Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Aransas River Above Tidal and Poesta Creek

Segments: 2004 and 2004B

Assessment Units: 2004_02 and 2004B_02

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

AU	Assessment Unit
CCN	Certificate of Convenience and Necessity
cfs	Cubic Feet per Second
DAR	Drainage-Area Ratio
DMR	Discharge Monitoring Report
DSLP	Days since last precipitation
ECHO	Enforcement & Compliance History Online
E coli	*Escherichia coli*
FDC	Flow Duration Curve
FG	Future Growth
ft	Feet
I&I	Inflow and infiltration
LA	Load Allocation
LDC	Load Duration Curve
MGD	Million Gallons per Day
mL	Milliliter
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer System
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	Onsite Sewage Facility
SSO	Sanitary Sewer Overflow
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USCB	United States Census Bureau
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 of 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 management 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 beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

The TCEQ first identified bacteria impairments within Aransas River Above Tidal and within Poesta Creek in the *2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (TCEQ, 2015a).

This document will consider bacteria impairments in two water bodies (segments), each consisting of a single assessment unit (AU). The complete list of water bodies and their identifying AU number is shown below:

1. Aransas River Above Tidal 2004_02; and
2. Poesta Creek 2004B_02

1.1. Water Quality Standards

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

The *Texas Surface Water Quality Standards* (TCEQ, 2010) 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; and
- 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 designated uses assigned to water bodies of which the primary uses assigned in the *Texas Surface Water Quality Standards* to water bodies are:

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

Fecal indicator bacteria are indicators of the risk of illness during contact recreation (e.g., swimming) from ingestion of water. *E. coli* (*Escherichia coli*) are bacteria present in the intestinal tracts of human 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).

On June 30, 2010, the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2010) and on June 29, 2011, the U.S. Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria. Recreational use consists of four categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for *E. coli* of 126 most probable number (MPN) per 100 milliliters (mL) and an additional single sample criterion of 399 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for *E. coli* of 630 MPN per 100 mL;
- Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 MPN per 100 mL; and
- 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 *E. coli* of 2,060 MPN per 100 mL (TCEQ, 2010).

1.2. Report Purpose and Organization

The TCEQ contracted the Texas Water Resources Institute (TWRI) for the Aransas and Poesta Creek 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 *E. coli* loadings; and (3) assist the TCEQ in preparing the TMDL.

This project intends to use historical bacteria and flow data in order to (1) review the characteristics of the watershed and explore potential sources of *E. coli* for the impaired segments; (2) develop an appropriate tool for development of a bacteria TMDL for the impaired segments; and (3) submit the draft and final technical support document for the impaired segments. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the Aransas River Above Tidal and Poesta Creek watersheds. This report contains:

- information on historical data,
- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to presence of indicator bacteria (*E. coli*),
- development of load duration curves (LDCs), and
- 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

Both water bodies included in this study are located within the Aransas River watershed shown in Figure 1. Both water bodies are located upstream of the Aransas River Tidal (Segment 2003) and will be added to the existing TMDL, *Two Total Maximum Daily Loads for Indicator Bacteria in the Tidal Segments of the Mission and Aransas Rivers* (TCEQ, 2016), through a Water Quality Management Plan update. This study incorporates a watershed approach where the drainage area upstream of each AU outlet is considered. The location of Aransas River Above Tidal (AU 2004_02) and Poesta Creek (AU 2004B_02) in relation to the original Mission and Aransas River TMDL project boundaries is shown in Figure 2.

The headwaters of Poesta Creek (Segment 2004B) begin in Bee County northwest of Beeville and flow approximately 28.7 miles southeast to Aransas Creek (Segment 2004A) forming the Aransas River Above Tidal (Segment 2004). The Aransas River Above Tidal begins at the confluence of Aransas and Poesta Creeks and flows 34.9 miles to a point just upstream of US 77. The Aransas River Tidal (Segment 2003) begins flow at this point and flows 28.3 miles to Copano Bay.

The drainage area for the impaired AU of Poesta Creek (AU 2004B_02) is 52.3 square miles and located entirely within Bee County. The drainage area for the impaired AU of Aransas River Above Tidal (AU 2004_02) includes the drainage area for Poesta Creek and is 314.4 square miles. The drainage area for Aransas River Above Tidal (AU 2004_02) is predominately in Bee County (98% of the watershed); Live Oak County includes approximately 1.5% of the watershed; San Patricio and Refugio counties each include less than 1% of the watershed area.

The *2014 Texas Integrated Report* (TCEQ, 2015a) provides the following segment and AU descriptions for the water bodies considered in this document:

- Segment 2004 (Aransas River Above Tidal) - From a point 1.6 kilometers (1.0 mile) upstream of US 77 in Refugio/San Patricio County to the confluence of Poesta Creek and Aransas Creek in Bee County
    - 2004_02 – From the confluence with Papalote Creek to the upstream end of segment at the confluence with Aransas Creek and Poesta Creek
- Segment 2004B (Poesta Creek) - From the confluence with the Aransas River to the headwaters of the stream about 7.5 km upstream of FM 673
    - 2004B_02 –From the confluence with Talpacate Creek to the headwaters of the stream approximately 7.5 km upstream of FM 673

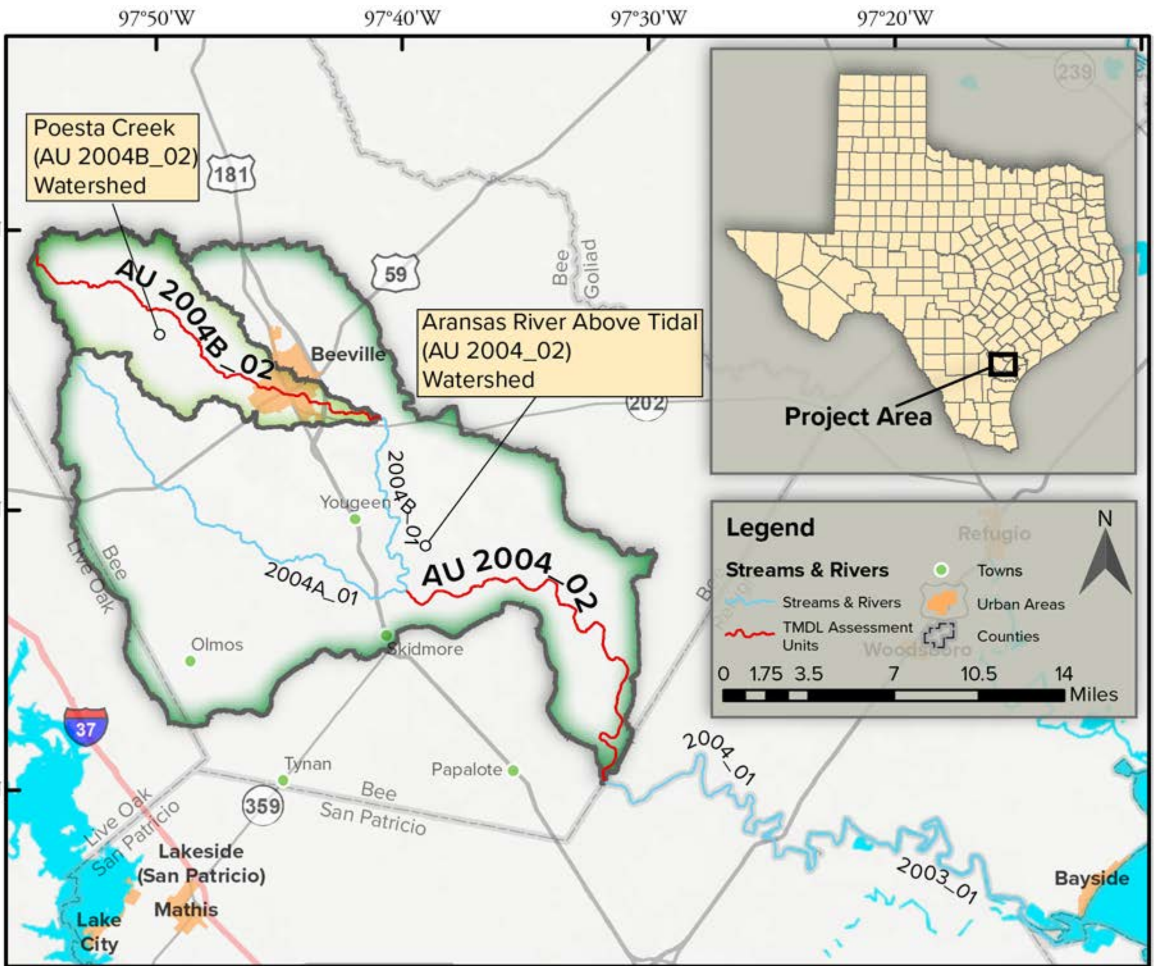

Figure 1. Total contributing drainage area for the study, including Assessment Units 2004_02 and 2004B_02
Source: TCEQ Assessment Units (TCEQ, 2015b)

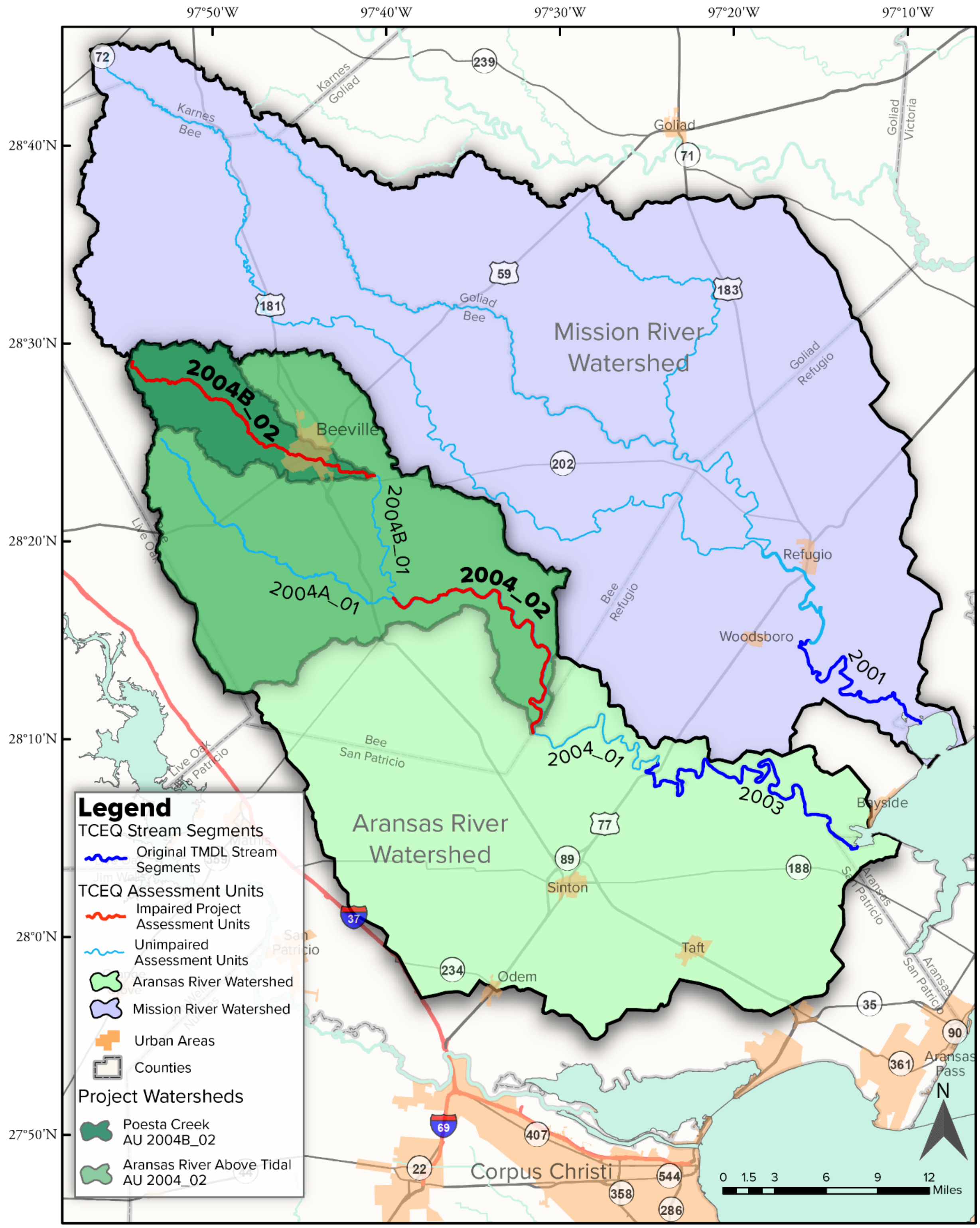

Figure 2. "Two Total Maximum Daily Loads for Indicator Bacteria in the Tidal Segments of the Mission and Aransas Rivers" TMDL project boundaries in relation to project watersheds.

2.2. Review of Routine Monitoring Data for TMDL Watersheds

2.2.1. Data Acquisition

The TCEQ Data Management and Analysis Team provided ambient *E. coli* data on 4 January 2017 (TCEQ, 2017a). The data represented all historical ambient *E. coli* data and field parameters collected in the project area. Data included *E. coli* collections from July 2002 through July 2016.

2.2.2. Analysis of Bacteria Data

Recent environmental monitoring has occurred within AUs 2004_02 and 2004B_02 at two TCEQ monitoring stations (Figure 3). *E. coli* data collected at these stations over the seven-year period of 1 December 2005 through 30 November 2012 were used in assessing attainment of the primary contact recreation use as reported in the *2014 Texas Integrated Report* (TCEQ, 2015a). The 2014 assessment data indicate non-support of the primary contact recreation use because of geometric mean concentrations exceeding the geometric mean criterion of 126 MPN/100 mL for Aransas River Above Tidal (AU 2004_02) and Poesta Creek (AU 2004B_02) as summarized in Table 1.

