Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek

Segment: 2453C, Assessment Unit: 2453C_01

Arenosa Creek (Assessment Unit 2453C_01) at County Road 103

By Texas Water Resources Institute, October 2020

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Segment: 2453C, Assessment Unit: 2453C_01

Prepared for
Total Maximum Daily Load Program
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List of Abbreviations

AU	assessment unit
CCN	Certificate of Convenience and Necessity
cfs	cubic feet per second
DAR	drainage-area ratio
E. coli	*Escherichia coli*
FDC	flow duration curve
FG	future growth
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
NPS	nonpoint source
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
RMU	Resource Management Unit
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TWRI	Texas Water Resources Institute
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's overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

TCEQ first identified bacteria impairments within Arenosa Creek in the *2010 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (TCEQ, 2011). The bacteria impairments have been identified in each subsequent edition through 2014.

This document will consider bacteria impairments in one water body (segment), consisting of a single assessment unit (AU). The water body and identifying AU number is shown below:

- Arenosa Creek 2453C_01

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by TCEQ. The water quality standards 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. 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 that 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, 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 these four categories:

1. 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.

2. Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and a geometric mean criterion for *E. coli* of 630 MPN per 100 mL.

3. 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.

4. 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).

The impaired AU Arenosa Creek (AU 2453C_01) is approved for primary contact recreation. The associated standard for *E. coli* is a geometric mean of 126 MPN per 100 mL.

1.3. Report Purpose and Organization

TCEQ contracted with the Texas Water Resources Institute (TWRI) for the Arenosa 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 TCEQ in preparing 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 segment; (2) develop an appropriate tool for development of a bacteria TMDL for the impaired segment; and (3) submit the draft and final technical support document for the impaired segment. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the Arenosa Creek watershed. This report contains:

- 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 (*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

Arenosa Creek is located along the Texas Central Gulf Coast, between the cities of Victoria and Edna (Figure 1). Arenosa Creek consists of a single Segment (2453C) and a single AU(2453C_01). The headwaters of Arenosa Creek begin in Victoria County at J2 Ranch Road and flow approximately 32.7 miles southeasterly until converging with Garcitas Creek. The drainage area for Arenosa Creek is 172.1 square miles and is located predominately in Victoria County (52 percent) and Jackson County (45 percent); Lavaca County includes approximately three percent of the watershed.

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

- Segment 2453C (Arenosa Creek) – From Garcitas Creek confluence upstream to J-2 Ranch Road
    - 2453C_01 - From Garcitas Creek confluence upstream to J-2 Ranch Road

2.2. Review of Routine Monitoring Data for TMDL Watersheds

2.2.1. Data Acquisition

TCEQ Data Management and Analysis Team provided all available ambient *E. coli* data records on October 19, 2017 (TCEQ, 2017a). The data represented all historical ambient *E. coli* data and field parameters collected in the project area. Ambient *E. coli* measurements were available from December 2000 through August 2015.

2.2.2. Analysis of Bacteria Data

Water quality monitoring has occurred at a single TCEQ monitoring station within Arenosa Creek (Figure 1). *E. coli* data collected at this station over the seven-year period of December 1, 2003 to November 30, 2010 were used in assessing attainment of the primary contact recreation use as reported in the *2012 Texas Integrated Report* (TCEQ, 2013). There were insufficient data available during the assessment period (December 1, 2005 to November 30, 2012) for the most recent *2014 Texas Integrated Report* (TCEQ, 2015a), resulting in a carry-forward of the impairment listing from the previous report. The 2012 assessment data indicate non-support of the primary contact recreation use because of the geometric mean concentrations exceeding the geometric criterion of 126 MPN/100mL for Arenosa Creek (AU 2453C_01) as summarized in Table 1.

2.3. Watershed Climate and Hydrology

Within the Arenosa Creek watershed, there are no active weather stations recording precipitation or temperature data. Therefore, the nearby Victoria Regional Airport USW00012912 weather station (NOAA, 2016) was used to determine the approximate

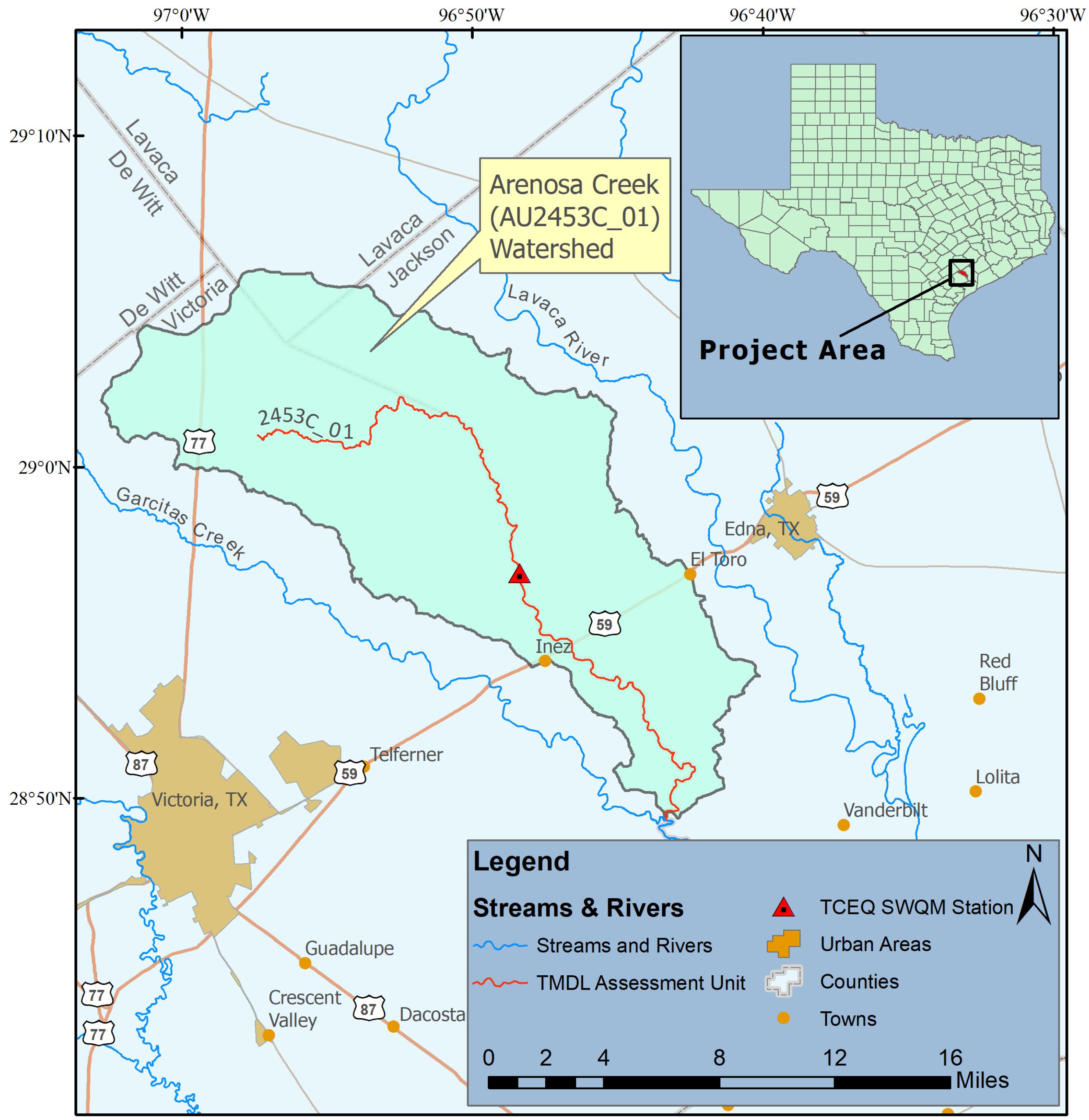

Figure 1. Overview map of the Arenosa Creek watershed

Sources: TCEQ Monitoring Station Locations (TCEQ, 2012), TCEQ Assessment Units (TCEQ 2015b)

Table 1. 2012 Integrated Report Summary for Arenosa Creek.

Water Body	Assessment Unit (AU)	Parameter	Station	Data Range	No. of Samples	Station Geometric Mean (MPN/100mL)
Arenosa Creek	2453C_01	*E. coli* Geomean	13295	12/01/2003 – 11/30/2010	32	197.6

precipitation and temperature data for the watershed. Monthly normal air temperature, also from the Victoria Regional Airport USW00012912 weather station (NOAA, 2016), indicates daily mean air temperature was 70.5°F (NOAA, 2016). Minimum average daily temperature reaches a low of 54.2°F in January. The maximum average daily temperature reached a peak of 84.7°F in August. Monthly normal precipitation, from the weather station, indicates that the area had a mean annual rainfall from 1981-2010 of 41.20 inches (NOAA, 2016). Rainfall normally peaks in May (5.19 inches) with the lowest totals occurring in February (2.08 inches) (NOAA, 2016). Average annual precipitation values across the study area from the PRISM Climate Group at Oregon State (2012) indicate average annual rainfall ranges from 40 to 43 inches per year across the watershed, with a clear East to West decreasing gradient (Figure 4).

