Technical Support Document for Four Total Maximum Daily Loads for Indicator Bacteria in Neches River Tidal

Segment: 0601

Assessment Units: 0601_01, 0601_02, 0601_03, 0601_04

Neches River Tidal at Collier's Ferry Park

Published by the Texas Commission on Environmental Quality
Water Quality Planning Division August 2022 AS-471

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Completed in July 2020 (Published in August 2022)

Acknowledgements

The United States Environmental Protection Agency and the Texas Commission on Environmental Quality provided financial support for this study. TCEQ was the study's lead agency.

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List of Abbreviations

AU	assessment unit
ARS	area of regulated stormwater
AVMA	American Veterinary Medical Association
CCN	Certificate of Convenience and Necessity
CGP	construction general permit
cfs	cubic feet per second
CFR	Code of Federal Regulations
cfu	colony forming unit
DAR	drainage-area ratio
DMR	Discharge Monitoring Report
ECHO	Enforcement and Compliance History Online
E. coli	*Escherichia coli*
FC	flow category
FDC	flow duration curve
FG	future growth
ft^3	cubic feet
FIB	fecal indicator bacteria
I&I	inflow and infiltration
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NHDPlus	National Hydrography Dataset Plus
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
OSSF	on-site sewage facility
ppt	parts per thousand
s/d	seconds per day
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department

TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
UA	urbanized area
U.S.	United States
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	wasteload allocation
WWTF	wastewater treatment facility

Section 1. Introduction

1.1. Background

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

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units in mass per period of time but may be expressed in other ways. In addition to the TMDL, an implementation plan is developed, which is a description of the regulatory and voluntary measures necessary to improve water quality and restore full use of the water body.

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 the water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

TCEQ first identified the impairments of the primary contact recreation 1 use of Neches River Tidal assessment units (AUs) 0601_04, 0601_03, and 0601_02 in the 2012 Texas Integrated Report (TCEQ, 2013). The impairment of the primary contact recreation 1 use of AU 0601_01 was first identified in the 2014 Texas Integrated Report (TCEQ, 2015). The AU impairments were identified in each subsequent edition through the EPA-approved 2020 Texas Integrated Report (TCEQ, 2020a).

This document will consider bacteria impairments in the Neches River Tidal segment, consisting of four AUs. The segment and identifying AUs are:

- Neches River Tidal: 0601_01, 0601_02, 0601_03, and 0601_04

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards are established by TCEQ. The water quality standards specifically protect appropriate uses for each segment and list appropriate limits for water quality indicators to assure water quality and attainment of uses. TCEQ assesses water bodies based on the water quality standards and publishes the Texas Integrated Report biennially.

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

- Designate the uses, or purposes, for which the state's water bodies should be suitable.
- Establish numerical and narrative goals for water quality throughout the state.

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

Standards are established to protect uses assigned to water bodies, of which the primary uses assigned in the *Texas Surface Water Quality Standards* are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

Fecal indicator bacteria (FIB) are indicators of the risk of illness during contact recreation (e.g., swimming) from ingestion of water. FIBs are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria indicates that associated pathogens from fecal wastes may be reaching water bodies, because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets in urban areas, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). *Escherichia coli* (*E. coli*) is widely used as an indicator in freshwater, while Enterococci are used as an indicator in saltwater. Enterococci are the relevant indicator bacteria for Neches River Tidal (Segment 0601).

On February 27, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2018a) and on November 21, 2018, the United States Environmental Protection Agency (USEPA) approved categorical levels of recreational use and their associated criteria. For saltwater, recreational use consists of three categories:

1. Primary contact recreation 1 is that with a significant risk of ingestion of water (such as swimming) and has a geometric mean criterion for Enterococci of 35 colony forming units (cfu) per 100 milliliters (mL) and a single sample criterion of 130 per 100 mL.
2. Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing). It has a geometric mean criterion for Enterococci of 175 per 100 mL.
3. Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for Enterococci of 350 per 100 mL.

The impaired AUs of Neches River Tidal (0601_01, 0601_02, 0601_03, and 0601_04) are designated for primary contact recreation use. The associated standard for Enterococci is a geometric mean of 35 cfu per 100 mL.

1.3. Report Purpose and Organization

TCEQ contracted with the Texas Water Resources Institute (TWRI) for the Neches River Tidal TMDL project. The tasks of this project were to (1) acquire existing (historical) data and information necessary to support assessment activities; (2) perform the appropriate activities necessary to allocate Enterococci loadings; and (3) assist TCEQ in preparing the TMDL.

This project used historical bacteria and flow data to (1) review the characteristics of the watershed and explore potential sources of Enterococci for the impaired AUs; (2) develop an appropriate tool for development of bacteria TMDLs for the impaired AUs; and (3) prepare the draft and final technical support document for the impaired AUs. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for the Neches River Tidal watershed. This report contains all of the following:

- Information on historical data.
- Watershed characteristics.
- Summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to the presence of indicator bacteria (Enterococci).
- Development of load duration curves (LDCs).
- Application of the LDC approach for the pollutant load allocation process.

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The Neches River Tidal watershed is located along the East Texas Gulf Coast (Figure 1). The Neches River Tidal runs approximately 30 stream miles, along the Jefferson and Orange county line, from the Neches River Saltwater Barrier to the confluence with Sabine Lake. The Neches River Tidal consists of a single classified Segment (0601) and four AUs (0601_01, 0601_02, 0601_03, and 0601_04). The drainage area for the segment is 210.75 square miles (134,881 acres).

The Neches River Tidal forms slightly downstream of the confluence of Pine Island Bayou and the Neches River below Lake B. A. Steinhagen. These two water bodies flow through the Big Thicket National Preserve, which is composed of over 112,000 acres of biologically diverse Pineywoods and Coastal Marsh ecoregions known at the Big Thicket of Texas. In 2003, a permanent, gated, saltwater barrier was constructed at the most upstream point of the segment. The saltwater barrier blocks saltwater intrusion during low flows. The lower 20 miles of the Neches River Tidal from south of Interstate Highway 10 to the confluence with Sabine Lake has been deepened and is maintained as a deep-water ship channel serving multiple ports and industrial terminals along the segment. The ship channel portion of the segment is part of the Sabine-Neches Waterway. This part of the segment is home to one of the busiest ports in the United States and several major petrochemical facilities. This low-lying watershed has been highly modified with canals and levees to facilitate development and control flood risk. The Neches River Tidal watershed was delineated with ArcGIS software utilizing digital elevation and catchment data from the National Hydrography Dataset Plus version 2 (NHDPlus); drainage line data from Jefferson County Drainage District No. 6, Jefferson County Drainage District No. 7, and the Orange County Drainage District; and permit application maps from TCEQ (USEPA & USGS, 2012; JCDD No. 6, 2019; OCDD, 2019; TCEQ, 2020b). The 2020 Texas Integrated Report (TCEQ, 2020a) provides the following segment and AU descriptions (downstream to upstream order) for the Neches River Tidal:

- Segment 0601 (Neches River Tidal) – From the confluence with Sabine Lake in Orange County to the Neches River Saltwater Barrier, which is a point 0.8 kilometers (0.5 miles) downstream of the confluence of Pine Island Bayou, in Orange County.
  - AU 0601_01 – Lower boundary to top of first oxbow, above Bird Island Bayou confluence.
  - AU 0601_02 – Top of first oxbow to top of U.S. National Defense Reserve Fleet Basin.
  - AU 0601_03 – Top of U.S. National Defense Reserve Fleet Basin to top of last oxbow below Kansas City Southern Railroad bridge.
  - AU 0601_04 – Top of last oxbow below Kansas City Southern Railroad bridge to saltwater barrier.

This report will often present AU and AU watershed data and information in upstream to downstream order.

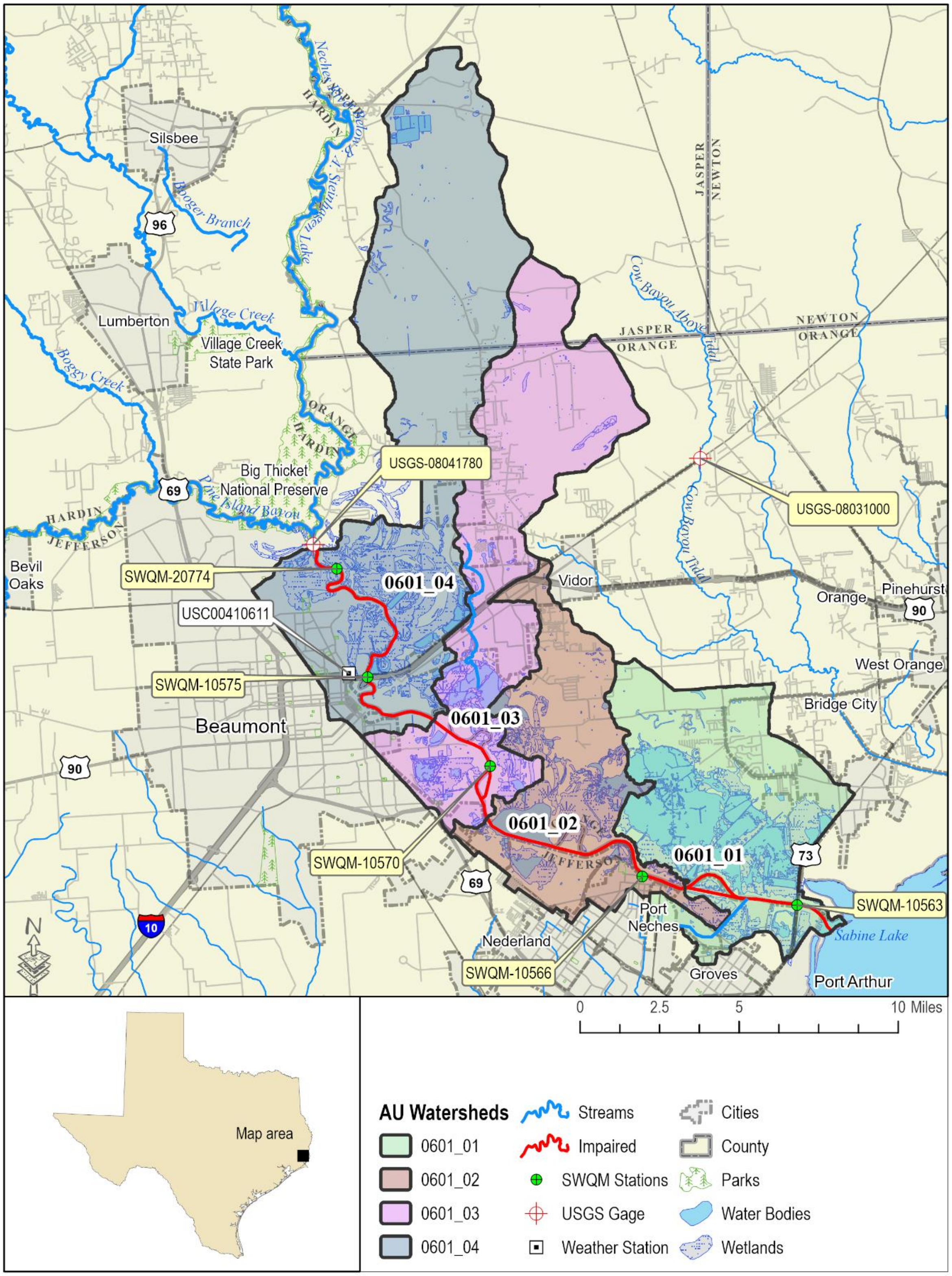

Figure 1. Map of the TMDL watershed

2.2. Review of Routine Monitoring Data for TMDL Watersheds

2.2.1. Data Acquisition

All available ambient Enterococci data records were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database (TCEQ, 2018b; TCEQ, 2019a). The data represented all historical ambient Enterococci data and field parameters collected in the TMDL watershed from October 9, 2001 through October 23, 2018. For AU 0601_01, 64 ambient Enterococci measurements were available at TCEQ Surface Water Quality Monitoring (SWQM) Station 10563. Sixty-five measurements were available for SWQM Station 10566 in AU 0601_02. Sixty-three measurements were available for SWQM Station 10570 in AU 0601_03. There are two SWQM stations (10575, 20774) in AU 0601_04 with a total of 91 ambient Enterococci measurements.

2.2.2. Analysis of Bacteria Data

Enterococci data has been collected at five SWQM stations on the Neches River Tidal (Segment 0601) (Figure 1). Enterococci data collected at these stations over the seven-year period of December 1, 2011 to November 30, 2018 were used in assessing attainment of the primary contact recreation use as reported in the 2018 Texas Integrated Report (TCEQ, 2020a). The 2020 assessment data indicate non-support of the primary contact recreation use because the geometric mean concentrations exceed the geometric mean criterion of 35 cfu/100 mL as summarized in Table 1. (Note that the 2022 Texas Integrated Report was approved after the completion of this document and is cited in the TMDL document.)

Table 1. 2020 Integrated Report summary for the impaired AUs

Water Body	AU	Parameter	TCEQ SWQM Station	Data Range	Number of Samples	Geometric Mean (cfu/100 mL)
Neches River Tidal	0601_04	Enterococci	10575, 20774	12/01/2011 – 11/30/2018	46	99.47
Neches River Tidal	0601_03	Enterococci	10570	12/01/2011 – 11/30/2018	27	159.33
Neches River Tidal	0601_02	Enterococci	10566	12/01/2011 – 11/30/2018	28	96.60
Neches River Tidal	0601_01	Enterococci	10563	12/01/2011 – 11/30/2018	28	85.62

2.3. Watershed Climate and Hydrology

The watershed is within the humid subtropical climate regime and receives the largest amounts of rainfall in the state. Summers can be characterized as hot and humid, with highs typically in the low to mid 90° F range. Winters are typically mild with lows in the mid 40° F range. Like most subtropical coastal areas around the world, the Neches River Tidal watershed is prone to the effects of hurricanes and tropical storms, which occasionally make landfall in and around Sabine Lake. Since 2000, this region of the state has experienced extensive negative impacts from hurricanes Rita, Ike, Harvey, and multiple tropical storms resulting in major flooding, power outages, and loss of water and sewer services. These events can have lasting effects on water quality, as environmental infrastructure can be damaged and sanitation services disrupted for long periods after these severe weather events occur.

The nearest active National Oceanic and Atmospheric Administration (NOAA) station, City of Beaumont Station USC00410611 (Figure 1) was used to retrieve temperature and precipitation data from 2002 through 2018 (NOAA, 2019). The highest average monthly precipitation occurs in August at 7.36 inches, and the lowest average monthly precipitation occurs in April at 3.82 inches (Figure 2). The highest average monthly maximum temperatures occur in August (93.1° F) and the lowest average monthly minimum temperatures occur in January (43.0° F) (Figure 2). From 2002 through 2018, the mean annual precipitation was 63.9 inches with a low of 34 inches occurring in 2011 and high of 93.4 inches occurring in 2017 (Figure 3).

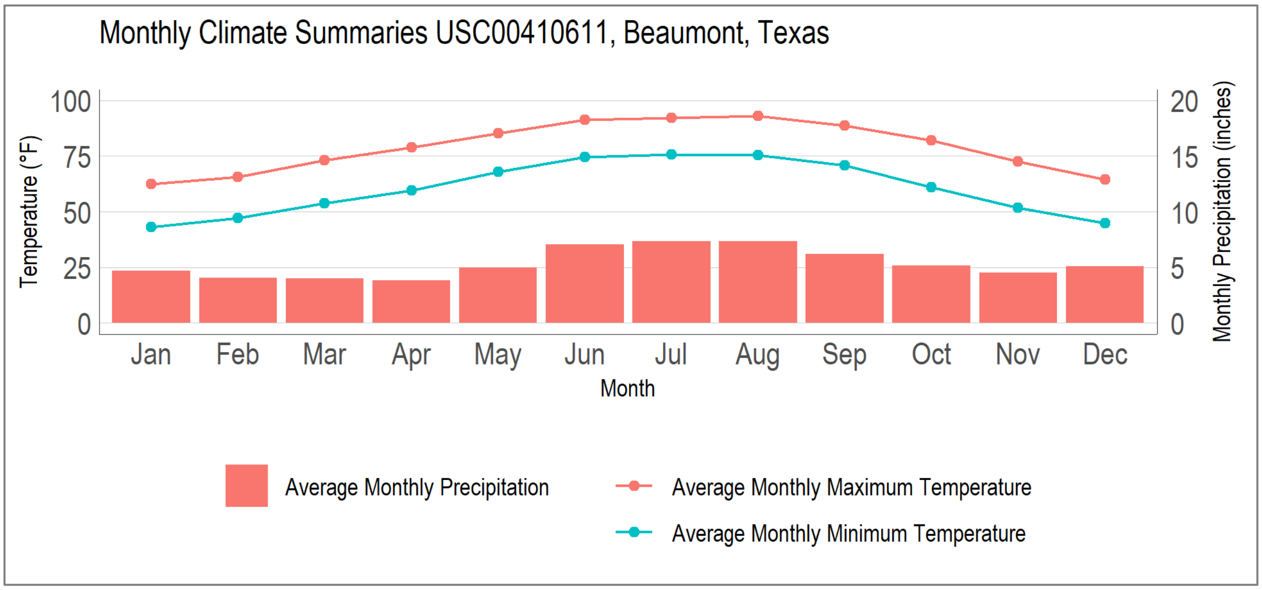

Figure 2. Average monthly temperature and precipitation from January 2002 through December 2018 at Beaumont, Texas Station USC00410611

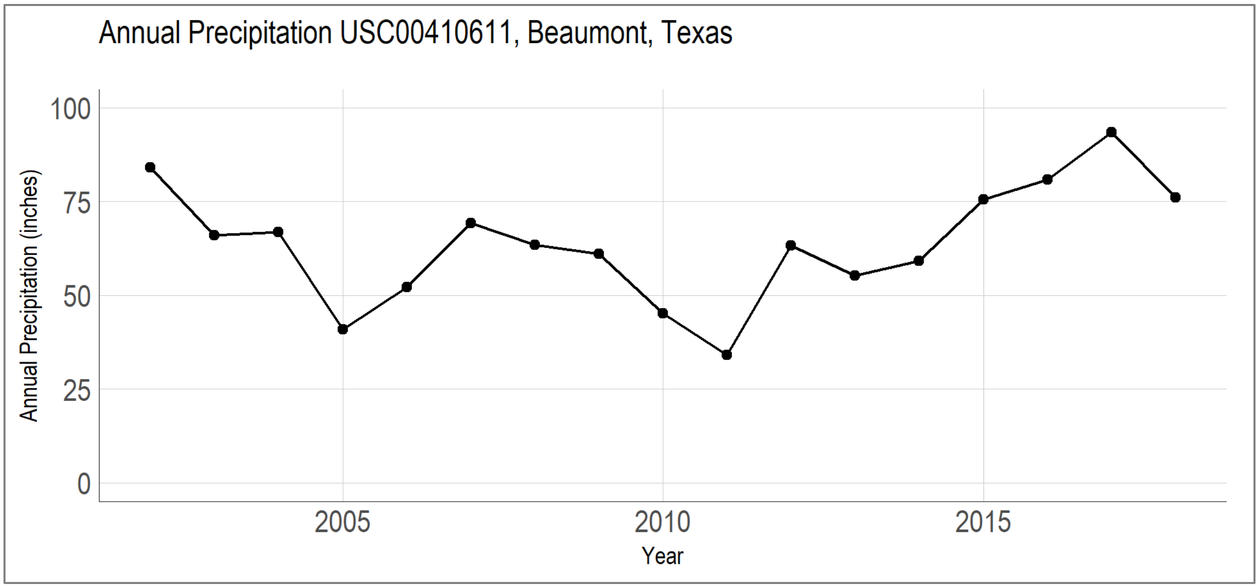

Figure 3. Annual precipitation from 2002 through 2018 at Beaumont, Texas Station USC00410611

2.4. Watershed Population and Population Projections

Watershed population estimates were developed using 2010 United States Census Bureau (USCB) census block geographic units and population data (USCB, 2010a). U.S. census blocks are the smallest geographic unit used by USCB to tabulate population data. The Neches River Tidal TMDL watershed includes 3,380 census blocks located entirely or partially in the watershed. Population was estimated for those census blocks partially located in the watershed by multiplying the census block population and the proportion of each block within each AU watershed. It was assumed for this estimation that populations were evenly distributed within a census block. These estimated partial census block populations were then summed with the populations from the census blocks entirely located within each AU watershed. The 2010 population of the Neches River Tidal TMDL watershed was estimated at 49,837 (Table 2, Figure 4).

Table 2. Population estimates and projections

AU Watershed	Estimated 2010 Population	Estimated 2020 Population	Estimated 2070 Population
0601_04	18,395	19,466	26,093
0601_03	13,849	14,617	16,891
0601_02	10,772	11,394	14,472
0601_01	6,821	7,202	8,464
Total	**49,837**	**52,679**	**65,920**

Texas Water Development Board (TWDB) 2021 Regional Water Plan Population and Water Demand Projection data (TWDB, 2019a) provide decadal population projections for counties within the watershed (Table 3) for 2020 through 2070. These population projections, developed by TWDB, indicate a 12.7% to 39.5% population increase for the more populated counties of the watershed and a 2.6% increase for Jasper County through 2070. Table 4 provides the estimated watershed population for 2070 based on the 2010 census block populations and TWDB population growth rates. Across the entire Neches River Tidal watershed, a total population increase of 25.1% is anticipated from 2020 through 2070 (Table 2).

Table 3. 2020-2070 population projections

County	2010 Census Population	2020	2030	2040	2050	2060	2070	2010-2020 Percent Increase	2020-2070 Percent Increase
Jefferson County	252,273	267,379	284,620	302,744	323,802	347,030	373,041	6.0	39.5
Orange County	81,837	86,327	90,233	92,984	94,848	96,269	97,298	5.5	12.7
Jasper County	35,710	36,878	37,695	37,849	37,849	37,849	37,849	3.3	2.6

Table 4. Estimated population increase calculations

County	AU Watershed	Estimated 2010 Population	2010 - 2020 % Growth	Estimated 2020 Population	2020-2070 % Growth	Estimated 2070 Population
Jasper	0601_03	47	3.3	49	2.6	50
Jasper	0601_04	666	3.3	688	2.6	706
Jefferson	0601_01	1,222	6.0	1,295	39.5	1,807
Jefferson	0601_02	5,742	6.0	6,087	39.5	8,491
Jefferson	0601_03	1,489	6.0	1,578	39.5	2,201
Jefferson	0601_04	14,870	6.0	15,762	39.5	21,988
Orange	0601_01	5,599	5.5	5,907	12.7	6,657
Orange	0601_02	5,030	5.5	5,307	12.7	5,981
Orange	0601_03	12,313	5.5	12,990	12.7	14,640
Orange	0601_04	2,859	5.5	3,016	12.7	3,399
	Total:	**49,837**		**52,679**		**65,920**

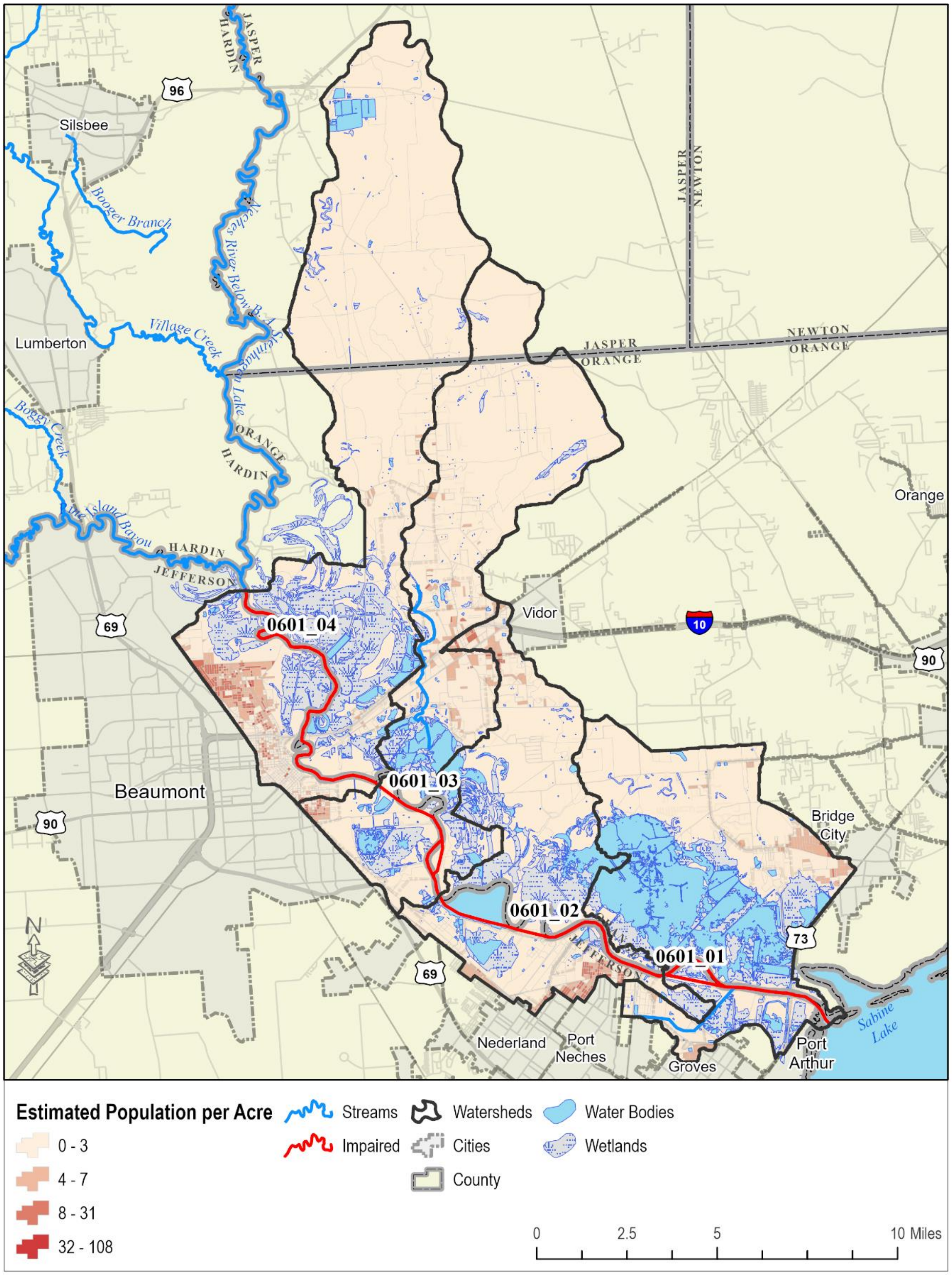

Figure 4. 2010 population density estimates using USCB census block data

2.5. Land Cover

Land cover for the watersheds were obtained from the 2016 National Land Cover Database (NLCD) (USGS, 2019a), displayed in Figure 5. The following categories and definitions represent land cover in the NLCD database:

- Open Water – Areas of open water, generally with less than 25% 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% of total cover. These areas most commonly include large-lot single-family housing units, 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% to 49% 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% to 79% of 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% to 100% of 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% of total cover.
- Deciduous Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
- Evergreen Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the species maintain their leaves all year. Canopy is never without green foliage.
- Mixed Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% total tree cover.
- Shrub/Scrub – Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20% 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% 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% of total vegetation.

- Cultivated Crops – Areas used to produce annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class includes all land being actively tilled.
- Woody Wetlands – Areas where forest or shrubland vegetation accounts for greater than 20% 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% of vegetative cover and the soil substrate is periodically saturated with or covered with water.