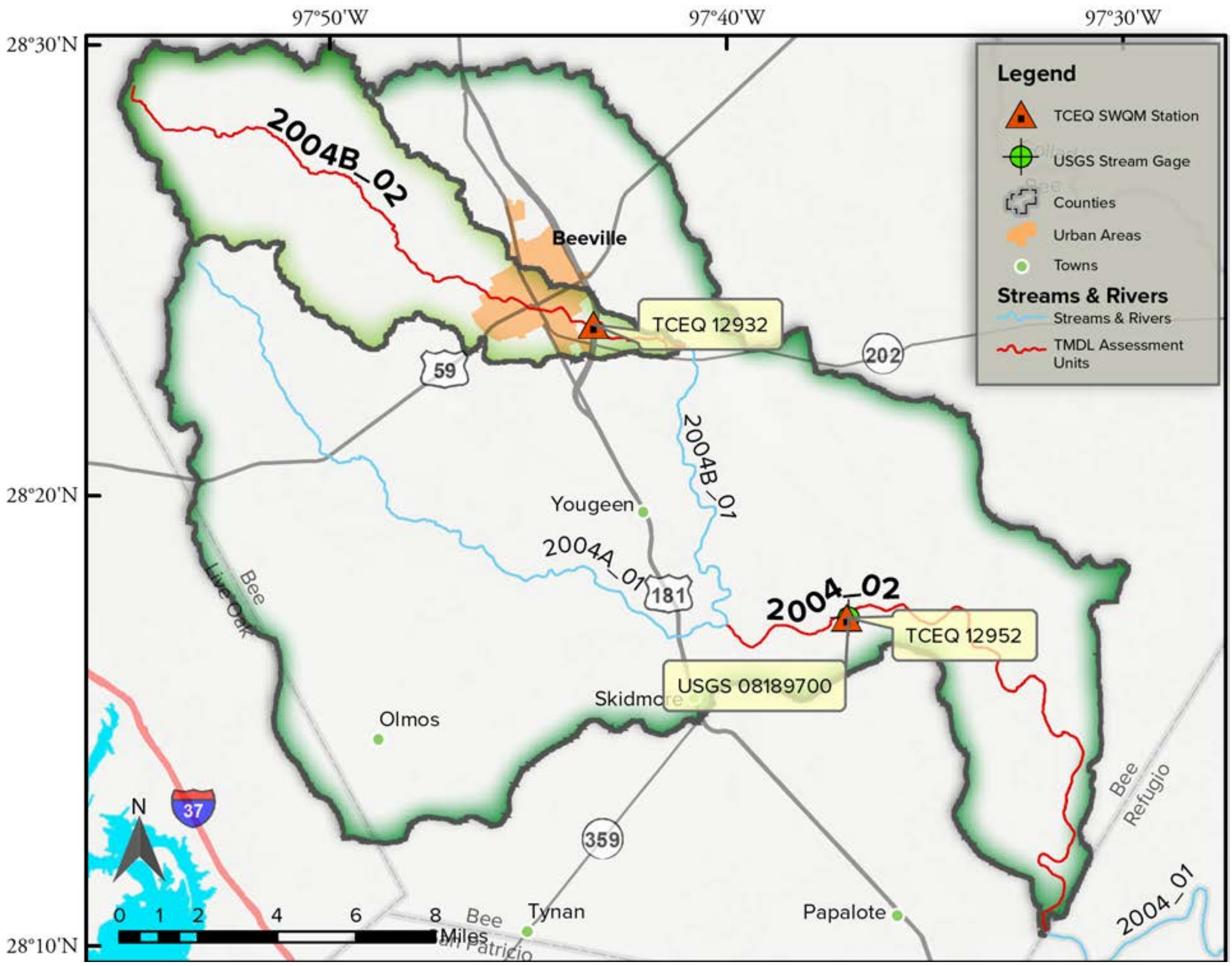

Figure 3. SWQM monitoring station and USGS streamflow gage locations in the Aransas River and Poesta Creek watersheds Source: TCEQ SWQM stations from TCEQ (TCEQ, 2012); USGS stream gage stations from USGS (USGS, 2011)

Table 1. 2014 Integrated Report Summary for Aransas River Above Tidal and Poesta Creek. Source: TCEQ, (2015a)

Water Body	Assessment Unit (AU)	Parameter	Station	Date Range	No. of Samples	Station Geometric Mean (MPN/100mL)
Aransas River Above Tidal	2004_02	*E. coli* Geomean	12952	12/01/2005 – 11/30/2012	50	166
Poesta Creek	2004B_02	*E. coli* Geomean	12932	12/01/2005 – 11/30/2012	21	311

2.3. Watershed Climate and Hydrology

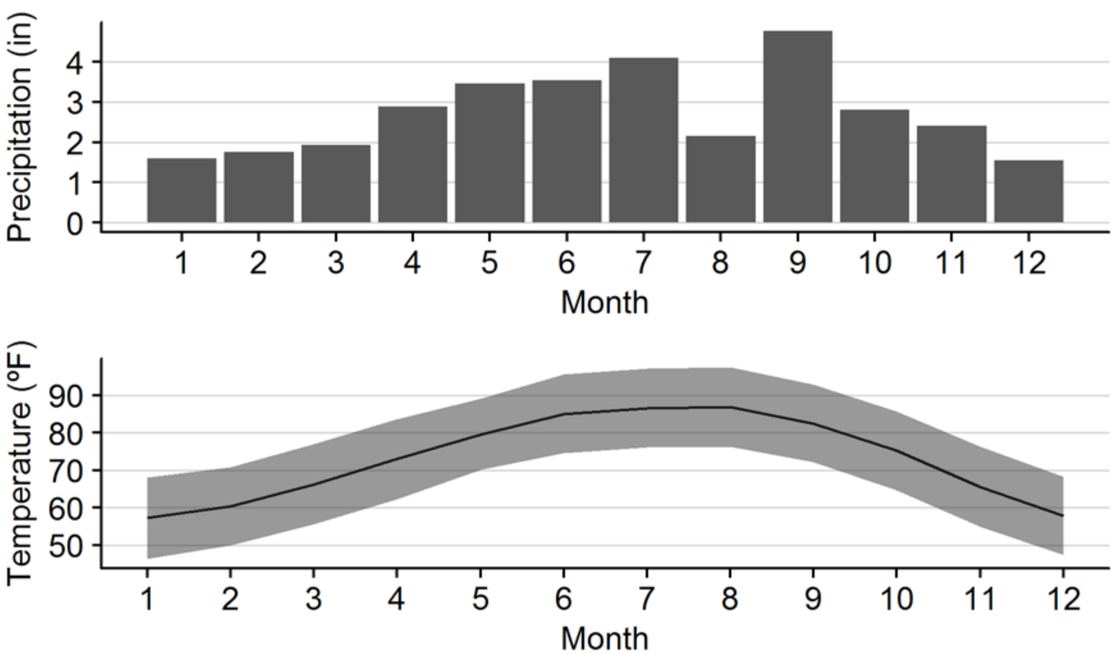

Figure 4. Beeville normal monthly precipitation by month and normal average, maximum, and minimum air temperature by month from 1981-2010 Source: NOAA (2016)

Monthly normal precipitation, from the Beeville Chase Station USW00012925 weather station (NOAA, 2016), indicate Beeville's mean annual rainfall from 1981-2010 was 31.96 inches (NOAA, 2016). Rainfall normally peaks in September (4.76 inches) with lowest totals occurring in December (1.55 inches) (Figure 4). Average annual precipitation values across the study area from the PRISM Climate Group at Oregon State (2012) indicate average annual rainfall ranges from 29 to 33 inches per year across the watershed, with a clear east to west decreasing gradient (Figure 5).

Monthly normal air temperature, also from the Beeville Chase Station USW00012925 weather station (NOAA, 2016), indicate daily mean air temperature was 73.0˚F. Minimum average daily temperature reaches a low of 46.3˚F in January. Maximum average daily temperature reached a peak of 97.4˚F in July.

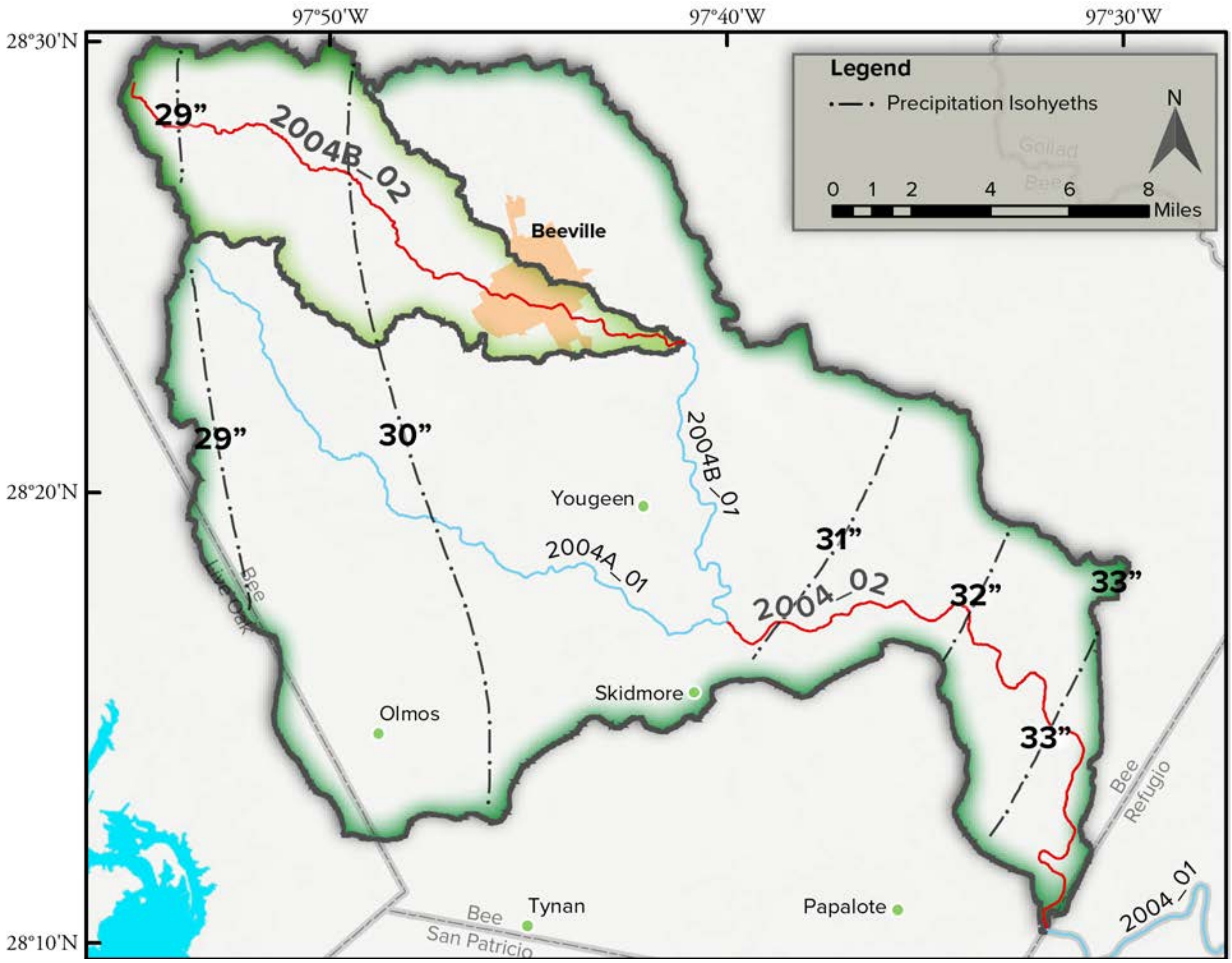

Figure 5. Average annual rainfall (inches) across the study area from 1981-2010 Source: PRISM Climate Group at Oregon State University (2012)

2.4. Watershed Population and Population Projections

Watershed population estimates were developed using 2010 US Census block data (USCB, 2010). Because US Census block boundaries are not the same as watershed boundaries, the population was estimated by multiplying the census block population to the percent of each block within the watershed. The population of the AU 2004_02 watershed is approximately 27,972. The population of the AU 2004B_02 watershed is approximately 11,663. The city of Beeville (population 12,863) is the only municipality in the study area.

Texas Water Development Board (TWDB) Regional Water Plan Population and Water Demand Projections (TWDB, 2017) were used to estimate population projections for counties and water user groups within the watershed. Population projections from Live

Oak, Refugio, and San Patricio counties are not included because they account for less than 2% of the total watershed area. Table 2 contains population projections.