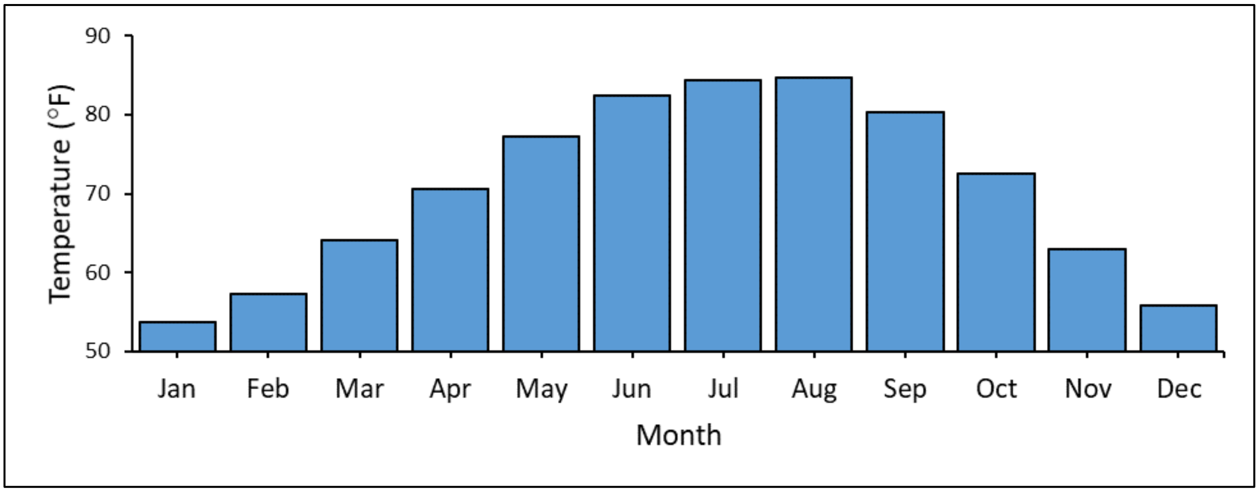

Figure 2. Victoria Regional Airport normal monthly air temperature from 1981-2010.
Source: NOAA (2016)

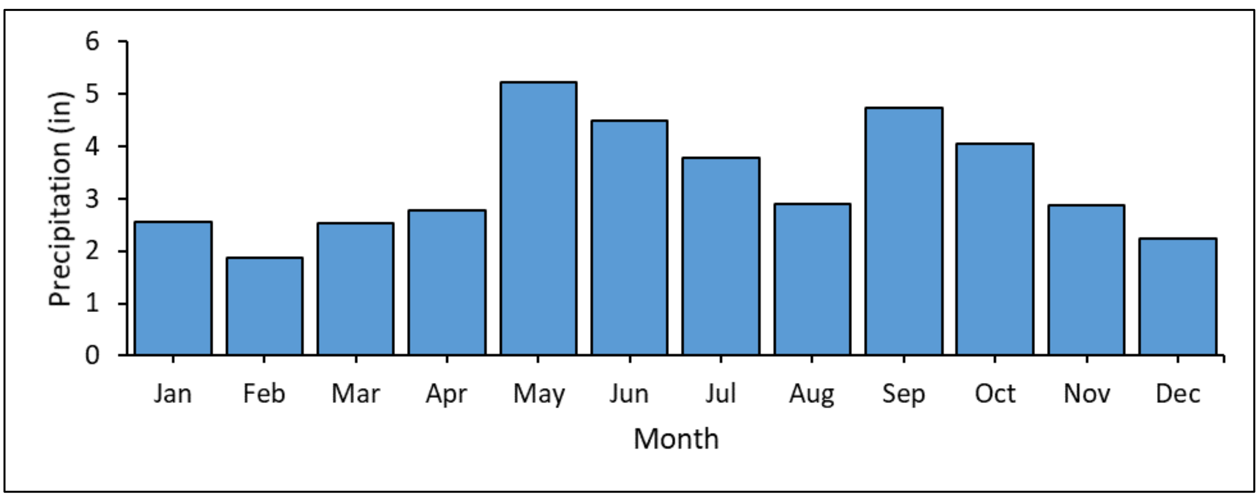

Figure 3. Victoria Regional Airport normal monthly precipitation from 1981-2010.
Source: NOAA (2016).

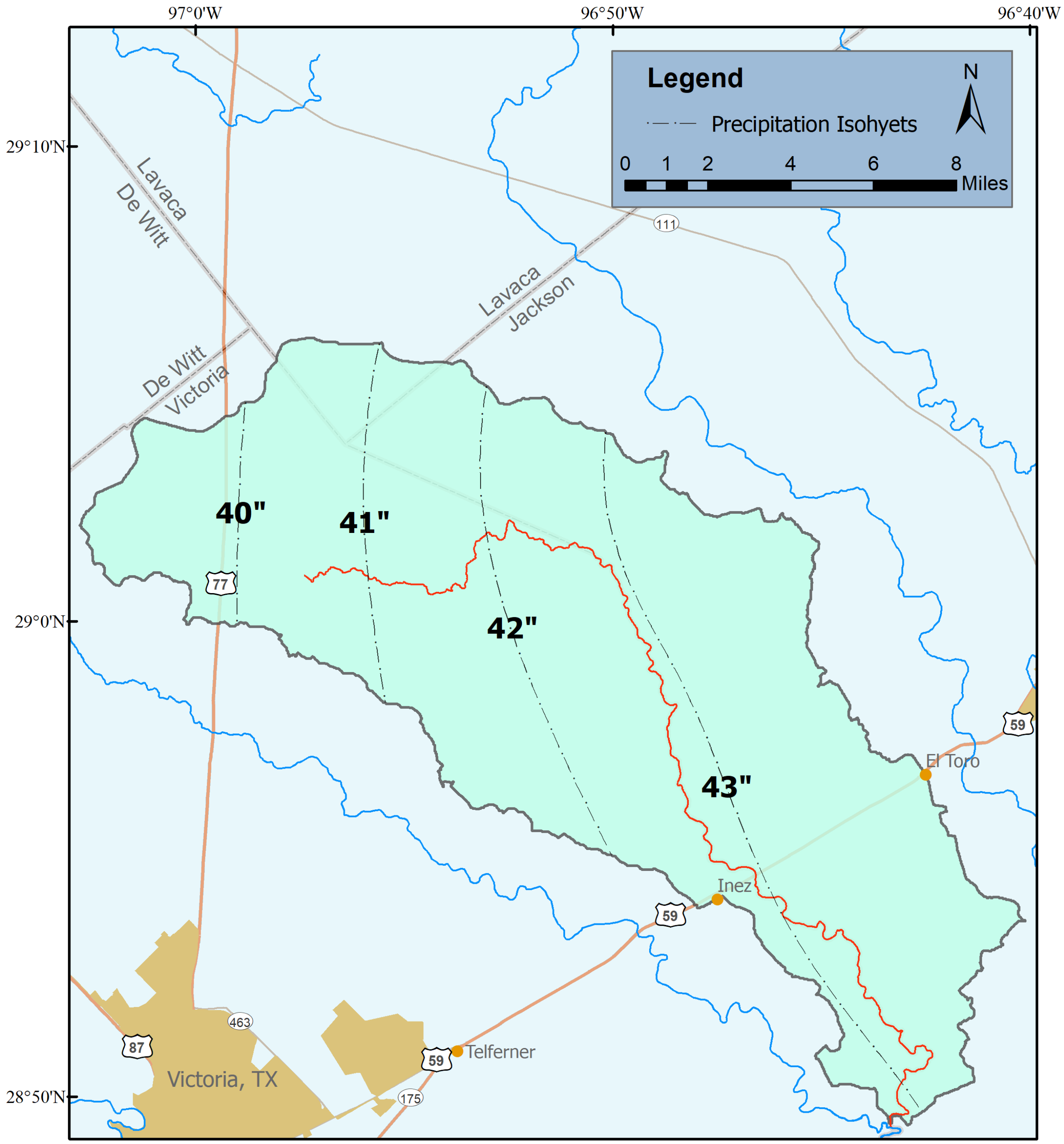

Figure 4. Average annual rainfall (inches) across the watershed from 1981-2010.
Source: PRISM Climate Group at Oregon State University (2012)

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 the 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 2453C_01 watershed is approximately 938 (Figure 5). There are no municipalities in the study area.

Population projections from the 2016 Region L Regional Water Plan (Region L (South Central Texas) Water Planning Group, 2015) and the 2016 Region P Regional Water Plan (Region P (Lavaca) Water Planning Group, 2015) were used to estimate population projections for counties within the watershed (Table 2).