The TMDL watershed is characterized by substantial amounts of wetlands and open water, with mixed development along the western side of the Neches River Tidal. The amount of forested lands increases in northern portions of the watershed, as it extends into Jasper County (Figure 5). The AU 0601_01 watershed is predominately open water and wetlands (approximately 66% of the watershed), with approximately 16% of the watershed classified as developed (Table 5). Approximately 58% of the AU 0601_02 watershed is classified as open water or wetlands and approximately 27% is classified as developed. The AU 0601_03 watershed is approximately 44% open water or wetlands and 23% developed. The amount of open water and wetlands is approximately 44% in the AU 0601_04 watershed. Approximately 17% of the AU 0601_04 watershed is developed, and 27% is evergreen and mixed forest.

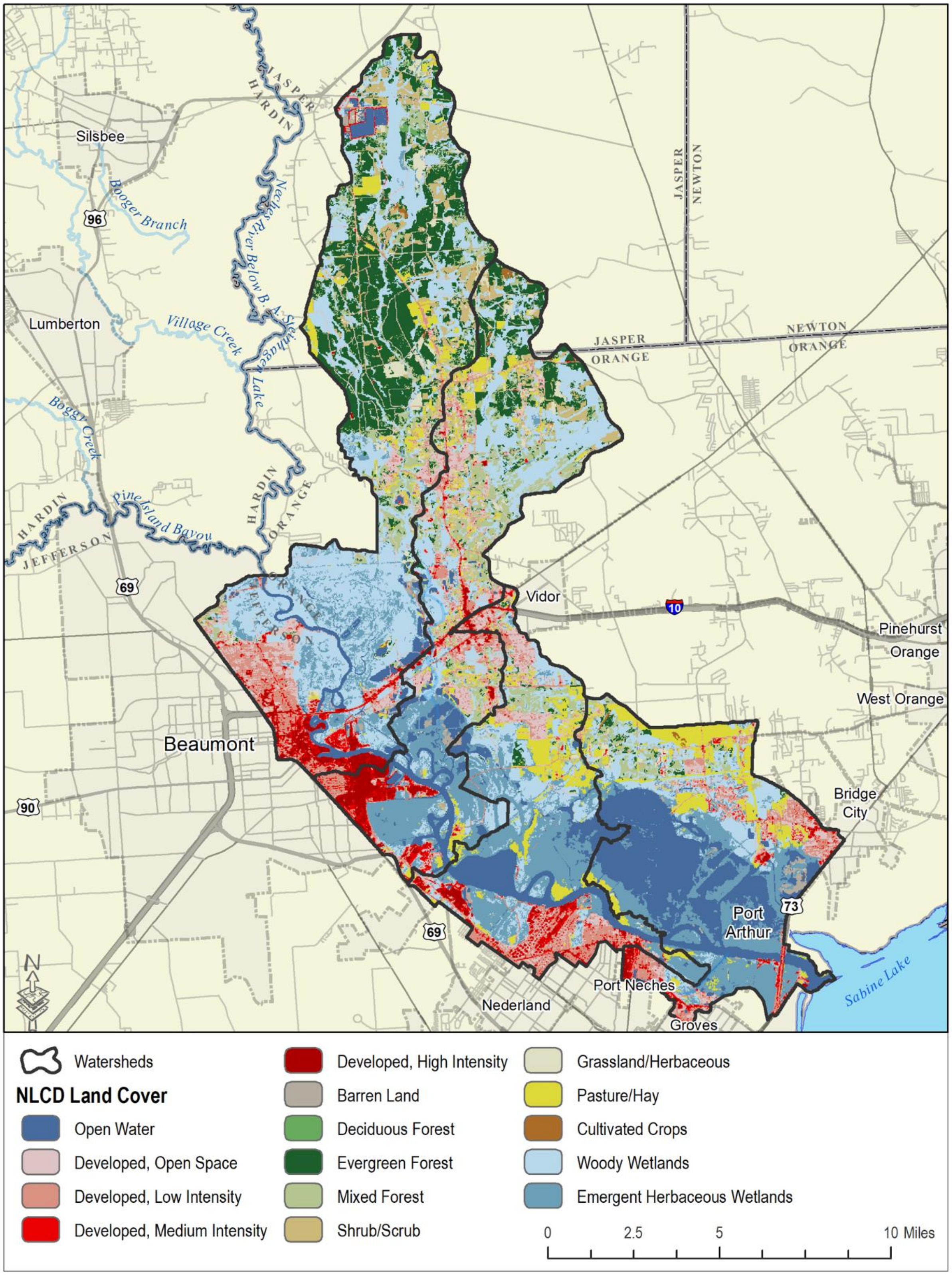

Figure 5. 2016 land cover map

Table 5. Land cover percentages

Land Cover	0601_01		0601_02		0601_03		0601_04	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Open Water	8,888	31.5	3,176	14.0	2,017	6.1	2,125	4.2
Developed, Open Space	1,375	4.9	1,912	8.4	2,909	8.8	3,177	6.2
Developed, Low Intensity	1,999	7.1	2,607	11.5	2,469	7.5	3,061	6
Developed, Medium Intensity	739	2.6	971	4.3	1,080	3.3	1,223	2.4
Developed, High Intensity	279	1.0	539	2.4	1,183	3.6	1,134	2.2
Barren Land	263	0.9	85	0.4	182	0.6	212	0.4
Deciduous Forest	0	0.0	0	0.0	11	0	123	0.2
Evergreen Forest	329	1.2	249	1.1	2,918	8.8	10,770	21.1
Mixed Forest	927	3.3	772	3.4	3,599	10.9	3,081	6
Shrub/Scrub	100	0.4	37	0.2	1,442	4.4	2,819	5.5
Grassland/Herbaceous	217	0.8	75	0.3	791	2.4	1,427	2.8
Pasture/Hay	3,283	11.6	2,436	10.7	1,716	5.2	1,659	3.3
Cultivated Crops	58	0.2%	2	0.0	115	0.3	79	0.2
Woody Wetlands	3,380	12.0	3,743	16.5	8,365	25.3	16,546	32.5
Emergent Herbaceous Wetlands	6,356	22.5	6,134	27.0	4,210	12.8	3,508	6.9
Total	**28,193**	**100**	**22,738**	**100[a]**	**33,007**	**100**	**50,944**	**100[a]**

[a] Total differs slightly from 100% due to rounding

2.6. Soils

Soil data was obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (USDA NRCS, 2018). The USDA NRCS SSURGO data assigns different soils to one of seven possible runoff potential classifications or hydrologic groups. These classifications are based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The four main groups are A, B, C, and D, with three dual classes (A/D, B/D, C/D). Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and undrained areas to the second letter. Only soils that are in group D in their natural condition are assigned to dual classes.

The USDA NRCS SSURGO database defines the classifications below:

- Group A – Soils having high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
- Group B – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have

moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

- Group C – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Spatial distribution of soil hydrologic groups within the TMDL watershed is shown in Figure 6. Most of the Neches River Tidal watershed is characterized by soils with very slow infiltration and high runoff, with isolated areas of high infiltration and low runoff. The AU 0601_01 and AU 0601_02 watersheds are predominately composed of Type D soils (Table 6). The majority of the AU 0601_03 and AU 0601_04 watersheds are composed of a dual group soil group C/D, generally indicating slow or very slow infiltration under most conditions.

Table 6. Hydrologic soil group percentages

Soil Group	0601_01		0601_02		0601_03		0601_04	
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
A	292	1.0	605	2.7	2,174	6.6	2,770	5.4
C	0	0.0	269	1.2	1,224	3.7	3,284	6.5
C/D	111	0.4	2,007	8.8	19,038	57.7	27,400	53.8
D	27,783	98.6	19,857	87.3	10,571	32.0	17,489	34.3
Total	**28,187**[a]	**100.0**	**22,738**	**100.0**	**33,007**	**100.0**	**50,943**	**100.0**[b]

[a]Acreage is less than the total acreage of the watershed due to missing soil type data.
[b] Total differs slightly from 100% due to rounding

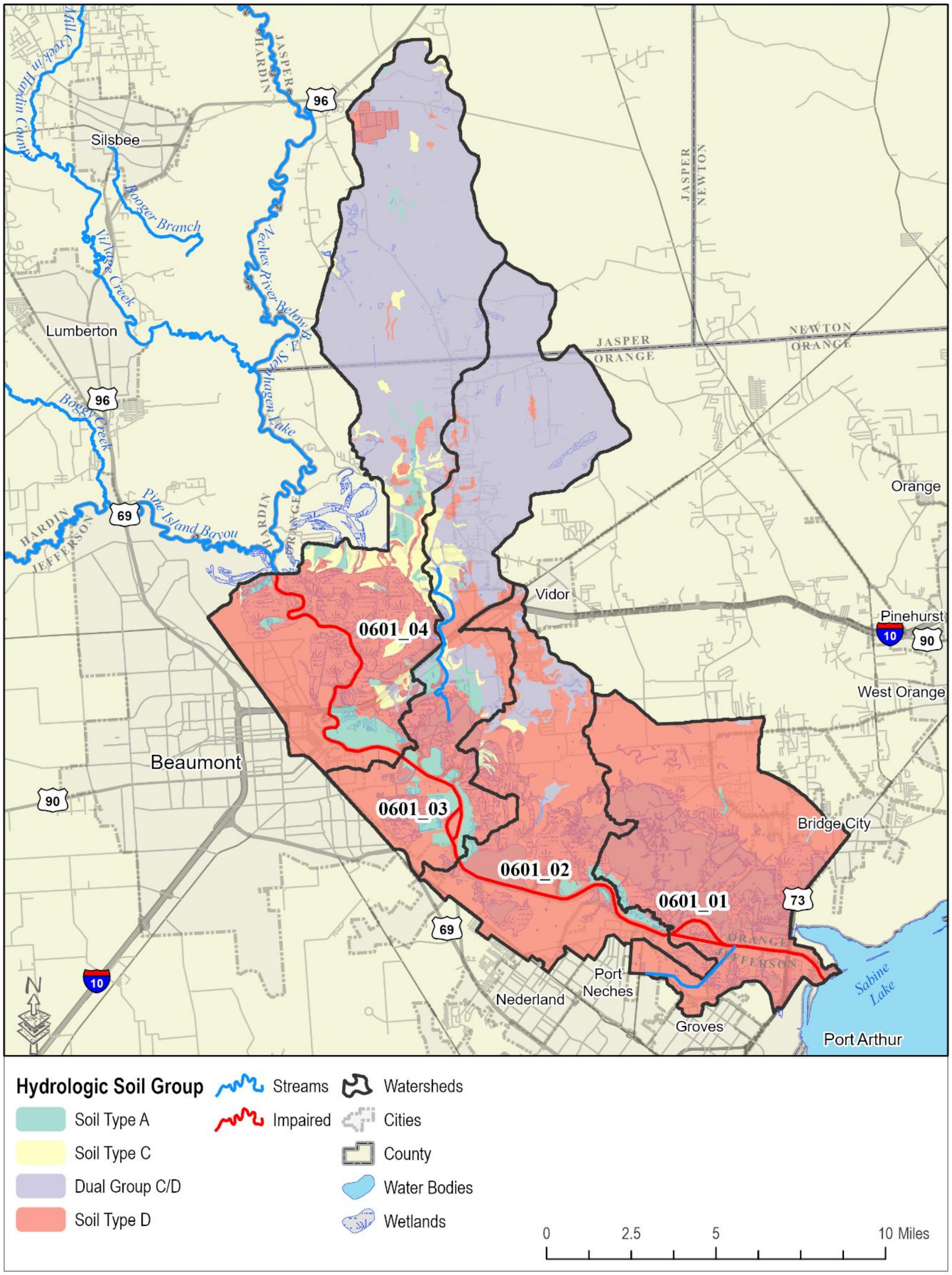

Figure 6. Hydrologic soil groups

2.7. Potential Sources of Fecal Indicator Bacteria

Potential sources of FIB pollution are divided into two primary categories: *regulated* and *unregulated*. Regulated pollution sources have permits under the Texas Pollutant Discharge Elimination System (TPDES) program. Wastewater treatment facility (WWTF) discharges and stormwater discharges from industry, construction activities, and municipal separate storm sewer systems (MS4s) are examples of regulated sources, also known as point sources. Unregulated sources are typically nonpoint source (NPS) in nature and are not regulated by a permit.

With the exception of WWTFs, which receive individual wasteload allocations (WLAs, Section 4.7.3), 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 source descriptions are not precise inventories or loadings.

2.7.1. Regulated Sources

Regulated sources in Texas are controlled by permits issued under the TPDES program. Domestic and industrial WWTFs, and municipal, construction, concrete production, and industrial stormwater discharges represent the permitted sources in the Neches River Tidal watershed.

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

As of December 2018, there were 29 active facilities with individual TPDES permits for domestic and/or industrial wastewater (Table 7) (TCEQ, 2019d) that discharge within the Neches River Tidal watershed. Nine of these facilities have bacteria effluent limits (Table 7, Figure 7). Within the watershed, 23 industrial facilities are covered by TPDES permits for wastewater discharges that include stormwater. Discharges are reported in units of million gallons per day (MGD).

Table 7. Permitted domestic and industrial WWTFs

TPDES Permit No./ NPDES ID	Facility/Permitee	Outfall(s)	Discharge Type[a]	Permitted Discharge (MGD)	Recent Discharge (MGD)[b]	Receiving AU or Segment	WLA[c]
WQ0000316000/ TX0002909	Beaumont Terminal/ Phillips 66 Gulf Coast Properties LLC and Phillips 66 Pipeline LLC	001, 003, 005	SW/IW	Intermittent and flow-variable	001 = 0.129 003 = 0 005 = 0.045	0601_02	WLA-SW
		002	IW/SW/WW	Continuous and flow-variable	0.283	0601_02	WLA-WWTF
WQ0000336000/ TX0006696	Sabine Plant/ Entergy Texas, Inc.	001	CW/PME/SW	1,306 (daily average)	1,102	0601_01	WLA-SW
		801	WW	Intermittent and flow-variable	0.001	0601_01	WLA-WWTF
WQ0000462000/ TX0004227	ExxonMobil Oil Corporation Beaumont Chemical Plant/ExxonMobil Oil Corporation	001	SW/IW	Intermittent and flow-variable	2.86	0601_03	WLA-SW
WQ0000473000/ TX0004669	Lucite Beaumont Facility/ Lucite International, Inc.	001	IW/SW/PME	9.99 (daily average)	3.95	0601_02	WLA-SW
		002, 004, 005, 006, 008, 011, 015, 018, 020, 021	SW/IW	Intermittent and flow-variable	002 = 0.337 004 = 0.236 005 = 0.412 006 = 0.205 008 = 0.136 011 = 0.127 015 = 0.244 018 = 0.023 020 = 0.017 021 = 0.044	0601_02	WLA-SW
		101	WW/IW	Flow-variable	0.145[d]	0601_02	WLA-WWTF
WQ0000491000/ TX0004201	Port Arthur Refinery/ Total Petrochemicals and Refining USA, Inc.	001	IW/SW	7.1 (daily average)	3.90	0601_01	WLA-SW
		002, 003, 005, 007	IW/SW	Intermittent and flow-variable	002 = 0.048 003 = 0.445 005 = 0.083 007 = NR	0601_01	WLA-SW
		004, 006, 008	IW/SW	Intermittent and flow-variable	004 = 0.458 006 = NR 008 = NR	0703	NA

TPDES Permit No./ NPDES ID	Facility/Permitee	Outfall(s)	Discharge Type[a]	Permitted Discharge (MGD)	Recent Discharge (MGD)[b]	Receiving AU or Segment	WLA[c]
WQ0000493000/ TX0003891	Evadale Mill/WestRock Texas, LP	001	IW/WW/SW	65 (daily average)	40.38	0601_04	WLA-WWTF WLA-SW
		002	SW/IW	Intermittent and flow-variable	0.193	0602	NA
WQ0000511000/ TX0005070	Joint Wastewater Treatment Plant/ Huntsman Petrochemical LLC, Huntsman Propylene Oxide LLC (now known as Indorama Ventures Propylene Oxides LLC), Bluehall Incorporated, and TPC Group LLC	001, 002, 004, 009, 010	PME/SW/IW	Flow-variable/ Intermittent and flow-variable	001 = 1.88 002 = 0.191 004 = 8.48 009 = 0.040 010 = 0.231	0601_01	WLA-SW
		006, 007, 008, 012	SW/IW	Intermittent and flow-variable	006 = 0.271 007 = 0.641 008 = 1.28 012 = 0.048	0702	NA
		301	IW/WW/SW	15.0 (daily average)	7.687	0601_01	WLA-WWTF
WQ0000647000/ TX0006726	Chemtrade Facility/Chemtrade Refinery Services Inc.	001	SW	Intermittent and flow-variable	0.707	0601_03	WLA-SW
WQ0001151000/ TX0005746	Nederland Marine Terminal/ Sunoco Partners Marketing & Terminals, LP	001	IW/SW	5.0 (daily maximum)	6.44	0601_02	WLA-SW
WQ0001202000/ TX0003662	Neches Terminal/ Martin Operating Partnership, LP	002, 003, 006, 007	SW/IW	Intermittent and flow-variable	002 = 0.038 003 = 0.019 006 = 0.042 007 = 0.036	0601_03	WLA-SW
		004	IW/SW	0.22 (daily average dry-weather flow)	0	0601_03	WLA-SW
		005	IW/SW/PME	0.0658 (daily average dry-weather flow)	0.027	0601_03	WLA-SW
		008	IW/SW	0.208 (daily average dry-weather flow)	0.038	0601_03	WLA-SW
WQ0001595000/ TX0007277	Air Liquide – Nederland ASU Facility/ Air Liquide Large Industries US LP	002	IW/FB/SW	0.175 (daily average)	0.081	0601_02	WLA-SW
WQ0001674000/ TX0064718	Carotex Facility/Integrity-Golden Triangle Marine Services LLC	001	IW/SW	0.048 (daily average)	0.018	0601_01	WLA-SW
		002	SW	Intermittent and flow-variable	0.018	0601_01	WLA-SW

TPDES Permit No./ NPDES ID	Facility/Permitee	Outfall(s)	Discharge Type[a]	Permitted Discharge (MGD)	Recent Discharge (MGD)[b]	Receiving AU or Segment	WLA[c]
WQ0001727000/ TX0062677	Lower Neches Valley Authority North Regional Treatment Plant/ Neches River Treatment Corporation and Lower Neches Valley Authority	001	WW/IW	21.0 (daily average)	15.444	0601_03	WLA-WWTF
WQ0001872000/ TX0052825	Arkema Beaumont Plant/ Arkema Inc.	001	SW/PME	Intermittent and flow-variable	0.255	0601_03	WLA-SW
WQ0001971000/ TX0067695	Optimus Steel - Beaumont Mill/Optimus Steel, LLC[e]	001	IW/SW	1.64 (daily average)	0.358	0601_04	WLA-SW
		002, 004, 007	SW	Intermittent and flow-variable	002 = 0.123 004 = 0.230 007 = 0.149	0601_04	WLA-SW
WQ0002487000/ TX0087602	Lion Elastomers/Lion Elastomers LLC	001	IW/SW	0.253 (daily average dry-weather flow)	0.087	0601_02	WLA-SW
WQ0003426000/ TX0118737	ExxonMobil Beaumont Refinery/ ExxonMobil Oil Corporation	001	IW/SW	Intermittent and flow-variable	4.11	0601_03	WLA-SW
		002	IW	3.0 (daily average)	NR	0601_03	NA
		003	SW	Intermittent and flow-variable	NR	0601_03	WLA-SW
WQ0005328000/ TX141682	Marine Fueling Services Inc.	001	IW	0.035 (daily average)	0.014	0601_01	NA
WQ0004074000/ TX0116921	Stanolind Cut Terminal/ Martin Operating Partnership LP	001	IW/SW/PME	Intermittent and flow-variable	0.111	0601_03	WLA-SW
WQ0004135000/ TX0119369	BASF TOTAL NAFTA Region Olefins Complex/ BASF TOTAL Petrochemical LLC	001	IW/SW	Intermittent and flow-variable	6.27	0703	NA
		002	IW	2.0 (daily average)	0.893	0601_01	NA
WQ0004731000/ TX0062448	INEOS Calabrian Corp	001	IW/SW	0.25 (daily average)	0.178	0601_01	WLA-SW
WQ0004840000/ TX0129887	TPC Group Port Neches Operations/ TPC Group LLC	201	SW	Intermittent and flow-variable	1.116	0601_01	WLA-SW
		005, 011	SW	Intermittent and flow-variable	005 = 0.170 011 = 0.129	0702	NA
WQ0004874000/ TX0131598	Rainbow Terminal Petcoke Handling Facility/ Kinder Morgan Petcoke, LP	001	SW/IW	Intermittent and flow-variable	0.014	0601_01	WLA-SW

TPDES Permit No./ NPDES ID	Facility/Permitee	Outfall(s)	Discharge Type[a]	Permitted Discharge (MGD)	Recent Discharge (MGD)[b]	Receiving AU or Segment	WLA[c]
WQ0005143000/ TX0135836	Beaumont Gas to Gasoline Plant/Natgasoline LLC	001	PME/IW/SW	3.5 (daily average)	0.524	0601_03	WLA-SW
		002	SW/IW	Intermittent and flow-variable	6.57	0601_03	WLA-SW
WQ0005188000/ TX0136824	Jefferson Railport Terminal I (Texas) Facility/ Jefferson Railport Terminal I (Texas) LLC	001, 002	IW/SW	Intermittent and flow-variable	001 = 3.96[f] 002 = 1.65[f]	0601_04	WLA-SW
WQ0005236000/ TX0137855	Ethane Cracker Facility/ Bayport Polymers LLC (formerly Total Petrochemicals & Refining USA, Inc)	001	IW	0.81 (daily average)	NR	0601_01	NA
		002	IW/SW	Intermittent and flow-variable	NR	0703	NA
		003	SW/IW	Continuous flow-variable	NR	NA[g]	WLA-SW
WQ0010477004/ TX0022926	Main Wastewater Treatment Facility/ City of Port Neches	001	WW	4.98 (annual average)	1.861	0601_02	WLA-WWTF
WQ0010875001/ TX0023795	Oak Lane Wastewater Treatment Facility/ Orange County Water Control and Improvement District No. 1	001	WW	3.0 (annual average)	0.946	0601_03	WLA-WWTF
WQ0014049001/ TX0117277	Sugar Pines Mobile Home Community Wastewater Treatment Facility/Vidor MHP No. 1 LLC	001	WW	0.0225 (daily average)	0.0044	0601_04	WLA-WWTF

NPDES = National Pollutant Discharge Elimination System

[a] Abbreviations as follows: WW (treated domestic wastewater), IW (treated industrial wastewater), SW (stormwater), FB (filter backwash), CW (once through cooling water), PME (previously monitored effluent), NA (not applicable due to effluent type, or receiving segment is out of TMDL area) NR (not reported for the reporting periods ending October 31, 2008 through November 30, 2018)

[b] Based on mean reported discharges in discharge monitoring reports (DMRs) for the reporting periods ending November 30, 2008 through November 30, 2018. Reports with no reported discharge treated as zero if the no-discharge indicator was marked one of the following: insufficient flow, operational shut down, no influent, or not constructed.

[c] Indicates if an individual allocation is included as part of the WLA for WWTFs (WLA-WWTF), or if it is included as part of the regulated stormwater WLA (WLA-SW).

[d] Lucite Beaumont Facility did not report any flows for internal outfall 101 for the reporting periods ending November 30, 2008 through November 30, 2018. The values shown is based on mean reported discharges in DMRs for the reporting periods ending February 28, 2019 through June 30, 2019.

[e] The permit for the Optimus Steel Facility renewed January 24, 2020. Outfall 003 was removed from the most recent permit.

[f] Jefferson Railport Terminal I (Texas) Facility/ Jefferson Railport Terminal I (Texas) LLC authorization was cancelled in August 2018. This record is included for completeness. Recent discharge is based on monthly mean reported discharges in DMRs for the reporting periods ending October 31, 2008 through August 30, 2018.

[g] Outfall 003 is routed to WQ0000491000, Port Arthur Refinery/ Total Petrochemicals and Refining USA, Inc.

Figure 7. Regulated sources

2.7.1.2. Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the 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 Central Office in Austin provided statewide data on SSO incidents from January 2016 through December 2018 (TCEQ, 2019f) and basin-wide data on SSO incidents from 2005 through 2015 (TCEQ, 2019g). Table 8 summarizes the number of reported SSO incidents within the watershed. From 2005-2018, the Orange County Water Control and Improvement District reported 498 SSOs. City of Beaumont reported 263 SSOs. Lucite International reported 19 SSOs. The Joint Wastewater Treatment Plant (Huntsman and others) reported 18 SSOs. Evadale Mill (Westrock) reported 14 SSOs. City of Port Neches reported 12 SSOs. City of Nederland reported nine SSOs. Lower Neches Valley Authority reported three SSOs. City of Port Arthur reported two SSOs. Although the discharge locations for the City of Beaumont, City of Nederland, and City of Port Arthur wastewater systems are not in the watershed, portions of their collection systems are within the watershed. Figure 8 shows the number of reported monthly SSO incidents from 2005 through 2018. Figure 9 shows the spatial distribution and density of reported SSO events within the watershed.

Table 8. Summary of reported SSO events from 2005 through 2018

Year	No. of incidents	Total Volume (Gallons)	Average Volume[a] (Gallons)	Minimum Volume (Gallons)	Maximum Volume (Gallons)
2005	22	70,510	3,526	15	28,000
2006	31	98,646	4,110	1	80,000
2007	65	286,336	5,403	10	100,000
2008	64	297,137	4,952	6	144,000
2009	71	56,909	813	4	20,000
2010	79	91,813	1,293	1	78,000
2011	85	2,173,910	28,604	1	535,000
2012	67	475,657	7,798	3	460,000
2013	38	4,122	115	1	600
2014	49	8,246	187	1	1,975
2015	69	132,450	2,284	2	60,000
2016	95	25,545	269	1	3,500
2017	52	21,416	412	<1	3,239
2018	51	31,055	609	5	10,000
Total	**838**	**3,773,752**	**4,895**		

[a] Some reported incidents did not include a volume. Therefore, the average volume is not equivalent to the total volume divided by the number of incidents. Average volume was calculated as the mean of incidents with reported volumes.