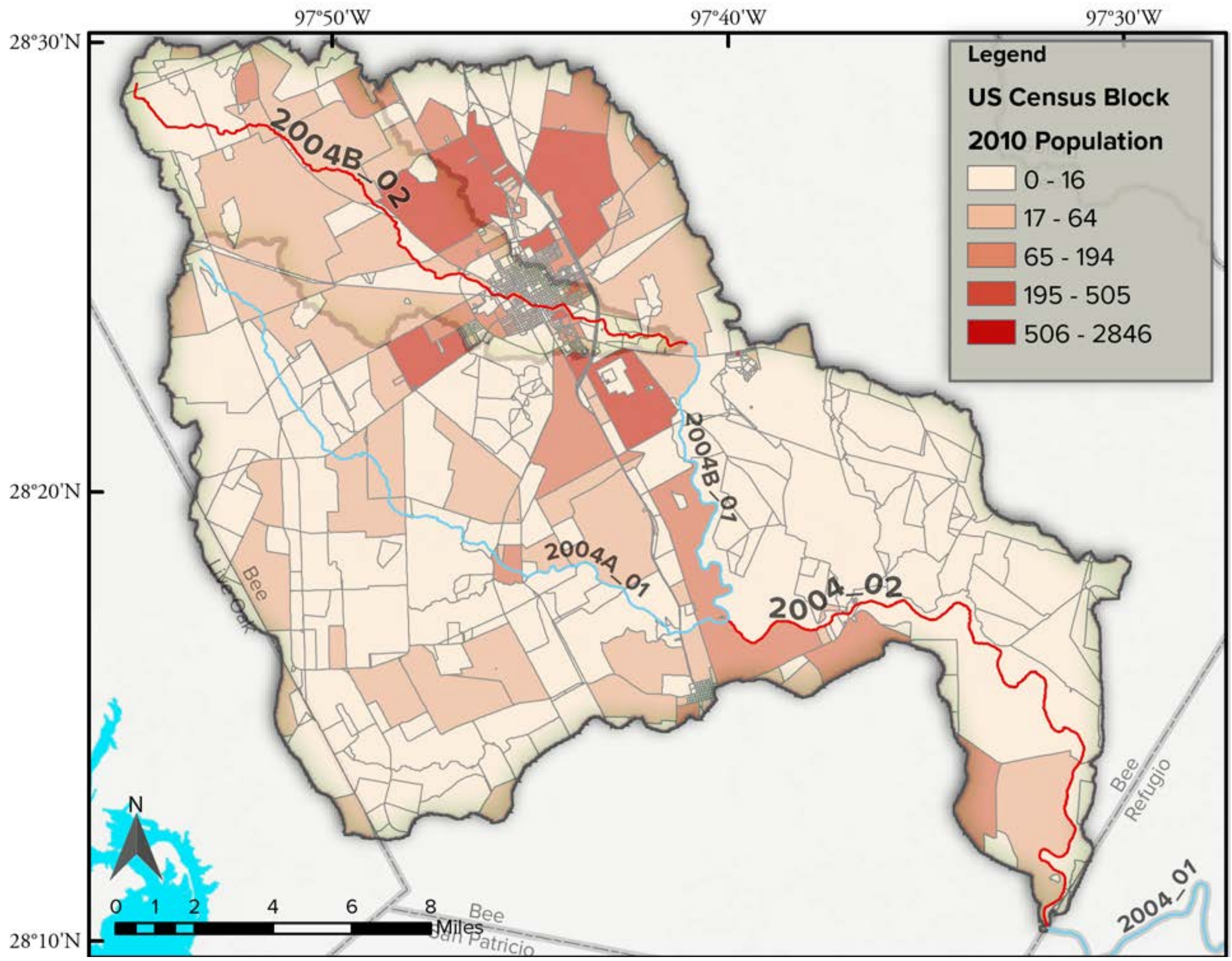

Figure 6. 2010 population by Census block Source: USCB (2010)

Table 2. 2010 population and 2020-2070 population projections in the study area Source: TWDB (2017) and USCB (2010)

Group	Projected Population							Percent Increase
	2010	2020	2030	2040	2050	2060	2070	
Beeville	12,863	13,516	14,082	14,327	14,351	14,365	14,369	11.7%
Bee County	31,861	33,478	34,879	35,487	35,545	35,579	35,590	11.7%

2.5. Land Use

Land use and land cover for the watersheds was obtained from the 2011 National Land Cover Database (NLCD) (USGS, 2015), displayed in Figure 7. The following categories and definitions represent land use/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, 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% percent of total cover. These areas most commonly include single-family housing units.
- Developed, Medium Intensity - Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
- Developed, High Intensity - Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
- Barren Land (Rock/Sand/Clay) - Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
- Deciduous Forest - Areas dominated by trees generally greater than 5 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 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
- Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- Shrub/Scrub - Areas dominated by shrubs; less than 5 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 gramanoid 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 for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.

- Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20% 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 or substrate is periodically saturated with or covered with water.

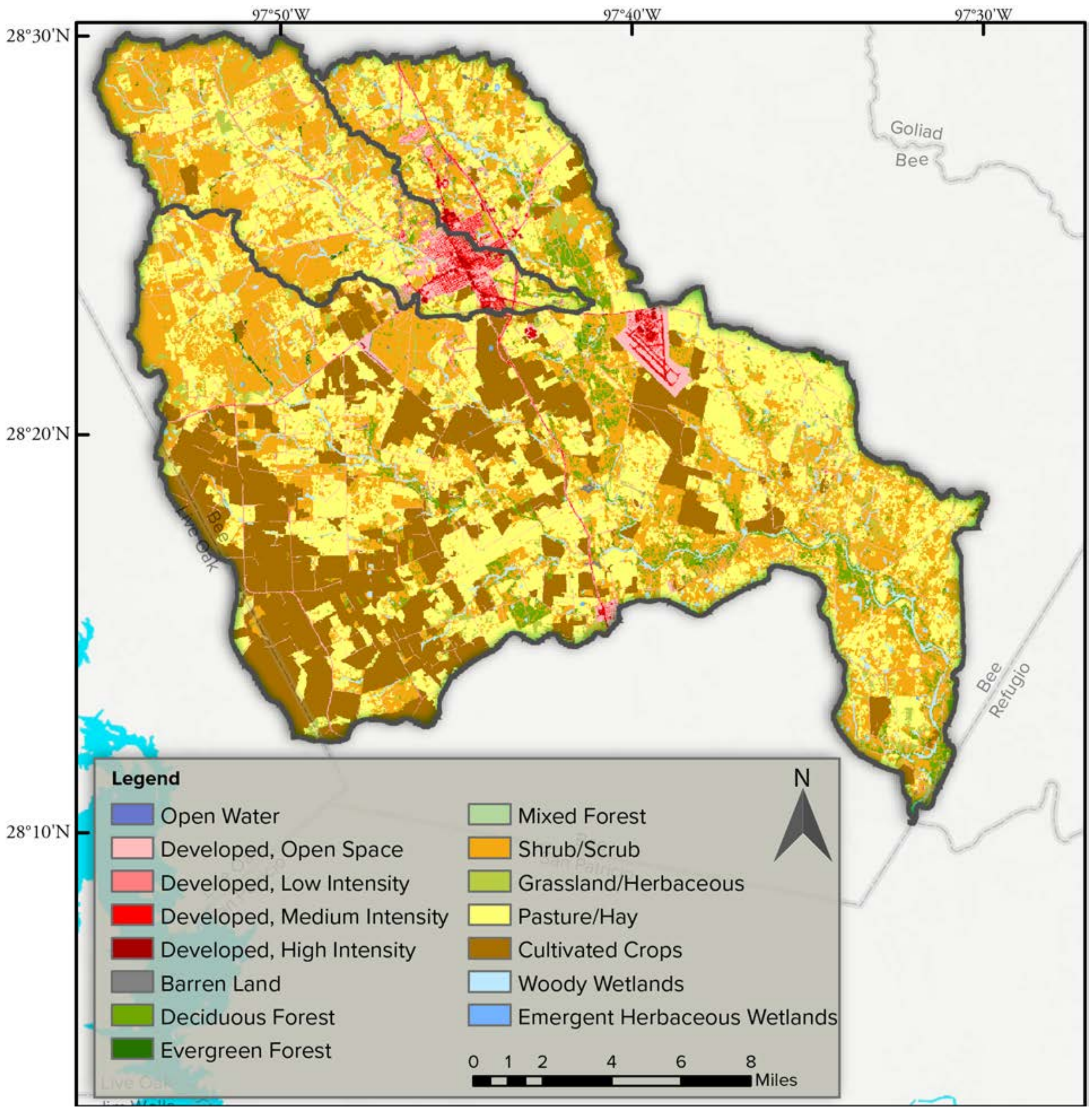

Figure 7. 2011 land use/land cover across the study area Source: National Land Cover Database (USGS, 2015)

The total Aransas River Above Tidal (AU 2004_02) watershed area is 201,226.6 acres and predominately composed of Pasture/Hay (32.5%) and Shrub/Scrub (30.7%) (Table 3). The Poesta Creek (AU 2004B_02) watershed, located within the Aransas River Above

Tidal watershed, is 33,441.7acres. The majority of land cover in the Poesta Creek watershed is also Shrub/Scrub (42.3%) and Pasture/Hay (32.8%). Urban development comprises less than 8% of the Aransas River Above Tidal watershed and nearly 15% of the Poesta Creek watershed.

Table 3. Land Use/Land Cover for the study area Source: National Land Cover Database (USGS, 2015)

Land Use/Land Cover	Aransas River Above Tidal (2004_02)		Poesta Creek (2004B_02)	
	Acres	Percent of Total	Acres	Percent of Total
Open Water	33.4	<0.1%	-	-
Developed, Open Space	9,891.4	4.9%	2,361.6	7.1%
Developed, Low Intensity	3,695.5	1.8%	1,430.0	4.3%
Developed, Medium Intensity	1,747.4	0.9%	772.6	2.3%
Developed, High Intensity	473.3	0.2%	218.8	0.7%
Barren Land	452.8	0.2%	166.4	0.5%
Deciduous Forest	7,763.6	3.9%	393.2	1.2%
Evergreen Forest	252.0	0.1%	45.4	0.1%
Mixed Forest	71.2	<0.1%	3.3	<0.1%
Shrub/Scrub	61,769.2	30.7%	14,145.4	42.3%
Grassland/Herbaceous	6,171.7	3.1%	1,585.5	4.7%
Pasture/Hay	65,329.3	32.5%	10,955.4	32.8%
Cultivated Crops	37,717.7	18.7%	432.8	1.3%
Woody Wetlands	5,752.0	2.9%	924.5	2.8%
Emergent Herbaceous Wetlands	106.1	0.1%	6.9	<0.1%
Total	201,226.6	100%	33,441.7	100

2.6. Soils

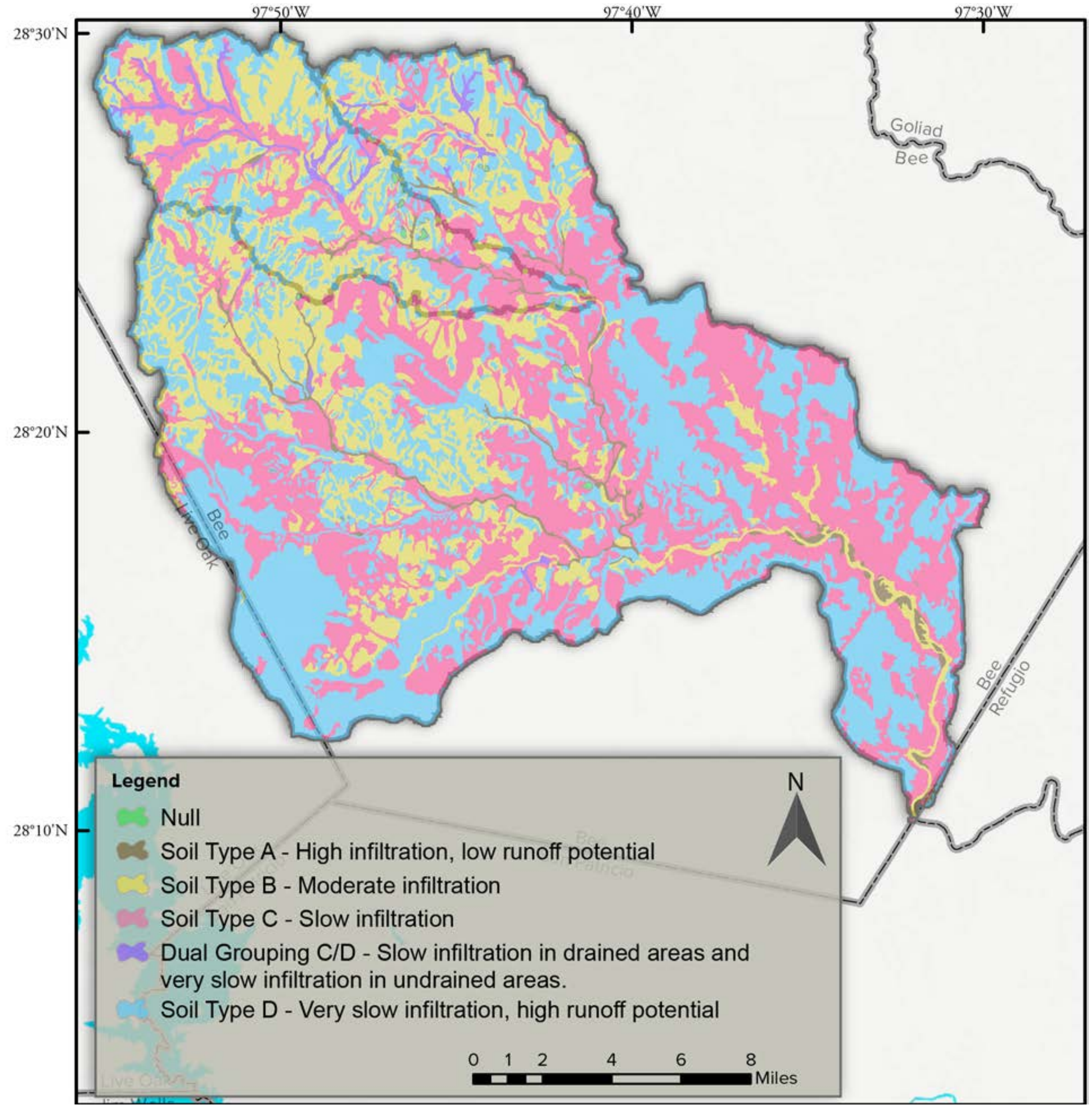

Figure 8. Soil hydrologic groups within the project watershed. Source: SSURGO database (NRCS, 2015)

Soil data was obtained through the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (NRCS, 2015). 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, and C/D). The USDA NRCS SSURGO database define 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 moderate rate of transmission.
- Group C - Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- Group D - Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.
- Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and the second letter is assigned to undrained areas. Only soils that are in group D in their natural condition are assigned to dual classes.