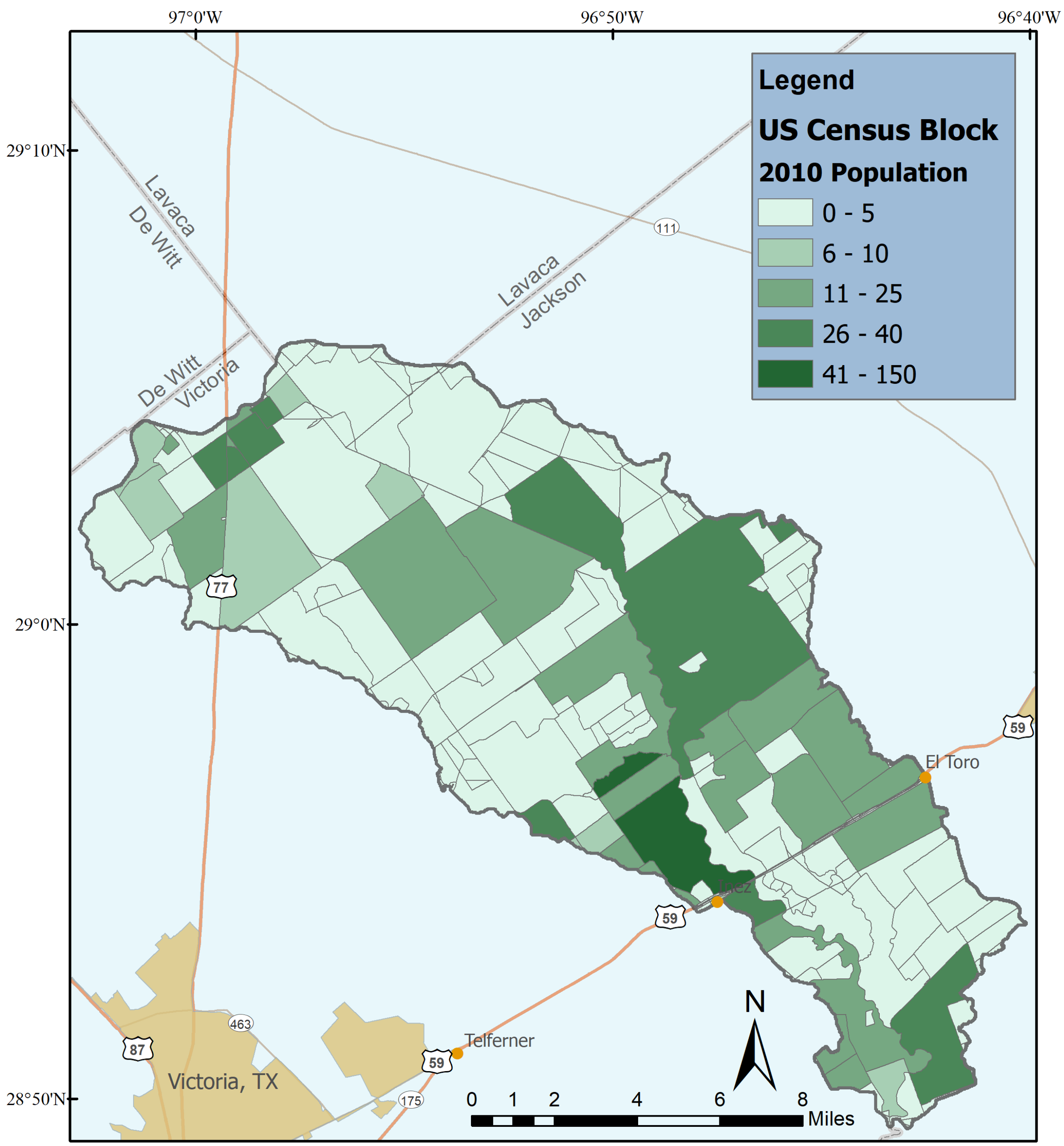

Figure 5. 2010 population estimates by US Census block.
Source: USCB (2010)

Table 2. 2010 population estimate and 2020-2070 population projections.
Source: Derived from Region L (South Central Texas) Water Planning Group (2015) and Region P (Lavaca) Water Planning Group (2015)

Group	2010	Projected 2020	Projected 2030	Projected 2040	Projected 2050	Projected 2060	Projected 2070	Percent Increase
Jackson County	203	211	218	221	224	226	227	11.8%
Lavaca County	4	4	4	4	4	4	4	0%
Victoria County	731	791	845	888	926	957	983	34.5%

2.5. Land Use

Land use and land cover for the watersheds were obtained from the 2011 National Land Cover Database (NLCD) (USGS, 2015), displayed in Figure 6. 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 percent cover of vegetation or soil.
- Developed, Open Space – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- Developed, Low Intensity – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 percent to 49 percent of total cover. These areas most commonly include single-family housing units.
- Developed, Medium Intensity – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 percent to 79 percent of total cover. These areas most commonly include single-family housing units.
- Developed, High Intensity – Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 percent to 100 percent of total cover.
- Barren Land (Rock/Sand/Clay) – Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.

- Deciduous Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
- Evergreen Forest – Areas dominated by trees generally greater than five meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the 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 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent total tree cover.
- Shrub/Scrub – Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
- Grasslands/Herbaceous – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
- Pasture/Hay – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
- Cultivated Crops – Areas used 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 percent of total vegetation. This class includes all land being actively tilled.
- Woody Wetlands – Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- Emergent Herbaceous Wetlands – Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil substrate is periodically saturated with or covered with water.

The total Arenosa Creek (AU 2453C_01) watershed area is 110,165.5 acres (Table 3) and predominately composed of Pasture/Hay (56.7 percent) and Cultivated Crops (15.3 percent). Urban development comprises less than one percent of the Arenosa Creek watershed.

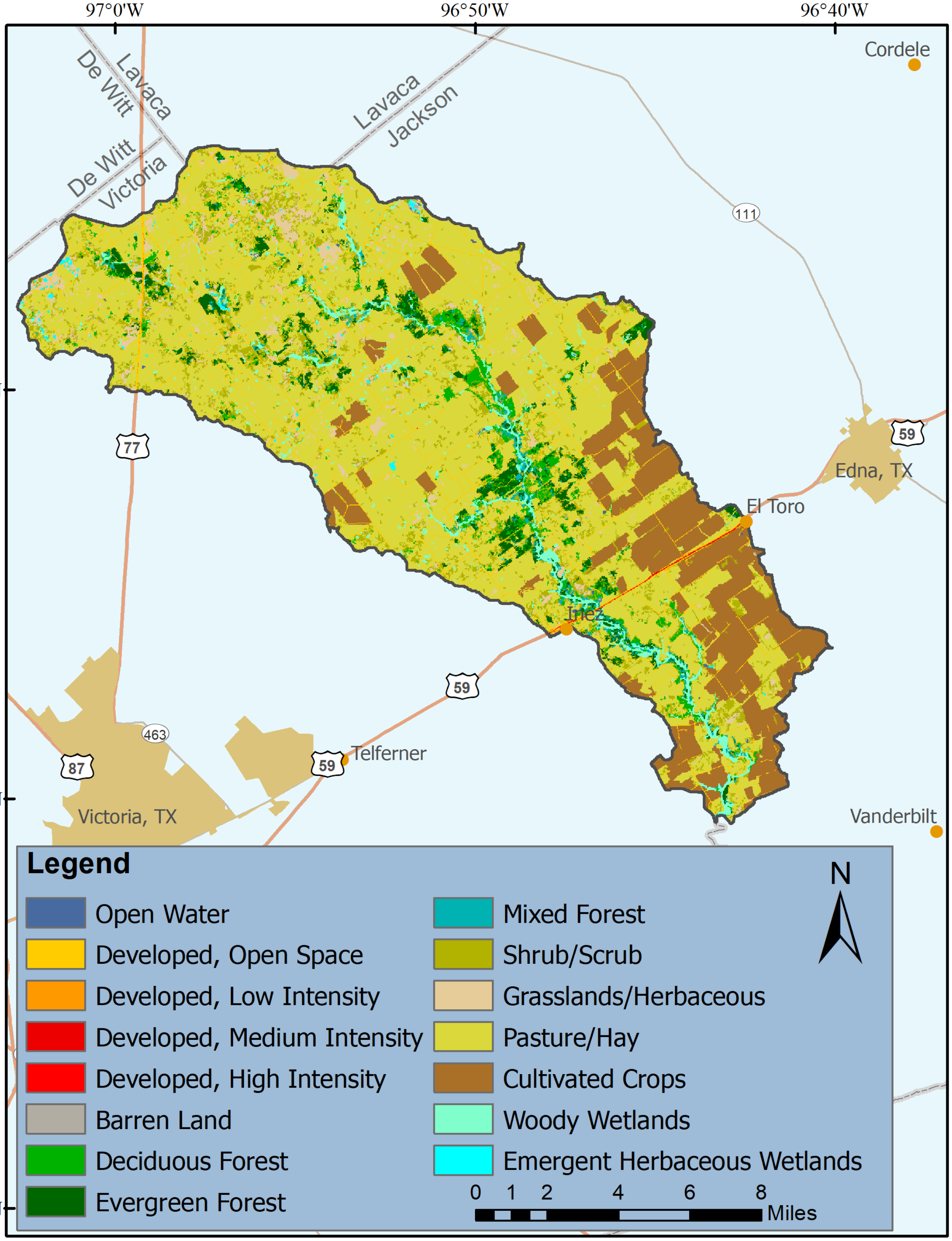

Figure 6. 2011 land use/land cover.
Source: National Land Cover Database (USGS, 2015)

Table 3. Land use/land cover breakdowns
Source: National Land Cover Database (USGS, 2015)

Land Use/Land Cover	Acres	Percent of Total
Open Water	81.84	0.1%
Developed, Open Space	3,733.34	3.4%
Developed, Low Intensity	185.25	0.2%
Developed, Medium Intensity	91.85	0.1%
Developed, High Intensity	1.11	< 0.1%
Barren Land	31.8	< 0.1%
Deciduous Forest	3,297.67	3.0%
Evergreen Forest	3,803.62	3.5%
Mixed Forest	1,156.01	1.0%
Shrub/Scrub	10,556.86	9.6%
Grassland/Herbaceous	4,373.84	4.0%
Pasture/Hay	62,422.23	56.7%
Cultivated Crops	16,880.88	15.3%
Woody Wetlands	3,249.86	2.9%
Emergent Herbaceous Wetlands	299.34	0.3%
Total	110,165.5	100%

2.6. Soils

Soil data was obtained from 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, C/D). 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.
- 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 watershed is depicted in Figure 7. Within the impaired Arenosa Creek watershed, soils are predominately composed of Type D (42.7 percent) and Type C (31.0 percent) hydrologic groups (Table 4).

