWTFs discharging to the TMDL segments will be assigned an effluent limit based on the TMDL. Monitoring requirements are based on permitted flow rates and are listed in 30 TAC 319.9.

The permit requirements will be implemented during the routine permit renewal process. However, there may be more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, the individual WLAs, as well as the WLAs for stormwater, are non-binding until implemented via a separate TPDES permitting action, which may involve

preparation of an update to the state's WQMP. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The executive director or commission may establish interim effluent limits and/or monitoring-only requirements for a permit amendment or permit renewal. These interim limits will allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet TCEQ- and EPA-approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits will not contain interim effluent limits because compliance schedules are not allowed for a new permit.

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the wasteload allocations. For TPDES-regulated municipal, construction stormwater discharges, and industrial stormwater discharges, water quality-based effluent limits (WQBELs) that implement the WLA for stormwater may be expressed as BMPs or other similar requirements, rather than as numeric effluent limits.

In urbanized areas currently regulated by an MS4 permit, development and/or re-development of land in urbanized areas must implement the control measures/programs outlined in an approved SWMP. Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in the TPDES permit and the SWMP.

The November 26, 2014 memorandum from EPA relating to establishing WLAs for stormwater sources states:

> "The Interim Permitting Approach Policy recognizes the need for an iterative approach to control pollutants in stormwater discharges. Specifically, the policy anticipates that a suite of BMPs will be used in the initial rounds of permits and that these BMPs will be tailored in subsequent rounds."

An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality. Using this iterative adaptive BMP approach to the maximum extent practicable is appropriate to address the stormwater component of this TMDL.

Updates to WLAs

This TMDL is, by definition, the total of the sum of the WLAs, and the sum of the LAs, FG, and MOS. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the TMDL document; instead, changes will be made through updates to TCEQ's WQMP. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Public Participation

TCEQ maintains an inclusive public participation process. From the inception of the TMDL process, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

The Orange County TMDL Stakeholder Advisory Group (SAG) was formed in 2002, during the initial stages of development of the first TMDLs. It was formed and approved according to guidance provided by HB 2912. The Sabine River Authority of Texas provided coordination for public participation in the 2007 TMDLs, helping to facilitate and maintain the Orange County TMDL SAG. Members of the SAG represented local, state and federal government, regulated industries, WWTFs, agriculture, business, environmental, and community interests in the Adams Bayou and Cow Bayou watersheds. Between April 2002 and November 2006, the SAG conducted 15 public meetings to present and discuss information related to the TMDLs adopted by TCEQ in 2007. Meetings usually consisted of a brief overview of the project, followed by a more in-depth discussion of the current project activity. Time was given for SAG members to offer advice and local insight to the TMDL project staff.

The SAG conducted five additional public meetings between May 2007 and August 2013 during the development of the TMDL Implementation Plan (I-Plan), which was approved by TCEQ on August 5, 2015. Two of those meetings, as well as a SAG meeting held in September 2016, included the presentation and discussion of information associated with the revisions of the TMDLs that are detailed in this document. The Sabine River Authority of Texas continues to provide assistance with stakeholder coordination and outreach.

Implementation and Reasonable Assurance

The issuance of TPDES permits consistent with TMDLs provides reasonable assurance that wasteload allocations in this TMDL report will be achieved. Per federal requirements, each TMDL is included in an update to the Texas WQMP as a plan element.

The WQMP coordinates and directs the state's efforts to manage water quality and maintain or restore designated uses throughout Texas. The WQMP is continually updated with new, more specifically focused plan elements, as identified in federal regulations [40 CFR 130.6(c)]. Commission adoption of a TMDL is the state's certification of the associated WQMP update.

Based on the TMDL and I-Plan, TCEQ will propose and certify WQMP updates to establish required WQBELs necessary for specific TPDES wastewater discharge permits.

For MS4 entities, where numeric effluent limitations are infeasible, the permits require that the MS4 develop and implement BMPs under each MCM, which are a substitute for effluent limitations, as allowed by federal rules. How a regulated MS4 meets each MCM is not prescribed in detail in the MS4 permits but is included in the permittee's SWMP. During the permit renewal process, TCEQ revises its MS4 permits as needed to require the implementation of other specific revisions in accordance with an approved TMDL and I-Plan.