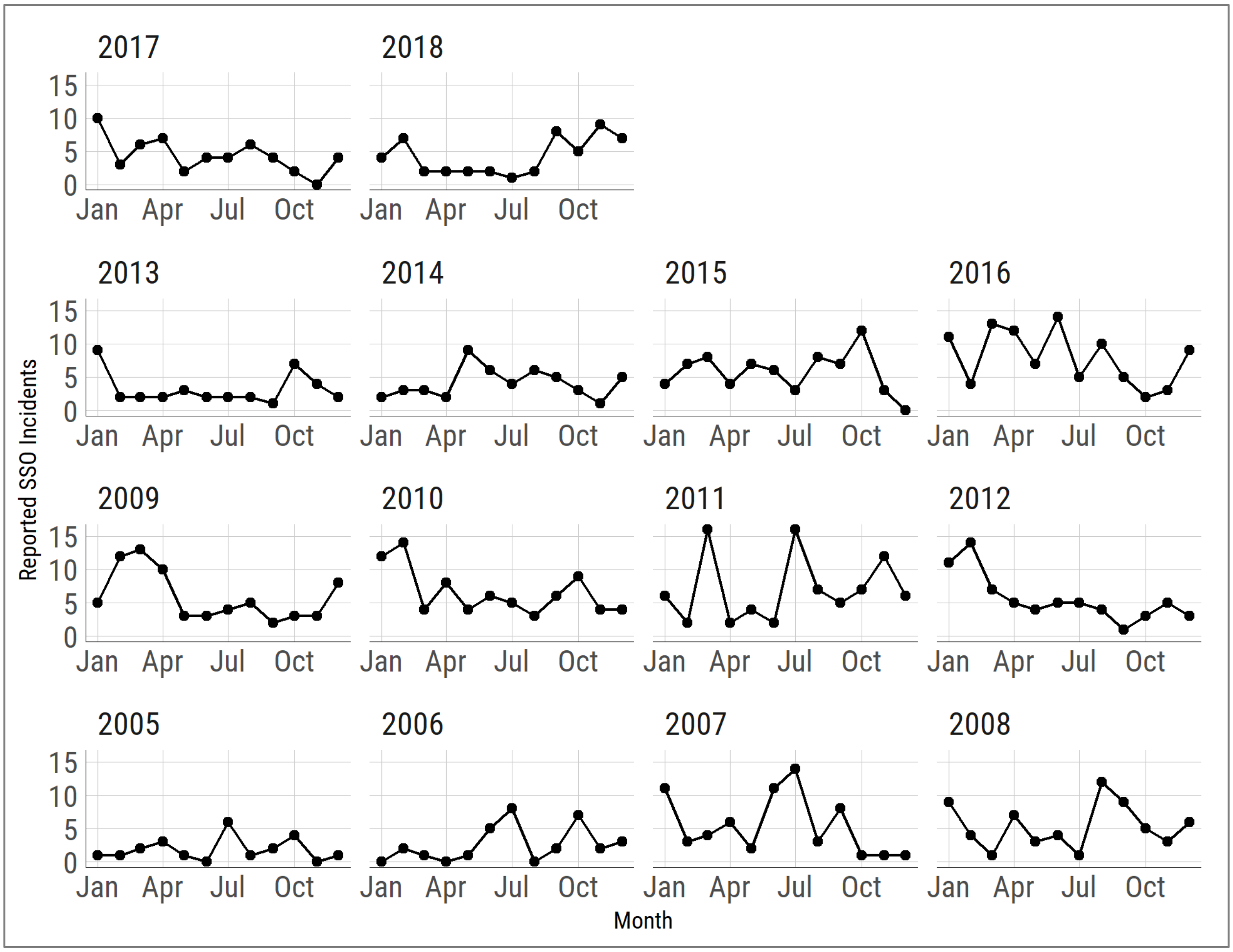

Figure 8. Number of reported SSO incidents by month and year

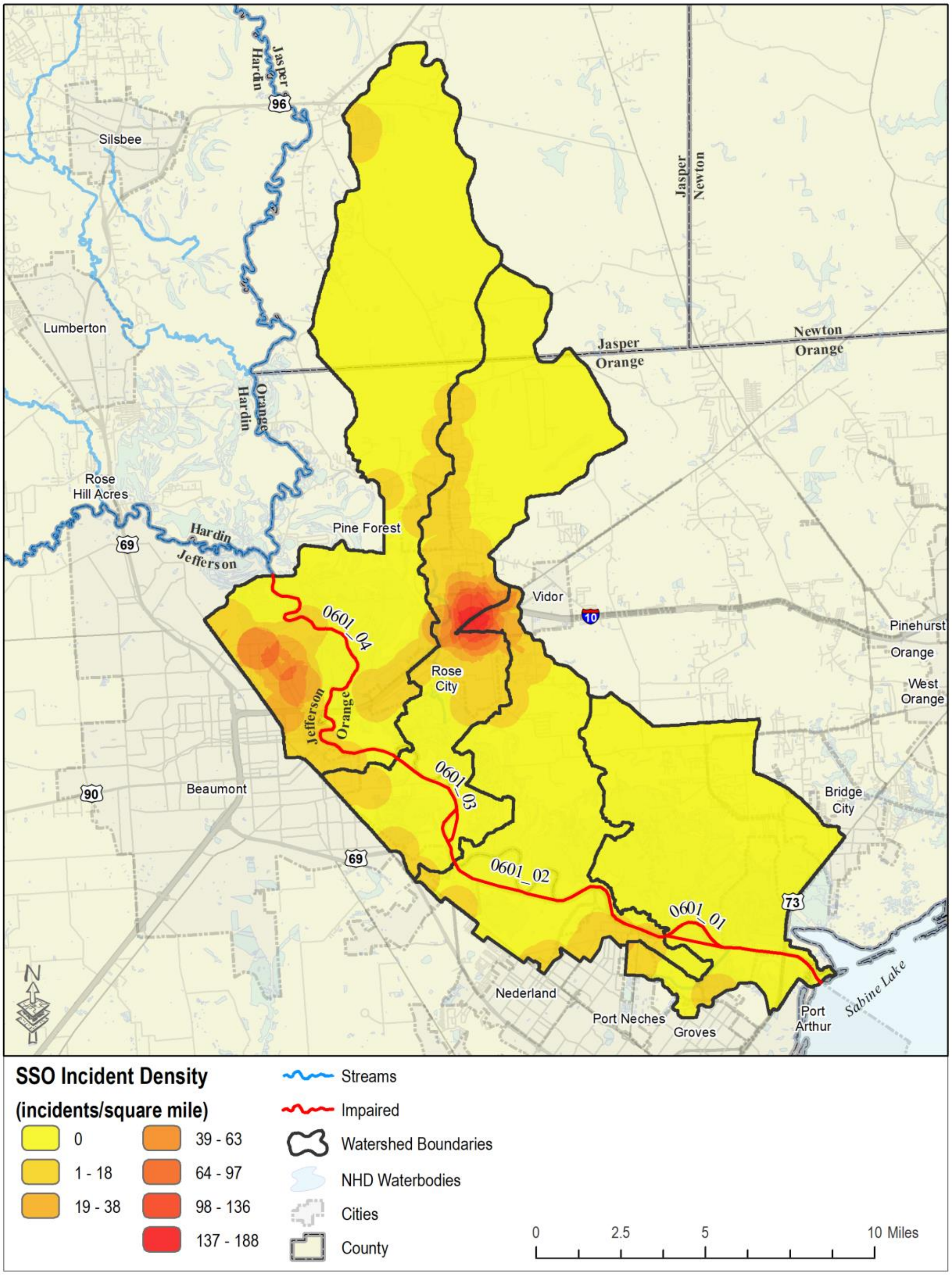

Figure 9. Density of SSO incidents from 2005 through 2018

2.7.1.3. TCEQ/TPDES Water Quality General Permits

In addition to the individual wastewater discharge permits, certain types of activities must be covered by one of several TCEQ/TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- TXG340000 – petroleum bulk stations and terminals
- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations (irrigation only)

The following general permit authorizations are not considered to affect the bacteria loading in the TMDL watersheds and were excluded from this investigation:

- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- WQG100000 – wastewater evaporation

A review of active general permit coverage (TCEQ, 2019e) in the Neches River Tidal watershed as of December 31, 2018 indicated one general permit authorization for a concrete production facility. This permit authorizes the discharge of stormwater and is implicitly included in the regulated stormwater allocations. No other active general permits with a potential bacteria loading were found for the Neches River Tidal watershed.

2.7.1.4. TPDES Regulated Stormwater

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

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

The Neches River Tidal watershed includes regulated stormwater from MS4s, industrial WWTFs, industrial authorizations under the Multi-Sector General Permit (MSGP), certain general wastewater facilities, and construction activities. These were reviewed to determine the aggregate area of regulated stormwater (ARS). The ARS is the geographic extent of the Neches

River Tidal Watershed subject to stormwater regulation. The 2010 USCB Urbanized Areas (UAs) were used as a surrogate to determine regulated stormwater areas associated with Phase II MS4s, MSGP authorizations, concrete production facilities, and construction activities (USCB, 2010b). The USCB's UAs are delineations of geographical areas of 50,000 or more people. The Phase I MS4 jurisdiction boundary was used as a surrogate for industrial facilities and construction activities outside of a UA. The ARS (Figure 7) is a compilation of the Phase I MS4 jurisdiction boundary, 2010 USCB UAs, and facility boundaries for individual industrial permits with regulated stormwater located outside a Phase I MS4 or UA delineation. Spatial data were obtained or developed from regulated entity permit information.

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 MS4 permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 Census of Population, whereas the Phase II MS4 general permit regulates smaller communities or entities within a USCB-defined UA.

The TCEQ Central Registry includes a Phase I MS4 permit held by the City of Beaumont and Jefferson County Drainage District No. 6 that covers the City of Beaumont jurisdictional boundary (TNRIS, 2015). A combined Phase I and Phase II MS4 permit held by the Texas Department of Transportation for rights-of-way in Phase I MS4 areas and UAs as designated by the USCB is also in effect in the Neches River Tidal watershed.

The Neches River Tidal watershed includes 23 industrial WWTFs (Table 7) with regulated stormwater. The areas of permitted facilities were estimated using the most recently available remote imagery in ArcGIS and permit information (TCEQ, 2019d). This spatial data was used to determine areas of regulated stormwater outside of Phase I MS4 or UAs.

The 2010 UAs were used as a surrogate to account for areas subject to the Phase II MS4 regulation and any general permits with regulated stormwater. The Neches River Tidal watershed includes two UAs: the Beaumont UA that includes portions of Beaumont, Vidor, Rose City, and Pine Forest; and the Port Arthur UA that includes portions of Port Arthur, Nederland, Central Gardens, Groves, and Bridge City. Discharges of stormwater from a Phase II MS4 area, industrial facility, construction site, or other facility involved in certain activities must be covered under one of the following TPDES general permits:

- TXR040000 – stormwater Phase II MS4 General Permit for urbanized areas
- TXR050000 – stormwater MSGP for industrial facilities
- TXR150000 – stormwater Construction General Permit (CGP) for construction activities disturbing more than one acre

The TCEQ Central Registry of active stormwater general permits in the Neches River Tidal watershed as of December 31, 2018 found 10 Phase II MS4 general permit authorizations (Table 9), 34 MSGP authorizations, and 13 CGP authorizations (TCEQ, 2019e). A review of MSGP authorizations in the Neches River Tidal watershed found that most were in the industrial areas near the banks of the Neches River Tidal and had associated industrial WWTFs. The lone concrete production facility in the watershed is in a UA. CGP authorizations in the Neches River Tidal watershed are typically short-term in nature and typically occur in the more urban areas covered by the MS4s. Typical construction activities include retail, residential subdivision, and industrial infrastructure development. For these reasons, areas authorized under the MSGP, CGP, and the concrete production facility were not specifically determined since the majority occur in an MS4 or another regulated stormwater area. These areas are already accounted for in the aggregate ARS.

Table 9. MS4 permit authorizations

Permit Holder	Authorization Type	TPDES Permit No./NPDES ID	Location
City of Beaumont, Jefferson County Drainage District No 6	Phase I MS4	WQ0004637000/ TXS000501	Jurisdictional boundary of Beaumont, TX
Texas Department of Transportation	Combined Phase I and Phase II MS4	WQ0005011000/ TXS002101	TXDOT rights-of-way located within Phase I MS4s and Phase II UAs
City of Vidor	Phase II MS4	TXR040028	Area within the City of Vidor limits that is located within the Beaumont UA
Orange County Drainage District	Phase II MS4	TXR040029	Area within the Orange County limits that is located within the Beaumont and Port Arthur UAs
Orange County	Phase II MS4	TXR040030	Area within Orange County that is located outside the city limits that is located within the Beaumont and Port Arthur UA
Jefferson County	Phase II MS4	TXR040129	Area within the Jefferson County limits that is located within the Port Arthur UA
Jefferson County Drainage District 7	Phase II MS4	TXR040130	Area within the Drainage District 7 limits that is located within Port Arthur UA
City of Port Neches	Phase II MS4	TXR040131	Area within the City of Port Neches limits that is located within the Port Arthur UA
City of Bridge City	Phase II MS4	TXR040429	Area within Bridge City limits that is located within the Port Arthur UA
City of Nederland	Phase II MS4	TXR040133	Area within the City of Nederland limits that is located within the Port Arthur UA
City of Groves	Phase II MS4	TXR040134	Area within the City of Groves limits that is located within the Port Arthur UA
City of Port Arthur	Phase II MS4	TXR040143	Area within the City of Port Arthur limits that is located within the Port Arthur UA

The total ARS for each watershed was estimated as the jurisdictional boundary of Beaumont, Beaumont UA, and Port Arthur UA within the watershed plus the estimated area of regulated entities that are not within the Phase I or Phase II MS4 permitted areas (Table 10). The total ARS in the Neches River Tidal TMDL watershed is 49.05 square miles, as shown in Figure 7. The total regulated stormwater areas listed in Table 10 indicate the total area within each AU plus the regulated area for each upstream AU.

Table 10. Area of regulated stormwater

AU	Total ARS (square miles)	Percent of Watershed Area
0601_04	16.24	20.4
0601_03	30.67	23.4
0601_02	42.18	25.3
0601_01	49.05	23.3

2.7.1.5. Review of Compliance Information on Permitted Sources

The Enforcement and Compliance History Online (ECHO) database was reviewed for non-compliance issues regarding bacteria for permitted wastewater dischargers in the watersheds (USEPA, 2019a). The ECHO database contains discharge monitoring report data (DMR) conducted and submitted by the permitted facilities. A four-year period from January 1, 2015 through December 31, 2018 was used to examine recent compliance with permit limits. Many facilities had four years of bacteria data, while other permits had numeric permit limits for bacteria implemented more recently. For permits with more recently implemented bacteria limits, only the data through the effective limit date is reported. There are also isolated incidences with missing reporting periods due to no reported data from the permittee. For example, WQ0000493000 (Evadale Mill) and WQ0014049001 (Sugar Pine Mobile Home Community WWTF) each missed one record in the ECHO DMR database due to no sampling or no received report. Table 11 provides a summary of compliance information for permitted facilities within the Neches River Tidal watershed.

Table 11. Summary of bacteria compliance information for permitted WWTFs

AU	TPDES Permit No.	Permit Period	Facility	Outfall	Bacteria Monitoring Requirement	Min. Monitoring Frequency	Daily Average Limit	Single Grab or Daily Max Limit	% of reported DMR Daily Average Values Exceeding Limit	% of reported DMR Single Grab or Daily Max Values Exceeding Limit
0601_04	WQ0014049001	8/10/2016 –8/1/2021	Sugar Pines Mobile Home Community Wastewater Treatment Facility	001	*E. coli*	Quarterly	126	399	38[j]	38[j]
0601_04	WQ0000493000	3/7/2018 –8/1/2021	Evadale Mill	001	Enterococci	Monthly	35	104	44[e]	44[e]
0601_04	WQ0010875001	12/11/2018 – 12/11/2023	Oak Lane Wastewater Treatment Facility	001	*E. coli*	Daily	126	399	2[i]	15[i]
0601_03	WQ0001727000	7/15/2014 –7/1/2019 Renewed 11/12/2019	Lower Neches Valley Authority North Regional Treatment Plant	001	Enterococci	Weekly	35	89	0[g]	6[g]
0601_02	WQ0010477004	11/26/2018 – 11/26/2023	Main Wastewater Treatment Facility	001	Enterococci	Weekly	35	104	0[h]	0[h]
0601_02	WQ0000473000	12/11/2018 – 12/11/2021	Lucite Beaumont Facility	101	Enterococci [c]	Monthly	35	104	6[d]	6[d]
0601_02	WQ0000316000	5/18/2016 – 5/1/2021	Beaumont Terminal	002	Enterococci	Monthly	35	89	6[a]	2[a]
0601_01	WQ0000511000	12/11/2018 – 12/11/2021	Joint Wastewater Treatment Plant	301	Enterococci	Weekly	35	104	0[f]	29[f]
0601_01	WQ0000336000	8/24/2016 –8/24/2019 Renewed 12/11/2019	Sabine Plant	801	Enterococci	Monthly	NA	89	NA	4[b]

[a] 48 monthly Enterococci records (January 1, 2015 – December 31, 2018).
[b] 28 monthly Enterococci records with daily maximum limit (September 1, 2016 – December 31, 2018). Numeric Enterococci limit effective 9/1/2017.
[c] The current permit issued on December 11, 2018 specifies Enterococci; the previous permit and exceedance values reported here are based on *E. coli*.
[d] 47 monthly *E. coli* records (January 1, 2015 – December 31, 2018).
[e] 16 monthly Enterococci records (September 1, 2017 – December 31, 2018). Numeric Enterococci limit effective 9/1/2017.
[f] 14 monthly Enterococci records (November 1, 2017 – December 31, 2018). Numeric Enterococci limit effective 11/1/2017.
[g] 17 monthly Enterococci records (August 1, 2017 – December 31, 2018). Numeric Enterococci limit effective 8/1/2017.
[h] One monthly Enterococci record (December 31, 2018). Numeric Enterococci limit effective 12/1/2018.
[i] 48 monthly *E. coli* records (January 1, 2015 – December 31, 2018).
[j] 13 quarterly *E. coli* records (January 1, 2015 – December 31, 2018).

2.7.2. Unregulated Sources

Unregulated sources include non-permitted, typically NPS, discharges that can contribute to fecal bacteria loading in the watershed. Potential sources, detailed below, include wildlife, agricultural runoff, and domestic pets.

2.7.2.1. Wildlife and Unmanaged Animal Contributions

Fecal bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify the potential for bacteria contributions from wildlife. The Neches River Tidal watershed is located in the Central Flyway migratory bird corridor. Numerous migrating shorebirds, waterfowl, and other species pass *en masse* through the region. A portion of the nearly 8,000-acre Lower Neches Wildlife Management Area is located within the southern portion of the watershed in Orange County. The wildlife management area is a broad coastal wetland that provides habitat and recreational opportunities related to resident and migratory birds, small mammals, alligators, and other species.

Riparian corridors of streams and rivers naturally attract wildlife. With direct access to the stream channel, direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Wildlife also deposit fecal bacteria onto land surfaces, where rainfall runoff may wash bacteria into nearby water bodies.

For deer, the Texas Parks and Wildlife Department (TPWD) has published data showing deer population-density estimates by Resource Management Unit and Ecoregion in the State (TPWD, 2018). The Neches River Tidal watershed lies within Resource Management Unit 13, with an average deer density of 208.46 acres per deer within suitable habitat over the period 2005 through 2016 (TPWD, 2018). Suitable NLCD classes for deer habitat classified in the 2016 NLCD include Pasture/Hay, Shrub/Scrub, Grassland/Herbaceous, Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, and Emergent Herbaceous Wetlands. Based on acres of suitable habitat, there are an estimated 438 deer in the TMDL watershed (Table 12).

For feral hogs, a study by Timmons et. al (2012) estimated feral hog density within suitable habitat in Texas to be one hog per 39 acres. The average hog density (12.65 hogs/square mile) was multiplied by hog habitat area for the TMDL watersheds. Habitat deemed suitable for hogs followed as closely as possible to the land cover selections of the study and includes the following classifications from the 2016 NLCD classes suitable for feral hogs in the watershed, which include Pasture/Hay, Shrub/Scrub, Grassland/Herbaceous, Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, and Emergent Herbaceous Wetlands. Based on acres of suitable habitat, there are an estimated 2,334 feral hogs in the TMDL watershed (Table 12).

Table 12. Estimated deer and feral hog populations

AU Watershed	Acres of habitat	Estimated Number of Deer	Estimated Number of Feral Hogs
0601_04	39,931	192	1,024
0601_03	23,052	111	591
0601_02	13,446	65	345
0601_01	14,593	70	374
Total	**91,022**	**438**	**2,334**

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Activities such as livestock grazing close to water bodies and farmers' use of manure as fertilizer can contribute fecal bacteria to nearby water bodies. AU watershed livestock counts were estimated using county-level data available from the 2017 Census of Agriculture (USDA, 2019). The county-level data were refined to reflect acres of grazeable land within each AU watershed. The refinement was determined by the grazeable area of each county and the grazeable acres of the AU watershed. The ratio was the grazeable area of the AU that resides within a county divided by the total grazeable area of the county. AU watershed-level livestock numbers are the ratio multiplied by county-level livestock population data (Table 13).

Table 13. Estimated livestock population

AU Watershed	Cattle and Calves	Hogs and Pigs	Goats and Sheep	Horses
0601_04	740	22	53	56
0601_03	617	28	59	48
0601_02	686	30	62	51
0601_01	967	43	89	73
Totals	**3,010**	**123**	**263**	**228**

Pets can also be a source of fecal bacteria because stormwater runoff carries the animal wastes into water bodies. The American Veterinary Medical Association (AVMA) estimates there are 0.614 dogs and 0.457 cats per American household (AVMA, 2018). We estimated the number of domestic cats and dogs in the AU watersheds by applying the AVMA estimates to the number of households in the watershed. The number of watershed households was estimated with 2010 census block household counts, multiplied by the proportion of the census block within each AU watershed. Table 14 summarizes the estimated number of pets in the TMDL watershed.

Table 14. Estimated households and pet population

AU Watershed	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
0601_04	7,784	4,779	3,557
0601_03	5,679	3,487	2,595
0601_02	4,640	2,849	2,120
0601_01	2,693	1,654	1,231
Totals	**20,796**	**12,769**	**9,503**

2.7.2.3. Failing On-site Sewage Facilities

Private residential on-site sewage facilities (OSSFs), commonly referred to as septic systems, consist of various designs based on physical conditions of the local soil. Typical designs consist of (1) one or more septic tanks and a drainage or distribution field (anaerobic system) and (2) aerobic systems that have an aerated holding tank and often an above-ground sprinkler system for distributing the liquid. In simplest terms, household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system, which may consist of buried perforated pipes or an above-ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for fecal bacteria to enter ground and surface waters if the systems are not properly operating. However, properly designed and operated OSSFs contribute virtually no fecal bacteria to surface waters. For example, less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel, 1996). The estimated OSSF failure rate in this region of Texas ranges from 12 to 19% (Reed, Stowe, and Yanke, 2001).

Estimates of the number of OSSFs within the General Land Office Texas Coastal Zone (coastal zone) portion of the watershed were determined using the TCEQ and Texas A&M AgriLife draft coastal zone OSSF database (TCEQ, 2019h). Estimates of the number of OSSFs in the TMDL watershed outside of the coastal zone were determined by using 911 addresses to estimate residence locations, which were then verified with aerial imagery data (Arctur and Maidment, 2018). OSSFs were estimated to be households that were outside of city boundaries and Certificate of Convenience and Necessity (CCN) areas (Public Utility Commission of Texas, 2017). Table 15 and Figure 10 show the total estimated OSSFs in the TMDL watershed.

Table 15. Estimated OSSFs in each AU watershed

AU Watershed	Estimated OSSFs
0601_04	1,221
0601_03	946
0601_02	965
0601_01	927
Total	**4,059**

2.7.2.4. Bacteria Survival and Die-off

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

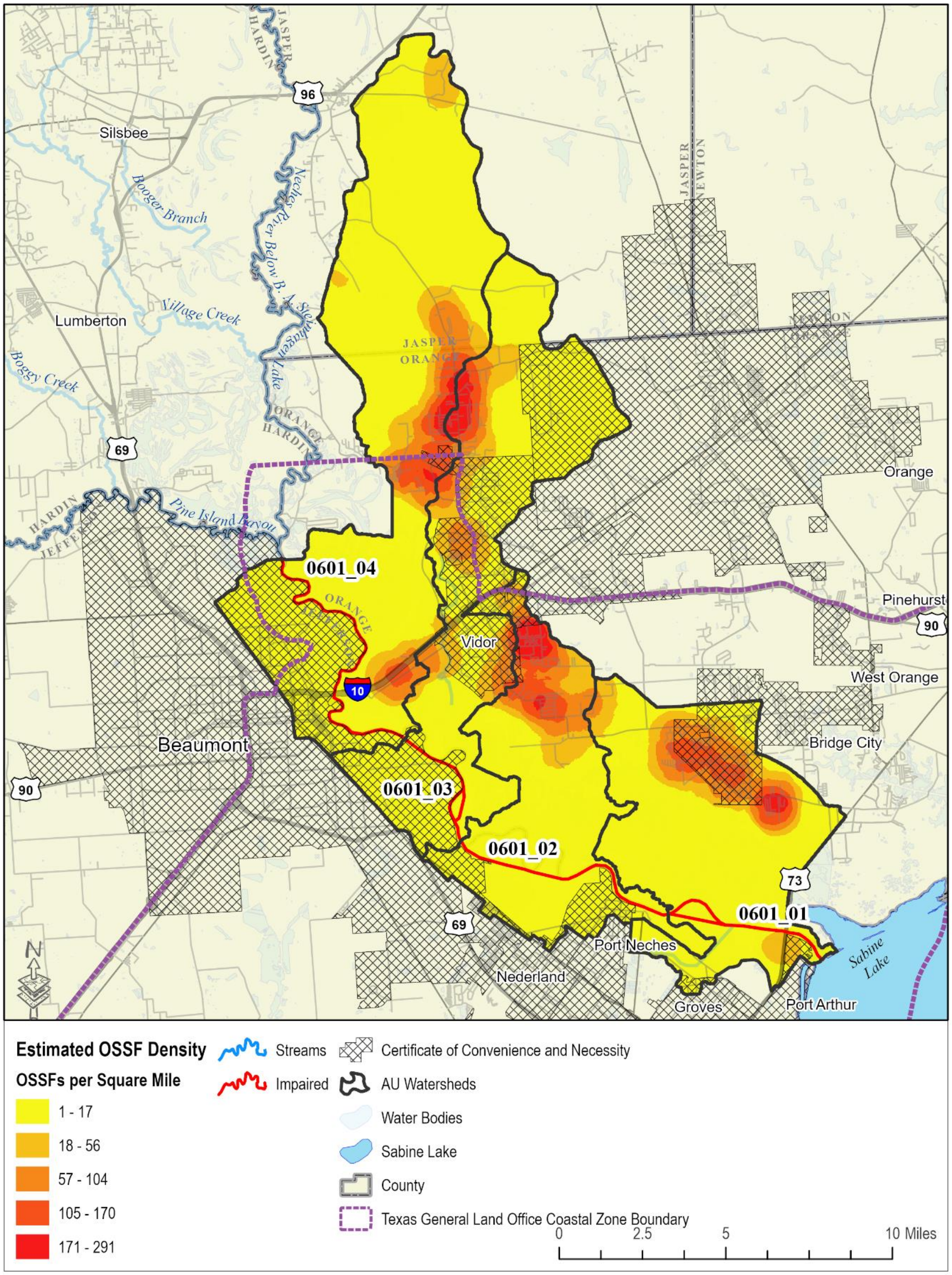

Figure 10. Estimated OSSF density

Section 3. Bacteria Tool Development

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

3.1. Tool Selection

The TMDL allocation process for bacteria involves assigning bacteria, e.g., Enterococci, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for the impaired AUs in the TMDL watersheds considered the availability of data and other information necessary for the supportable application of the selected tool and guidance in the Texas Bacteria Task Force report (TWRI, 2007). Mechanistic models and empirically derived LDCs are the two approaches commonly used for bacteria TMDLs in the Texas.