Spatial distribution of soil hydrologic groups within the project watersheds is depicted in Figure 8. Within the impaired Aransas River Above Tidal AU watershed, soils are predominately composed of Type D (37.9%) and Type C (36.6%) hydrologic groups (Table 4). Within the impaired Poesta Creek AU watershed, soils are predominately composed of Type B (36.2%) and Type D (29.7%) hydrologic groups.

Table 4. Soil hydrologic groups for the study area Source: SSURGO Database (NRCS, 2015)

Hydrologic Group	Aransas River Above Tidal (2004_02)		Poesta Creek (2004B_02)	
	Acres	Percent of Total	Acres	Percent of Total
A	3,478.5	1.7%	488.8	1.5%
B	45,215.2	22.5%	12,118.5	36.2%
C	73,605.2	36.6%	9,133.4	27.3%
D	76,239.0	37.9%	9,940.2	29.7%
C/D	2,327.6	1.2%	1,584.6	4.7%
Not Available	361.1	0.2%	176.2	0.5%
Total	201,226.6	100%†	33,441.7	100%†

† The sum of the percent of total column is 100.1% and 99.9% for Aransas River Above Tidal and Poesta Creek respectively. This discrepancy is due to rounding for the reported individual percent of total values.

2.7. Potential Sources of Fecal Indicator Bacteria

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

Unregulated sources are typically nonpoint source in nature and are not regulated by a permitting system.

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 and/or loadings.

2.7.1. Permitted Sources

As mentioned above, TPDES and NPDES regulate and permit discharges from WWTFs, and stormwater from industries, constructions sites, and MS4s. Within the project watershed, permitted sources only include WWTFs and regulated stormwater from industry and construction sites. Permitted discharges are described below.

2.7.1.1. Domestic Wastewater Treatment Facility Discharges

Three facilities in the project watershed treat domestic wastewater (Figure 9). The City of Beeville Moore Street Facility discharges directly into the impaired Poesta Creek (AU 2004B_02). The Chase Field WWTP operated by the City of Beeville discharges into the mainstem of the impaired Aransas River Above Tidal (AU 2004_02) slightly downstream of USGS streamflow gage 08189700. The Skidmore WSC discharges into an unnamed tributary that flows into the impaired Aransas River Above Tidal (AU 2004_02). Table 5 summarizes final permitted discharges and recent discharges obtained from the USEPA (2017) Enforcement & Compliance History Online (ECHO) website. Permitted discharges in the watershed range from 0.131 to 3.0 million gallons per day (MGD).

Table 5. Permitted domestic wastewater treatment facilities in the project watersheds

TPDES Permit No.	Facility	AU	Receiving Waters	Final Permitted Discharge (MGD)	Recent Discharge (MGD)[1]
10124-002	City of Beeville Moore Street WWTP	2004B_02	Poesta Creek	3.0	2.03
10124-004	Chase Field WWTP	2004_02	Aransas River Above Tidal	2.5	0.43
14112-001	Skidmore WSC	2004_02	Unnamed Trib, Aransas River Above Tidal	0.131	0.05

[1] Average discharge from January 2009 through October 2016

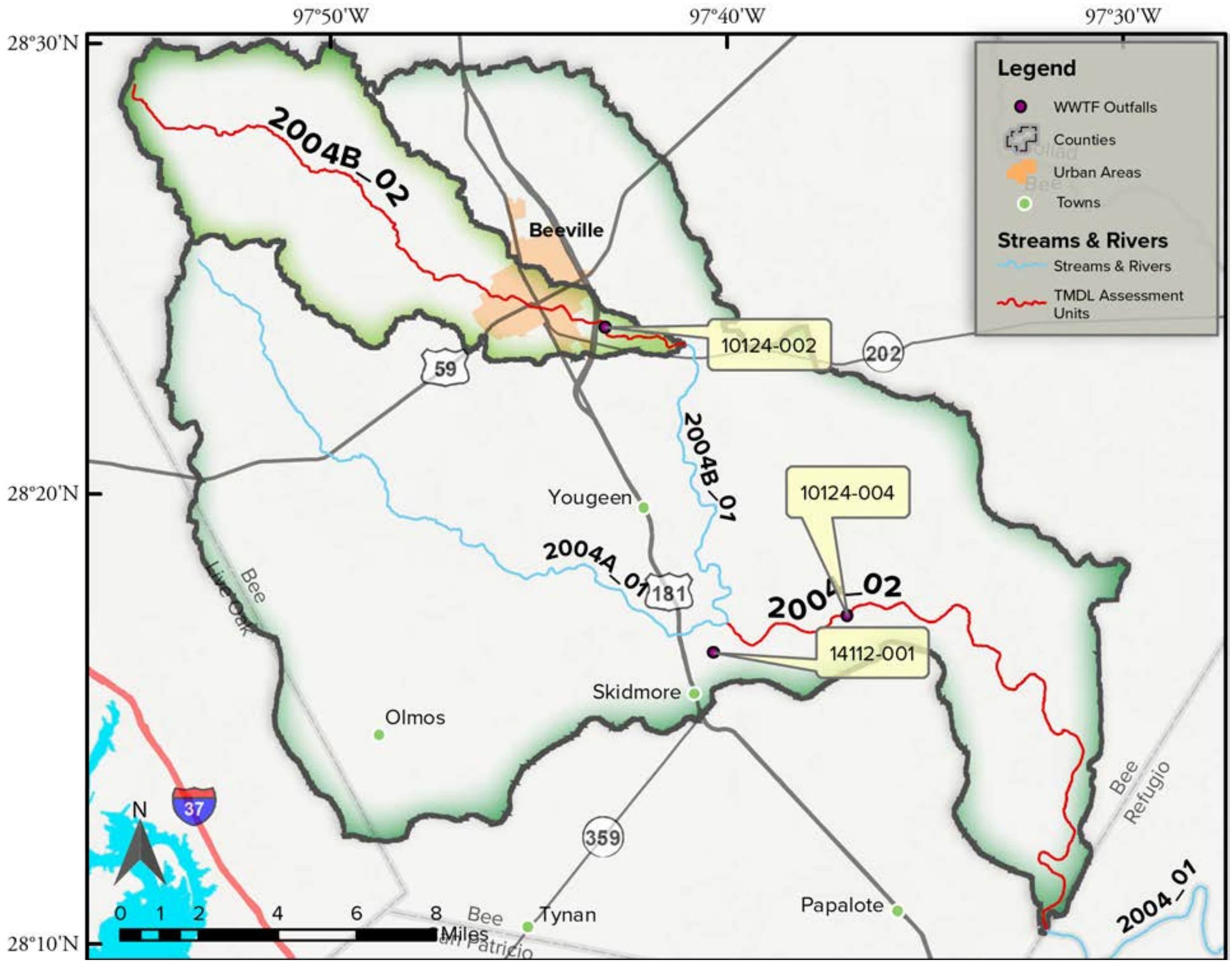

Figure 9. WWTF outfall locations across the project watershed

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 sewer 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.

The TCEQ Region 14 office maintains a database of SSO data reported by municipalities (personal communication with TCEQ Region 14 on Jan 11, 2017). These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. Table 6 provides a summary of SSOs that occurred within respective project AUs from August 2009 through December 2016. Fifteen separate incidents reported by two facilities occurred in the project watershed during this timeframe.

Table 6. Summary of SSO incidents reported in project watersheds from August 2009 through February 2016 Source: personal communication TCEQ Region 14 (Jan 11, 2017)

AU	Number of Incidents†	Mean Volume (gallons)	Median Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)	Total Volume (gallons)
2004_02	15	25,221.429	10,000	350	93,750	353,100
2004B_02	11	24,310.000	9,000	350	93,750	243,100

† Total number of reported incidents. One incident reported that an unknown volume was discharged during the event. Therefore, the number of incidents used to calculate statistics included in the table are 14 and 10 for AU 2004_02 and 2004B_02 respectively.

2.7.1.3. TPDES General Wastewater Permits

A review of the USEPA ECHO database (USEPA, 2017) conducted on February 2, 2017, indicated non-compliance issues regarding *E. coli* permit limits for two facilities in the project watershed. For the reporting period May 2010 through December 2016, the City of Beeville - Moore Street WWTF and Skidmore WSC WWTF reported bacteria discharges in exceedance of permitted limits (Table 7). No significant non-compliance violations were reported.

Table 7. Monitoring requirements and compliance status for WWTFs in the project watershed Source: USEPA ECHO database (2017)

TPDES Permit No.	Facility	Monitoring Frequency	Daily Average Limit[1] (Geometric Mean)	Single Grab Limit[1] (Daily Max)	% Monthly Exceedance – Daily Average[2]	% Monthly Exceedances – Single Grab[2]
10124-002	City of Beeville Moore Street WWTP	Monthly	126	399	3.75	16.25
10124-004	Chase Field WWTP	Monthly	126	399	0	0
14112-001	Skidmore WSC	Monthly	126	399	11.76†	5.88†

[1] MPN/100mL *E. coli*
[2] Reporting period May 2010 – December 2016
† Reported data was from August 2015 – December 2016

2.7.1.4. TPDES Regulated Stormwater

TPDES general permits cover stormwater discharges from Phase II urbanized areas, industrial facilities and construction sites over one acre. A review of active stormwater general permits in the project watershed resulted in eight active industrial site permits (six of those permits also occurred in the 2004B_02 Poesta Creek watershed), as of January 20, 2017 (TCEQ, 2017b) (Table 8). The project watershed contains no MS4 permits. The acreage associated with active stormwater general permits was estimated by importing location information into a Geographic Information System and measuring the estimated disturbed area from available aerial imagery. Construction permits were summarized by average daily acreage for permits issued over the entire available period of record (January 2003 through May 2016). Over that time period, twenty construction permits were issued in the Aransas River Above Tidal (AU 2004_02) watershed, seven of which were also in the Poesta Creek (AU 2004B_02) watershed.

Table 8. Summary of land area covered by stormwater permits in project watersheds as of January 20, 2017 Source: TCEQ Central Registry (TCEQ, 2017b)

AU	Industrial General Permits (number)	Industrial General Permits (acres)	Construction Permits (number)	Construction Permits (average acres)	Total Area of Permits (acres)
2004_02	8	46.3	20	104.9	151.2
2004B_02	6	27.9	7	20.5	48.4

2.7.2. Unregulated Sources

Unregulated sources include non-permitted, typically nonpoint source, discharges that can contribute to fecal bacteria loading in the watershed. Potential sources, detailed below, include wildlife, agricultural runoff, domestic pets, and onsite sewage facilities (OSSFs).

2.7.2.1. Wildlife and Unmanaged Animal Contributions

E. coli bacteria are common inhabitants of the intensities 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. 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 streams.

For deer, Texas Parks and Wildlife biologists provided estimates for deer management units in Bee County, including deer management units 8E, 9, and 11. Based on estimates from 2011 through 2016, an average of one whitetail deer per 34.5 acres of habitat was calculated across the watershed. This density was applied to land classified in the 2011 NLCD as pasture/hay, cultivated crops, shrub/scrub, grassland/herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, and emergent herbaceous wetlands (TWRI, 2009) (Table 9).

For feral hogs, an estimate of one hog per 33.3 acres was applied to land classified in the 2011 NLCD as pasture/hay, cultivated crops, shrub/scrub, grassland/herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, and emergent herbaceous wetlands (TWRI, 2009) (Table 9).

Table 9. Estimated deer and feral hog populations in project watershed Source: Estimates derived from previous watershed studies (TWRI, 2009) and communication with TPWD staff.

AU	Deer	Feral Hogs
2002_02	5,360	5,554
2004B_02	826	856

2.7.2.2. Non-Permitted Agricultural Activities and Domesticated Animals

Activities, such as livestock grazing close to waterbodies and farmers' use of manure as fertilizer, can contribute *E. coli* to nearby water bodies. We estimated watershed livestock counts using county level data available from the 2012 Census of Agriculture (USDA, 2014). The county-level data were refined to reflect acres of un-urbanized land within each TMDL watershed. The refinement was determined by the total area of each county and each impaired AU that was designated as un-urbanized by the 2010 U.S. Census. The ratio was the un-urbanized area of the AU that resides within a county divided by the total un-urbanized area of the county. Watershed level livestock numbers are the ratio multiplied by county level data (Table 10).

Table 10. Livestock estimates for project watersheds Source: Estimates derived from USDA Census of Agriculture (USDA, 2014)

AU	Cattle and Calves	Hogs	Chickens	Goats and Sheep	Horses
2004_02	10,472	26	604	749	491
2004B_02	1,643	4	96	118	77

Pets can also be a source of *E. coli* bacteria, because stormwater runoff carries the animal wastes into streams. We estimated the number of domestic cats and dogs based on 0.584 dogs and 0.638 cats per household estimates from the American Veterinary Medical Association (AVMA, 2012). The number of watershed households were estimated with 2010 US Census Block household counts, multiplied by the proportion of the Census block within the watershed. Table 11 summarizes the estimated number of pets in the project watersheds.

Table 11. Estimated households and pet populations Source: Estimates derived from USCB Census Blocks (USCB 2010) and American Veterinary Medical Association (AVMA) pet estimates (AVMA, 2012)

AU	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
2004_02	8,748	5,109	5,581
2004B_02	4,884	2,852	3,116

2.7.2.3. Failing On-Site Sewage Facilities

Private residential 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 bacteria to enter ground and surface waters, if the systems are not properly operating. However, properly designed and operated OSSFs are expected to contribute virtually no fecal bacteria to surface waters. For example, it is reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel, 1996). The estimated OSSF failure rate in this region of Texas is about 12 percent (Reed, Stowe, and Yanke, 2001).