Strategies for achieving pollutant loads in TMDLs from both point and nonpoint sources are reasonably assured by the state's use of an I-Plan. TCEQ is committed to supporting implementation of all TMDLs adopted by the commission.

I-Plans for Texas TMDLs use an adaptive management approach that allows for refinement or addition of methods to achieve environmental goals. This adaptive approach reasonably assures that the necessary regulatory and voluntary activities to achieve pollutant reductions will be implemented. Periodic, repeated evaluations of the effectiveness of implementation methods ascertain whether progress is occurring and may show that the original distribution of loading among sources should be modified to increase efficiency. Implementation plans will be adapted as necessary to reflect needs identified in evaluations of progress.

Key Elements of an I-Plan

An I-Plan includes a detailed description and schedule of the regulatory and voluntary management measures to implement the WLAs and LAs of particular TMDLs within a reasonable time. I-Plans also identify the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress.

Ultimately, the I-Plan identifies the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the approved I-Plan may not approximate the predicted loadings identified category-by-category in the TMDL and its underlying assessment. The I-Plan is adaptive for this very reason; it allows for continuous update and improvement.

In most cases, it is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction is required by the TMDL, there is high uncertainty with the TMDL analysis, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

In 2015, TCEQ approved an I-Plan for the TMDLs it adopted in 2007 (TCEQ, 2015a). The plan includes six management measures and one control action designed to reduce point and nonpoint source loading of pollutants affecting the support of the contact recreation and aquatic life uses designated and presumed for water bodies in the Adams and Cow Bayou watersheds. TCEQ periodically evaluates the progress in achieving the load reductions expected as a result of carrying out the I-Plan and will also evaluate the need to revise the I-Plan as a result of the TMDL revisions described in this document. In September 2019, TCEQ worked with stakeholders in the Adams Bayou and Cow Bayou watersheds to compile a status update of the management measures and control action included in the Adams Bayou and Cow Bayou I-Plan.

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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:

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

Where

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

V_s = volume of daily seawater flow

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 (assumed to be 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).

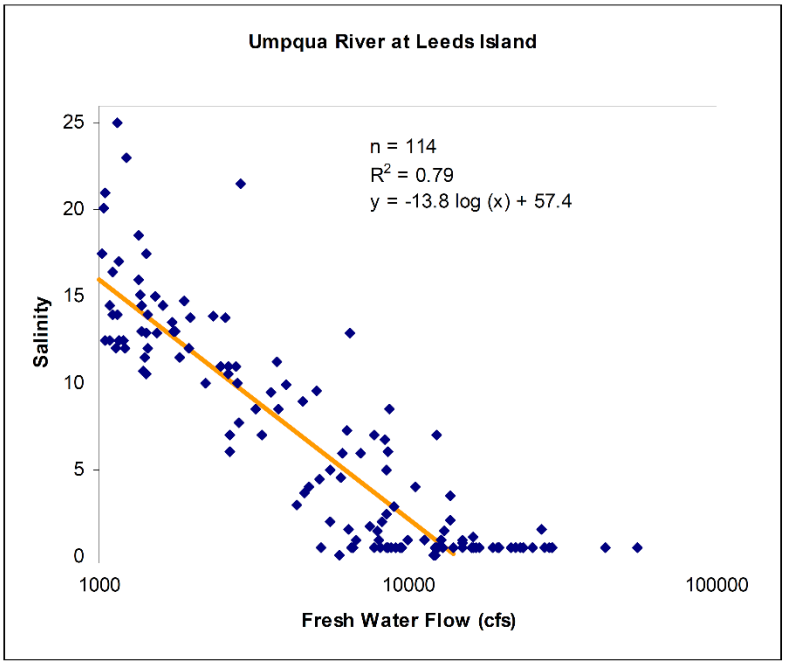

Figure A-1. Example salinity to flow regression from Umpqua Basin Tidal streams.

Source: 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 22 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. 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.