Mechanistic models, also referred to as process models, are based on theoretical relationships that numerically describe the physical processes that determine streamflows and bacteria concentrations, in addition to other related response variables. Mechanistic models are available that reliably represent streamflow and bacteria response to land use, rainfall, tidal inputs, and other processes. While hydrologic processes integrated within these models are quite robust, the numeric representations of bacteria transport processes are considered less reliable (TWRI, 2007). Painter et al. (2017) also note that while mechanistic bacteria modeling has progressed significantly, the application of these models relies on more specific watershed information than is required for representation of hydrologic processes. As a result, decisions on input parameters that affect bacteria response must be made by the modeler when the actual numeric values may not be available within an acceptable range of certainty (Painter et al., 2017). However, under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides an understanding of the important biological, chemical, and physical processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). 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 regulated community recognizes the frequent information limitations with the bacteria TMDLs that constrain the use of the more powerful mechanistic models. Further, the Bacteria Task Force appointed by TCEQ and the Texas State Soil and Water Conservation Board supports the application of the LDC method within their three-tiered approach to TMDL development (TWRI, 2007). The LDC method lacks the predictive capabilities to evaluate alternative allocation approaches to reach TMDL goals, and it cannot be used to quantify specific source contributions and instream fate and transport processes. However, the method does provide 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.

3.1.1. Available Data Resources

The good availability of streamflow, discharges, water diversion, salinity, and Enterococci data were used to provide guidance in the allocation tool selection process. Salinity data provided a measure of the degree of mixing of seawater and freshwater in the tidal segment. The information and data necessary to allow adequate definition of many of the physical and biological processes influencing in-stream bacteria concentrations for mechanistic model application are largely unavailable for the Neches River Tidal TMDL watershed, and these limitations became an important consideration in the allocation tool selection process. Specific data requirements for mechanistic models vary based on the specific model chosen. However, additional data that is currently not available for appropriate mechanistic models include stormwater network routing and controls, stream geometry and capacity, sub-basin hydrologic calibration/validation data, and direct measured loadings from point and nonpoint sources. Additional information about data requirements for mechanistic model are available in the Bacteria Task Force Final Report (TWRI, 2007).

Streamflow

Hydrologic data in the form of mean daily discharge and tidally filtered discharges are available at the U.S. Geological Survey (USGS) gage 08041780 at the Neches River Saltwater Barrier (USGS, 2019b) (Table 16, Figure 12). Tidally filtered discharges are the computed mean daily discharge effectively filtered of cyclical variations in stage and velocity that have periods less than 30 hours (Ruhl & Simpson, 2005). The daily variations filtered are mostly due to daily astronomical tides but other variations with less than 30-hour periods such as meteorological tides, hydrologic, and operational cycles. Some tidal variations with periods greater than 30 hours, such as spring/neap cycles are not filtered. The tidally filtered discharges are essentially the net downstream (or upstream) flow. Mean daily tidally filtered discharges at USGS gage 08041780 became available June 8, 2003, soon after the saltwater barrier became operational. The Neches River Saltwater Barrier gage reflects daily mean streamflow discharge coming into the Neches River Tidal (Segment 0601) and accounts for all upstream discharges and diversions.

Additionally, mean daily streamflows in cubic feet per second (cfs) were available at USGS gage 08031000 (Cow Bayou, near Mauriceville, TX) (Table 16, Figure 12). The mean daily flows at Cow Bayou are used for estimating daily discharges within the Neches River Tidal watershed. Mean daily streamflows at Cow Bayou became available in 1952. However, the daily streamflow record available for USGS gage 08031000 is missing the period from October 1, 1986 to August 27, 2002. Drainage areas (Tables 16 and 18) were calculated using elevation-based local drainage areas called catchments developed using NHDPlus Version 2 (USEPA & USGS 2012).

Table 16. Basic information on the USGS streamflow gages used for streamflow development

Gage No.	Site Description	Daily Streamflow Record	Drainage Area (sq miles)	Mean Daily Streamflow (cfs)	Minimum Daily Streamflow (cfs)	Maximum Daily Streamflow (cfs)
08041780	Neches River Saltwater Barrier at Beaumont, TX	06/08/2003 - 12/31/2018	9,789[b]	7,691[a]	-5,220[a]	224,000
08031000	Cow Bayou near Mauriceville, TX	06/08/2003 - 12/31/2018	88.90[b]	130.9	0	21,700

[a] Streamflow statistics for USGS gage 08041780 are based on tidally filtered discharge. Twenty-four occurrences of negative values in the record are indicative of reversal of flow direction due to extreme tides, storm surge, and/or wind direction.

[b] The Neches River Saltwater Barrier drainage area is based on information provided in USGS streamflow gage metadata. The Cow Bayou drainage area is based on a watershed delineation in ArcGIS using elevation data in the NHDPlus Version 2 database.

Ambient data

Historical ambient Enterococci and salinity data were obtained through the TCEQ SWQMIS database (TCEQ, 2019a) (Figure 11). Table 17 summarizes the available data corresponding to the hydrological record used for the TMDLs.

Table 17. Summary of historical dataset

AU	SWQM Station	No. of Enterococci Samples	No. of Salinity Samples	Data Date Range
0601_04	10575	57	60	06/08/2003 – 12/31/2018[a]
0601_03	10570	57	60	06/08/2003 – 10/23/2018
0601_02	10566	59	59	06/08/2003 – 12/31/2018
0601_01	10563	58	59	06/08/2003 – 12/31/2018

[a] The full dataset of Enterococci samples ranges from October 2001 through December 2018. However, the Enterococci dataset was reduced to match the available USGS flow record at USGS Gage 08041780.

Water Diversion

A search of TCEQ's active water rights database, GIS files, and geospatial viewer indicate that, within the Neches River Tidal watershed, there are 15 surface water rights with 18 authorized diversion points. Most authorized uses on the Neches River Tidal are for industrial use and include provisions stating that water diverted but not consumed be returned to the river. One of the water rights is authorized for both municipal and industrial use; however, the water right holder primarily diverts its authorized water from an upstream diversion point outside of the TMDL watershed. Many water right holders in the Neches River Tidal watershed also have wastewater permits for discharge of diverted water. One water right holder diverts water from Sabine Lake for cooling purposes with a specified point of return to the Neches River Tidal. This return flow is accounted for through the wastewater permit (Entergy Texas Incorporated WQ0000336000). A review of the water use data file (TCEQ, 2019c) containing self-reported diversions (2000-2008), the Texas Water Rights Viewer (TCEQ, 2019b) containing more recent self-reported diversions (2009-2018), and the water right authorizations indicate that most major water right diversions from Neches River Tidal return water to the river.

A review of final actions on water rights permit applications (TCEQ, 2020c) for fiscal years 2018, 2019, and 2020 found no new water rights for the Neches River Tidal had been granted during that period, although one had been amended. However, the 2016 Regional Water Plan projects an increase in industrial use in Jefferson County as a whole, some of which may be in Neches River Tidal. The review of the water right authorizations indicates they will not significantly impact streamflow estimates and therefore, are not considered in the development of TMDL load allocations.

Regulated Discharge
Full permitted discharges and annual or daily average discharges reported in DMRs from 29 permitted facilities and associated outfalls (Appendix B) were also incorporated into streamflow estimations and are further described in sections 3.2.3 and 3.2.5 (USEPA, 2019a; USEPA, 2019b).

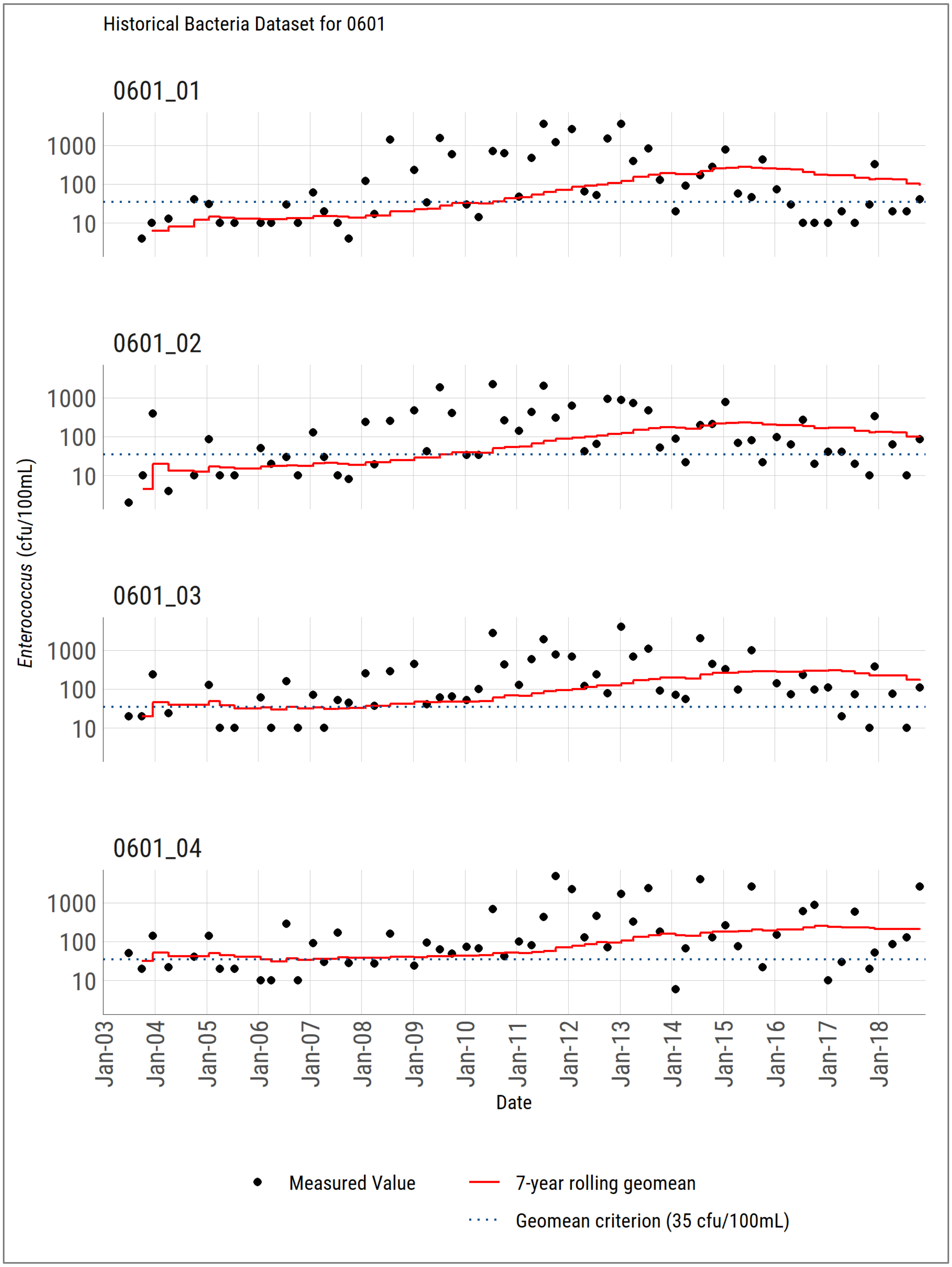

Figure 11. Summary plots of historical bacteria datasets for impaired AUs including the 7-year rolling geometric mean from June 2003 through December 2018

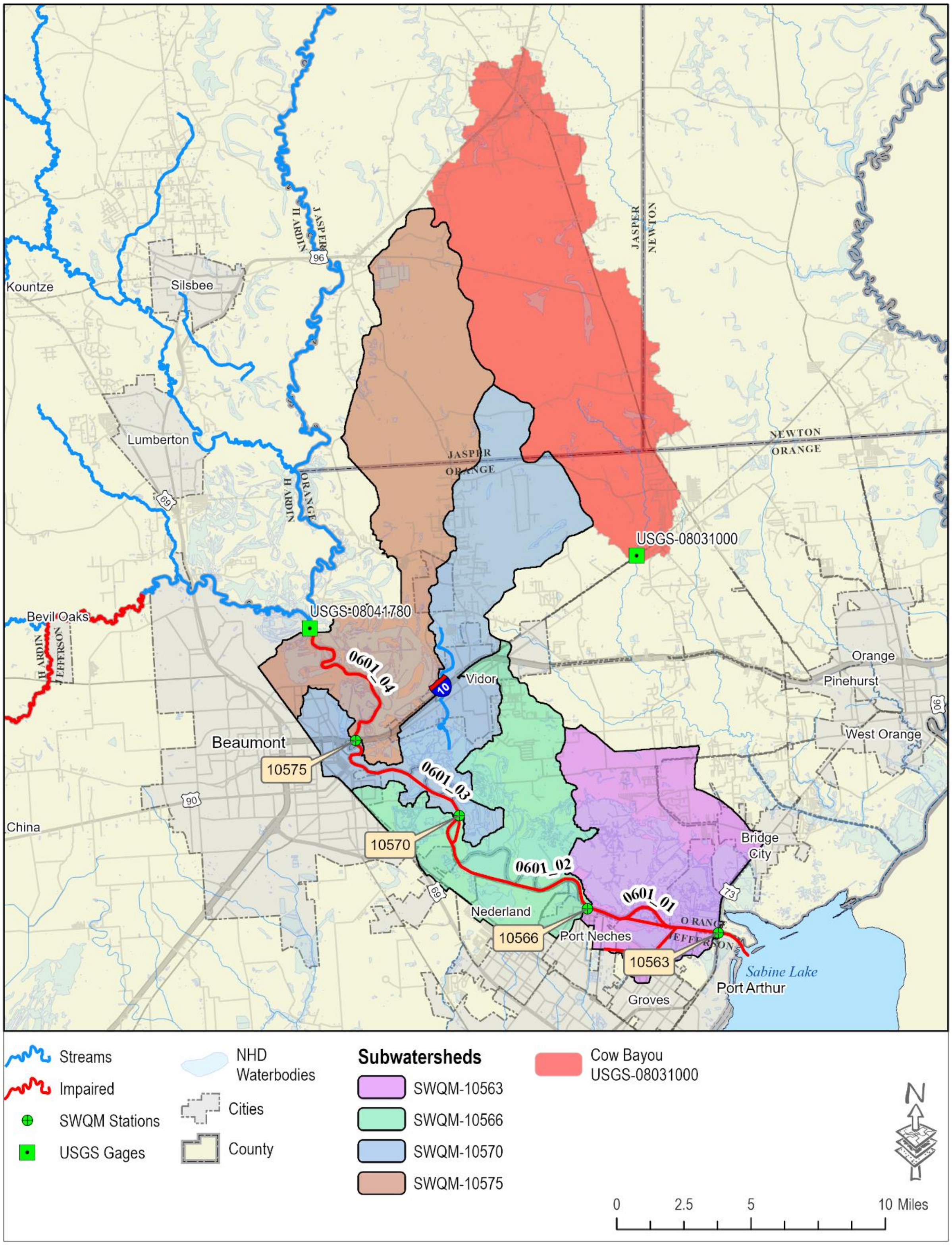

Figure 12. USGS streamflow gauges and SWQM stations used in streamflow development

3.1.2. Allocation Tool Selection

The decision was made to use the LDC method with modifications to include tidal influences (as opposed to a mechanistic watershed loading and hydrologic/water quality model) based on the following factors: good availability of historical daily streamflow records, discharge information for industrial and municipal WWTFs, Enterococci and salinity data, as well as deficiencies in data to describe bacterial landscape and in-stream processes. A modification of the LDC method (modified LDC method) developed by State of Oregon Department of Environmental Quality for bacteria TMDLs of tidal streams of the Umpqua River Basin (ODEQ, 2006) was adapted to the Neches River Tidal (Segment 0601). The modified LDC method assumes that combining freshwater with seawater increases the loading capacity in the tidal river because seawater typically contains lower concentrations of indicator bacteria, such as Enterococci, than freshwater. The geometric means of Enterococci concentrations collected at five SWQM stations in Sabine Lake were assessed to verify this assumption (Figure 13). Figure 14 indicates that geometric mean Enterococci concentrations decrease in Sabine Lake as the SWQM stations get closer to the Gulf of Mexico.

3.2 Methodology for Modified Flow Duration and Load Duration Curve Development

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

- Step 1: Determine the hydrologic period of record to be used in developing the FDCs.
- Step 2: Determine the desired stream location for which FDC and LDC development is desired.
- Step 3: Develop naturalized streamflow record at desired stream location using daily gaged streamflow records, drainage area ratios, and reported daily average discharges.
- Step 4: Develop regressions of salinity to streamflow at each stream location.
- Step 5 Develop daily streamflow record at desired location using naturalized streamflow from Step 3, full permitted discharges, and daily tidal volumes for each stream location.
- Step 6: Develop a modified FDC at each stream location, segmented into discrete flow regimes.
- Step 7: Develop allowable bacteria modified LDC at the same stream location based on the relevant criteria and the data from the modified FDC.
- Step 8: Superimpose historical bacteria data on the allowable bacteria modified LDC.

You can find additional information explaining the LDC method in Cleland (2003) and USEPA (2007). Information on the modified LDC method is found in (ODEQ, 2006).

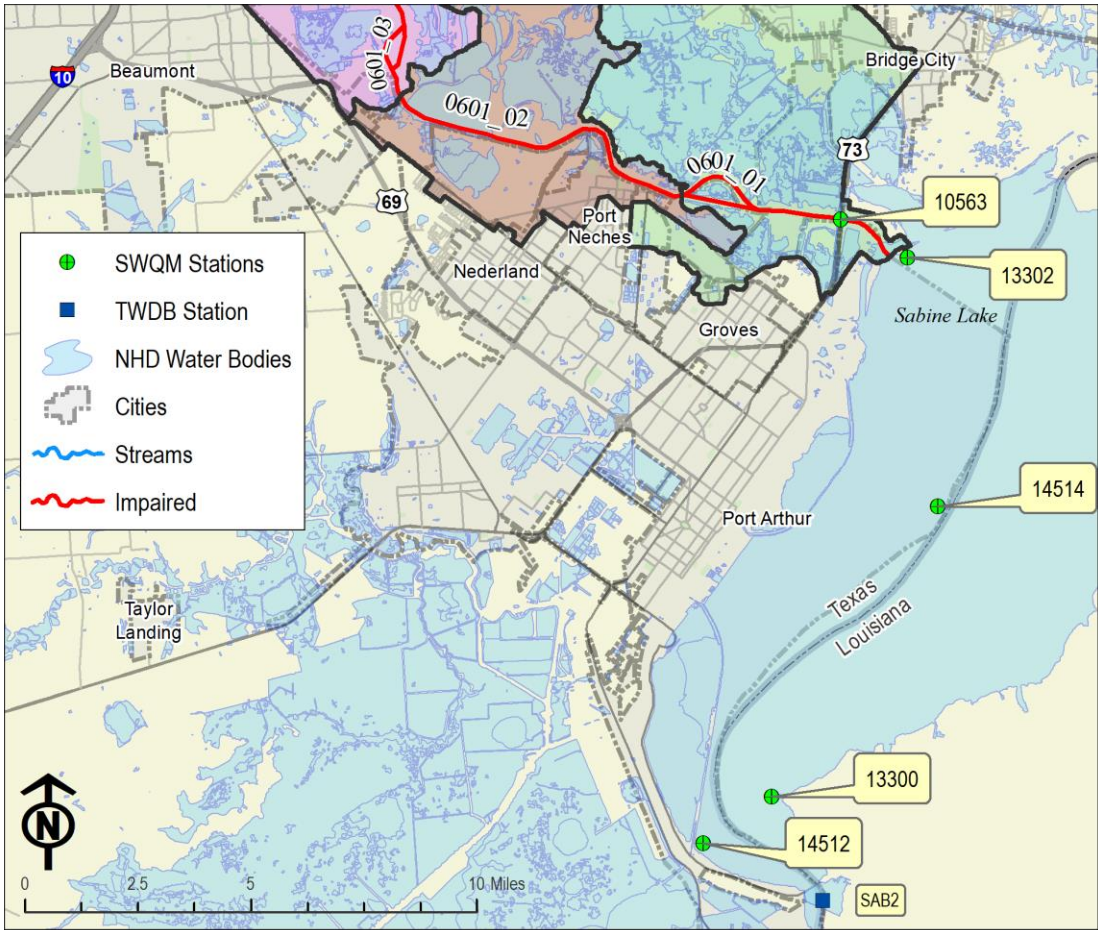

Figure 13. Locations of SWQM stations and a TWDB continuous monitoring station in Sabine Lake

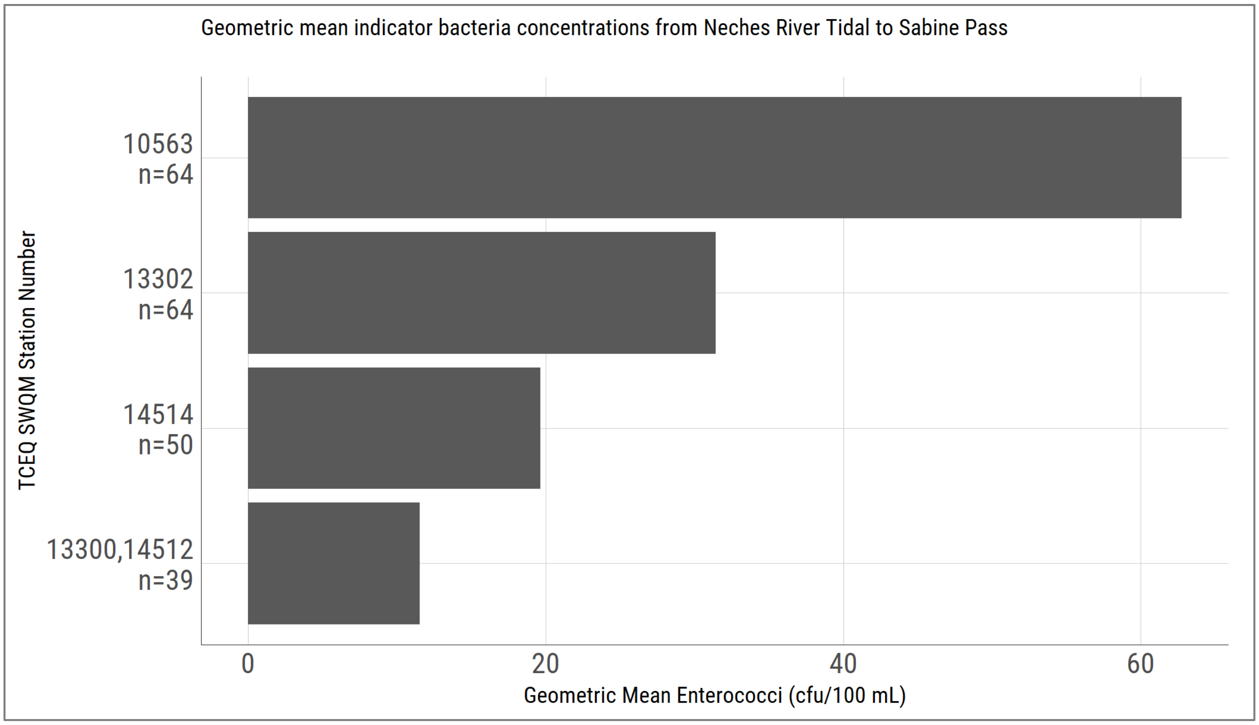

Figure 14. Geometric mean concentrations of Enterococci bacteria for the downstream SWQM station in Neches River Tidal and four SWQM stations in Sabine Lake

Data obtained from SWQMIS for the period of January 2001 – December 2018.

3.2.1. Step 1: Determine Hydrologic Period

Optimally, the period of record to develop a modified FDC should include as much data as possible to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the Enterococci data were collected.

The available tidally filtered mean daily streamflow available for USGS gage 08041780 at the Neches River Saltwater Barrier was June 8, 2003 through December 31, 2018. This approximately 15-year period of record was considered sufficient to capture the variations in high and low flow and represents most of the period in which Enterococci samples were collected.

3.2.2. Step 2: Determine Desired Stream Location

Sufficient Enterococci samples were available at SWQM stations in each impaired AU for LDC development. SWQM stations 10563 (AU 0601_01), 10566 (AU 0601_02), and 10570 (0601_03) were selected for FDC and LDC development as they were the only stations in each AU with substantial bacteria data. Two SWQM stations were available for AU 0601_04. Station 10575 was chosen as it was located at the most downstream portion of the AU. Table 17 provides a summary of the historical bacteria data used for the LDC method.

3.2.3. Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and the stream location were determined, the next step was to develop the naturalized daily streamflow record for each SWQM station. As used herein, naturalized flow is referring to the flow without the withdrawals from water rights and the additions of permitted discharges, i.e., the flows that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The naturalized daily streamflow records were developed from extant USGS records.

The method to develop the necessary streamflow record involved a flow percentile drainage-area ratio (DAR) approach. With this basic approach, each USGS gage's mean daily streamflow value was multiplied by a factor to estimate flow at the desired SWQM station location (Eq. 1).

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

Where:

Y = streamflow for the ungaged location,

X = streamflow for the gaged location,

A_y = drainage area for the ungaged location,

A_x = drainage area for the gaged location, and

ϕ = bias correction factor based on streamflow percentile (Asquith et al. 2006)

Often, $\phi = 1$ is used in the DAR approach. However, empirical analysis of streamflows in Texas indicates that $\phi = 1$ results in substantial bias in streamflow estimates at very low and very high streamflow percentiles (Asquith et al. 2006). Based on these observations, 54 different values of ϕ are used based on suggestions by Asquith et al. (2006). The value of ϕ varies with streamflow percentiles and lies between 0.7 and 0.935. Table 18 provides the DARs used to develop streamflows for each SWQM station.

Daily streamflows at each SWQM station were developed using the DAR values applied to naturalized mean daily streamflow values for Cow Bayou (USGS gage 08031000) followed by the addition of downstream mean daily streamflow from the Neches River Saltwater Barrier (USGS gage 08041780).

Table 18. Drainage area ratios used at each SWQM station

Locations	Drainage Area (square miles)	Drainage Area Ratio
SWQM Station 10575 (0601_04)	71.45	0.80
SWQM Station 10570 (0601_03)	124.20	1.40
SWQM Station 10566 (0601_02)	164.62	1.85
SWQM Station 10563 (0601_01)	208.88	2.35
Cow Bayou – USGS 08031000	88.90	NA

To properly apply the DAR, the naturalized flow at the Cow Bayou USGS gage was estimated first. The naturalized flow is the gaged flow without water rights diversions or permitted discharges. WWTF flows in the form of estimated daily reported discharge for all WWTFs upstream of the USGS gage location (based on DMRs) were subtracted from the streamflow record of the Cow Bayou gage, resulting in an adjusted streamflow record with point source discharge influences removed.

For Cow Bayou, there is one permitted discharger upstream of the USGS gage 08031000—WQ0010808001, Jasper County WCID 1 WWTF (USEPA, 2019a; USEPA, 2019b). No permitted diversions were identified upstream of USGS gage 08031000 (TCEQ, 2019b). Therefore, the only streamflow adjustments made were to subtract the average daily reported discharge from the USGS reported streamflow.

After development of the naturalized streamflows in Cow Bayou, the flow percentile DAR approach was applied using Equation 1 and the DARs in Table 18 to develop flows for SWQM stations 10575, 10570, 10566, and 10563. The resulting streamflow record is the naturalized flow from only the contributing watershed at each station.

Next, the mean daily tidally filtered streamflows from USGS gage 08041780 (Neches River Saltwater Barrier) were added to each resulting naturalized stream flow time series to provide the total estimated naturalized streamflow at each SWQM station. The tidally filtered streamflow at USGS gage 08041780 is the net streamflows entering the segment. Twenty-four occurrences of negative values (representing extreme tidal swings, storm surges, or similar circumstance) were transformed to 0 cfs.