Estimates of the number of OSSFs in the project watershed were determined using 2010 Census block data. OSSFs were estimated to be households that were outside of city boundaries and Certificate of Convenience and Necessity (CCN) areas. Table 12 and Figure 10 show the total estimated OSSFs in the project watershed.

Table 12. OSSF estimate for the project watersheds Source: Estimates derived from Census Blocks (USCB, 2010) and CCNs (Public Utility Commission of Texas, 2017).

AU	Estimated OSSFs
2004_02	2,545
2004B_02	763

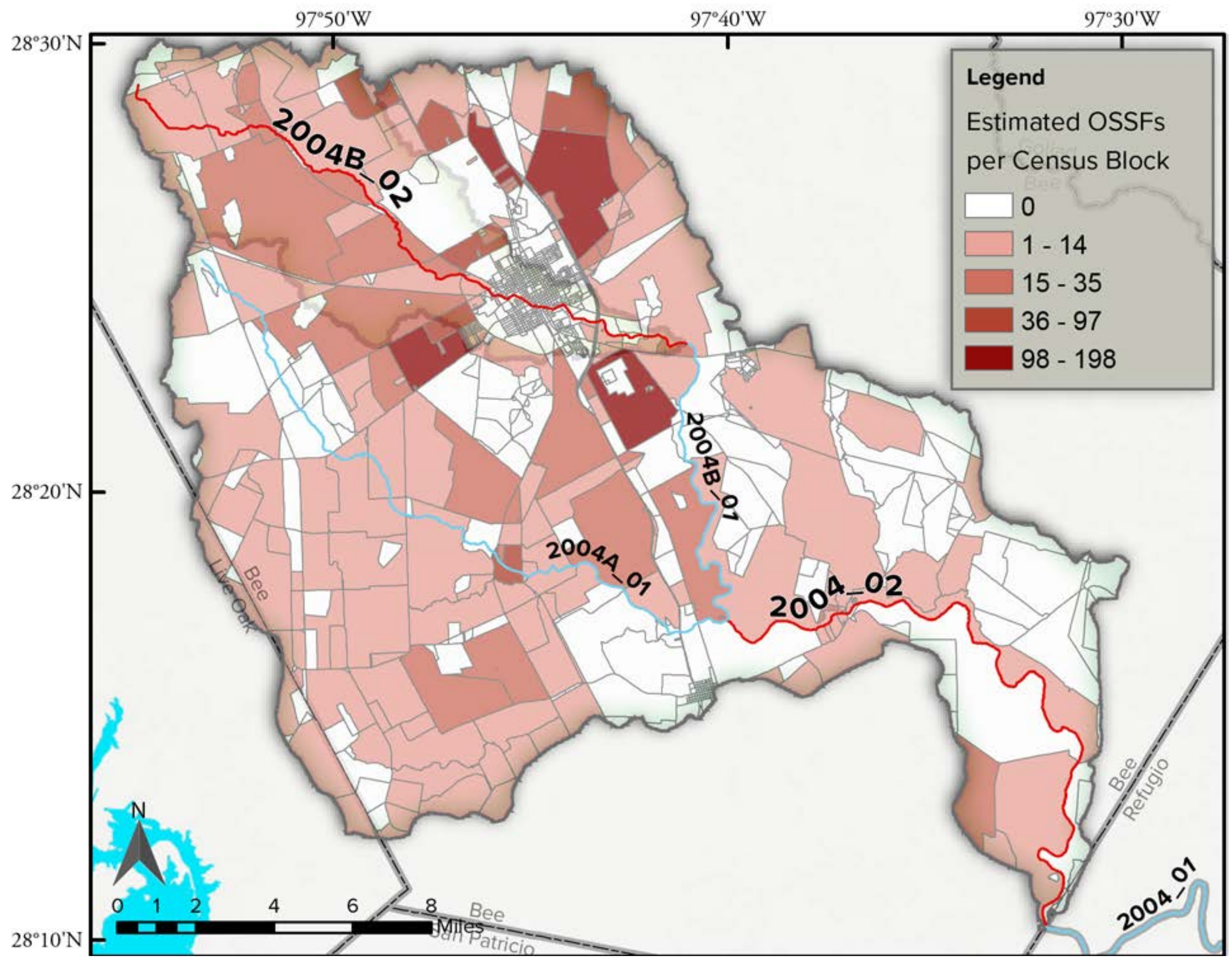

Figure 10. OSSF estimates for the project watersheds Sources: Estimates derived from Census Blocks (USCB, 2010) and CCNs (Public Utility Commission of Texas, 2017).

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 the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL watersheds.

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., *E. coli*, 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 impaired AUs in the TMDL watersheds considered availability of data and other information necessary for supportable application of the selected tool and guidance in the Texas bacteria task force report (TWRI, 2007). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models and an empirical approach referred to as the LDC.

Mechanistic computer models provide analytical abstractions of a real or prototype system. Mechanistic models, also referred to as process models, are based on theoretical principles that provide for representation of governing physical processes that determine the response of certain variables, such as streamflow and bacteria concentration such as precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides 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 regulatory community recognizes the frequent information limitations with bacteria TMDLs that constrain use of the more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the LDC curve 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, nor can it 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 nonpoint source.

3.1.1. Situational Limitation of Mechanistic Modeling

Because the present surface water bacteria standards for AUs within the TMDL watersheds, as most Texas waters, do not restrict under what streamflow conditions the primary contact recreation criteria should be met, the allocation process must consider all streamflow conditions ranging from low to high flows. The allocation tool, therefore, must be capable of characterizing streamflows and bacteria loads at desired locations under the wide variety of environmental conditions experienced in the TMDL watersheds. If a mechanistic modeling tool is applied, it must be capable of simulating response of bacterial loadings to hydrologic (streamflow) conditions during base flow as well as during times of response to rainfall runoff and those intermediate conditions between well-defined base flow and strong rainfall-runoff response. The type of mechanistic tool with capabilities to simulate all these complexities is often referred to as a combined watershed loading and hydrologic/water quality model. These models simulate the hydrologic response of the watershed's land uses and land covers to rainfall, route runoff water through the conveyance channels of the watershed, add in point source contributions, and may include other hydrologic processes such as interaction of surface waters with shallow ground water.

The bacteria component of the model is in many ways even more complex than the hydrologic component and typically must include many different processes. Point sources and nonpoint sources of bacteria need to be defined and simulated by the model. Movement or washoff of bacteria from the various landscapes (e.g., urban yards, roads, pastures, wooded areas, areas of animal concentration), potential illegal connections of sewage lines to stormwater lines, broken sewer lines, and sewer overflows in response to rainfall are only some of the sources possibly needing to be represented in the model. Streamflow transport of the bacteria in tributaries and in the mainstem river and the response of the bacteria while in transport to settling, die-off, resuspension, regrowth in the water column, regrowth in the sediment, etc. need to be defined with adequate certainty to allow proper model representation for each of these physical and biological processes.

While hydrologic processes requiring simulation are complex, these processes are generally better understood and more readily simulated within needed levels of confidence by a mechanistic model than the bacterial processes. The hydrologic processes regarding response of the landscape to rainfall are well studied over many decades because of implications on transport of waterborne constituents, of which bacteria is only one of many. But even more importantly, these hydrologic processes are well investigated because of needs to design reservoirs and flood-control structures, define floodplains, and design the myriad of other structures required to direct and retain stormwater in both urban and rural situations. While each watershed is unique, the experienced hydrologist is able to readily and successfully apply these mechanistic models to most watersheds.

Mechanistic bacteria modeling has evolved over the last several decades beginning in the late 1960s to early 1970s as increasing computer resources made such endeavors possible. Regrettably for the application of mechanistic bacteria models, while the numerical equations to represent many pertinent processes exist and are incorporated in readily available models, these processes are appreciably more watershed specific than hydrologic processes. As one simple example, whether or not there are failed on-site treatment systems, such as septic systems, in a watershed rarely makes measurable differences to streamflow, but can dramatically impact *E. coli* concentrations present in the same streamflow. In the vast majority of circumstances, only very limited watershed-specific information is available to define many of the physical and biological processes that affect bacteria concentrations and loadings. Consequentially, the operator of the mechanistic model must specify, in many circumstances, numerous input parameters governing bacteria processes for which actual numeric values may not be known within a reasonable range of certainty. Compounding implications of these data limitations, the bacteria concentrations and loadings predicted by the model, which potentially contain high uncertainty, will of necessity be used in direct comparison to the relevant numeric criteria that protect the contact recreation use.

3.1.2. Available Data Resources

Streamflow and *E. coli* data availability were used to provide guidance in the allocation tool selection process. As already mentioned, the necessary information and data are largely unavailable for the study area to allow adequate definition of many of the physical and biological processes influencing in-stream bacteria concentrations for mechanistic model application, and these limitations became an important consideration in the allocation tool selection process.

Hydrologic data in the form of daily streamflow records are collected and made available by the U.S. Geological Survey (USGS), which operates one streamflow gage in the watershed (Figure 3,Table 13). USGS streamflow gage 08189700 is used to calculate streamflows for AUs 2004_02 and 2004B_02.

Table 13. Basic information on USGS streamflow gages in project area

Gage No.	Site Description	AU Location	Drainage Area (sq miles)	Daily Streamflow Record
08189700	Aransas River near Skidmore, TX	2004_02	243.1	1964-03-27 – 2016-10-05

Self-reported data in the form of monthly discharge information were available for WWTFs located within the TMDL watersheds via USEPA's ECHO database (USEPA, 2017). Historical ambient *E. coli* data used for development of LDCs was obtained through a data request to the TCEQ Data Management and Analysis Team (TCEQ, 2017a) (Table 14).

Table 14. Summary of historical E. coli concentrations

Waterbody	AU	Station	Station Location	No. of Samples	Data Date Range	Geomean	% exceeding single sample criterion
Aransas River Above Tidal	2004_02	12952	Aransas River near Skidmore	96	2002-02-07 – 2016-07-20	150.2	15.6%
Poesta Creek	2004B_02	12932	Poesta Creek at US 181 Bypass	44	2007-10-02 – 2015-07-28	272.2	34.1%

3.1.3. Allocation Tool Selection

Based on good availability of historical daily streamflow records, discharge information for large municipal WWTFs, and ambient *E. coli* data and deficiencies in data to describe bacterial loads and in-stream processes, the decision was made to use the LDC method as opposed to a mechanistic watershed loading and hydrologic/water quality model.

3.2. Methodology for Flow Duration & Load Duration Curve Development

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

- Step 1: Determine the hydrologic period of record to be used in developing the FDCs.
- Step 2: Determine desired stream locations for which flow and LDCs will be developed. (The stream locations will be at monitoring stations along the impaired AUs for which adequate *E. coli* data are available.)
- Step 3: Develop daily streamflow records at desired stream locations using the daily gauged streamflow records and WWTF discharge monitoring report (DMR) data.
- Step 4: Develop FDCs at desired stream locations, segmented into discrete flow regimes.
- Step 5: Develop the allowable bacteria LDCs at the same stream locations based on the relevant criteria and the data from the FDC.
- Step 6: Superimpose historical bacteria data, if such data exists at the location, on the allowable bacteria LDCs.

Additional information explaining the LDC method may be found in Cleland (2003) and USEPA (2007).

3.2.1. Step 1: Determine Hydrologic Period

Daily hydrologic (streamflow) records were available for one USGS gage in the project watershed. Optimally the period of record to develop FDCs 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 conditions experienced when the *E. coli* data were collected. A 15-year period from August 2001 through August 2016 was selected. This 15-year period of record was selected in an effort to capture a reasonable range of extreme high and low streamflow and represents a period in which all the *E. coli* data were collected.

3.2.2. Step 2: Determine Desired Stream Locations

The SWQM stations that were located within the impaired reached for which adequate *E. coli* data were available determined the stream locations for which FDCs and LDCs were developed. In the Aransas River Above Tidal (AU 2004_02) the station was located near the top of the watershed. While the Poesta Creek (AU 2004B_02) station was located upstream of the Moore Street WWTF outlet. Therefore, neither station was ideal for capturing the flow characteristics representative of the watershed as a whole. Therefore, the decision was made to develop FDCs and LDCs at the outlets of each respective AU and assume the station measurements were characteristic of bacteria concentrations of each AU.

3.2.3. Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step was to develop the 15-year daily streamflow record for each station. The daily streamflow records were developed from extant USGS records.

The method to develop the necessary streamflow record for each FDC/LDC location involved a drainage-area ratio (DAR) approach. With this basic approach, each USGS gage daily streamflow value within the 15-year period was multiplied by a factor to estimate flow at a desired SWQM station location. The factor was determined by dividing the drainage area at the outlet of each impaired reach by the drainage area above the USGS gage (Table 15). Further, WWTFs are evaluated at their full permitted discharge as listed in Table 5 and their contributions to streamflow are accumulated in a downstream direction.

Because an assumption of the DAR approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land use/land cover, point source derived flows should first be removed from the flow record prior to application of the ratio. To address this complication within the TMDL watersheds, the discharges from WWTFs located above a USGS gauge were removed (subtracted) prior to applying the drainage area ratio. In practice this complication was addressed by determining the average discharge for each WWTF located above relevant USGS gauges. The average discharge for each needed WWTF was computed by averaging the data obtained the USEPA ECHO database (USEPA, 2017). The WWTF discharge data included the period of 2001-2016. The database contains summaries of the DMR data, which are a reporting requirement of all permitted discharge facilities under TPDES and NPDES. These computed discharge averages were subtracted from each daily record of the appropriate USGS gauge. To account for WWTFs at their daily permitted discharge limit, as required in the TMDL, the DAR approach was applied at each FDC location and to that calculated streamflow record was added the summation of the full permitted daily average discharges from all upstream WWTFs.