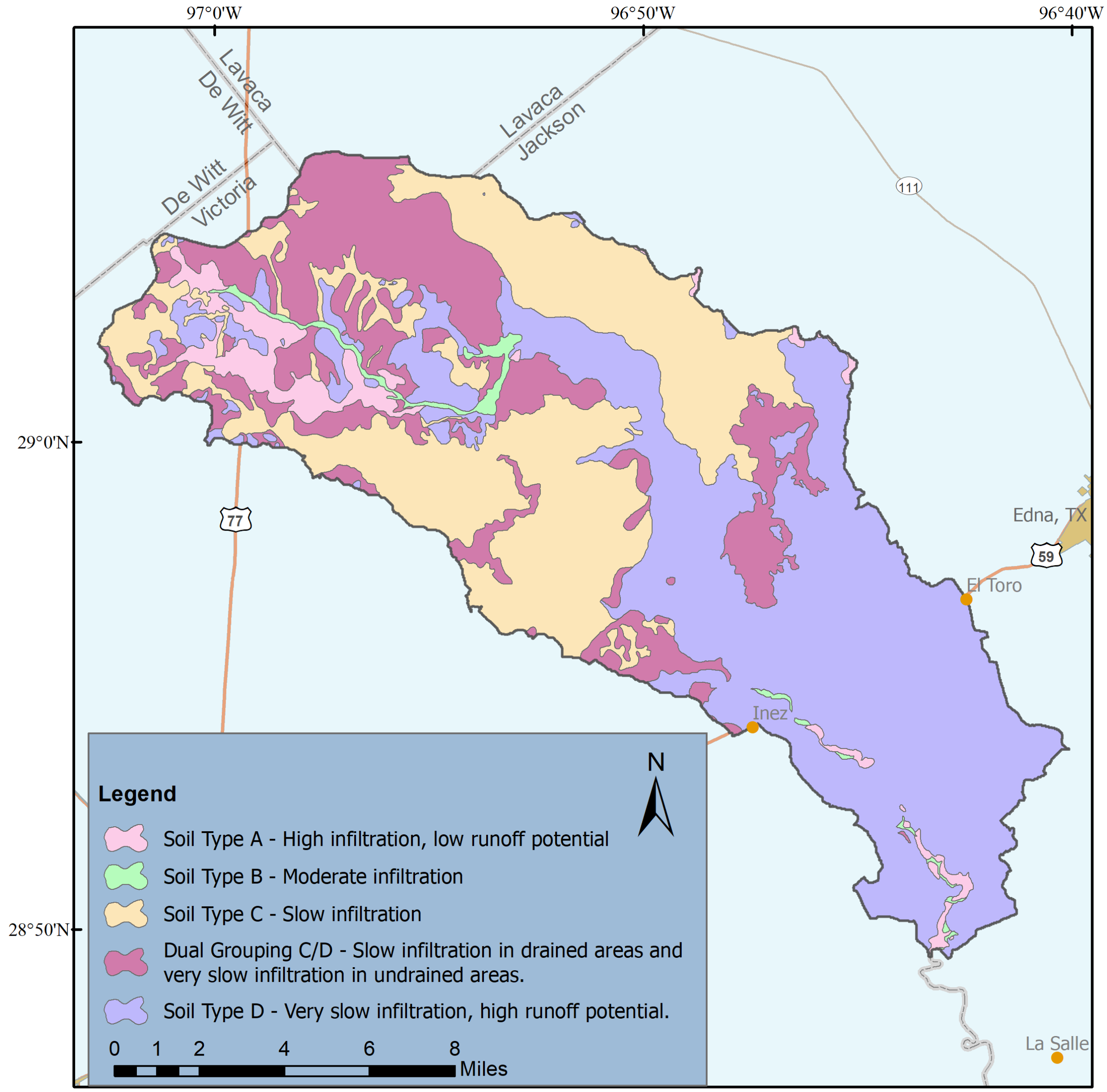

Figure 7. Hydrologic soil groups.
Source: SSURGO database (NRCS, 2015)

Table 4. Hydrologic soil group breakdowns.
Source: SSURGO Database (NRCS, 2015)

Hydrologic Group	Acres	Percent of Total
A	4,512.8	4.1%
B	1,230.8	1.1%
C	34,099.1	31.0%
D	47,032.8	42.7%
C/D	23,290.0	21.1%
Total	**110,165.5**	**100%**

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 (NPS) 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. Regulated Sources

As mentioned above, TPDES and NPDES regulate and permit discharges from WWTFs, and stormwater from industries, construction sites, and MS4s. Within the project watershed, permitted sources only include regulated stormwater from a single construction site and a sludge land application permit. There are no regulated discharges from WWTFs.

2.7.1.1. Sewage Sludge Land Application Permits

In the project watershed, TCEQ had issued a permit for the land application of sewage sludge on 793.4 acres of land in Victoria County (Table 5). The permit states that the sludge application rate cannot exceed eight dry tons per year and does not allow for discharge or runoff from the property.

Table 5. Regulated sludge land application.
Source: TCEQ 2017b

TPDES Permit No.	Permit Issue Date	Customer Name	Dates Monitored	Monthly Average Discharge (MGD)	Final Regulated Discharge (MGD)	Permit Requirement: Report Fecal Coliform Bacteria	Permit Disinfection Requirement2
WQ0004666000	05/31/07	Beneficial Land Management LLC (Sludge)[1]	NA	NA	NA	NA	NA

NA = Not applicable; MGD = million gallons per day

[1]Permit does not contain a discharge provision

[2]An equivalent method of disinfection may be substituted with approval from TCEQ. Only chlorination (no dechlorination) is required for facilities operating under a capacity of 1 MGD

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 regulated system. Since there are no collection systems or regulated dischargers in the watershed, SSO data is not reported.

2.7.1.3. 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 one active construction site permit as of November 07, 2017 (TCEQ, 2017b). The project watershed contained no MS4s, concrete production facilities, petroleum bulk stations, or terminals permits. The construction permit acreage was given as acres disturbed in the authorization details of the permit. The number of acres disturbed was 163. The construction permit was issued on August 01, 2016.

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

E. coli 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, the Texas Parks and Wildlife Department (TPWD) provided deer population-density estimates by Resource Management Unit (RMU) and Ecoregion in the state (TPWD, 2012). The Arenosa Creek watershed lies within RMU 12, for which average deer density over the period 2005-2011 was calculated to be one deer per 18.1 acres.

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, grasslands/herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, and emergent herbaceous wetlands (TWRI, 2009) (Table 6).

Table 6. Estimated deer and feral hog populations in the project watershed.
Source: Estimates derived from densities derived in previous studies (TWRI, 2009; TPWD, 2012).

AU	Deer	Feral Hogs
2453C_01	6,086	3,184

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 *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 non-urbanized land within each TMDL watershed. The refinement was determined by the total area of each county and the impaired AU that was designated as non-urbanized by the 2010 U.S. Census. The ratio was the non-urbanized area of the AU that resides within a county divided by the total non-urbanized area of the county. Watershed-level livestock numbers are the ratio multiplied by county-level data (Table 7).

Table 7. Livestock estimates for the project watershed.
Source: Estimates derived from USDA Census of Agriculture (USDA, 2014).

AU	Cattle and Calves	Hogs and Pigs	Chickens	Goats and Sheep	Horses
2453C_01	9,321	53	6,970	187	116

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 was estimated with 2010 Census Block household counts, multiplied by the proportion of the Census Block within the watershed. Table 8 summarizes the estimated number of pets in the project watershed.

Table 8. Estimated number of households and pet populations.
Source: Estimates derived from USCB Census blocks (USCB, 2010) and AVMA household pet estimates (AVMA, 2012).

AU	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
2453C_01	340	199	217

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 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 0.01percent 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 by using 911 addresses to estimate residence locations and these were verified with aerial imagery data (TWRI, 2014). OSSFs were estimated to be households that were outside of city boundaries and Certificated of Convenience and Necessity (CCN) areas (Public Utility Commission of Texas, 2017). Table 9 and Figure 8 show the total estimated OSSFs in the project watershed.

Table 9. OSSF estimate for the project watershed.
Source: Estimates derived from obtained 911 address data (TWRI, 2014) and CCN locations (Public Utility Commission of Texas, 2017).

AU	Estimated OSSFs
2453C_01	206

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 processes (replication and die-off) are instream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL watershed.