The estimated actual daily streamflow was then estimated by adding in the sum of reported mean daily or annual discharges in DMRs from permitted facilities above each SWQM station (USEPA, 2019a; USEPA, 2019b). Table 19 is a summary of reported discharges (converted from MGD to cfs) used to adjust daily streamflows at each SWQM station. Figure 15 through Figure 18 show the total estimated daily discharge from permitted facilities added back to the DAR-estimated flows for each station.

3.2.4. Step 4: Develop Salinity to Streamflow Regression

As part of the development of the modified LDC method, it was necessary to develop a relationship between estimated actual daily streamflow and measured salinity for the Neches River Tidal SWQM stations. Following the development of estimated actual daily streamflows at each SWQM station, a salinity to streamflow regression was developed for each SWQM station (Figure 19 through Figure 21). Due to the nonlinear relationship between streamflow and salinity (salinity will never fall below zero parts per thousand (ppt) and is assumed to approach some maximum value based on the salinity of incoming tidal water), an extension of the generalized linear regression method called beta regression was used (Cribari-Neto & Zeileis, 2010). The regressions were used to calculate the volume of seawater that would flow through the SWQM station cross section over the period of a day. The beta regressions estimate proportional salinity as a function of downstream freshwater flow (Eq. 2). Beta regressions model continuous values between zero and one. Therefore, salinity was converted to a proportion of full salinity prior to fitting the regression. Full salinity was assumed to be 29.299 ppt, slightly less than full strength seawater. This choice of 29.299 ppt was due to the slightly depressed salinity observed in Sabine

Lake, which is assumed to supply most of the tidal flows into the Neches River and is further described in section 3.2.5. Additional information on beta regression is in Appendix A.

$$\ln(\text{Salinity}/(1-\text{Salinity})) = \beta_0 + \beta_1(\log_{10}(\text{Streamflow})) \quad \text{(Eq. 2)}$$

Where:

Salinity = predicted salinity/29.299 ppt,

β_0 = constant intercept,

β_1 = coefficient for streamflow, and

$\log_{10}$(Streamflow) = common log transformed naturalized mean daily streamflow plus reported mean daily discharges.

Table 19. TPDES permitted discharges used to adjust DAR-estimated daily streamflows at each SWQM station

AU, SWQM	TPDES Permitted Dischargers—Outfall Number[a]
0601_04, 10575	WQ0014049001-001, WQ0000493000-001, WQ0001971000-001
0601_03, 10570	WQ0014049001-001, WQ0000493000-001, WQ0001971000-001, ***WQ0001202000-002, WQ0001202000-003, WQ0001202000-004, WQ0001202000-005, WQ0001202000-006, WQ0001202000-007, WQ0001202000-008, WQ0000462000-001, WQ0010875001-001, WQ0001872000-001, WQ0001727000-001, WQ0001971000-002, WQ0001971000-003, WQ0001971000-004, WQ0001971000-007, WQ0003426000-001, WQ0003426000-002, WQ0003426000-003, WQ0005188000-001, WQ0005188000-002***
0601_02, 10566	WQ0014049001-001, WQ0000493000-001, WQ0001971000-001, WQ0001202000-002, WQ0001202000-003, WQ0001202000-004, WQ0001202000-005, WQ0001202000-006, WQ0001202000-007, WQ0001202000-008, WQ0000462000-001, WQ0010875001-001, WQ0001872000-001, WQ0001727000-001, WQ0001971000-002, WQ0001971000-003, WQ0001971000-004, WQ0001971000-007, WQ0003426000-001, WQ0003426000-002, WQ0003426000-003, WQ0005188000-001, WQ0005188000-002, ***WQ0000316000-001, WQ0000316000-002, WQ0000316000-003, WQ0000316000-005, WQ0000473000-001, WQ0000473000-004, WQ0000473000-005, WQ0000473000-011, WQ0000473000-015, WQ0000473000-018, WQ0000473000-020, WQ0000473000-002, WQ0000473000-006, WQ0000473000-008, WQ0000473000-021, WQ0000473000-101 WQ0001151000-001, WQ0000647000-001, WQ0001595000-002, WQ0004074000-001, WQ0005143000-001, WQ0005143000-002***
0601_01, 10563[b]	WQ0014049001-001, WQ0000493000-001, WQ0001971000-001, WQ0001202000-002, WQ0001202000-003, WQ0001202000-004, WQ0001202000-005, WQ0001202000-006, WQ0001202000-007, WQ0001202000-008, WQ0000462000-001, WQ0010875001-001, WQ0001872000-001, WQ0001727000-001, WQ0001971000-002, WQ0001971000-003, WQ0001971000-004, WQ0001971000-007, WQ0003426000-001, WQ0003426000-002, WQ0003426000-003,WQ0005188000-001, WQ0005188000-002, WQ0000316000-001, WQ0000316000-002, WQ0000316000-003, WQ0000316000-005, WQ0000473000-001, WQ0000473000-004, WQ0000473000-005, WQ0000473000-011, WQ0000473000-015, WQ0000473000-018, WQ0000473000-020, WQ0000473000-002, WQ0000473000-006, WQ0000473000-008, WQ0000473000-021, WQ0000473000-101, WQ0001151000-001, WQ0000647000-001, WQ0001595000-002, WQ0004074000-001, WQ0005143000-001, WQ0005143000-002, ***WQ0000491000-001, WQ0000491000-002, WQ0000491000-003, WQ0000491000-005, WQ0000491000-007, WQ0000511000-001, WQ0000511000-009, WQ0000511000-010, WQ0000511000-002, WQ0000511000-004, , WQ0000336000-001, WQ0010477004-001, WQ0004731000-001, WQ0002487000-001, WQ0004135000-002, WQ0004840000-201, WQ0004874000-001, WQ0005236000-001***

[a] IDs and permits not included in the upstream AU SWQM station flow adjustment are bolded and italicized for convenience.

[b] WQ0005328000-001, WQ0001674000-001 and WQ0001674000-002 discharge downstream of SWQM Station 10563 and reported discharges were not used to adjust the daily streamflow for the salinity regression. However, the numeric full permitted flows were added to the daily streamflow record for the AU 0601_01 TMDL flow calculation.

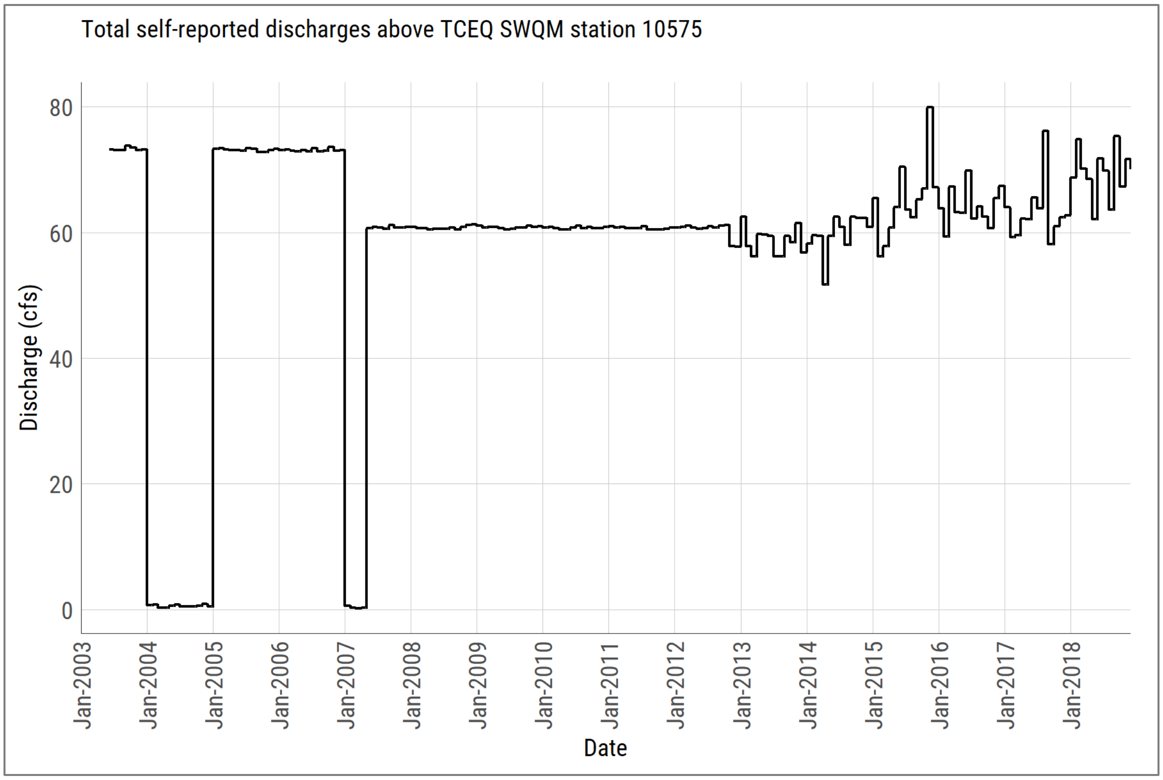

Figure 15. Reported discharge volumes for permitted facilities upstream of SWQM Station 10575

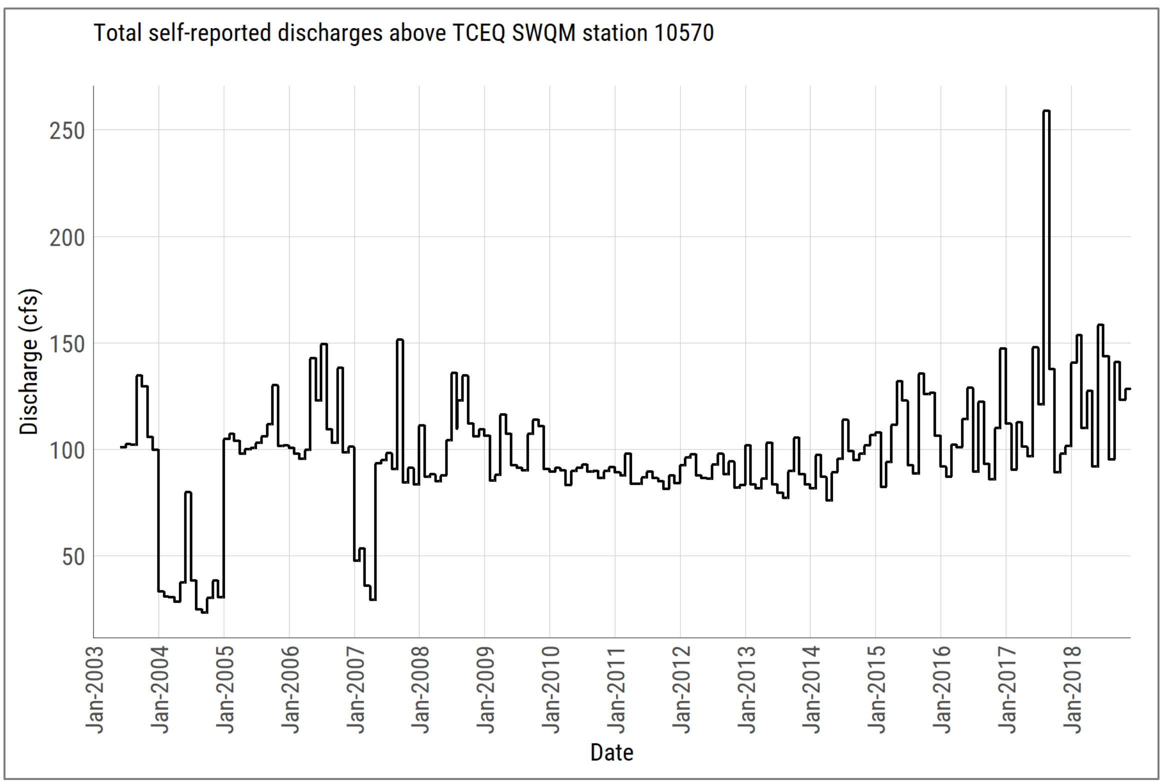

Figure 16. Reported discharge volumes for permitted facilities upstream of SWQM Station 10570

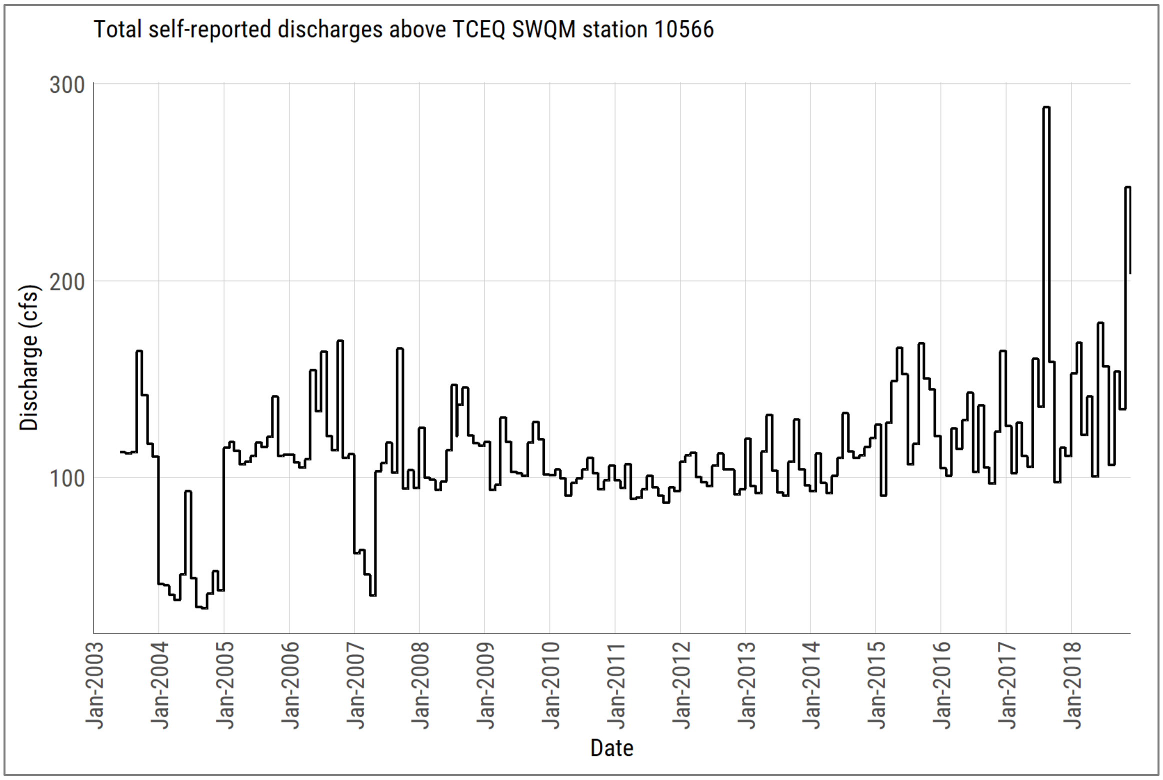

Figure 17. Reported discharge volumes for permitted facilities upstream of SWQM Station 10566

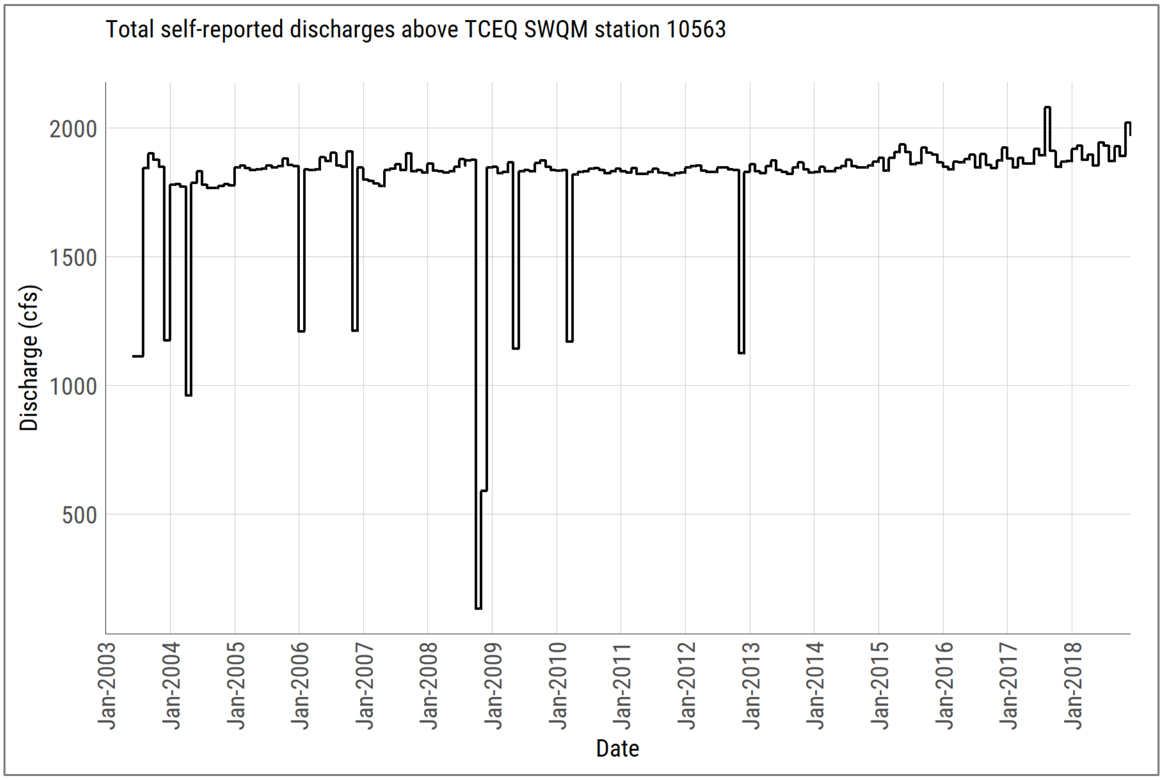

Figure 18. Reported discharge volumes for permitted facilities upstream of SWQM Station 10563

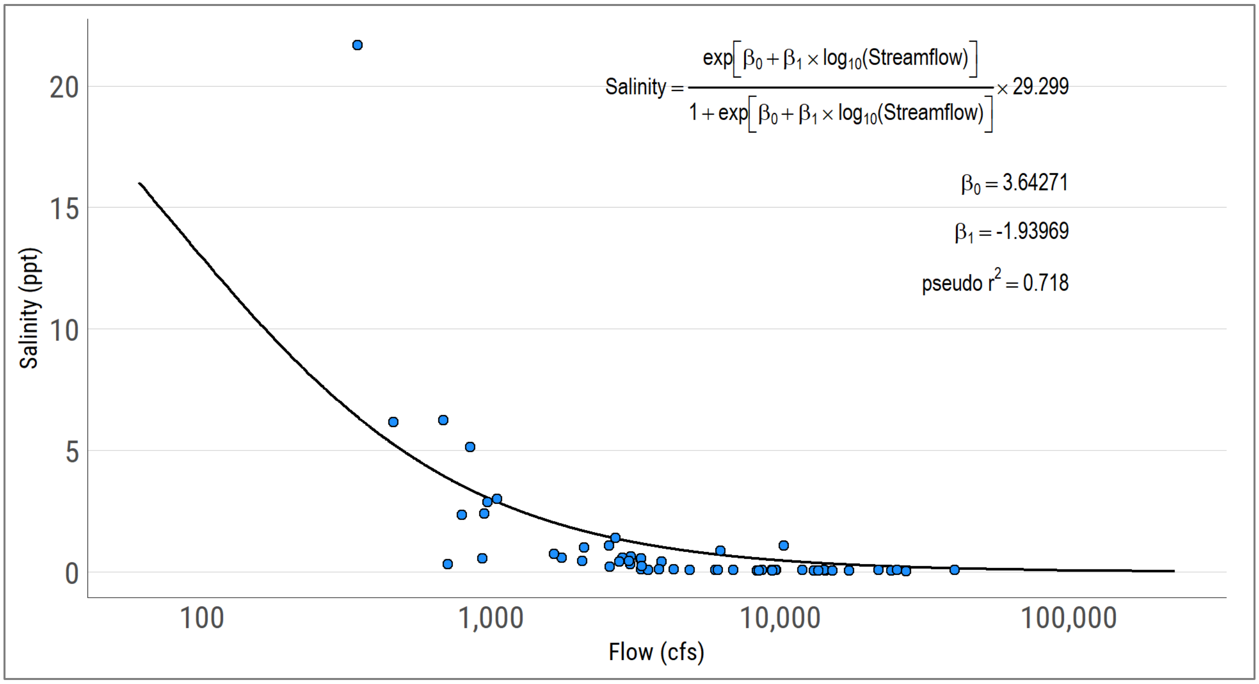

Figure 19. Salinity to flow regression for SWQM Station 10575

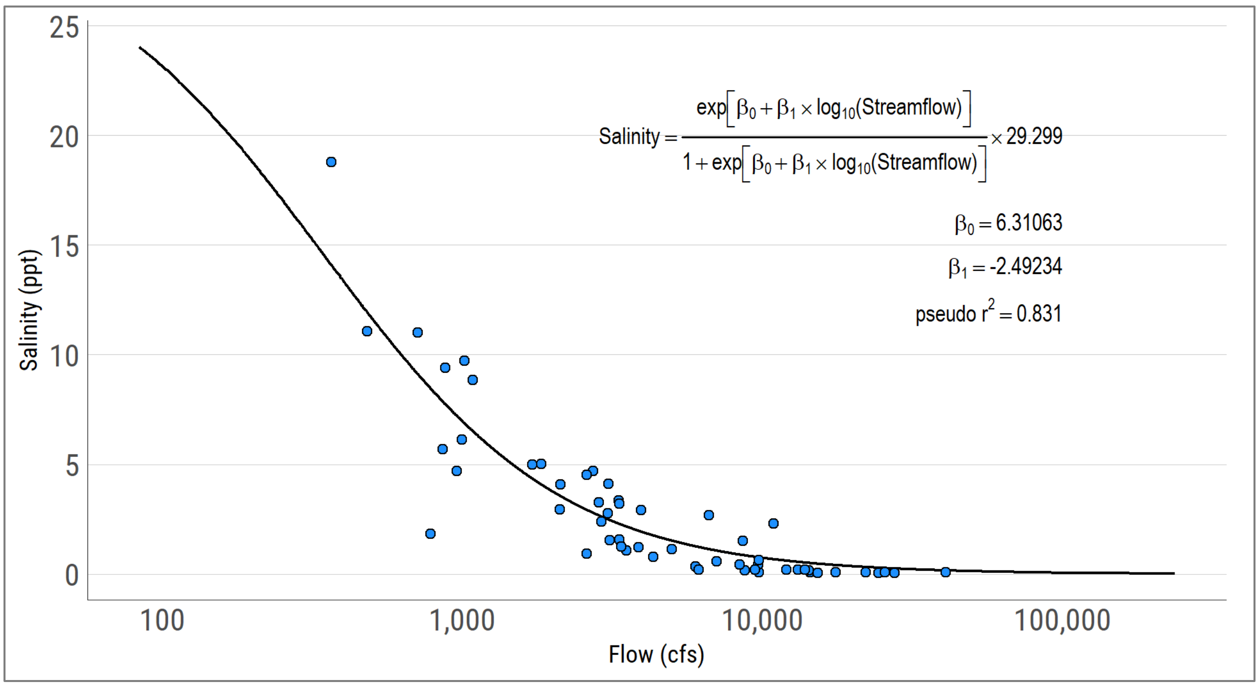

Figure 20. Salinity to flow regression for SWQM Station 10570

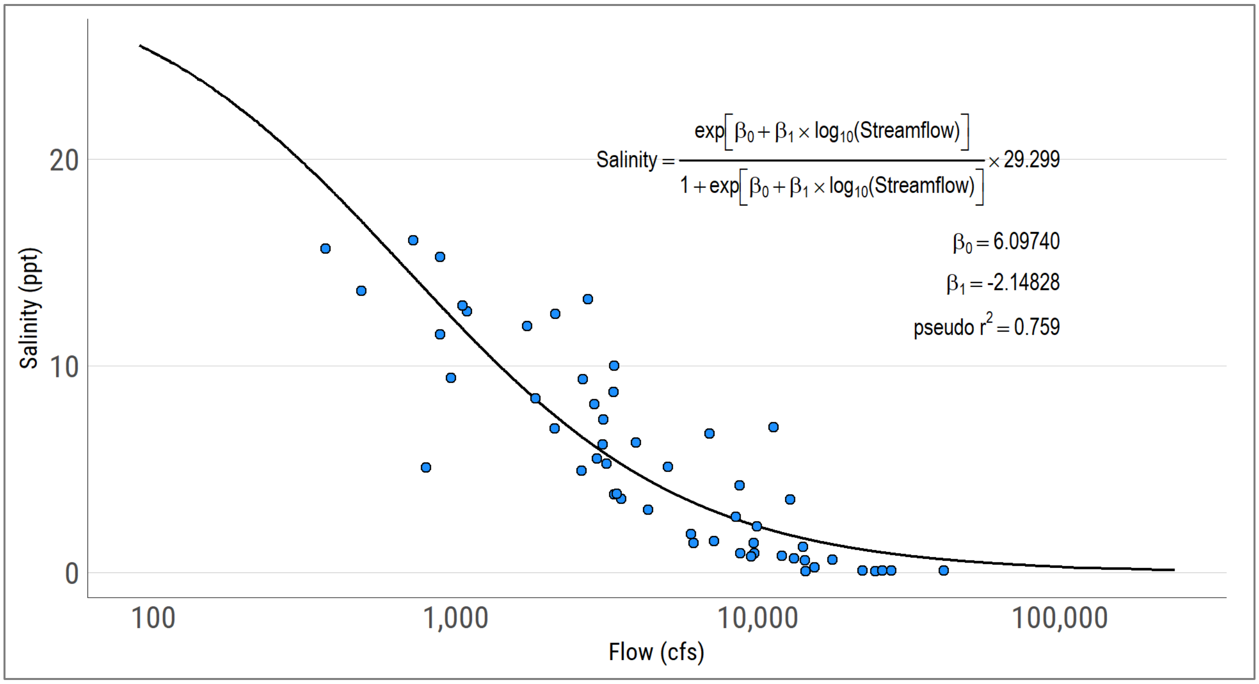

Figure 21. Salinity to flow regression for SWQM Station 10566

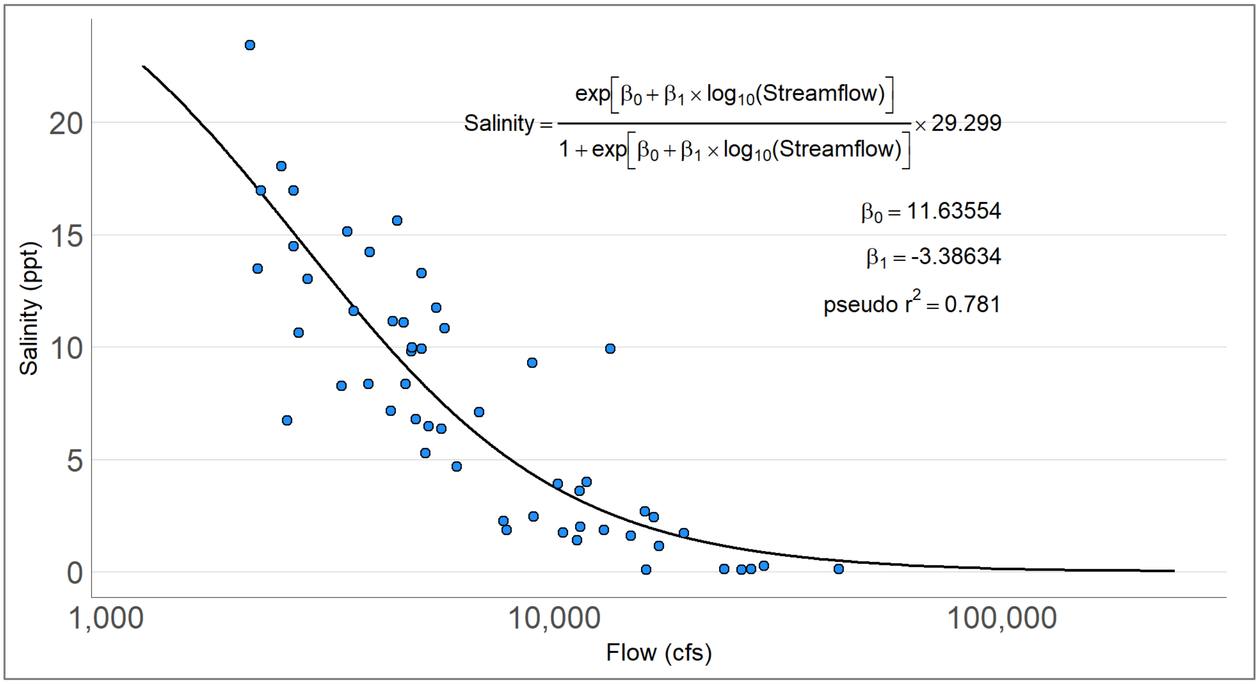

Figure 22. Salinity to flow regression for SWQM Station 10563

3.2.5. Step 5: Develop Streamflow Records

The regression equations from Step 4 were used in Step 5 to provide information to allow the computation of a total daily flow volume including freshwater and seawater. The process required manipulation of the following mass balance equation for salinity at a tidally influenced site:

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

Where:

V_r = volume of daily freshwater (river) flow (cfs),

V_s = volume of daily seawater flow (cfs),

S_t = salinity in the river (ppt),

S_r = background salinity of the upstream river water (ppt); assumed to equal 0.07 ppt, and

S_s = salinity of seawater.