Table 15. Drainage Area Ratios (DARs) used to estimate flow

AU	Location	Drainage Area (acres)	Drainage Area Ratio (DAR)
2004_02	USGS 08189700	155,554	1.00
2004_02	2004_02 Outlet	201,227	1.29
2004B_02	2004B_02 Outlet	33,442	0.21

3.2.4. Steps 4 Through 6: Flow Duration Curve and Load Duration Curve

FDCs and LDCs are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. To develop an 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 percent of days each flow was exceeded by dividing each rank by the total number of data points plus 1; and
3. plot the corresponding flow data against exceedance percentages.

Further, when developing an LDC:

- Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL or 1.26 MPN/mL) and by a conversion factor (2.44658×10^{9}), which gives a loading unit of MPN/day;
- and plot the exceedance percentages, which are identical to the value for streamflow data points, against geometric mean criterion of *E. coli*.

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

- Using the unique data for each monitoring station, compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^{9}); and
- plot on the LDC for each station the load for each measurement at the exceedance percentage for its corresponding streamflow.

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

3.3. Flow Duration Curves for TMDL Watersheds

FDCs were developed for the outlet of Aransas River Above Tidal (AU 2004_02) (Figure 11) and the outlet of Poesta Creek (AU 2004B_02) (Figure 12). For this report, the FDCs were developed by applying the DAR method and using the USGS gage and period of record (2001-2016) described in the previous section.

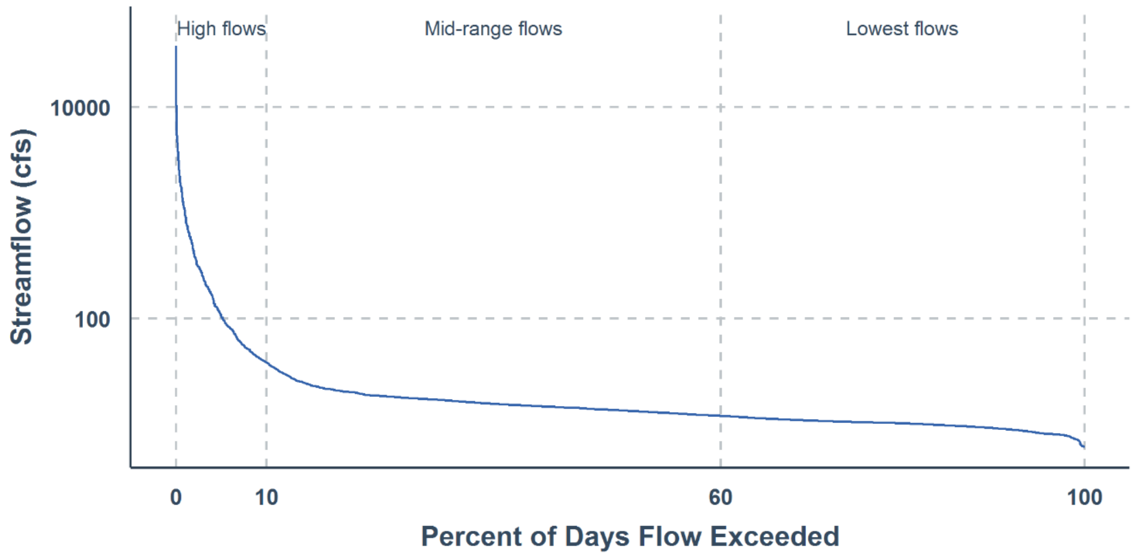

Figure 11. Flow duration curve for Aransas River Above Tidal (AU 2004_02)

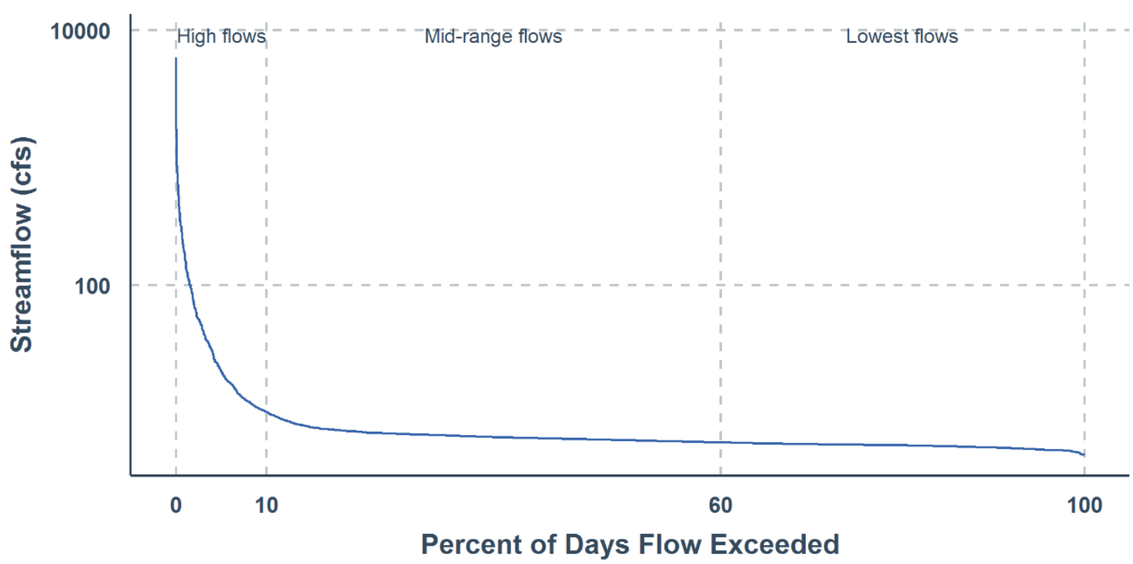

Figure 12. Flow duration curve for Poesta Creek (AU 2004B_02)

3.4. Load Duration Curves for TMDL Watersheds

LDCs were developed for Aransas River Above Tidal (AU 2004_02) and Poesta Creek (AU 2004B_02). The curve was divided into three flow regimes to assist in determining streamflow conditions under which exceedances occurred. Streamflows were divided into: high flow (0-10% flow exceedance), mid-range flow (10-60% flow exceedance), and lowest flows (60-100% flow exceedance). The selection of the flow regime intervals was based on general observation of the developed LDCs, but also based on intervals used in the LDC developed for the Aransas River Tidal (AU 2003_01) in the existing TMDL (TCEQ, 2016).

Figures 13 and 14 depict the LDCs for the Aransas River Above Tidal (AU 2004_02) and Poesta Creek (AU 2004B_02). The geometric mean loading in each flow regime is also shown to aid interpretation. Furthermore, *E. coli* data are shown as a “wet event” or “dry event.” A sample was determined to be influenced by a wet weather event based on the reported “days since last precipitation” (DSLP) as noted on the field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic conditions. A sample with a DSLP value of 2 or less was defined as a wet weather event. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

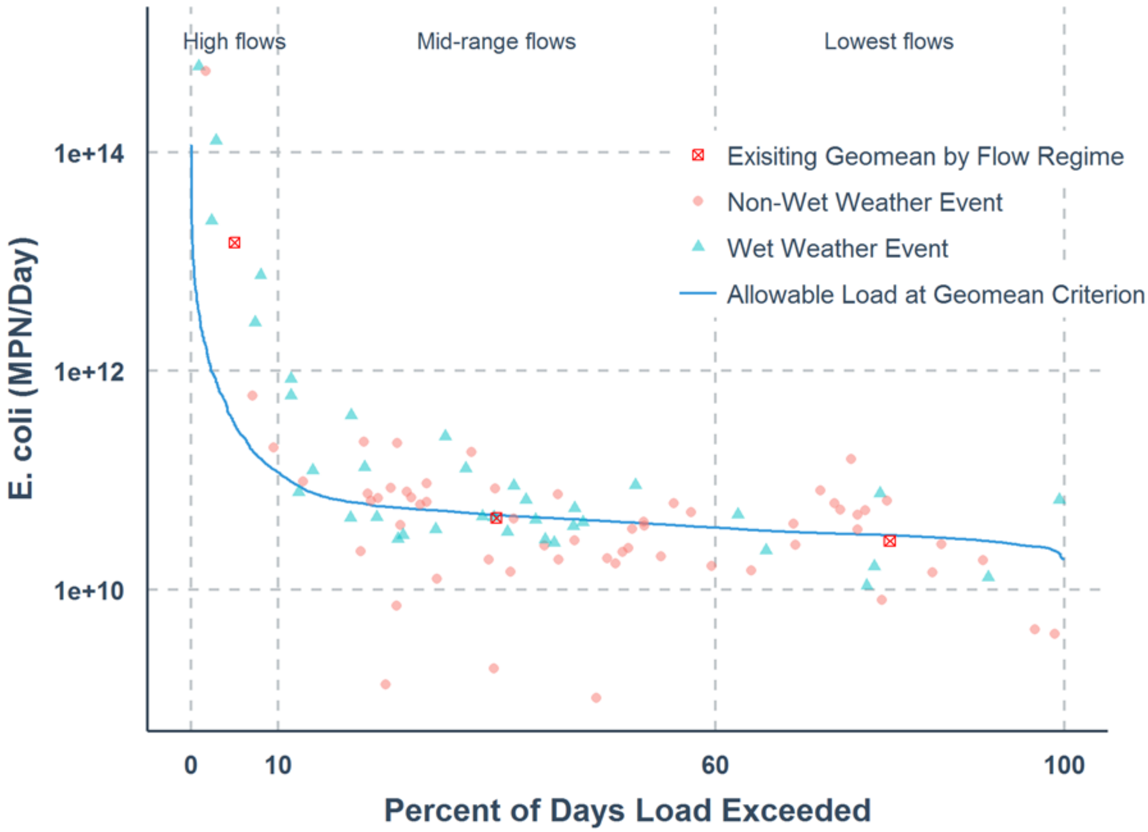

Figure 13. Load Duration Curve for Aransas River Above Tidal (AU 2004_02)

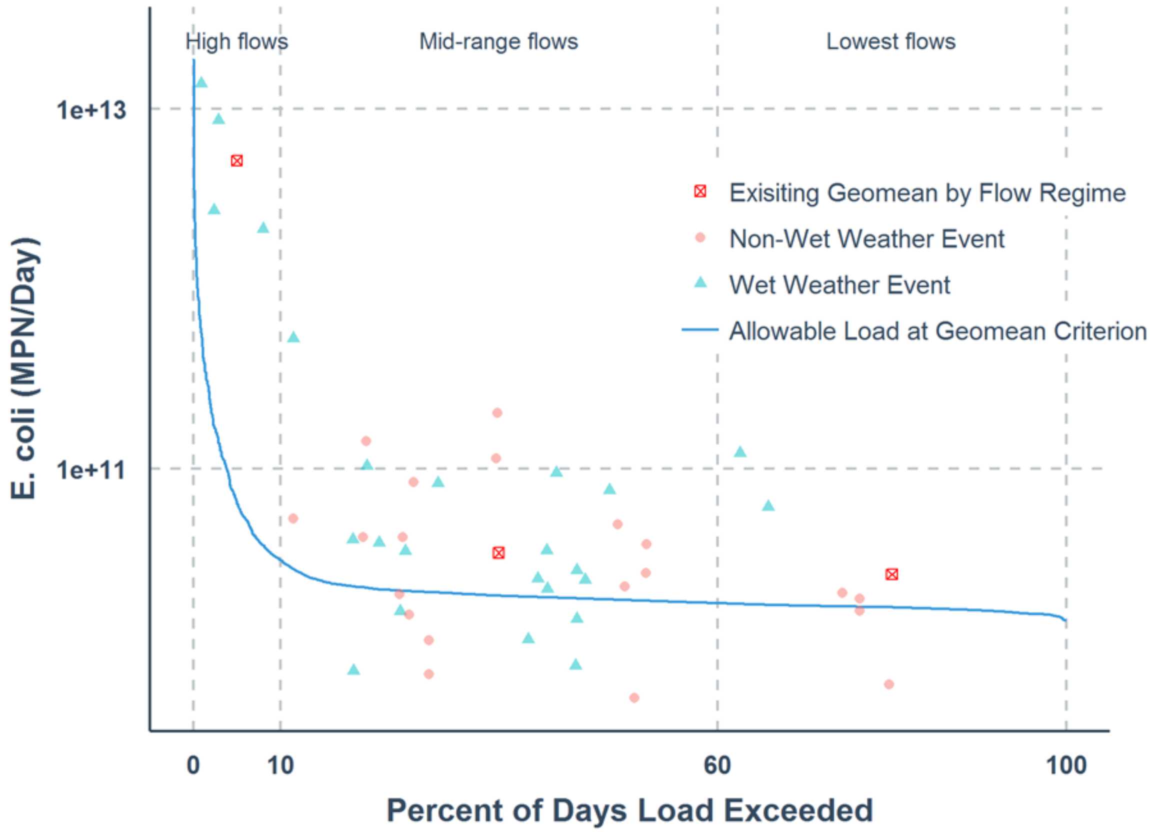

Figure 14. Load Duration Curve for Poesta Creek (AU 2004B_02)

Section 4. TMDL Allocation Analysis

4.1. Endpoint Identification

The waterbodies within the TMDL watersheds have a use of primary contact recreation, which utilizes a geometric mean numeric criterion of 126 MPN/100 mL for *E. coli* indicator bacteria (TCEQ, 2010). All TMDLs must identify a quantifiable water quality target that indicated 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 the TMDL is to maintain concentration of *E. coli* below the geometric mean criterion of 126 MPN/100mL. This endpoint was applied to both AUs addressed by this TMDL. This endpoint is identical to the geometric mean criterion for primary contact recreation in the 2010 Surface Water Quality Standard (TCEQ, 2010).