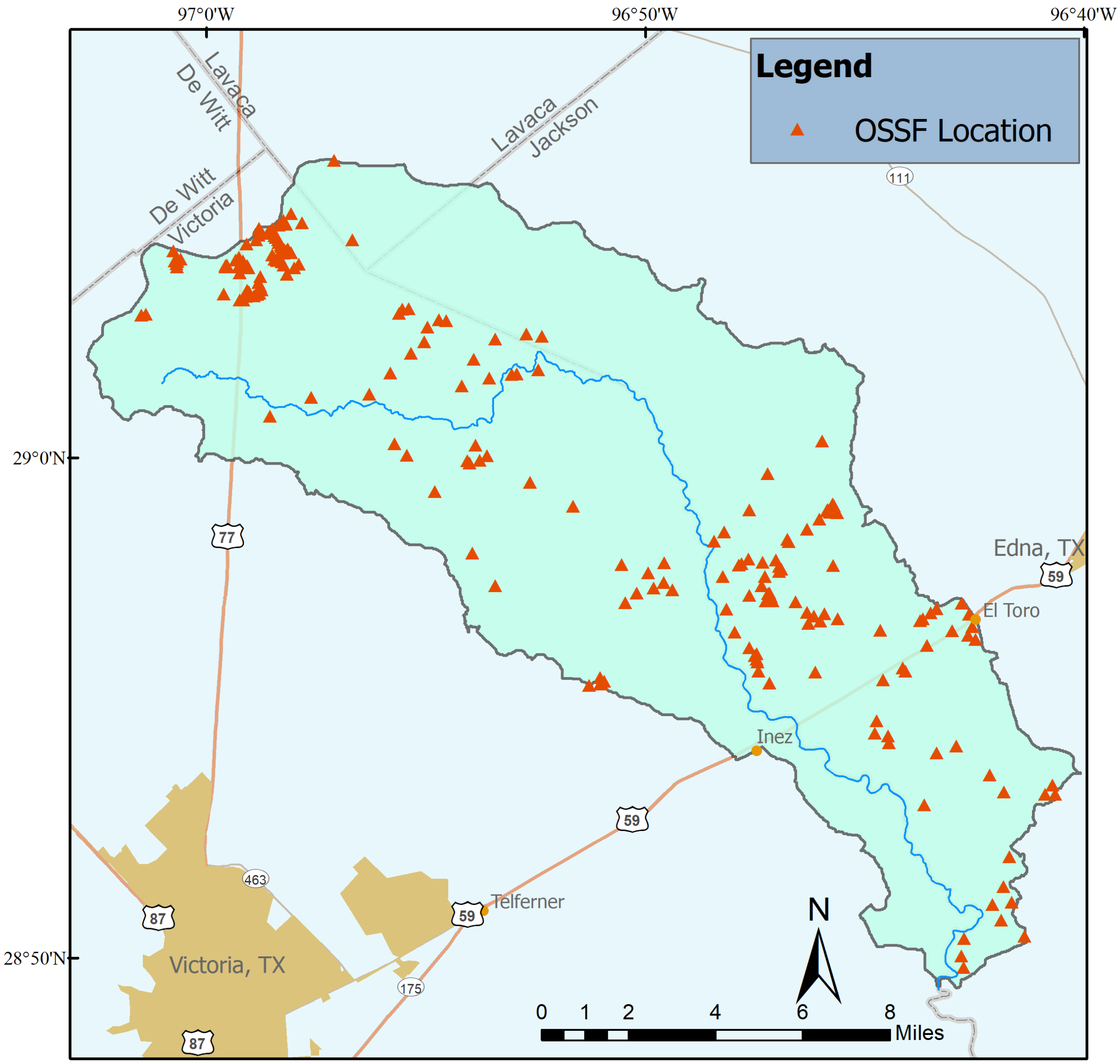

Figure 8. Estimated OSSF locations.
Sources: Estimates derived from obtained 911 address data (TWRI, 2014) and CCN locations (Public Utility Commission of Texas, 2017).

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 the impaired AU in the TMDL watershed 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). 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 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 regulatory 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 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, 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 Limitations of Mechanistic Modeling

Because the present surface water bacteria standards for the AU within the TMDL watersheds, as with 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 watershed. If a mechanistic modeling tool is applied, it must be capable of simulating the 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 the interaction of surface waters with shallow groundwater.

The bacteria component of the models is in many ways even more complex than the hydrologic component and typically must include different processes. Point sources and nonpoint sources of bacteria need to be defined and simulated by the model. Movement or washoff of bacteria from 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 resuspension, regrowth in the water column, regrowth in 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 bacterial processes. The hydrologic processes regarding the response of the landscape to rainfall are well studied over many decades because of implications on the transport of waterborne constituents, of which bacteria is only one of many. But even more importantly, these hydrologic processes are well-investigated because of the need 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. While advancements have improved mechanistic model representation of hydrologic and bacteria transport processes, the processes that contribute to bacteria loading remain appreciably more watershed-specific than the hydrologic processes represented in readily available models. 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 affect *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 loading predicted by the model, which potentially contain high uncertainty, will 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 the adequate definition of many of the physical and biological processes influencing instream 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 were unavailable in the TMDL watershed. However, streamflow records are available in an adjacent watershed (Garcitas Creek) with similar characteristics. Garcitas Creek daily streamflow records are collected and made available by the U.S. Geological Survey (USGS), which operates one streamflow gage in the watershed (Figure 9, Table 10). USGS streamflow gage 08164600 was used to develop mean daily streamflow for AU 2453C_01.

Table 10. Basic information on USGS streamflow gage used for streamflow development in Arenosa Creek

Gage No.	Site Description	AU Location	Drainage Area (square miles)	Daily Streamflow Record
08164600	Garcitas Creek near Inez, Texas	2453C_01	91.7	01-01-2000 – 10-09-2017

Historical ambient *E. coli* data used for the development of LDCs was obtained through a data request to TCEQ Data Management and Analysis Team (TCEQ, 2017a) (Table 11).

Table 11. Summary of historical bacteria dataset for station 13295

Water Body	AU	Station	Station Location	No. of Samples	Data Date Range	Geomean	% exceeding single sample criterion
Arenosa Creek	2453C_01	13295	Arenosa Creek north of Inez	44	12-11-2000 – 08-06-2015	233.6	61.4%

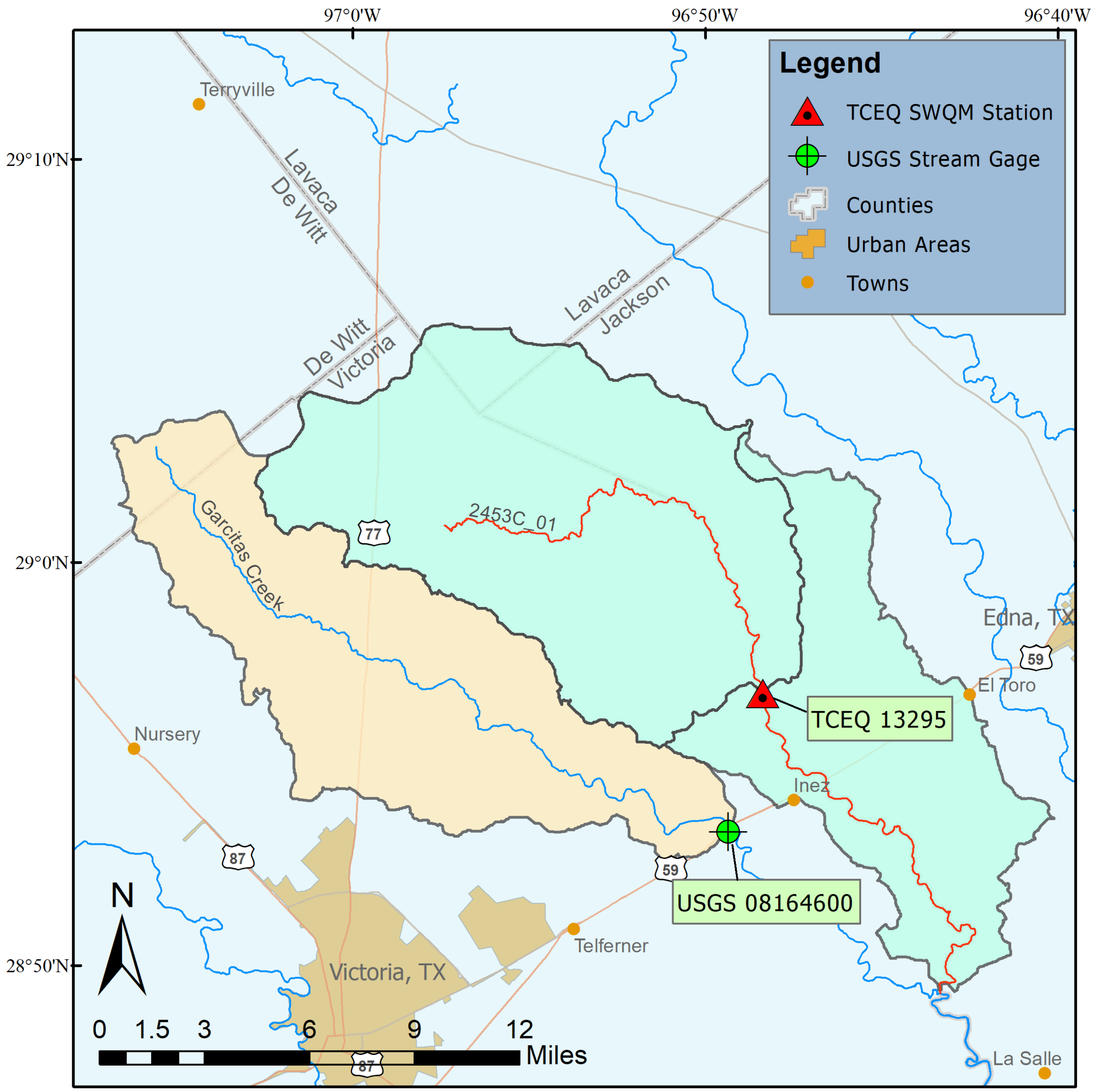

Figure 9. USGS streamflow gage and watershed used in streamflow development for Arenosa Creek.
Sources: USGS Gage Locations (USGS, 2011), TCEQ Monitoring Station Locations (TCEQ, 2012), TCEQ Assessment Units (TCEQ 2015b)

3.1.3. Allocation Tool Selection

Based on good availability of ambient *E. coli* data and developed daily streamflow records, as well as deficiencies in data to describe bacteria loads and instream 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 the desired stream location for which FDC and LDC development is desired.
- Step 3: Develop daily streamflow records at desired stream location using daily gaged streamflow records and drainage area ratios.
- Step 4: Develop FDC at the desired stream location, segmented into discrete flow regimes.
- Step 5: Develop allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 6: Superimpose historical bacteria data on the allowable bacteria LDC.