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 = 0.07 ppt), resulting in the equation found in the ODEQ (2006) technical information:

$$V_s = V_r/(S_s/S_t - 1)$$
$$\text{For } S_t > \text{than background salinity, otherwise } V_s = 0 \qquad \text{(Eq. 4)}$$

S_t was computed for each day of the streamflow record using the SWQM station-specific regression equations of Step 4 and the estimated actual daily streamflow (V_r), from Step 3, as input to the equation. S_s is normally assumed to be 35 ppt. However, the salinity of Sabine Lake, which supplies the tidal flow to the Neches River, has substantially lower salinity than full strength seawater and exhibits seasonal fluctuations due to freshwater inputs from both the Sabine and Neches rivers. Therefore, near daily continuous salinity data collected from the TWDB and TPWD Ambient Bay Water Quality Monitoring Program from January 01, 2006 through December 31, 2018 were used to estimate S_s (TWDB, 2019b; Figure 13). The 95th percentile of daily maximum salinities at SAB2 is 29.299 ppt and assumed to represent the full-strength seawater inflow (Figure 23). Background salinity was assumed at 0.07 ppt, which equates to the median value of specific conductance measurements (converted to salinity in ppt) for samples taken at SWQM Station 10580 (Neches River below B. A. Steinhagen Lake) and 10599 (Pine Island Bayou) upstream of Neches River Tidal from January 01, 2006 through December 31, 2018 (Figure 24).

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

$$V_t = V_r + V_s \tag{Eq. 5}$$

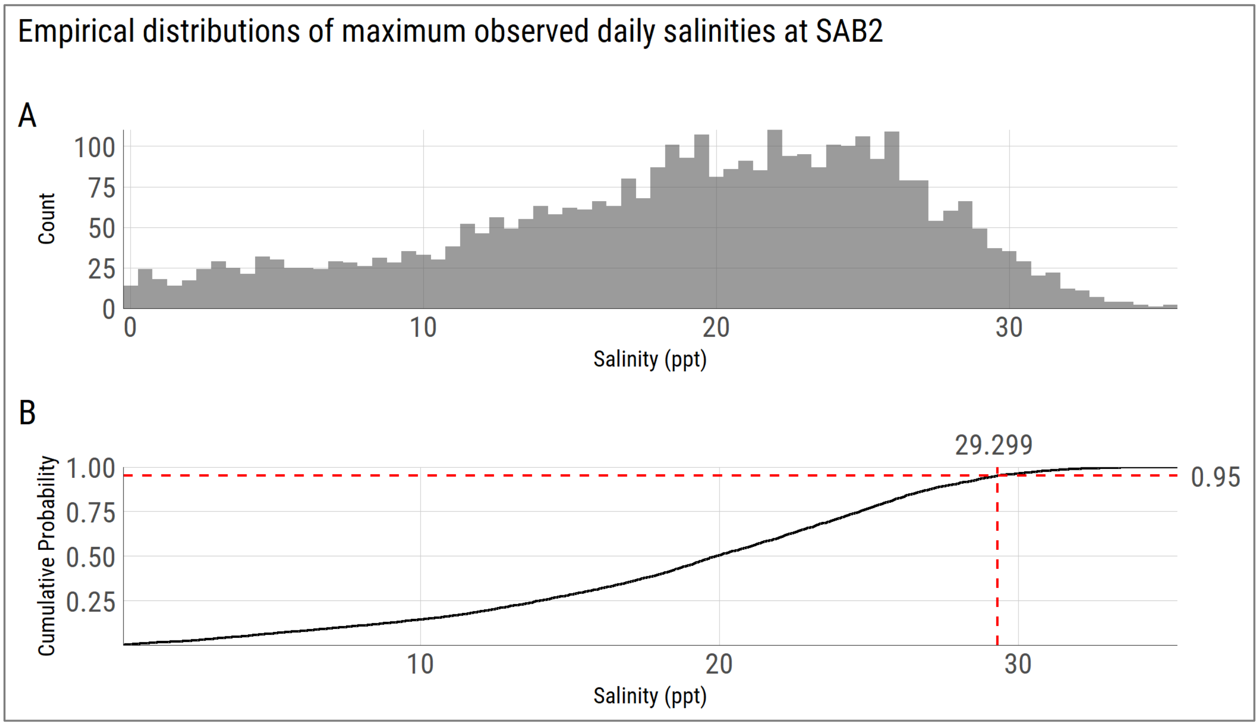

Figure 23. Distribution of maximum daily salinity observed at SAB2 from January 2006 through December 2018 as a (A) histogram and (B) empirical cumulative distribution function.

The dotted red lines indicate the 95th percentile of observed daily values used as seawater salinity value.

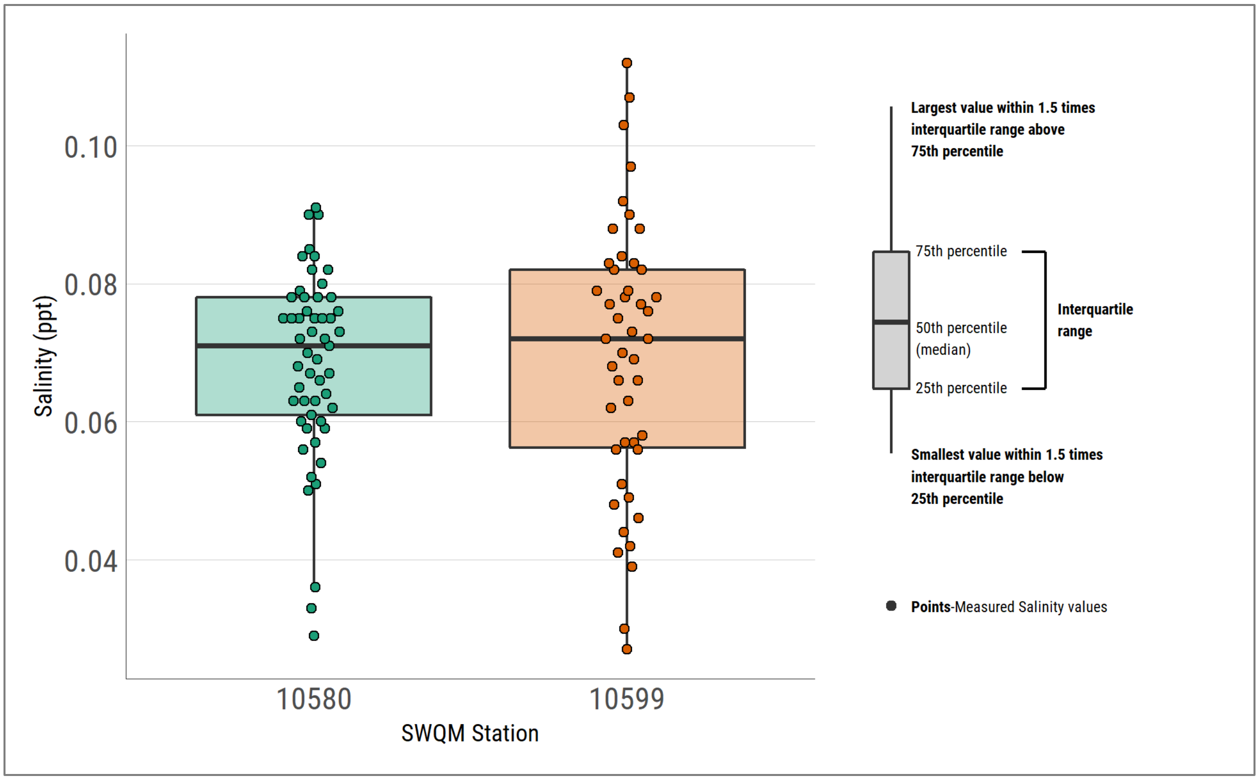

Figure 24. Distribution of specific conductance (converted to salinity) collected at SWQM stations 10580 (Neches River below B. A. Steinhagen Lake) and 10599 (Pine Island Bayou) upstream of Neches River Tidal

Vt is the estimated daily streamflow volume at each SWQM station developed using a DAR on the naturalized flows from Cow Bayou, plus tidally filtered flows reported by the Neches River Saltwater Barrier USGS stream gage, plus the reported permitted discharges above the respective SWQM station. Flows used in the TMDL must consider the full permitted flow and future growth (FG) of permitted WWTFs. The final streamflow record was developed by subtracting reported daily discharges and adding full permitted discharges (for facilities with daily average numeric flow limits) above each respective SWQM station and adding permitted discharges attributed to FG (Table 20). The calculation of FG flows is discussed in Section 4.7.4.

Table 20. Full permitted daily discharges used for modified FDC development

AU	SWQM Station	TPDES Number	Outfall	Permittee	Full Permitted Discharge (MGD)
0601_04	10575	WQ0014049001	001	Vidor MHP No. 1 LLC	0.0225
0601_04	10575	WQ0000493000	001	WestRock Texas LP	65.0
0601_04	10575	WQ0001971000	001	Optimus Steel LLC	1.64
0601_03	10570	WQ0010875001	001	Orange County Water Control and Improvement District No. 1	3.0
0601_03	10570	WQ0003426000	002	ExxonMobil Oil Corporation	3.0
0601_03	10570	WQ0001727000	001	Neches River Treatment Corporation and Lower Neches Valley Authority	21.0
0601_03	10566	WQ0005143000	001	Natgasoline LLC	3.5
0601_02	10566	WQ0000473000	001	Lucite International Inc.	9.99
0601_02	10566	WQ0001595000	002	Air Liquide Large Industries US LP	0.175
0601_02	10563	WQ0010477004	001	City of Port Neches	4.98
0601_01	10563	WQ0000511000	301	Huntsman Petrochemical LLC, Huntsman Propylene Oxide LLC (now known as Indorama Ventures Propylene Oxides LLC), Bluehall Incorporated, and TPC Group LLC	15.0
0601_01	10563	WQ0004731000	001	INEOS Calabrian Corp	0.25
0601_01	10563	WQ0000336000	001	Entergy Texas Inc.	1,306.0
0601_01	10563	WQ0000491000	001	Total Petrochemicals and Refining USA Inc.	7.1
0601_01	10563	WQ0005236000	001	Bayport Polymers LLC (formerly Total Petrochemicals & Refining USA Inc)	0.81
0601_01	10563	WQ0004135000	002	BASF TOTAL Petrochemical LLC	2.0
0601_01	10563	WQ0001674000	001	Integrity-Golden Triangle Marine Services LLC[a]	0.048
0601_01	10563	WQ0005328000	001	Marine Fueling Services Inc.[a]	0.035
				SWQM Station 10575 Total	**66.6625**
				SWQM Station 10570 Total	**93.6625**
				SWQM Station 10566 Total	**107.3275**
				SWQM Station 10563 Total	**1443.5505**

3.2.6. Step 6: Develop Modified Flow Duration Curves

Modified FDCs and LDCs are graphs that visually present the percentage of time during which a value of flow or load is equaled or exceeded. To develop a modified FDC for a location, the following steps were undertaken:

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

Exceedance values along the x-axis represent the percentage of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100% occur during low flow or drought conditions while values approaching 0% occur during periods of high flow or flood conditions. This graphical representation provides information on basic hydrological characteristics in the stream based upon flows observed within specific reaches. The amount of estimated seawater present is presented in the intermediate FDCs (Figure 25 through Figure 28). As expected from the modified daily flow volume equation, the amount of seawater present increases as both the freshwater flow decreases and the percentage of days the flow is exceeded increases. Note that the x-axis direction of increase on the seawater plot is reversed from that on the FDC.

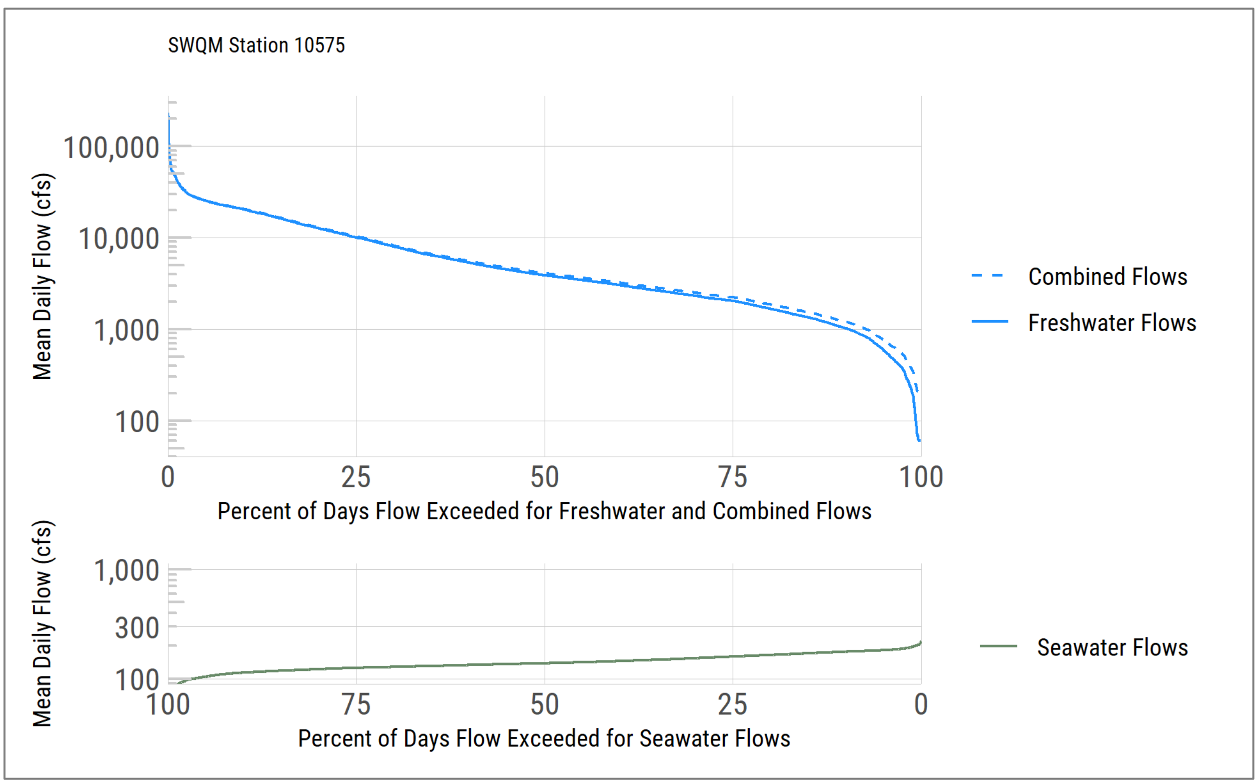

Figure 25. FDC components at AU 0601_04 for SWQM Station 10575

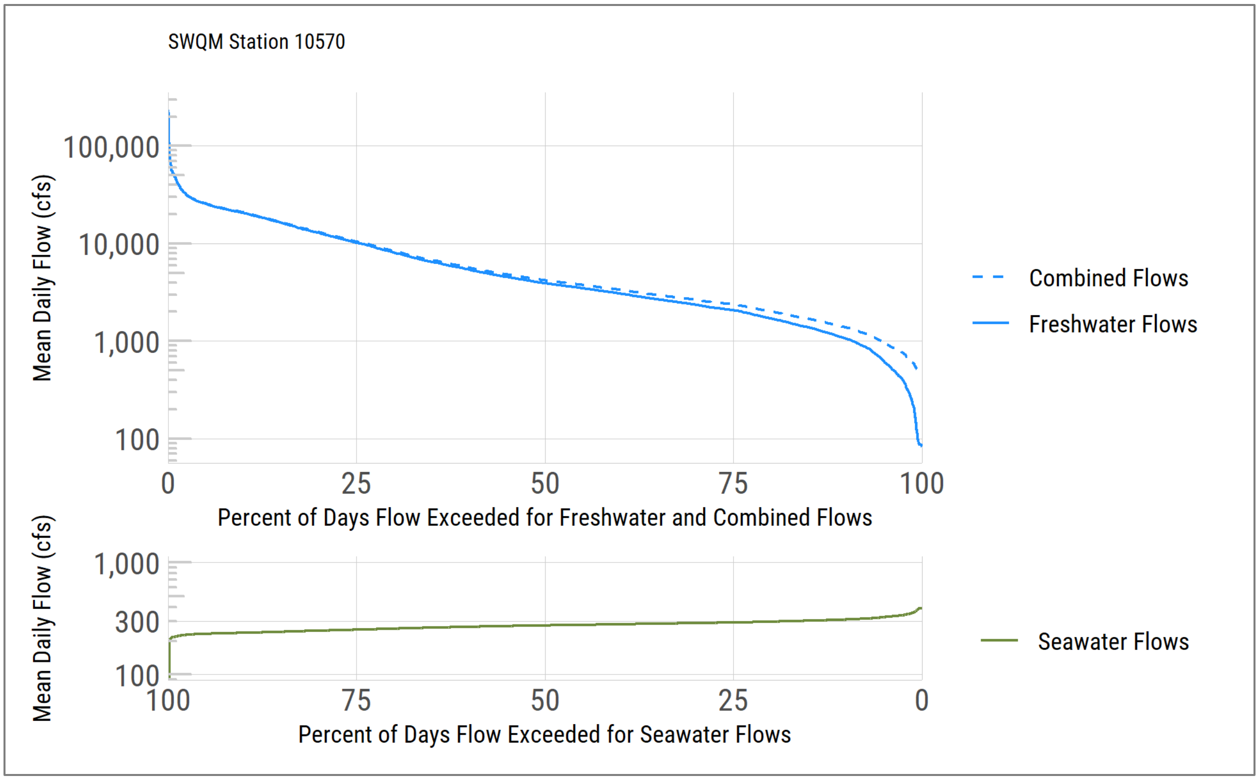

Figure 26. FDC components for AU 0601_03 at SWQM Station 10570

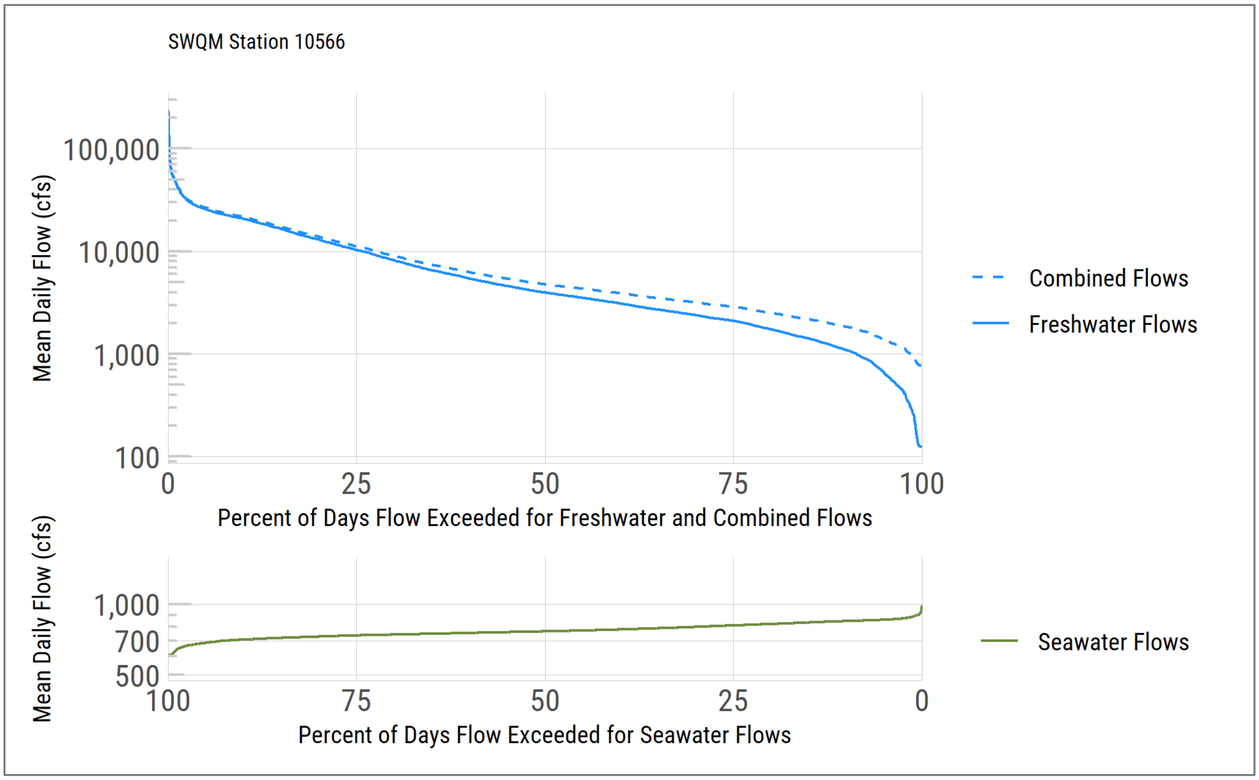

Figure 27. FDC components for AU 0601_02 at SWQM Station 10566

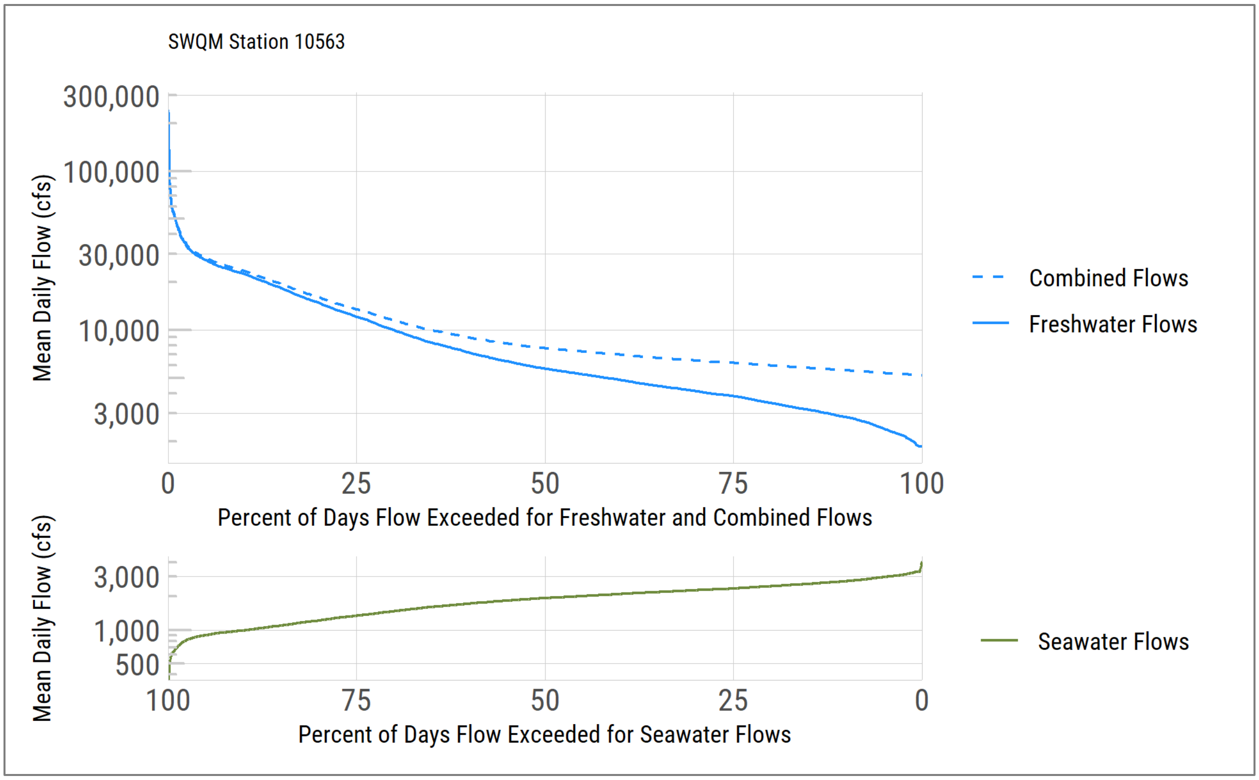

Figure 28. FDC components for AU 0601_01 at SWQM Station 10563

The final modified FDCs for AUs 0601_01, 0601_02, 0601_03, and 0601_04 are shown in Figure 29. For this report, the modified FDCs were developed from the estimated daily streamflow volume at each SWQM station. The estimated daily streamflows were developed using a DAR on the naturalized flows from Cow Bayou, plus tidally filtered flows reported by the Neches River Saltwater Barrier USGS stream gage, plus the full permitted discharges and FG of permitted discharges above the respective SWQM station. As expected, the modified FDCs depict an increase in streamflows moving downstream as subwatershed drainage area size increases and tidal influences increase.