4.2. Seasonality

Seasonal variations or seasonality occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations collected in warmer months (May-September) against those collected during cooler months (November-March). The months of April and October were considered transitional between the 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-normal data without requiring data transformation. The test was considered significant at the $\alpha=0.05$ level.

The Wilcoxon Rank Sum test did not detect a significant difference in seasonal *E. coli* measurements in the Aransas River Above Tidal (AU 2004) ($W=709.5$, $p=0.357$, Figure 15a). A significant difference was detected in seasonal *E. coli* measurements for Poesta Creek (AU 2004B_02) ($W=228.5$, $p<0.001$, Figure 15b), indicating that higher *E. coli* concentrations typically occur during the warm season.

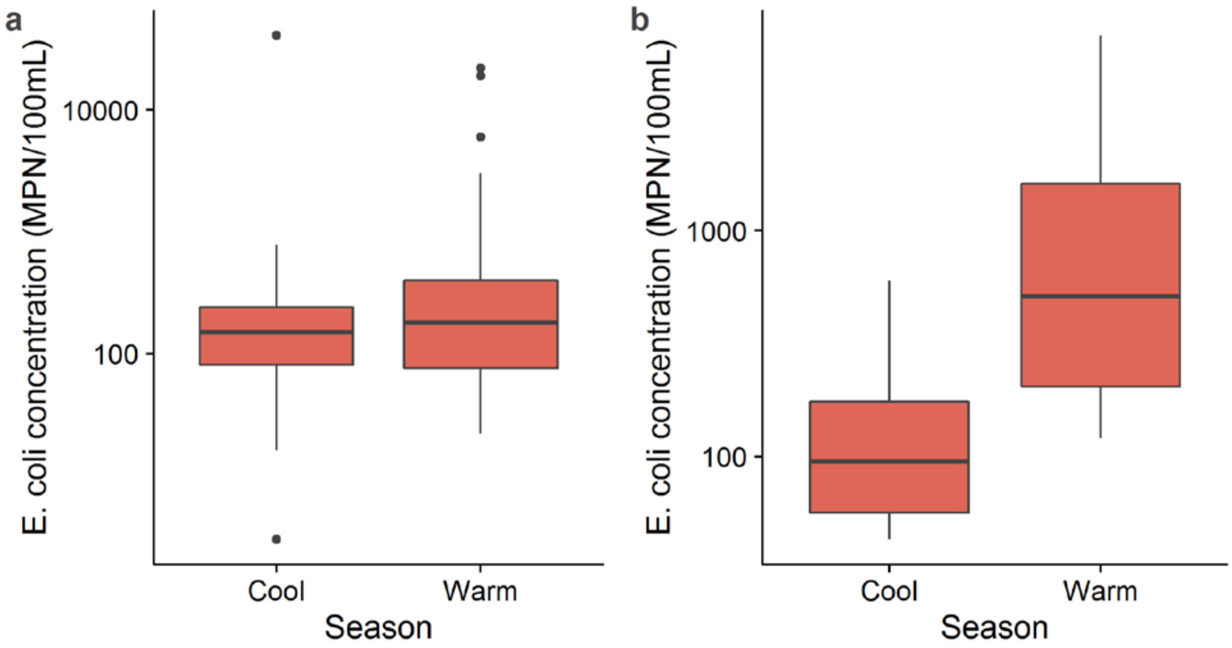

Figure 15. Distribution of E. coli concentrations by season in (a) Aransas River Above Tidal (AU 2004_02) and (b) Poesta Creek (AU 2004B_02)

4.3. Linkage Analysis

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

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

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

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

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality, 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 nonpoint sources in the watershed. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

The LDC method allows for estimation of existing and TMDL 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 hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater) and provides a means to allocate allowable loadings.

Based on the LDCs to be used in the pollutant load allocation process with historical *E. coli* data added to the graphs (Figure 13, Figure 14) and Section 2.6 (Potential Source of Fecal Indicator Bacteria), the following broad linkage statements can be made. For the Aransas River Above Tidal (AU 2004_02) watershed, *E. coli* loading exceedances occur frequently at high flows and are generally below or near the loading criterion at mid-range and low flows. However, elevated loadings occur under all flow conditions for the Poesta Creek (AU 2004B_02) watershed.

Regulated stormwater comprises a minor portion of both watersheds; therefore, non-regulated stormwater likely contribute to the majority of high flow related loadings in both watersheds. Elevated loadings in Poesta Creek (AU 2004B_02) at low and median flow conditions cannot be attributed exclusively to WWTFs due to the WWTF outfall location occurring downstream of the SWQM sampling station. Therefore, other sources of bacteria loadings under lower flow conditions and in the absence of overland flow contributions (i.e., without stormwater contribution) are most likely to contribute bacteria directly to the water. These sources may include direct deposition of fecal material from sources such as wildlife, feral hogs, and livestock (See Section 2.7.2) However, the actual contributions of bacteria loadings directly attributable from 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 two methods:

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

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

The TMDL covered by this report incorporates an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target of *E coli* of 120 MPN/100mL. The net effect of the TMDL with MOS is that assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6. Load Reduction Analysis

While the TMDLs for the project watersheds will be developed using load allocations, additional insight may be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each flow regime was determined using the historical *E. coli* data obtained from stations within the impaired reached (Table 16).

Table 16. Percent reductions for project watersheds

AU	High Flows		Mid-Range flows		Lowest Flows	
	Geometric Mean (MPN/100mL)	% Reduction Required	Geometric Mean (MPN/Day)	% Reduction Required	Geometric Mean (MPN/Day)	% Reduction Required
2004_02	3,864	97%	111	0	114	0
2004B_02	4,214	97%	210	40%	188	33%

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:

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

Eq. 1

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 non-regulated or non-permitted sources
FG = loading associated with future growth from potential permitted facilities
MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli*, TMDLs are expressed as MPN/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 two impaired AUs covered in this report are derived using the median flow within the high flow regime (or 5% flow) of the LDC developed for the outlet of each AU watershed. 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 each impaired AU were developed as a pollutant load allocation based on information from the LDCs developed for the outlet of each impaired AU (Figure 13, Figure 14). As discussed in more detail in Section 3, bacteria LDCs were developed by multiplying each streamflow value along the FDCs by the primary contact recreation *E. coli* criterion (126 MPN/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:

$$TMDL = Criterion \times Flow \times Conversion\ Factor$$

Eq. 2

Where:

Criterion = 126 MPN/100mL (*E. coli*)
Conversion factor (to MPN/day) = 28,316.8 mL/ft^3 × 86,400 seconds/day

At the 5% load duration exceedance, the TMDL values are provided in Table 17.

Table 17. Summary of allowable loadings for project watersheds

AU	5% Exceedance Flow (cfs)	5% Exceedance Load (MPN/day)	TMDL (Billion MPN/day)
2004_02	103.54	319,170,037,180	319.170
2004B_02	20.73	63,891,335,069	63.891

4.7.2. Margin of Safety (MOS)

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

$$MOS = 0.05 \times TMDL$$

Eq. 3

Where:

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

The MOS for each AU is presented in Table 18.

Table 18. Summary of MOS for project watersheds

AU	TMDL (Billion MPN/day)	MOS (Billion MPN/day)
2004_02	319.170	15.959
2004B_02	63.891	3.195

4.7.3. Wasteload Allocation (WLA)

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

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

Eq. 4

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric mean criterion and also reduced to account for the required MOS. The *E. coli* primary contact recreation geometric mean criterion of 126 MPN/100mL is used as the WWTF target. This is expressed as:

$$WLA_{WWTF} = Criterion \times Flow \times Conversion\ Factor \times (1 - F_{MOS})$$

Eq. 5

Where:

Criterion = 126 MPN/100mL *E. coli*
Flow = full permitted flow (MGD)

Conversion Factor (to MPN/day) = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d
F_{MOS} = fraction of loading assigned to MOS (5% or 0.05)

The daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of each WWTF using Eq. 5 and summed for all plants upstream of each project watershed. Table 19 presents the wasteload allocations for each individual WWTF located in the project watersheds.

Table 19. Summary of WLAs for WWTFs in the project watersheds

TPDES Permit	Facility	AU	Final Permitted Discharge	WLA_{WWTF} (Billion MPN/day)
10124-002	City of Beeville – Moore Street WWTF	2004B_02†	3.0	13.593
2004B_02 Total WLA_{WWTF}			3.0	13.593
10124-004	City of Beeville – Chase Field WWTF	2004_02	2.5	11.328
14112-001	Skidmore WSC WWTF	2004_02	0.131	0.594
2004_02 Total WLA_{WWTF}			5.631	25.515

†the total WLA_{WWTF} for AU 2004_02 includes WWTFs in AU 2004B_02

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

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

Eq. 6

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 permitted facilities
MOS = the margin of safety load
FDA_{SWP} = the fractional proportion of drainage area under jurisdiction of stormwater permits

In order 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 in order to estimate the amount of runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. As described in Section 2.7.1.4, a search of stormwater general permits was performed. The results are displayed in Table 20.

Table 20. Permitted Stormwater Acreage and FDA_{SWP} calculation

AU	Industrial General Permits (acres)	Construction Permits (average acres)†	Total Area of Permits (acres)	Watershed Area	FDA_{SWP}
2004_02	46.3	104.9	151.2	201,227	0.075%
2004B_02	27.9	20.5	48.4	33,442	0.145%

† Average daily permitted acreage from January 2003 – May 2016

The Future Growth (FG) term required to calculate WLA_{SW} is described in the next section. However, the WLA_{SW} calculations are presented in Table 21 for continuity.

Table 21. Regulated stormwater calculations for the project watersheds

AU	TMDL†	WLA_{WWTF}†	FG†	MOS†	FDA_{SWP}	WLA_{SW}†
2004_02	319.170	25.515	2.985	15.959	0.075%	0.206
2004B_02	63.891	13.593	1.590	3.195	0.145%	0.066

† in units of billion MPN/day *E. coli*

With the WLA_{SW} and WLA_{WWTF} terms, the total WLA term can be determined using Eq. 4 (Table 22).

Table 22. Wasteload allocation summary for the project watersheds

AU	WLA_{WWTF}†	WLA_{SW}†	WLA†
2004_02	25.515	0.206	25.721
2004B_02	13.593	0.066	13.659

† in units of billion MPN/day *E. coli*

4.7.4. Future Growth (FG)

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 increase as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentration are at or below the contact recreation standard.

Three domestic wastewater facilities are located in the project watersheds. To account for the FG component of the impaired AUs, the loadings from all WWTFS are included in the FG computation, which is based on the WLA_{WWTF} formula (Eq. 5). The FG equation contains an additional term to account for project population growth within the WWTF service areas between 2010 and 2070, based on data obtained from the TWDB 2017 State Water Plan (TWDB, 2017).

$$FG = Criterion \times (\%POP_{2010-2070} \times WWTF_{FP}) \times Conversion\ Factor \times (1 - F_{MOS})$$

Eq. 7

Where:

Criterion = 126 MPN/100mL (*E. coli*)
$\%POP_{2010\text{-}2070}$ = Estimated % increase in population between 2010 and 2070
$WWTF_{FP}$ = Full permitted discharge (MGD)
Conversion Factor =1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d
F_{MOS} = fraction of loading assigned to MOS (5% or 0.05)

Table 23. Future growth summary for the project watersheds

Water User Group	% Population Increase (2010-2070)	Facility	AU	Full Permitted Flow (MGD)	Future Growth (MGD)	FG (*E. coli* Billion MPN/100mL)
Beeville	11.7	City of Beeville Moore Street WWTP	2004B_02	3.0	0.351	1.590
					2004B_02 Total FG	1.590
Bee County	11.7	City of Beeville Chase Field WWTP	2004_02	2.5	0.293	1.325
Bee County	11.7	Skidmore WSC WWTF	2004_02	0.131	0.015	0.069
					2004_02 Total FG	2.985

4.7.5. Load Allocation (LA)

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

$$LA = TMDL - WLA - FG - MOS$$

Eq. 8

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 permitted facilities
MOS = margin of safety load

Table 24 summarizes load allocation calculations.

Table 24. Load allocation summary for project watersheds

AU	TMDL†	WLA†	FG†	MOS†	LA†
2004_02	319.170	25.721	2.985	15.959	274.505
2004B_02	63.891	13.659	1.590	3.195	45.447

† in units of billion MPN/day *E. coli*

4.8. Summary of TMDL Calculations

Table 25 summarizes the TMDL calculations for the project watersheds. Each of the TMDLs were calculated based on median flow in the 0-10 percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for the outlet of each AU. Allocations are based on the current geometric mean criterion for *E. coli* of 126 MPN/100mL for each component of the TMDL.

Table 25. TMDL allocation summary for project watersheds

AU	TMDL†	MOS†	WLA_{WWTF}†	WLA_{SW}†	LA†	FG†
2004_02	319.170	15.959	25.515	0.206	274.505	2.985
2004B_02	63.891	3.195	13.593	0.066	45.447	1.590

† in units of billion MPN/day *E. coli*

The final TMDL allocations (Table 26) needed to comply with the requirements of 40 CFR 103.7 include the FG component within the WLA_{WWTF}. The WLA_{WWTF} for each AU includes the sum of the WWTF allocations for that AU and all upstream AUs. Similarly, the WLA_{SW} for each AU includes the sum of all regulated stormwater areas of that AU and upstream AUs. The LA component of the final TMDL allocations is comprised of the sum loadings arising from within each AU and all upstream AUs that are associated with non-permitted sources.