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 developed from USGS gage 08164600 in the adjacent Garcitas Creek watershed (Figure 9). 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 September 2000 to September 2015 was selected. This 15-year period of record was selected 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 Location

There is a single SWQM station (13295) within the impaired AU with adequate data for LDC development. 44*E. coli* samples are available at the station, meeting the 24 minimum sample suggestion for development of LDCs (TWRI, 2007). It was determined to develop an FDC and LDC at station 13295.

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 15-year daily streamflow record for the station. The daily streamflow record was developed from extant USGS records.

The method to develop the necessary streamflow record for the FDC/LDC location involved a drainage-area ratio (DAR) approach. With this basic approach, each USGS gage's daily streamflow value within the 15-year period was multiplied by a factor to estimate flow at the desired SWQM station location. The equation for this approach is

$$Y = X\left(\frac{A_y}{A_x}\right)^{\phi}$$

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,

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

Often, ϕ = 1 is used in the DAR approach. However, empirical analysis of streamflows in Texas indicates that ϕ = 1 results in substantial bias in streamflow estimates at very low and very high streamflow percentiles (Asquith et al. 2006). Based on these observations, 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 12 provides the DAR used to develop streamflows at SWQM station 13295. Garcitas Creek was chosen because of its proximity and the similar land use characteristics above USGS gage 08164600 to Arenosa Creek. Because there are no regulated dischargers in either watershed, further adjustments were not required to develop streamflow estimates.

Table 12. Drainage-area ratio calculation

Watershed	Drainage Area (square miles)	DAR
Garcitas Creek above USGS Gage 08164600	91.7	NA
SWQM Station 13295[1]	109.1	1.2
Outlet of 2453C_01[2]	172.1	1.9

[1] location of FDC and LDC development

[2] included for informational purposes, not used for flow development

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.

5. 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).
6. Compute the percent of days each flow was exceeded by dividing each rank by the total number of data points plus 1.
7. 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 (2.44658×109), which gives you a loading unit of MPN/day.

- Plot the exceedance percentages, which are identical to the value for streamflow data points, against the geometric mean criterion for *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 steps.

- 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 (2.44658×109.

- 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 indicated an exceedance of the water quality criterion, while those below a curve show compliance.

3.3. Flow Duration Curve for TMDL Watershed

An FDC was developed for Arenosa Creek (AU 2453C_01) at SWQM station 13295 (Figure 10). For this report, the FDC was developed by applying the DAR method and using the USGS gage and period record (2000-2015) described in the previous section. As with Garcitas Creek, FDC indicates no instream flow approximately 19 percent of the time, which is anticipated to be reflective of actual conditions in the creek.

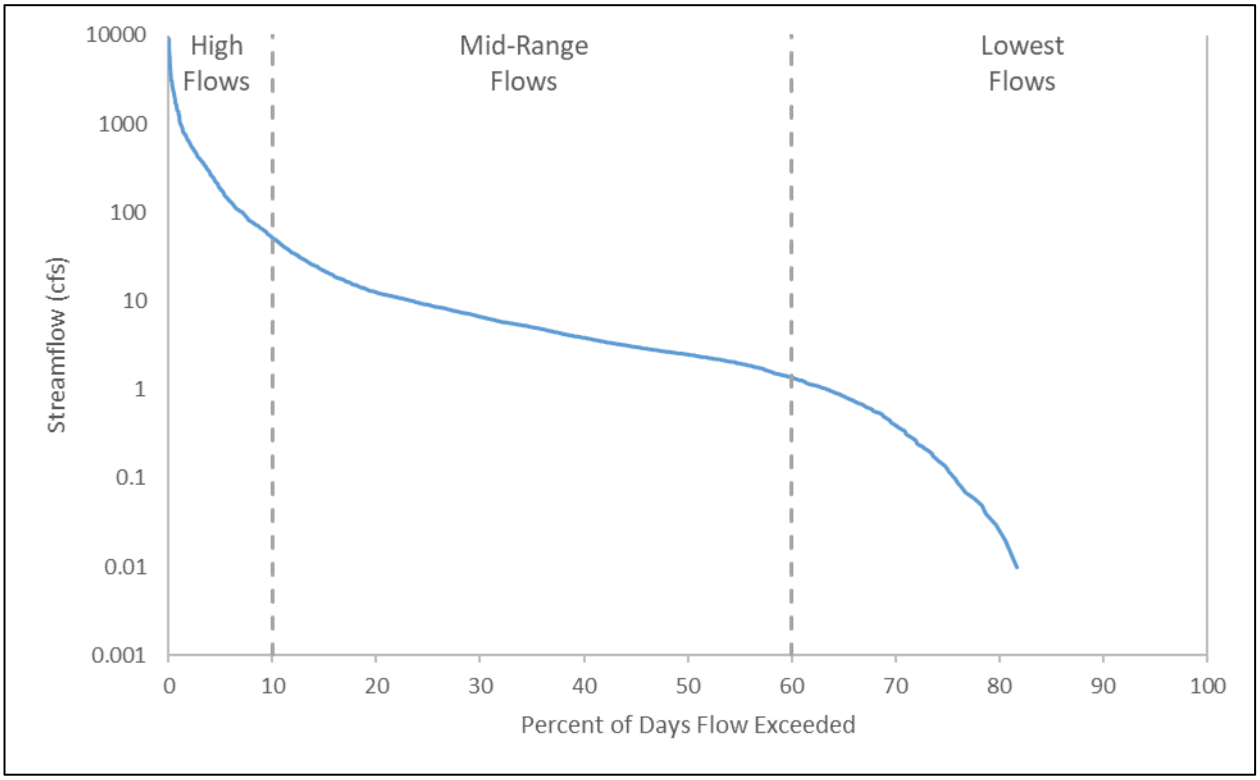

Figure 10. Flow duration curve for Arenosa Creek (AU 2453C_01) at station 13295

3.4. Load Duration Curve for TMDL Watershed

An LDC was developed for Arenosa Creek (AU 2453C_01) at SWQM station 13295 (Figure 11). 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 percent (high flows); (2) 10-40 percent (moist conditions); (3) 40-60 percent (mid-range flows); (4) 60-90 percent (dry conditions); and (5) 90-100 percent (low flows).

For Arenosa Creek the curve was divided into three flow regimes to assist in determining streamflow conditions under which exceedances occurred.

- High flow (0-10 percent flow exceedance) – related to flood conditions and nonpoint sources loadings
- Mid-range flow (10-60 percent flow exceedance) – intermediate conditions of receding hydrographs after storm runoff and baseline conditions
- Lowest flows (60-100 percent flow exceedance) – related to dry conditions

The selection of the flow regime intervals was based on general observation of the developed LDC. Figure 11 depicts the LDC for Arenosa Creek (AU 2453C_01). The geometric mean loading in each flow regime is also shown to aid interpretation.