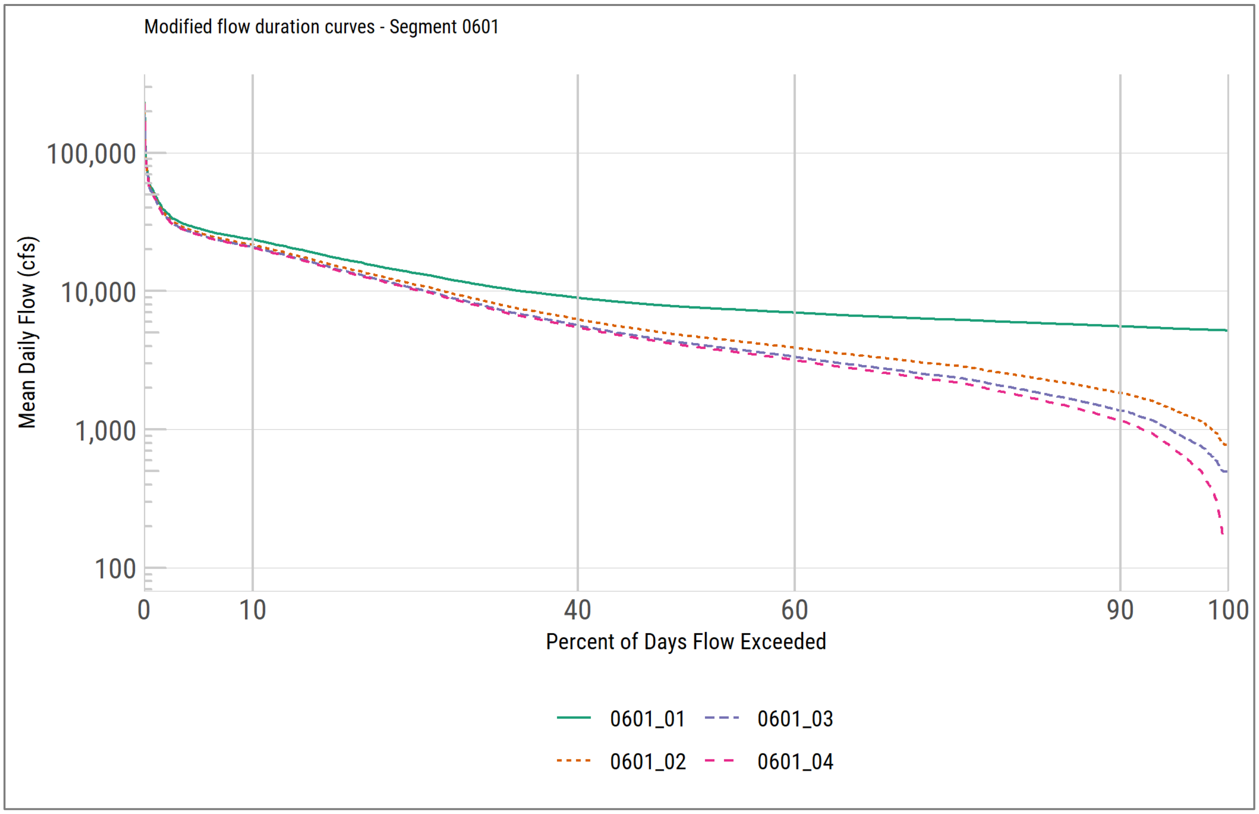

Figure 29. Modified FDCs for Neches River Tidal

3.2.7. Steps 7-8: Develop Modified Load Duration Curves

The modified FDCs were combined with the numeric water quality criterion and measured bacteria concentrations to create the modified LDC with the following steps:

- Multiply the streamflow in cfs by the appropriate water quality criterion for Enterococci (geometric mean of 35 cfu/100 mL or 0.35 cfu/mL) and by a conversion factor (28,316.8 mL/feet3 (ft3) × 86,400 seconds/day (s/d) × 1.0E-09 billion), which gives you a loading unit of billion cfu/day; and
- Plot the exceedance percentages, which are identical to the value for streamflow data points, against the geometric mean criterion for Enterococci.

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

- Compute the daily loads by multiplying the measured Enterococci concentrations (in cfu/mL) on a particular day by the corresponding daily full-permitted streamflow (in cfs) and the conversion factor (to billion cfu/day) 28,316.8 mL/ft3 × 86,400 s/d × 1.0E-09 billion; and
- Plot on the LDC for each SWQM station the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots (Figure 30 through Figure 33) of the LDCs with the measured values (Enterococci concentrations multiplied by full permitted streamflow) display the frequency and magnitude at which measured values exceed the geometric mean criterion at full permitted flows. Measured values that are above the geometric mean criterion curve indicated an exceedance of the water quality criterion, while those below a curve show compliance.

3.3. Modified Load Duration Curve for TMDL Watershed

Modified LDCs were developed for Neches River Tidal (AUs: 0601_01, 0601_02, 0601_03, 0601_04) using the modified FDCs and Enterococci data for SWQM stations 10563, 10566, 10570, and 10575. A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0-10% (high flows); (2) 10-40% (moist conditions); (3) 40-60% (mid-range flows); (4) 60-90% (dry conditions); and (5) 90-100% (low flows). The selection of the flow regime intervals was based on general observation of the developed LDC. The geometric mean loading in each flow regime is also shown to aid interpretation.

The modified LDC developed for AU 0601_04 indicates Enterococci loadings exceed allowable loadings across all flow conditions, with the highest exceedances under moist conditions (Figure 30). The modified LDC for AU 0601_03 indicates geometric mean Enterococci loadings exceeded allowable loadings across all flow regimes, with the highest relative exceedances occurring under low flow conditions (Figure 31). The modified LDC developed for AU 0601_02 also indicates geometric mean Enterococci loadings exceeded allowable loadings across all flow regimes, with the highest exceedances occurring in moist conditions through low flow regimes (Figure 32). The modified LDC for AU 0601_01 indicates geometric mean Enterococci loadings were exceeded in all flow regimes, with the highest exceedances occurring under dry conditions and low flow regimes.

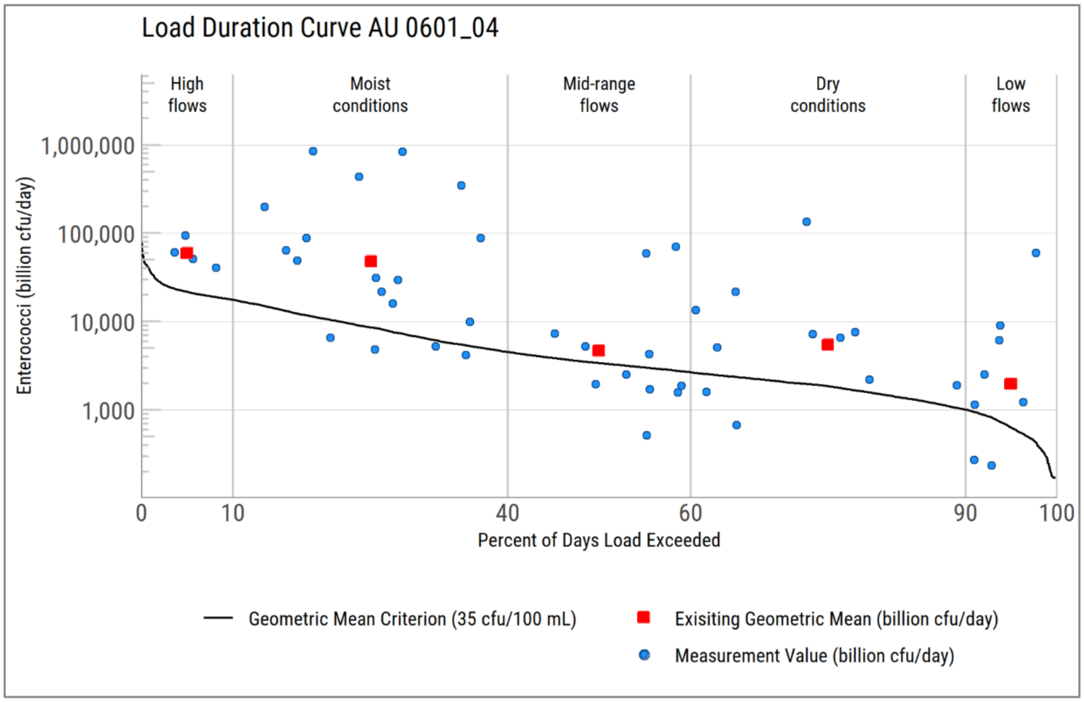

Figure 30. Modified LDC for AU 0601_04 at SWQM Station 10575

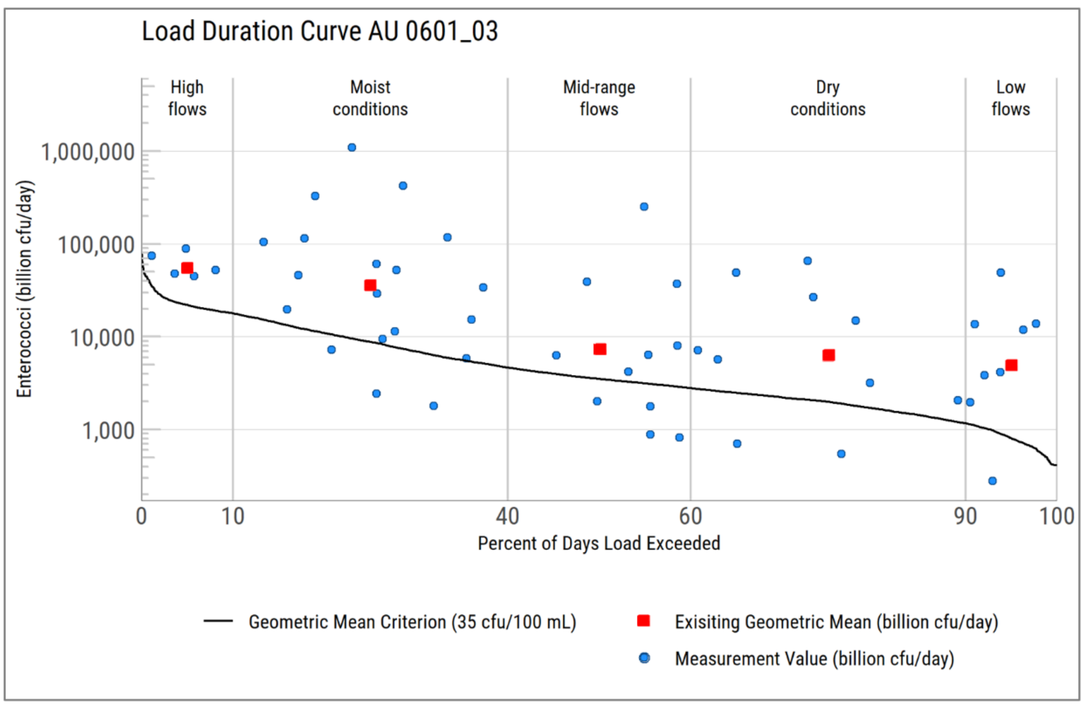

Figure 31. Modified LDC for AU 0601_03 at SWQM Station 10570

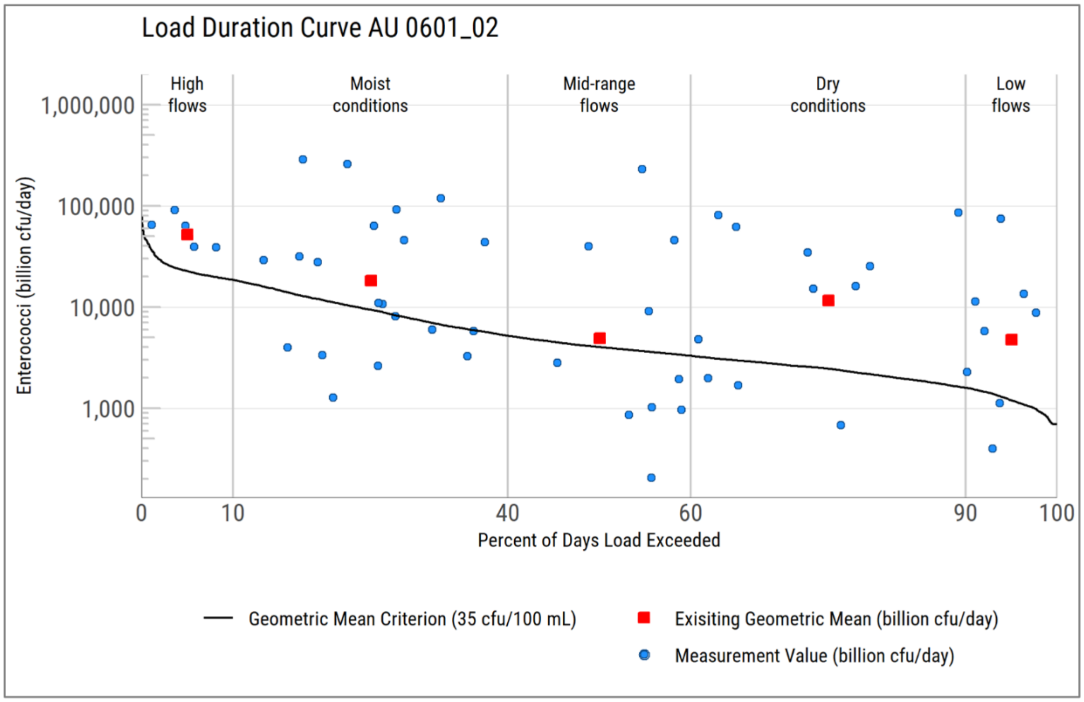

Figure 32. Modified LDC for AU 0601_02 at SWQM Station 10566

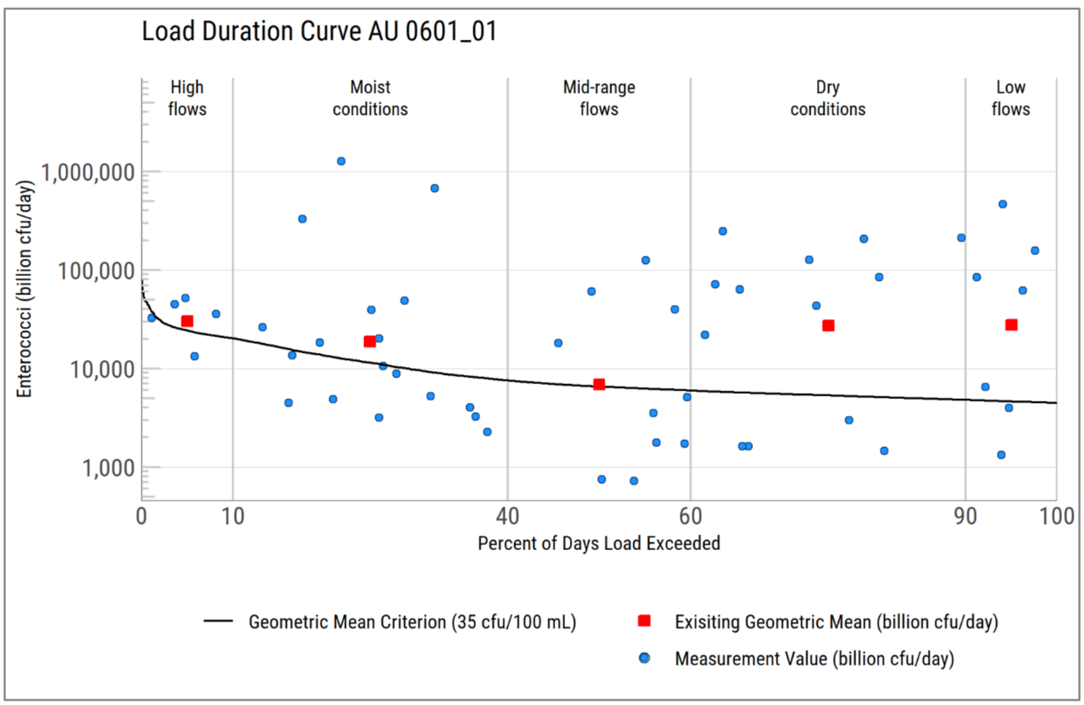

Figure 33. Modified LDC for AU 0601_01 at SWQM Station 10563

Section 4. TMDL Allocation Analysis

4.1. Endpoint Identification

The Neches River Tidal segment has a use of primary contact recreation 1, which has a geometric mean numeric criterion of 35 cfu/100 mL for Enterococci indicator bacteria (TCEQ, 2018a). All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for these TMDLs is to maintain the concentration of Enterococci below the geometric mean criterion of 35 cfu/100 mL for primary contact recreation (TCEQ, 2018a). This endpoint was applied to the AUs addressed with this TMDL.

4.2. Seasonality

Seasonal variations or seasonality occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. The Code of Federal Regulations (CFR) [40 CFR 130.7(c)(1)] requires that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Seasonal differences in indicator bacteria concentrations were assessed by comparing Enterococci during warmer months (May-September) against those collected during cooler months (November-March). The months of April and October were considered transitional between warm and cool seasons and were excluded from the seasonal analysis. Differences in seasonal concentrations were then evaluated with a Wilcoxon Rank Sum test (also known as the "Mann-Whitney" test). The Wilcoxon Rank Sum test was chosen for its ability to handle non-normally distributed data without requiring data transformation. The test is considered significant at the $\alpha = 0.05$ level.

Enterococci data for the period of June 2003-December 2018, coinciding with the period used in the LDCs, were used in the analysis. The Wilcoxon Rank Sum test did not indicate a seasonal difference in Enterococci concentrations at SWQM stations 10566 (AU 0601_02), 10563 (AU 0601_01), or 10570 (AU 0601_03) ($p > 0.05$, Table 21, Figure 34). The Wilcoxon Rank Sum test did detect a significant difference in seasonal Enterococci concentrations at SWQM Station 10575 (AU 0601_04) ($W = 54$, $p = 0.0275$, Table 21, Figure 34). Based on Figure 34, the distribution of warm season Enterococci concentrations at SWQM Station 10575 (AU 0601_04) is significantly higher than the cool season measurements.

Table 21. Summary of *E. coli* data and Wilcoxon test results

AU	SWQM Station	W-statistic	p-value	Seasonal n	Seasonal Geometric Mean (cfu/100 mL)
0601_04	10575	54	0.0275	Cool = 14 Warm = 15	Cool = 87 Warm = 336
0601_03	10570	114	0.950	Cool = 15 Warm = 15	Cool = 202 Warm = 189
0601_02	10566	136	0.329	Cool = 15 Warm = 15	Cool = 178 Warm = 93
0601_01	10563	108	0.930	Cool = 15 Warm = 14	Cool = 91 Warm = 100

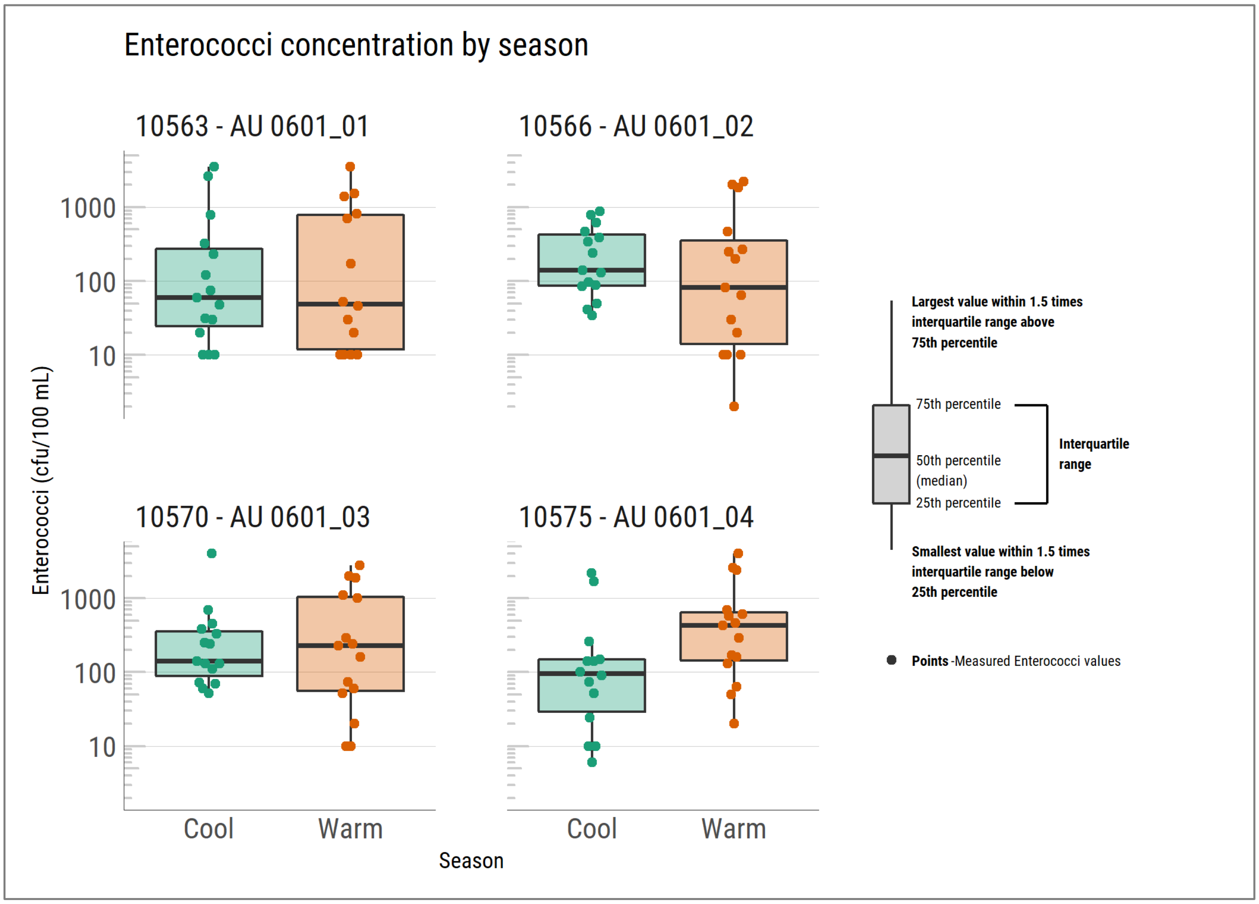

Figure 34. Distribution of Enterococci concentration by season at SWQM stations 10566, 10563, 10570, and 10575

4.3. Linkage Analysis

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

Generally, if high bacteria concentrations are measured in a water body at low to median flows in the absence of runoff events, the main contributing sources are likely to be point sources (direct fecal deposition into the water body). During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in 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, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

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

4.4. Load Duration Curve Analysis

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

The weaknesses of this method include the limited information it provides regarding the magnitude or specific origin of the various sources. Only limited information is gathered regarding point and NPSs in the watershed. The general difficulty in analyzing and characterizing Enterococci in the environment is also a weakness of this method.

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

Based on the LDCs to be used in the pollutant load allocation process with historical Enterococci data added to the graphs (Figure 30 through Figure 33) and Section 2.8 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made:

- For AUs 0601_03 and 0601_04, historical Enterococci data indicate that elevated bacteria loading occurs under all flow conditions. Bacteria loads in these two AUs are notably elevated under dry conditions and low flow conditions. However, the largest exceedances in AU 0601_04 occur under moist conditions.
- For AUs 0601_01 and 0601_02, bacteria loads exceed the geometric mean criterion under all conditions. Within these two AUs, loads become most elevated under dry conditions and low flows.

Regulated stormwater comprises between 20 and 25% of each AU watershed, and in addition to unregulated sources, likely contributes to loadings under moist and high flow conditions. The compliance history of permitted dischargers indicates periodic exceedances of permitted bacteria limits from domestic and industrial discharges that may contribute to loadings under dry and low flow conditions (refer to Section 2.7.1.5. Review of Compliance Information on Permitted Sources). Other sources of bacteria loadings under mid-range and low flow conditions and in the absence of overland flow contributions (i.e., without stormwater contribution) are also likely to contribute bacteria directly to the stream. These sources may include SSOs and direct deposition of fecal material from sources such as wildlife, feral hogs, and livestock (See Section 2.8.2). However, the actual contributions of bacteria loadings directly attributable to these sources cannot be determined using LDCs.

4.5. Margin of Safety

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

1) Implicitly incorporating the MOS using conservative model assumptions to develop allocations.

2) Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning an MOS. The TMDLs covered by this report incorporate an explicit MOS of 5%.

4.6. Load Reduction Analysis

While the TMDL for the Neches River Tidal watershed will be developed using load allocations, additional insight may be gained through a load reduction analysis. A single % load reduction required to meet the allowable loading for each flow regime was determined using the historical Enterococci data obtained from the SWQM station in each impaired AU (Table 22). The estimated existing load in each flow regime was calculated with the geometric mean concentration in each flow category (FC) and the median flow in each FC (Eq. 6).

$$\text{Exisiting Load}_{FC} = \bar{Q}_{FC} \times C_{FC} \times \text{Conversion Factor} \tag{Eq. 6}$$

Where:

Existing Load$_{FC}$ = Existing bacteria load at the median flow in each FC
$\bar{Q}_{FC}$ = Median flow for each FC
C_{FC} = Geometric mean of bacteria (Enterococci cfu/100 mL) samples in each FC
Conversion Factor (to billion cfu/day) = 28,316.8 mL/ft^3 × 86,400 s/d × 1.0E-09 billion=2.44658

The allowable load (Eq. 7) was calculated as:

$$\text{Allowable Load}_{FC} = \bar{Q}_{FC} \times \text{Criterion} \times \text{Conversion Factor} \tag{Eq. 7}$$

Where:

Allowable Load$_{FC}$ = Allowable load at the median flow in each FC
$\bar{Q}_{FC}$ = Median flow in each FC
Criterion = 35 cfu/100 mL (Enterococci)
Conversion Factor (to billion cfu/day) = 28,316.8 mL/ft^3 × 86,400 s/d ×1.0E-09 billion=2.44658

Percentage reduction for each flow category (PR_{FC}) was then calculated as:

$$PR_{FC} = (\text{Existing Load}_{FC} - \text{Allowable Load}_{FC})/\text{Existing Load}_{FC} \tag{Eq. 8}$$

Table 22. Percentage daily load reductions needed to meet water quality standards in each flow regime

SWQM Station/AU	Flow Regime	Median Flow (cfs)	Geometric Mean for Flow Regime	Existing Load (Billion cfu/Day)	Allowable Load (Billion cfu/Day)	Percent Reduction Required
10563/ 0601_01	High Flows	28,916	43.43	30,724.58	24,760.77	19
10563/ 0601_01	Moist Conditions	13,874	57.23	19,426.00	11,880.31	39
10563/ 0601_01	Mid-Range Flows	8,048	37.64	7,411.32	6,891.50	7
10563/ 0601_01	Dry Conditions	6,590	130.83	21,093.60	5,643.02	73
10563/ 0601_01	Low Flows	5,730	209.35	29,348.47	4,906.60	83
10566/ 0601_02	High Flows	26,675.00	80.84	52,758.04	22,841.80	57
10566/ 0601_02	Moist Conditions	11,171.00	67.91	18,560.24	9,565.73	48
10566/ 0601_02	Mid-Range Flows	4,787.00	40.14	4,701.09	4,099.11	13
10566/ 0601_02	Dry Conditions	2,906.00	167.25	11,891.03	2,488.41	79
10566/ 0601_02	Low Flows	1,402.00	139.76	4,793.90	1,200.53	75
10570/ 0601_03	High Flows	25,962	87.81	55,775.06	22,231.26	60
10570/ 0601_03	Moist Conditions	10,564	143.08	36,979.86	9,045.95	76
10570/ 0601_03	Mid-Range Flows	4,278	73.52	7,694.92	3,663.25	52
10570/ 0601_03	Dry Conditions	2,459	110.59	6,653.23	2,105.64	68
10570/ 0601_03	Low Flows	1,046	214.93	5,500.30	895.69	84
10575/ 0601_04	High Flows	25,662	96.32	60,473.47	21,974.37	64
10575/ 0601_04	Moist Conditions	10,253	196.96	49,406.82	8,779.64	82
10575/ 0601_04	Mid-Range Flows	4,046	59.45	5,884.85	3,464.59	41
10575/ 0601_04	Dry Conditions	2,215	105.64	5,724.80	1,896.70	67
10575/ 0601_04	Low Flows	748	109.13	1,997.12	640.51	68

4.7. Pollutant Load Allocations

A 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 equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{FG} + \text{MOS} \quad \text{(Eq. 9)}$$

Where:

TMDL = total maximum daily load
WLA = wasteload allocation, the amount of pollutant allowed by existing regulated or permitted dischargers
LA = load allocation, the amount of pollutant allowed by unregulated sources
FG = loading associated with future growth from potential regulated facilities
MOS = margin of safety

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

The TMDL component for the impaired AUs covered in this report are derived using the median flow within the high flow regime (or 5% flow) of the modified LDCs developed for Neches River Tidal. For the remainder of this report, each section will present an explanation of the TMDL component first, followed by the results of the calculation for that component.