Table 26. Final TMDL allocations for project watersheds

AU	TMDL†	WLA_{WWTF}†*	WLA_{SW}†	LA†	MOS†
2004_02	319.170	28.500	0.206	274.505	15.959
2004B_02	63.891	15.183	0.066	45.447	3.195

† in units of billion MPN/day *E. coli*
* WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities

In the event that the criterion changes due to a change in the designated recreational use, Appendix A provides guidance for recalculating the allocations in Table 26.

Section 5. References

AVMA [American Veterinary Medical Association] (2012). *In: U.S. Pet Ownership & Demographics Sourcebook (2012 Edition).* Retrieved Jan 9, 2017, from <www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx>

Cleland, B. (2003). *TMDL Development From the "Bottom Up" - Part III: Duration Curves and Wet-Weather Assessments.* Retrieved Jan 9, 2017, from <https://doi.org/10.2175/193864703784828976>

NOAA [National Oceanic and Atmospheric Administration] (2016). *Station 12925, Beeville Chase NAAS, TX US. Monthly Normals.* Retrieved Sept 21 2016, from <https://www.ncdc.noaa.gov/cdo-web/datasets/NORMAL_MLY/stations/GHCND:USW00012925/detail>

NRCS [Natural Resources Conservation Service] (2015). *Web Soil Survey*. SSURGO data retrieved June 28, 2017, from < https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>

PRISM Climate Group at Oregon State University. (2012). *PRISM Products Matrix*. Retrieved Jan 3, 2017, from PRISM Climate Group: <www.prism.oregonstate.edu/normals/>

Public Utility Commission of Texas (2017). *CCN Mapping Information*. PUC CCN Water and Sewer GIS Data Retrieved Jan 10, 2017, from < https://www.puc.texas.gov/industry/water/utilities/gis.aspx >

Reed, Stowe, and Yanke, LLC. (2001). *Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas.* Retrieved from <www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/StudyToDetermine.pdf>

TCEQ [Texas Commission on Environmental Quality]. (2006). *Preserving & Improving Water Quality – The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters*. Retrieved Jan 9, 2017, from <https://www.tceq.texas.gov/publications/gi/gi-351.html>

TCEQ [Texas Commission on Environmental Quality] (2010). Texas Surface Water Quality Standards, 2010 Rule Amendment, 30 TAC 307. Retrieved Jan 9, 2017, from < https://www.tceq.texas.gov/assets/public/waterquality/standards/TSWQS2010/TSWQS2010_rule.pdf >

TCEQ [Texas Commission on Environmental Quality] (2012). *TCEQ Surface Water Quality Monitoring Stations.* Retrieved Jan 3, 2017, from <https://www.tceq.texas.gov/gis/download-tceq-gis-data/>

TCEQ [Texas Commission on Environmental Quality] (2015a). *2014 Texas Integrated Report for Sections 305(b) and 303(d)*. (Approved by USEPA on November 19, 2015). Retrieved Jan 9, 2017, from <https://www.tceq.texas.gov/waterquality/assessment/14twqi/14txir>

TCEQ [Texas Commission on Environmental Quality] (2015b) *TCEQ 2014 Assessment Units.* Retrieved Jan 3, 2017 from <https://www.tceq.texas.gov/gis/download-tceq-gis-data/>

TCEQ [Texas Commission on Environmental Quality] (2016). *Two Total Maximum Daily Loads for Indicator Bacteria in the Tidal Segments of the Mission and Aransas Rivers.* (Adopted May 25, 2016) <https://www.tceq.texas.gov/assets/public/waterquality/tmdl/76copano/76A-MissionAransasTMDL-adopted.pdf>

TCEQ [Texas Commission on Environmental Quality] (2017a) updated daily. Surface Water Quality Monitoring Information System. 12/18/1972 - 7/20/2016. Compiled by Data Management and Analysis Team. Austin, Texas USA. Request ID 304

TCEQ [Texas Commission on Environmental Quality] (2017b). *TCEQ Information Resources Division Central Registry.* Retrieved Jan 20, 2017 from <http://www15.tceq.texas.gov/crpub/>

TWDB [Texas Water Development Board] (2017) *Regional Water Plan Population & Water Demand Projections.* Retrieved Jan 3, 2017, from <http://www.twdb.texas.gov/waterplanning/data/projections/2017/popproj.asp>

TWRI [Texas Water Resources Institute] (2007*). Bacteria Total Maximum Daily Load Task Force Final Report.* TR-341. Retrieved Jan 9, 2017, from <twri.tamu.edu/reports/2009/tr341.pdf>

TWRI [Texas Water Resources Institute] (2009). *Education Program for Improved Water Quality in Copano Bay Task Two Report.* TR-347. Retrieved Jan 9, 2017, from <http://twri.tamu.edu/reports/2009/tr347.pdf>

USCB [United States Census Bureau] (2010). *2010 TIGER/Line Shapefiles.* Retrieved Jan 3, 2017, from <www.census.gov/geo/maps-data/data/tiger-line.html>

USDA [United States Department of Agriculture] (2014). 2012 *Census of Agriculture.* Retrieved Jan 9, 2017, from <https://www.agcensus.usda.gov/Publications/2012/>

USGS [United States Geological Survey] (2011). *GAGES-II: Geospatial Attributes of Gages for Evaluating Streamflow.* Retrieved Dec 6, 2016, from <https://water.usgs.gov/GIS/dsdl/gagesII_9322_point_shapefile.zip>

USGS [United States Geological Survey] (2015). *Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database (NLCD 2011).* Retrieved May 3, 2016, from <https://www.mrlc.gov/nlcd2011.php>

USEPA [United States Environmental Protection Agency] (1991). *Guidance for Water Quality-Based Decisions: The TMDL Process.* EPA 440/4-91-001. Retrieved Feb 2, 2017, from <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=00001KIO.txt>

USEPA [United States Environmental Protection Agency] (2007). *An Approach for Using Load Duration Curves in the Development of TMDLs.* EPA 841-B-07-006. Retrieved Jan 10, 2017, from <https://www.epa.gov/sites/production/files/2015-07/documents/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf>

USEPA [United States Environmental Protection Agency] (2017). *Enforcement & Compliance History Online* [ECHO].Retrieved Jan 10, 2017, from <http://echo.epa.gov/echo/>

Weiskel, P.K., B.L. Howes, and G.R. Heufelder. (1996). Coliform contamination of coastal embayment: Sources and transport pathways. *Environmental Science and Technology*. 30:1872-1881.

Appendix A. Equations for Calculating TMDL Allocations for Revised Water Quality Standards

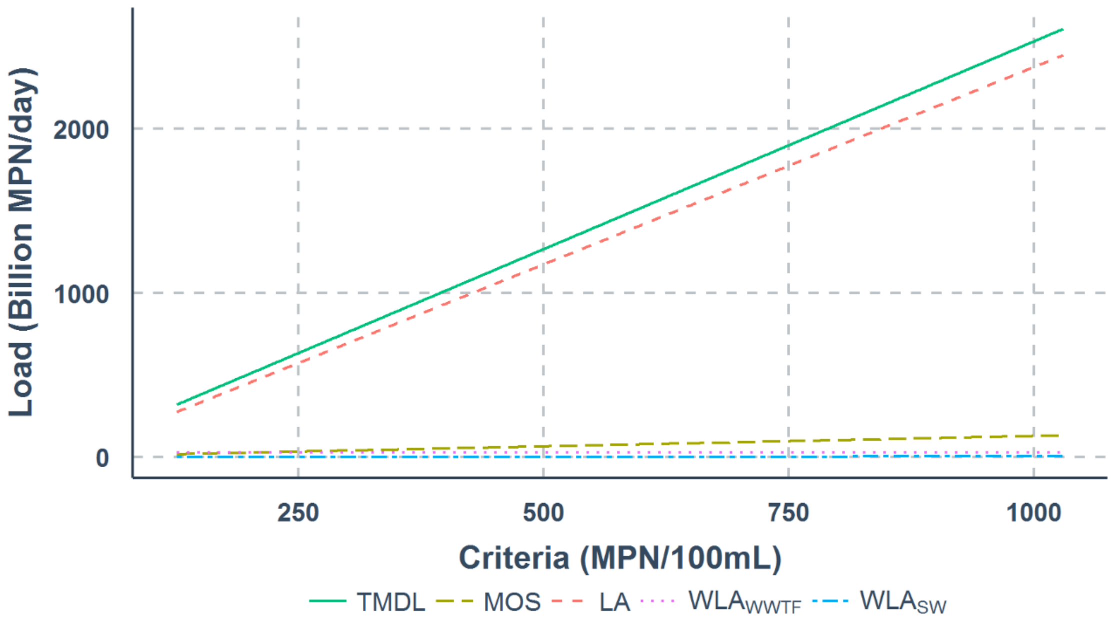

Figure A- 1. Allocation loads for Aransas River Above Tidal (AU 2004_02) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day) for Aransas River Above Tidal (AU 2004_02):

$TMDL = 2.533095 \times Std$
$MOS = 0.1266547 \times Std$
$LA = 2.404635 \times Std - 28.478676$
$WLA_{WWTF} = 28.50005$
$WLA_{SW} = 0.00180483 \times Std - 0.02137504$

Where:

Std = Revised Water Quality Standard
MOS = Margin of Safety
LA = Total load allocation (non-permitted source contributions)
WLA_{WWTF} = Wasteload allocation (permitted WWTF + future growth) [Note: WWTF load held at existing primary contact (126 MPN/100mL) criteria]
WLA_{SW} = Wasteload allocation (permitted stormwater)

Table A- 1. Summary of allocation loads for Aransas River Above Tidal (AU 2004_02) at selected revised water quality standards

Std (MPN/100mL)	TMDL†	MOS†	LA†	WLA_{WWTF}†*	WLA_{SW}†
126	319.170	15.959	274.505	28.50005	0.206
630	1595.850	79.792	1486.441	28.50005	1.116
1030	2609.087	130.454	2448.295	28.50005	1.838

† in units of billion MPN/day *E. coli*

* WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities and held at the primary contact (126 MPN/100mL) criteria

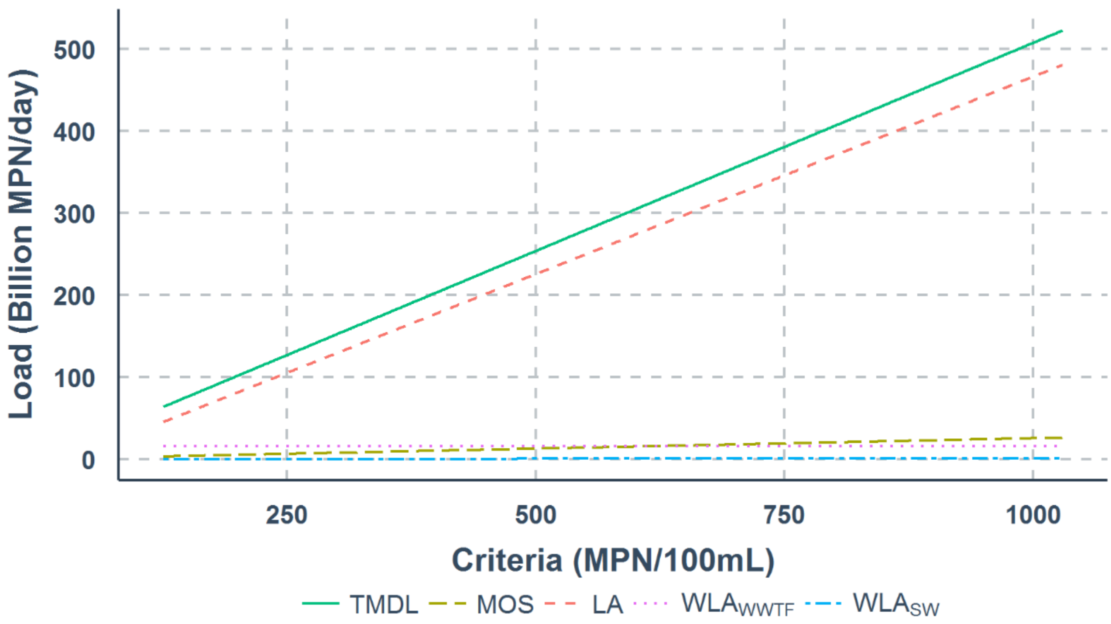

Figure A- 2. Allocation loads for Poesta Creek (AU 2004B_02) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day) for Poesta Creek (AU 2004B_02):

$$TMDL = 0.5070740 \times Std$$
$$MOS = 0.02535370 \times Std$$
$$LA = 0.4810218 \times Std - 15.1618148$$
$$WLA_{WWTF} = 15.18383$$
$$WLA_{SW} = 0.00069849 \times Std - 0.02202$$

Where:

Std = Revised Water Quality Standard

MOS = Margin of Safety
LA = Total load allocation (non-permitted source contributions)
WLA_{WWTF} = Wasteload allocation (permitted WWTF + future growth) [Note: WWTF load held at existing primary contact (126 MPN/100mL) criteria]
WLA_{SW} = Wasteload allocation (permitted stormwater)

Table A- 2. Summary of allocation loads for Poesta Creek (AU 2004B_02) at selected revised water quality standards

Std (MPN/100mL)	TMDL†	MOS†	LA†	WLA_{WWTF}†*	WLA_{SW}†
126	63.891	3.195	45.447	15.18383	0.066
630	319.457	15.973	287.882	15.18383	0.418
1030	522.286	26.114	480.291	15.18383	0.697

† in units of billion MPN/day *E. coli*
* WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities and held at the primary contact (126 MPN/100mL) criteria