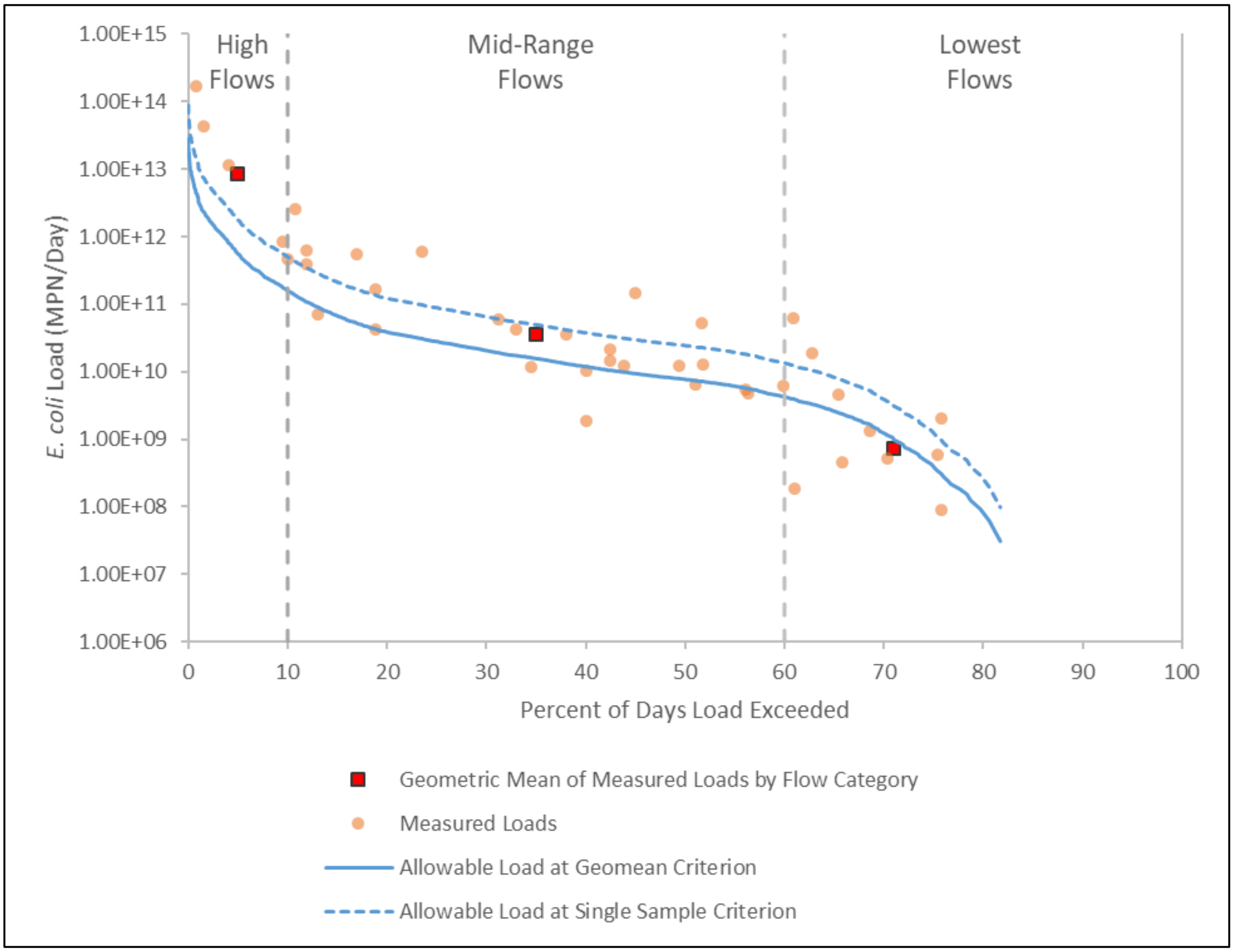

Figure 11. Load Duration Curve for Arenosa Creek (AU 2453C_01) at station 13295

Section 4. TMDL Allocation Analysis

4.1. Endpoint Identification

The water body within the TMDL watershed has 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 the concentration of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This endpoint was applied to the AU addressed with 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 was assessed by comparing *E. coli* 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-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 Arenosa Creek (AU 2453C_01) ($W=294.5$, $p=0.074$, Figure 12).

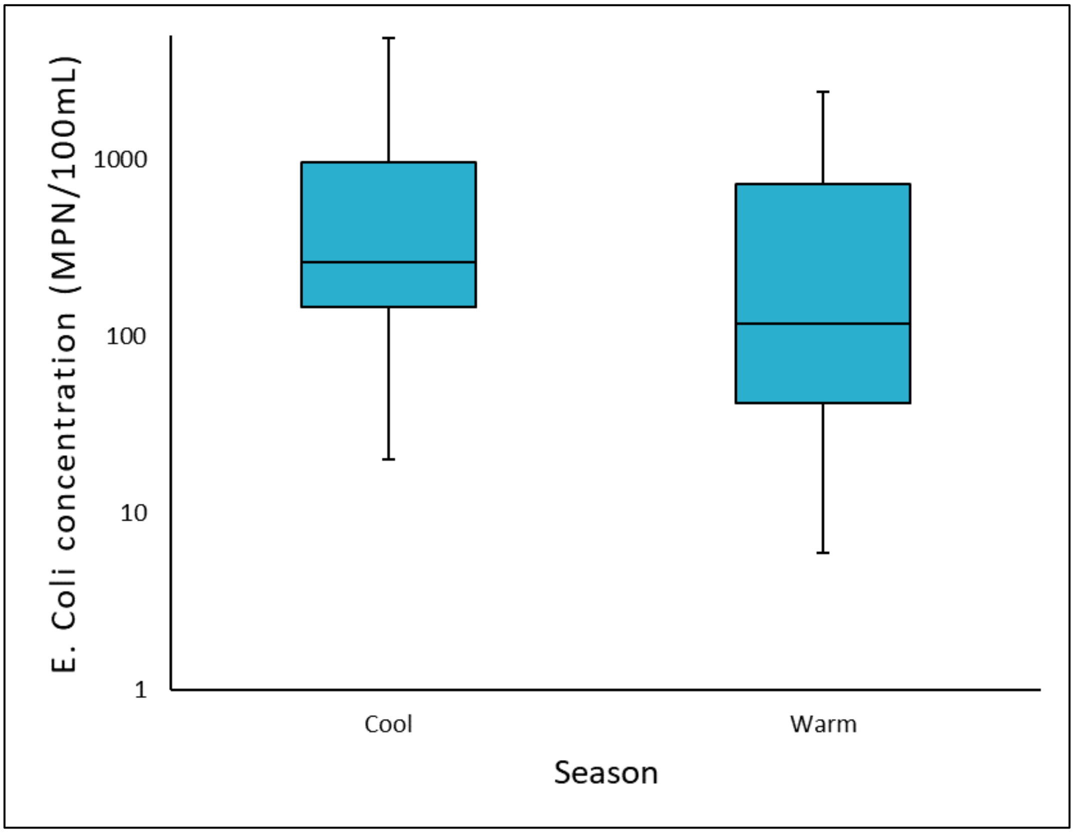

Figure 12. Distribution of E. coli concentration by season in Arenosa Creek

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 lower concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Load duration curves were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a direct relationship between pollutant load sources (regulated and non-regulated) 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 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 they 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. 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 hydrological 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 11) and Section 2.6 (Potential Source of Fecal Indicator Bacteria), the following broad linkage statements can be made. For the Arenosa Creek (AU 2453C_01) watershed, historical *E. coli* data indicate that elevated bacteria loading primarily occurs under high and mid-range flow conditions. However, bacteria loads are most elevated under the highest flow conditions. Under the lowest flow conditions, bacteria loads are typically under the single sample criterion and approach the geometric mean criterion.

Regulated stormwater comprises a minor portion of the watershed; therefore, non-regulated stormwater likely contributes to the majority of high flow related loadings in the watershed. Since there are no WWTFs in the watershed, 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 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 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 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 TMDL for the project watershed 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 the station in the impaired watershed (Table 13). The estimated existing load in each flow regime was calculated with the geometric mean concentration in each flow category and the median flow in each flow category (excluding days with zero flow) as estimated in Section 3.3.

The existing load was calculated as:

$$Exisiting\ Load_{FC} = \tilde{Q}_{FC} \times G_{FC} \times Conversion\ Factor$$

Where:

Existing Load $_{FC}$ = Existing bacteria load at the median flow for flow category *FC*

FC = Respective flow category, representing high (0-10 percent), mid-range (10-60 percent), and lowest (60-100 percent) flow regimes

$\tilde{Q}_{FC}$ = Median flow for flow category *FC*

C_{FC} = Geometric Mean of bacteria (MPN *E. coli*/100mL) samples for flow category *FC*

Conversion Factor = 28,316.8 mL/ft^3 × 86,400 seconds/day

The allowable load was calculated as:

$$Allowable\ Load_{FC} = \tilde{Q}_{FC} \times Criterion \times Conversion\ Factor$$

Where:

Allowable Load $_{FC}$ = Allowable load at the median flow for flow category *FC*

$\tilde{Q}_{FC}$ = Median flow in each flow category

Criterion = 126MPN/100 mL (*E. coli*)

Conversion Factor = 28,316.8 mL/ft^3 × 86,400 seconds/day

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

$$PR_{FC} = (Exisiting\ Load_{FC} - Allowable\ Load_{FC})/Allowable\ Load_{FC}$$

Table 13. Percent reductions needed to meet water quality standards in Arenosa Creek

Flow Regime	Existing Load (Billion MPN/Day)	Allowable Load (Billion MPN/Day)	Percent Reduction Required (%)
High Flows	8,391.397	558.859	93.340
Mid-Range Flows	35.423	15.691	55.700
Low Flows	0.742	1.048	Not Applicable

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 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 *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 impaired AU covered in this report is derived using the median flow within the high flow regime (or five percent flow) of the LDC developed for Arenosa Creek at SWQM station 13295. 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 TMDL for the impaired AU was developed as a pollutant load allocation based on information from the LDC developed for the outlet of the impaired AU (Figure 10). As discussed in more detail in Section 3, a bacteria LDC was developed by multiplying the streamflow value along the FDC by the primary contact recreation *E. coli* criterion (126 MPN/100mL) 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:

$$\text{TMDL} = \text{Criterion} \times \text{Flow} \times \text{Conversion Factor} \qquad \text{Eq. 2}$$

Where:

Criterion = 126 MPN/100 mL (*E. coli*)

Conversion Factor (to MPN/day) = 28,316.8 mL/ft^3 × 86,400 seconds/day

At the five percent load duration exceedance, the TMDL value is provided in Table 14.

Table 14. Summary of allowable loadings for Arenosa Creek

AU	5% Exceedance Flow (cfs)	5% Exceedance Load (MPN/day)	TMDL (Billion MPN/day)
2453C_01	181.29	558,859,078,085	558.8591

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:

$$MOS = 0.05 \times TMDL \qquad \text{Eq. 3}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

The MOS for each AU is presented in Table 15.

Table 15. Summary of MOS for the Arenosa Creek

AU	TMDL (Billion MPN/day)	MOS (Billion MPN/day)
2453C_01	558.859	27.943

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}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{Eq. 4}$$

Wastewater (WLA_{WWTF})

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

$$WLA_{WWTF} = \text{Criterion} \times \text{Flow} \times \text{Conversion Factor} \qquad \text{Eq. 5}$$

Where:

Criterion = 126 MPN/100mL *E. coli*

Flow = full regulated flow (MGD)

Conversion Factor (to MPN/day) = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d

The daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined to be zero because there are no WWTFs in the watershed, therefore there is no regulated flow from any WWTFs.