4.7.1. AU-Level TMDL Calculations

The TMDLs for the impaired AUs were developed as a pollutant load allocation based on information from the LDC developed at SWQM stations within each AU, as described in Section 3.2 Methodology for Modified Flow Duration and Load Duration Curve Development. As discussed in more detail in Section 3.2, bacteria LDCs were developed by multiplying the streamflow value along the FDC by the primary contact recreation Enterococci criterion (35 cfu/100 mL) and by the conversion factor to convert to loading in colonies per day. This effectively displays the LDC as the TMDL curve of maximum allowable loading:

$$\text{TMDL} = \text{Criterion} \times \text{Flow} \times \text{Conversion Factor} \qquad \text{(Eq. 10)}$$

Where:

Criterion = 35 cfu/100 mL (Enterococci)
Conversion Factor (to billion cfu/day) = 28,316.8 mL/ft^3 × 86,400 s/d × 1.0E-09 billion

The TMDL values calculated at the 5% load duration exceedance are provided in Table 23.

Table 23. Summary of allowable loadings

AU	5% Exceedance Flow (cfs)	5% Exceedance Load (Billion cfu/day)	TMDL (Billion cfu/day)
0601_04	25,662	21,974.371	21,974.371
0601_03	25,962	22,231.261	22,231.261
0601_02	26,675	22,841.803	22,841.803
0601_01	28,916	24,760.772	24,760.772

4.7.2. Margin of Safety

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

$$MOS = 0.05 \times TMDL \tag{Eq. 11}$$

Where:

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

Table 24 includes the MOS calculation for each AU.

Table 24. MOS calculations

AU	TMDL (Billion cfu/day)	MOS (Billion cfu/day)
0601_04	21,974.371	1,098.719
0601_03	22,231.261	1,111.563
0601_02	22,841.803	1,142.090
0601_01	24,760.772	1,238.039

4.7.3. Wasteload Allocation

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}). The WLA is expressed as:

$$WLA = WLA_{WWTF} + WLA_{SW} \tag{Eq. 12}$$

Wastewater (WLA_{WWTF})

TPDES-regulated WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric mean criterion. The saltwater Enterococci criterion (35 cfu/100 mL) is used as the WWTF target. The WLA_{WWTF} term is also calculated for the freshwater *E. coli* primary contact recreation geometric mean criterion of 126 cfu/100 mL, since WWTF bacteria permit limits are often expressed in terms of *E. coli*. Both the Oak Lane WWTF and Sugar Pines Mobile Home Community WWTF have *E. coli* limits of 126 cfu/100 mL specified in their permits. This is expressed as:

$$WLA_{WWTF} = Criterion \times Flow \times Conversion\ Factor \tag{Eq. 13}$$

Where:

Criterion = 35 cfu/100 mL (Enterococci); 126 cfu/100 mL for *E. coli*
Flow = full permitted flow in MGD

Conversion Factor (to billion cfu/day) = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d × 1.0E-09 billion = 3.78540885

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 cumulatively summed for each watershed. Table 25 presents the WLAs for each individual WWTF located within the Neches River Tidal watershed. Since the pollutant load allocations are developed in terms of Enterococci as the indicator bacteria, it is the Enterococci loadings from Table 25 that will be used in subsequent computations. Three industrial facilities (Beaumont Terminal, Sabine Plant, and Lucite Beaumont Facility) are authorized to discharge treated effluent with a human waste component. Their permits include effluent limits for Enterococci and monitoring requirements. These permits, however, do not have numeric final permitted flows for the outfalls with the human waste component. They are included in Table 25 for completeness but will not receive an individual WLA.

Table 25. Wasteload allocations for TPDES-permitted facilities

AU	TPDES Permit	Outfall	Permittee	Bacteria Limit (cfu/100 mL)	Full Permitted Discharge (MGD)*	*E. coli* WLA_{WWTF} (Billion cfu/ day)	Enterococci WLA_{WWTF} (Billion cfu/ day)
0601_04	WQ0014049001	001	Vidor MHP No. 1 LLC	126 (*E. coli*)	0.0225	0.107	0.030
0601_04	WQ0000493000	001	WestRock Texas LP	35 (Enterococci)	65.0	310.025	86.118
0601_03	WQ0010875001	001	Orange County Water Control and Improvement District No. 1	126 (*E. coli*)	3.0	14.309	3.975
0601_03	WQ0001727000	001	Neches River Treatment Corporation and Lower Neches Valley Authority	35 (Enterococci)	21.0	100.162	27.823
0601_02	WQ0010477004	001	City of Port Neches	35 (Enterococci)	4.98	23.753	6.598
0601_02	WQ0000473000	101	Lucite International Inc.	35 (Enterococci)	n/a	n/a	n/a
0601_02	WQ0000316000	002	Phillips 66 Gulf Coast Properties LLC and Phillips 66 Pipeline LLC	35 (Enterococci)	n/a	n/a	n/a
0601_01	WQ0000511000	301	Huntsman Petrochemical LLC, Huntsman Propylene Oxide LLC (now known as Indorama Ventures Propylene Oxides LLC), Bluehall Incorporated, and TPC Group LLC	35 (Enterococci)	15.0	71.544	19.873
0601_01	WQ0000336000	801	Entergy Texas Inc.	89 (Daily Max, Enterococci)	n/a	n/a	n/a
					AU 0601_04 Total	**310.132**	**86.148**
					AU 0601_03 Total	**424.603**	**117.946**
					AU 0601_02 Total	**448.356**	**124.544**
					AU 0601_01 Total	**519.900**	**144.417**

*Final Permitted Flow as listed in permit (decimal place values may vary).

Stormwater (WLA_{SW})

Stormwater discharges from MS4, industrial, and construction sites are considered permitted or 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 the watershed was used in the development of the TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading. The percentage of land area included in each watershed that is under the jurisdiction of stormwater permits (Figure 7) is used to estimate the amount of overall runoff load that should be allocated as the regulated stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct NPS runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) \times FDA_{SWP} \tag{Eq. 14}$$

Where:

WLA_{SW} = the sum of all regulated stormwater loads
TMDL = the total maximum daily load
WLA_{WWTF} = the sum of WWTF loads
FG = the sum of future growth loads from potential regulated facilities
MOS = the margin of safety load
FDA_{SWP} = the proportion of drainage area under jurisdiction of stormwater permits

To calculate the WLA_{SW} component of the TMDL, the fractional proportion of the drainage under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits (combined area of MS4s and individual permits that are outside of MS4s) as described in Section 2.7.1.4. TPDES Regulated Stormwater and shown in Table 26. The estimated areas in Table 26 are cumulative and therefore include the upstream AU watersheds areas.

Table 26. Regulated stormwater FDA_{swp} calculations

AU	Estimated Area Under Stormwater Regulation (square miles)	Watershed Area (square miles)	FDA_{SWP}
0601_04	16.24	79.60	0.204
0601_03	30.67	131.17	0.234
0601_02	42.18	166.70	0.253
0601_01	49.05	210.75	0.233

The FG term required to calculate WLA_{SW} is described in the next section. However, the WLA_{SW} calculations are presented in Table 27 for continuity.

Table 27. Regulated stormwater load calculations

(units of billion cfu/day Enterococci)

AU	TMDL	WLA_{WWTF}	FG	MOS	FDA_{SWP}	WLA_{SW}
0601_04	21,974.371	86.148	21.623	1,098.719	0.204	4,236.648
0601_03	22,231.261	117.946	29.604	1,111.563	0.234	4,907.483
0601_02	22,841.803	124.544	31.260	1,142.090	0.253	5,450.609
0601_01	24,760.772	144.417	36.249	1,238.039	0.233	5,438.702

With the WLA_{SW} and WLA_{WWTF} terms, the total WLA term can be determined using Eq. 12 (Table 28).

Table 28. WLA calculations

(units of billion cfu/day Enterococci)

AU	WLA_{WWTF}	WLA_{SW}	WLA
0601_04	86.148	4,236.648	4,322.796
0601_03	117.946	4,907.483	5,025.429
0601_02	124.544	5,450.609	5,575.153
0601_01	144.417	5,438.702	5,583.119

4.7.4. Future Growth

The FG component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that might occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

To account for the FG component of the impaired AUs, the loadings from WWTFs with a sanitary waste component are included in the FG computation, which is based on the WLA_{WWTF} formula (Eq. 13). The FG equation contains an additional term to account for population growth within the watershed between 2020 and 2070, based on TWDB Regional Water Plan Population and Water Demand Projections (Table 2, TWDB, 2019a). Section 2.5 discusses the method used to estimate population increases in each AU watershed. Table 29 includes the calculations used to determine FG.

$$FG = \text{Criterion} \times (\%POP_{2020\text{-}2070} \times WWTF_{FP}) \times \text{Conversion Factor} \quad \text{(Eq. 15)}$$

Where:

FG = Future growth from existing WWTFs
Criterion = 35 cfu/100 mL (Enterococci)
$\%POP_{2020\text{-}2070}$ = Estimated percentage increase in population between 2020 and 2070
$WWTF_{FP}$ = Full permitted discharge (MGD)

Conversion Factor (to billion cfu/day) = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d × 1.0E-09 billion = 3.78540885

Table 29. FG calculations

AU	Full Permitted Flow (MGD)	Percentage Population Increase	FG Flow (MGD)	FG (Billion cfu/day)
0601_04	65.0225	25.1	16.321	21.623
0601_03	89.0225	25.1	22.345	29.604
0601_02	94.0025	25.1	23.595	31.260
0601_01	109.0025	25.1	27.360	36.249

4.7.5. Load Allocation

The load allocation (LA) is the load from unregulated sources and is calculated as:

$$LA = TMDL - WLA - FG - MOS \qquad \text{(Eq. 16)}$$

Where:

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

Table 30 summarizes the LA calculations.

Table 30. LA calculations

(units of billion cfu/day Enterococci).

AU	TMDL	WLA	FG	MOS	LA
0601_04	21,974.371	4,322.796	21.623	1,098.719	16,531.233
0601_03	22,231.261	5,025.429	29.604	1,111.563	16,064.665
0601_02	22,841.803	5,575.153	31.260	1,142.090	16,093.300
0601_01	24,760.772	5,583.119	36.249	1,238.039	17,903.365

4.8. Summary of TMDL Calculations

Table 31 summarizes the TMDL calculations for the Neches River Tidal watershed. The TMDLs were calculated based on median flow in the 0-10percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed at the SWQM station within each AU. Allocations are based on the current geometric mean criterion for Enterococci of 35 cfu/100 mL for each component of the TMDL.

Table 31. TMDL allocations

(units of billion cfu/day Enterococci).

AU	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA	FG
0601_04	21,974.371	1,098.719	86.148	4,236.648	16,531.233	21.623
0601_03	22,231.261	1,111.563	117.946	4,907.483	16,064.665	29.604
0601_02	22,841.803	1,142.090	124.544	5,450.609	16,093.300	31.260
0601_01	24,760.772	1,238.039	144.417	5,438.702	17,903.365	36.249

The final TMDL allocations (Table 32) needed to comply with the requirements of 40 CFR 103.7 include the FG component within the WLA_{WWTF}. The WLA_{WWTF} for the AU is the sum of the WWTF allocations for the AU. Similarly, the WLA_{SW} for each AU includes the sum of all regulated stormwater areas of the AU. The LA component of the final TMDL allocations is the sum of loadings arising from within the AU that are associated with unregulated sources.

Table 32. Final TMDL allocations

(units of billion cfu/day Enterococci).

AU	TMDL	WLA_{WWTF}	WLA_{SW}	LA	MOS
0601_04	21,974.371	107.771	4,236.648	16,531.233	1,098.719
0601_03	22,231.261	147.550	4,907.483	16,064.665	1,111.563
0601_02	22,841.803	155.804	5,450.609	16,093.300	1,142.090
0601_01	24,760.772	180.666	5,438.702	17,903.365	1,238.039

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Appendix A. Salinity to Streamflow Regression

Estimates of daily salinity were required to calculate the volume of seawater expected to pass a SWQM station on a given day. Estimates of daily salinity were developed using statistical regressions of measured salinity values at each SWQM station and estimated daily streamflow values described in Section 3.2.3. During exploratory data analysis, it was evident that linear regression predicted salinity responses above seawater salinity values, despite log transformations on predictor and response variables. This was attributed to the nonlinear relationship between streamflow and salinity, the bounded distribution of salinity (seawater salinity is always expected to be between 0 and 36 ppt) and the lack of salinity data at low flows. For example, at low freshwater inflows, salinity will increase linearly until it begins to approach full strength seawater. At that point, the relationship between streamflow and salinity becomes nonlinear since salinity will not exceed the full strength of the incoming seawater.

Beta regression was utilized to fit and predict daily salinity. Beta regression allows a nonlinear relationship between the predictor and response variable bounded by zero and one (Cribari-Neto & Zeileis, 2010). The "betareg" package in R version 3.5.3 was used to fit beta regressions at each SWQM station (Cribari-Neto & Zeileis, 2010). The beta regression was setup as:

$$\ln(p(\text{Salinity})/1-p(\text{Salinity})) = \beta 0 + \beta 1(\log 10(\text{Streamflow})) \qquad \text{(Eq. 17)}$$

Where p(Salinity), is the proportion measured salinity based on the highest expected salinity (29.299 ppt). Streamflow is the naturalized streamflow plus reported average daily discharges at each SWQM station. β_0 is the constant intercept and β_1 is the coefficient for log base 10 transformed streamflow. For interpretability, the regression results were transformed back to units of ppt.

The form of Eq. 17 is equivalent to a logistic regression describing the log-odds ratio which can mathematically be converted to probability. The same series of steps are used to solve Eq. 17 for p(Salinity), describing the proportion of full Salinity. First, both sides of Eq. 17 are exponentiated and converted to the multiplicative inverse:

$$(1-p(\text{Salinity}))/p(\text{Salinity}) = 1/\exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} \qquad \text{(Eq. 18)}$$

Partial out the fraction on the left hand side of the equation and add one to both sides:

$$1/p(\text{Salinity}) = 1 + (1/\exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\}) \qquad \text{(Eq. 19)}$$

Change 1 to a common denominator:

$$1/p(\text{Salinity}) = (\exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} + 1) / \exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} \qquad \text{(Eq. 20)}$$

Take the multiplicative inverse again to solve for p(Salinity):

$$p(\text{Salinity}) = \exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} / 1 + \exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} \qquad \text{(Eq. 21)}$$

Eq. 21 describe salinity as a proportion of full salinity (29.299 ppt). In the final step, salinity in measured units can be determined by multiplying the right hand side by full salinity (29.299 ppt):

$$\text{Salinity} = p(\text{Salinity}) \times 29.299 \text{ ppt}$$

or

$$\text{Salinity} = \exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} / 1 + \exp\{\beta_0 + \beta_1(\log_{10}(\text{Streamflow}))\} \times 29.299 \text{ ppt} \qquad \text{(Eq. 22)}$$

Regression results and plots indicate reasonable fits with streamflow being a significant predictor of salinity (Table A-1, Figure A-1). The equations used to predict salinity for given streamflow values are in Table A-2.

Table A- 1. Streamflow-salinity regression results

SWQM Station	Regression Term	Coefficient	Standard Error	p-value
SWQM 10575	Intercept	3.64271	0.7941	<0.001
	Log_{10}(Streamflow)	-1.93969	0.2394	<0.001
SWQM 10570	Intercept	6.31063	0.5862	<0.001
	Log_{10}(Streamflow)	-2.49234	0.1782	<0.001
SWQM 10566	Intercept	6.09740	0.6327	<0.001
	Log_{10}(Streamflow)	-2.14828	0.1833	<0.001
SWQM 10563	Intercept	11.63554	1.0613	<0.001
	Log_{10}(Streamflow)	-3.38634	0.2863	<0.001

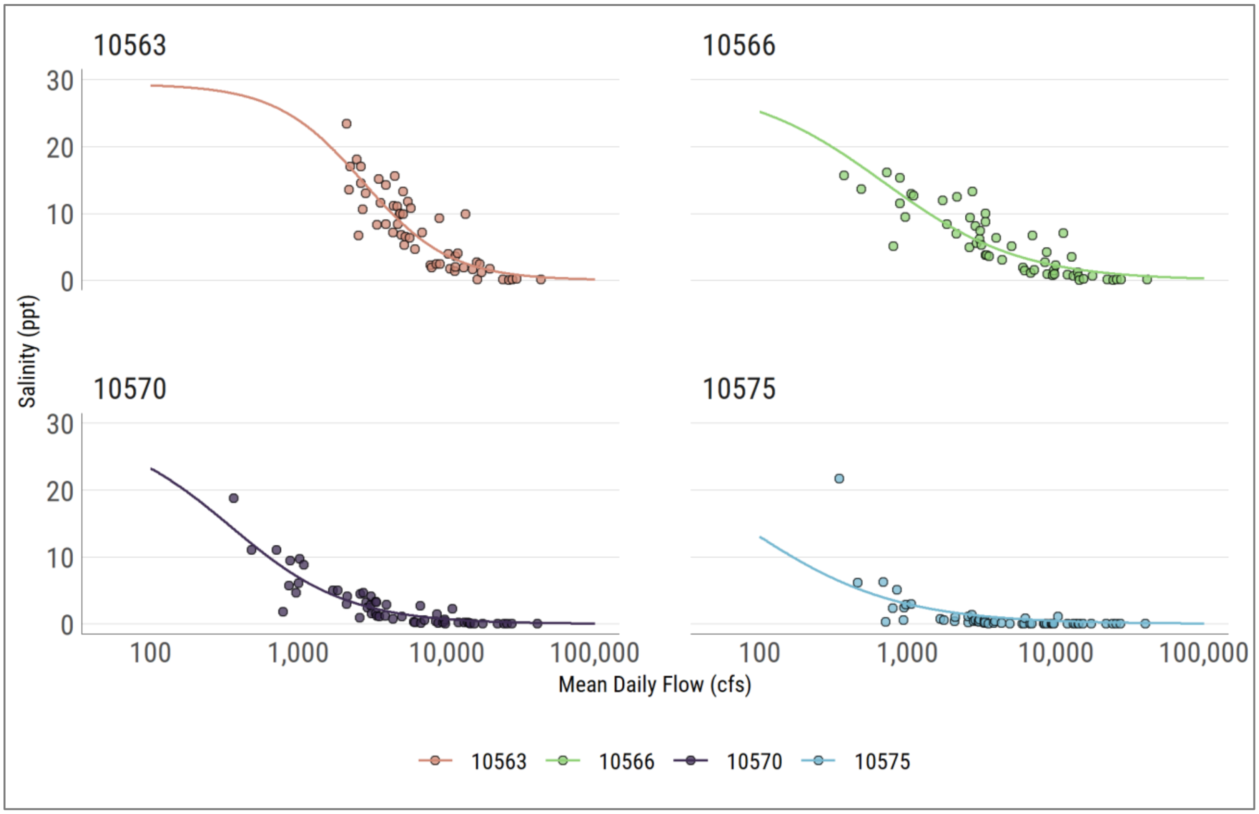

Figure A- 1. Salinity and streamflow regressions at each SWQM station.

Points are measured salinity values and the solid line is the fitted beta regression.

Table A- 2. Final regression equations used to predict salinity at a given streamflow

SWQM Station	Regression Equation	Pseudo R^2
10575	Salinity = exp{3.64271 – 1.93969 × $\log_{10}$(Streamflow)} ÷ 1 + exp{3.64271 – 1.93969 × $\log_{10}$(Streamflow)} × 29.299	0.718
10570	Salinity = exp{6.31063 – 2.49234 × $\log_{10}$(Streamflow)} ÷ 1 + exp{6.31063 – 2.49234 × $\log_{10}$(Streamflow)} × 29.299	0.831
10566	Salinity = exp{6.09740 – 2.14828 × $\log_{10}$(Streamflow)} ÷ 1 + exp{6.09740 – 2.14828 × $\log_{10}$(Streamflow)} × 29.299	0.759
10563	Salinity = exp{11.63554 – 3.38634 × $\log_{10}$(Streamflow)} ÷ 1 + exp{11.63554 – 3.38634 × $\log_{10}$(Streamflow)} × 29.299	0.781

Appendix B. Permit Flows

Table B- 1. Summary statistics for reported discharges used in streamflow adjustment procedures

Data are calculated using reported daily or annual average discharges from all available DMRs retrieved from ECHO and ICIS (USEPA, 2019a; USEPA, 2019b).

TPDES Permit No.	Outfall	Receiving SWQM Station	First Reporting Date	Last Reporting Date	Mean discharge (MGD)	Minimum discharge (MGD)	Maximum discharge (MGD)
WQ0000493000	001	10575	7/31/2003	12/31/2018	38.135	0.00	51.00
WQ0001971000	001	10575	6/30/2003	12/31/2018	0.326	0.01	0.84
WQ0014049001	001	10575	6/30/2003	12/31/2018	0.005	<0.01	0.04
WQ0001202000	002	10570	10/31/2006	12/31/2018	0.033	0.00	0.91
WQ0001202000	003	10570	6/30/2003	12/31/2018	0.016	<0.01	0.38
WQ0001202000	004	10570	6/30/2003	7/31/2009	0.025	0.00	0.16
WQ0001202000	005	10570	6/30/2003	4/30/2015	0.022	<0.01	0.44
WQ0001202000	006	10570	10/31/2006	12/31/2018	0.036	0.00	1.62
WQ0001202000	007	10570	6/30/2003	12/31/2018	0.027	<0.01	0.53
WQ0001202000	008	10570	6/30/2003	7/31/2009	0.047	0.01	0.20
WQ0000462000	001	10570	6/30/2003	12/31/2018	2.855	0.00	14.70
WQ0010875001	001	10570	6/30/2003	12/31/2018	0.778	0.27	2.97
WQ0001872000	001	10570	6/30/2003	12/31/2018	0.286	0.00	1.36
WQ0001727000	001	10570	6/30/2003	12/31/2018	15.533	6.24	20.15
WQ0001971000	002	10570	6/30/2003	12/31/2018	0.118	0.00	0.85
WQ0001971000	003	10570	6/30/2003	12/31/2018	0.002	0.00	0.30
WQ0001971000	004	10570	6/30/2003	12/31/2018	0.184	0.00	7.50
WQ0001971000	007	10570	6/30/2003	12/31/2018	0.142	0.00	1.10
WQ0003426000	001	10570	6/30/2003	12/31/2018	8.011	0.00	72.00
WQ0003426000	002	10570	NR[a]	NR	NR	NR	NR
WQ0003426000	003	10570	NR	NR	NR	NR	NR
WQ0005188000	001	10570	10/31/2016	8/31/2018	4.341	0.08	14.80
WQ0005188000	002	10570	10/31/2016	8/31/2018	2.104	0.04	14.03
WQ0000316000	001	10566	6/30/2003	12/31/2018	0.183	0.00	6.14
WQ0000316000	002	10566	6/30/2003	12/31/2018	0.260	0.00	6.10
WQ0000316000	003	10566	6/30/2003	12/31/2018	0.000	0.00	0.00
WQ0000316000	005	10566	6/30/2003	12/31/2018	0.041	0.00	0.74
WQ0000473000	001	10566	6/30/2003	12/31/2018	4.021	1.28	6.79
WQ0000473000	004	10566	6/30/2003	12/31/2018	0.234	0.00	1.72
WQ0000473000	005	10566	6/30/2003	12/31/2018	0.403	0.00	5.68

TPDES Permit No.	Outfall	Receiving SWQM Station	First Reporting Date	Last Reporting Date	Mean discharge (MGD)	Minimum discharge (MGD)	Maximum discharge (MGD)
WQ0000473000	011	10566	6/30/2003	12/31/2018	0.127	0.00	0.92
WQ0000473000	015	10566	6/30/2003	12/31/2018	0.254	0.00	1.91
WQ0000473000	018	10566	6/30/2003	12/31/2018	0.026	0.00	0.18
WQ0000473000	020	10566	6/30/2003	12/31/2018	0.022	0.00	0.14
WQ0000473000	002	10566	6/30/2003	12/31/2018	0.318	0.00	2.44
WQ0000473000	006	10566	6/30/2003	12/31/2018	0.190	0.00	2.34
WQ0000473000	008	10566	6/30/2003	12/31/2018	0.170	0.00	2.89
WQ0000473000	021	10566	12/31/2007	12/31/2018	0.050	0.00	0.33
WQ0000473000	101	10566	NR	NR	NR	NR	NR
WQ0001151000	001	10566	6/30/2003	12/31/2018	0.470	0.00	2.29
WQ0000647000	001	10566	6/30/2003	12/31/2018	0.599	0.00	8.99
WQ0001595000	002	10566	11/30/2008	12/31/2018	0.085	0.01	0.19
WQ0004074000	001	10566	6/30/2003	12/31/2018	0.159	0.00	10.03
WQ0005143000	001	10566	1/31/2018	12/31/2018	0.482	<0.01	1.61
WQ0005143000	002	10566	1/31/2018	12/31/2018	14.055	0.04	69.99
WQ0000491000	001	10563	6/30/2003	12/31/2018	3.611	0.23	5.54
WQ0000491000	002	10563	7/31/2003	12/31/2018	0.041	0.01	0.15
WQ0000491000	003	10563	6/30/2003	12/31/2018	0.433	0	4.208
WQ0000491000	005	10563	6/30/2003	12/31/2018	0.079	0.00	0.79
WQ0000491000	007	10563	NR	NR	NR	NR	NR
WQ0000511000	001	10563	6/30/2003	12/31/2018	1.700	0.00	9.55
WQ0000511000	009	10563	11/30/2014	12/31/2018	0.040	<0.01	0.35
WQ0000511000	010	10563	11/30/2014	12/31/2018	0.232	0.01	1.84
WQ0000511000	002	10563	11/30/2014	12/31/2018	0.790	0.00	6.19
WQ0000511000	004	10563	11/30/2014	12/31/2018	8.897	0.88	14.20
WQ0000336000	001	10563	6/30/2003	12/31/2018	1,085.927	0.00	1,112.10
WQ0010477004	001	10563	6/30/2003	12/31/2018	1.762	0.83	4.43
WQ0004731000	001	10563	5/31/2005	12/31/2018	0.181	0.00	0.37
WQ0002487000	001	10563	10/31/2008	12/31/2018	0.086	0.00	0.41
WQ0004135000	002	10563	6/30/2003	12/31/2018	0.860	<0.01	1.11
WQ0004840000	201	10563	10/31/2008	12/31/2018	1.290	0.04	4.91
WQ0004874000	001	10563	3/31/2011	12/31/2018	0.268	0.21	0.38
WQ0005236000	001	10563	7/31/2018	12/31/2018	NR	NR	NR
WQ0005236000	003	10563	7/31/2018	12/31/2018	NR	NR	NR
WQ0001674000	001	10563	6/30/2003	12/31/2018	0.018	0	0.05

TPDES Permit No.	Outfall	Receiving SWQM Station	First Reporting Date	Last Reporting Date	Mean discharge (MGD)	Minimum discharge (MGD)	Maximum discharge (MGD)
WQ0001674000	002	10563	6/30/2003	12/31/2018	0.012	0	0.22

[a] NR = No Record