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 area 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 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 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:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) \times FDA_{SWP} \qquad \text{Eq. 6}$$

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 regulated 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 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 16.

Table 16. Regulated stormwater acreage and FDA_{swp} calculation for Arenosa Creek

AU	Industrial General Permits (acres)	Construction Permits (acres)	Total Area of Permits (acres)	Watershed Area	FDA_{SWP}
2453C_01	0	163	163	110,165.5	0.148%

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 17 for continuity.

Table 17. Regulated stormwater calculations for Arenosa Creek

AU	TMDL†	WLA_{WWTF}†	FG†	MOS†	FDA_{SWP}†	WLA_{SW}†
2453C_01	558.859	0	0.289	27.943	0.148%	0.785

† 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 18).

Table 18. Wasteload allocation summary for Arenosa Creek

AU	WLA_{WWTF}†	WLA_{SW}†	WLA†
2453C_01	0	0.785	0.785

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

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 AU, the loadings from 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 projected population growth within WWTF service areas between 2010 and 2070, based on data obtained from the 2016 Region L Regional Water Plan (Region L (South Central Texas) Water Planning Group, 2015) and the 2016 Region P Regional Water Plan (Region P (Lavaca) Water Planning Group, 2015).

$$FG = Criterion \times (\%POP_{2010\text{-}2070} \times WWTF_{FP}) \times Conversion\ Factor \qquad \text{Eq. 7}$$

Where:

FG = Future growth from existing WWTFs

Criterion = 126 MPN/100mL (*E. coli*)

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

$WWTF_{FP}$ = Full regulated discharge (MGD)

Conversion Factor = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d

For this TMDL, conventional FG calculations are hampered by the $WWTF_{FP}$ being zero. While there are no plans for a WWTF to be built in the watershed, the TMDL must still account for the possibility of FG for the impaired segment. In order to address this shortcoming, an FG term was calculated for the Arenosa Creek (AU 2453C_01) watershed to accommodate the potential of a WWTF to serve residents within the watershed.

Discharge flow for the potential WWTF was determined by first estimating the population served. The FG of the Arenosa Creek (AU 2453C_01) watershed population was estimated by totaling the 2070 population estimates for all three counties in the watershed. Because of the low population density, it was assumed that only half the population could feasibly be connected to a WWTF. Rule §217.32 of the TAC states that a new WWTF must be designed for a wastewater flow of 75-100 gallons per capita per day (TAC, 2008). The discharge flow was then estimated by multiplying the estimated population served by 100 gallons per capita per day and converted to MGD.

Since FG from existing plants equals zero, FG from a hypothetical potential plant was calculated as:

$$FG = \text{Criterion} \times (0.5 \times POP_{2070}) \times \text{Design Standard} \times \text{Conversion Factor} \qquad \text{Eq. 8}$$

Where:

FG = future growth for a potential WWTF

Criterion = 126 MPN/100mL (*E. coli*)

POP2070 = Estimated watershed population in 2070

Design Standard = 1×10^{-7} million gallons per capita per day

Conversion Factor = 1.54723 cfs/MGD × 28,316.8 mL/ft^3 × 86,400 s/d

Table 19. Future growth calculation attributed to potential WWTF service in Arenosa Creek

Arenosa Creek (AU 2453C_01) Watershed Population	Potential WWTF Service Population	Potential WWTF Discharge (MGD)	FG†
1,214	607	0.061	0.289

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

4.7.5. Load Allocation (LA)

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

$$LA = TMDL - WLA - FG - MOS \qquad \text{Eq. 8}$$

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 regulated facilities

MOS = margin of safety load

Table 20 summarizes LA calculations

Table 20. Load allocation summary for Arenosa Creek

AU	TMDL†	WLA†	FG†	MOS†	LA†
2453C_01	558.859	0.785	0.289	27.943	529.841

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

4.8. Summary of TMDL Calculations

Table 21 summarizes the TMDL calculations for the project watershed. The TMDL was calculated based on median flow in the 0-10 percentile range (five percent exceedance, high flow regime) for flow exceedance from the LDC developed for the outlet of the AU. Allocations are based on the current geometric mean criterion for *E. coli* of 126 MPN/100mL for each component of the TMDL.

Table 21. TMDL allocation summary for Arenosa Creek

AU	TMDL†	MOS†	WLA_{WWTF}†	WLA_{SW}†	LA†	FG†
2453C_01	558.859	27.943	0	0.785	529.841	0.289

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

The final TMDL allocations (Table 22) 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 comprised of the sum of loadings arising from within the AU that is associated with unregulated sources.

Table 22. Final TMDL allocations for Arenosa Creek

AU	TMDL†	WLA_{WWTF}†	WLA_{SW}†	LA†	MOS†
2453C_01	558.859	0.289	0.785	529.841	27.943

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

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 22.

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

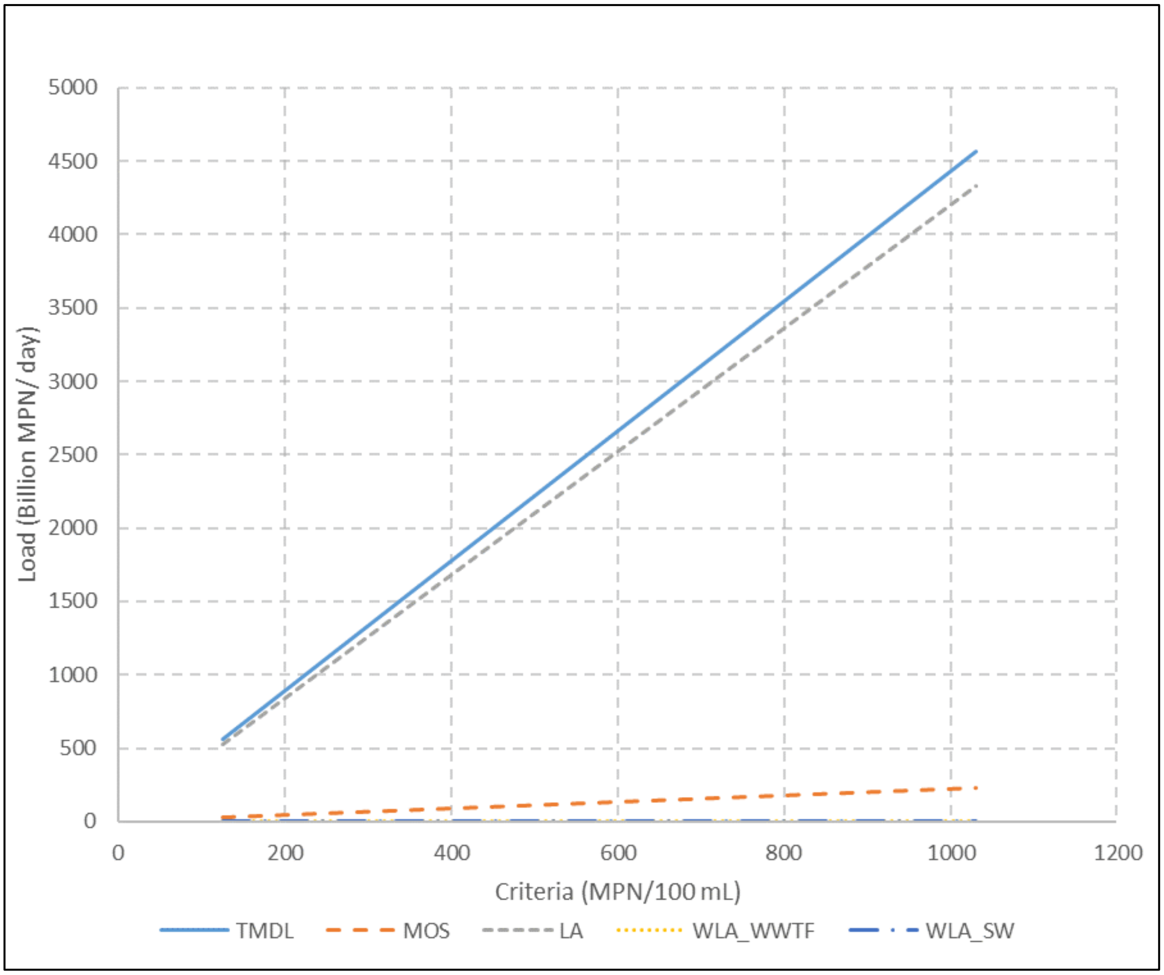

Figure A- 1. Allocation loads for Arenosa Creek as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day) for Arenosa Creek:

$$TMDL = 4.4353895 \times Std$$

$$MOS = 0.2217695 \times Std$$

$$LA = 4.20738384 \times Std - 0.2890821$$

$$WLA_{WWTF} = 0.28950$$

$$WLA_{SW} = 0.0062362 \times Std - 0.0004382$$

Where:

Std = Revised Water Quality Standard

MOS = Margin of Safety

LA = Total load allocation (unregulated source contributions)

WLA_{WWTF} = Wasteload allocation (regulated WWTF + FG)

WLA_{SW} = Wasteload allocation (permitted stormwater)

Table A- 1. Summary of allocation loads for Arenosa Creek at selected revised water quality standards

Std (MPN/100mL)	TMDL†	MOS†	LA†	WLA_{WWTF}†*	WLA_{SW}†
126	558.859	27.943	529.841	0.289	0.785
630	2794.295	139.715	2650.363	0.289	3.928
1030	4568.451	228.423	4333.316	0.289	6.423

† in units of a 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