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One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek

Assessment Unit 2453C_01

Water Quality Planning Division, Office of Water
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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This total maximum daily load report is based in large part on the report titled:
"Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek"
prepared by the Texas Water Resources Institute.

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Abbreviations

AU	assessment unit
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming units
DAR	drainage-area ratio
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FDC	flow duration curve
FG	future growth
I&I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
LDC	load duration curve
MCM	minimum control measures
mL	milliliter
MGD	million gallons per day
MOS	margin of safety
MSGP	multi-sector general permit
MS4	municipal separate storm sewer system
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
RMU	resource management unit
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic Database
SWMP	Stormwater Management Program
SWQM	surface water quality monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load

TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TWRI	Texas Water Resources Institute
UA	urbanized area
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WQBEL	water quality-based effluent limit
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek

Executive Summary

This document describes one total maximum daily load (TMDL) for Arenosa Creek, where concentrations of indicator bacteria exceed the criteria used to evaluate attainment of primary contact recreation use. This TMDL takes a watershed approach to address the indicator bacteria impairment. The Texas Commission on Environmental Quality (TCEQ) first identified the impairment to Arenosa Creek in the *2010 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report) (TCEQ, 2011).

Arenosa Creek Segment 2453C is composed of a single assessment unit (AU) identified as AU 2453C_01 (Figure 1). The Arenosa Creek watershed is 172.1 square miles and includes portions of Victoria, Jackson, and Lavaca counties. Arenosa Creek flows approximately 32.7 miles downstream from J-2 Ranch Road in Victoria County along the Jackson-Victoria county line to the confluence with Garcitas Creek Tidal. This document will consider the bacteria impairment in the single AU of one segment:

- Arenosa Creek (AU 2453C_01)

No facilities are currently authorized to discharge wastewater into the impaired watershed. One land application permittee was identified. However, land application permits do not have authorized discharges or bacteria reporting limits in their permits.

Regulated stormwater accounts for less than 1% of the watershed. There are no Phase I or Phase II municipal separate storm sewer systems (MS4s) or industrial permittees. Only one active construction permit was identified in the watershed. The area included within the construction permit was used to estimate the area under stormwater regulation.

Escherichia coli (*E. coli*) and Enterococci are used as indicator bacteria in freshwater and saltwater, respectively. *E. coli* is the relevant indicator for the Arenosa Creek assessment unit. The primary contact recreation use is not supported when the geometric mean of *E. coli* samples exceeds the geometric mean criterion of 126 colony forming units (cfu) per 100 milliliters (mL) for *E. coli* in freshwater streams.

Water quality monitoring has occurred at a single TCEQ monitoring station on Arenosa Creek. *E. coli* data collected at this station from the assessment period of December 1, 2000, to November 30, 2008, were used in assessing attainment

of the primary contact recreation use as reported in the 2010 Texas Integrated Report. The geometric mean concentration during the assessment period was 197.6 cfu/100 mL, thereby exceeding the geometric mean criterion of 126 cfu/100 mL and indicating non-support of the primary contact recreation use. The impairment has been carried forward due to insufficient data in each subsequent Texas Integrated Report through the recently EPA-approved 2020 Texas Integrated Report (TCEQ, 2020a).

A load duration curve (LDC) analysis was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources of indicator bacteria. The wasteload allocation (WLA) for wastewater treatment facilities (WWTFs) could not be calculated, because there are no WWTFs in the Arenosa Creek watershed. Future growth (FG) of existing or new point sources was determined using population projections.

For the Arenosa Creek watershed, unregulated nonpoint sources such as wildlife, feral animals, livestock failing on-site sewage facilities (OSSFs), and domestic pets are the most likely sources of indicator bacteria during high-flow conditions. The sources of indicator bacteria loadings occurring under low-flow conditions and in the absence of overland-flow contributions (i.e., without stormwater contribution) are expected to originate from direct deposition sources such as wildlife (avian and non-avian), feral hogs, and livestock.

The TMDL calculations in this report will guide determination of the assimilative capacity of the water body under changing conditions, including FG. Future wastewater discharge facilities will be evaluated on a case by case basis.

Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a TMDL for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. 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.

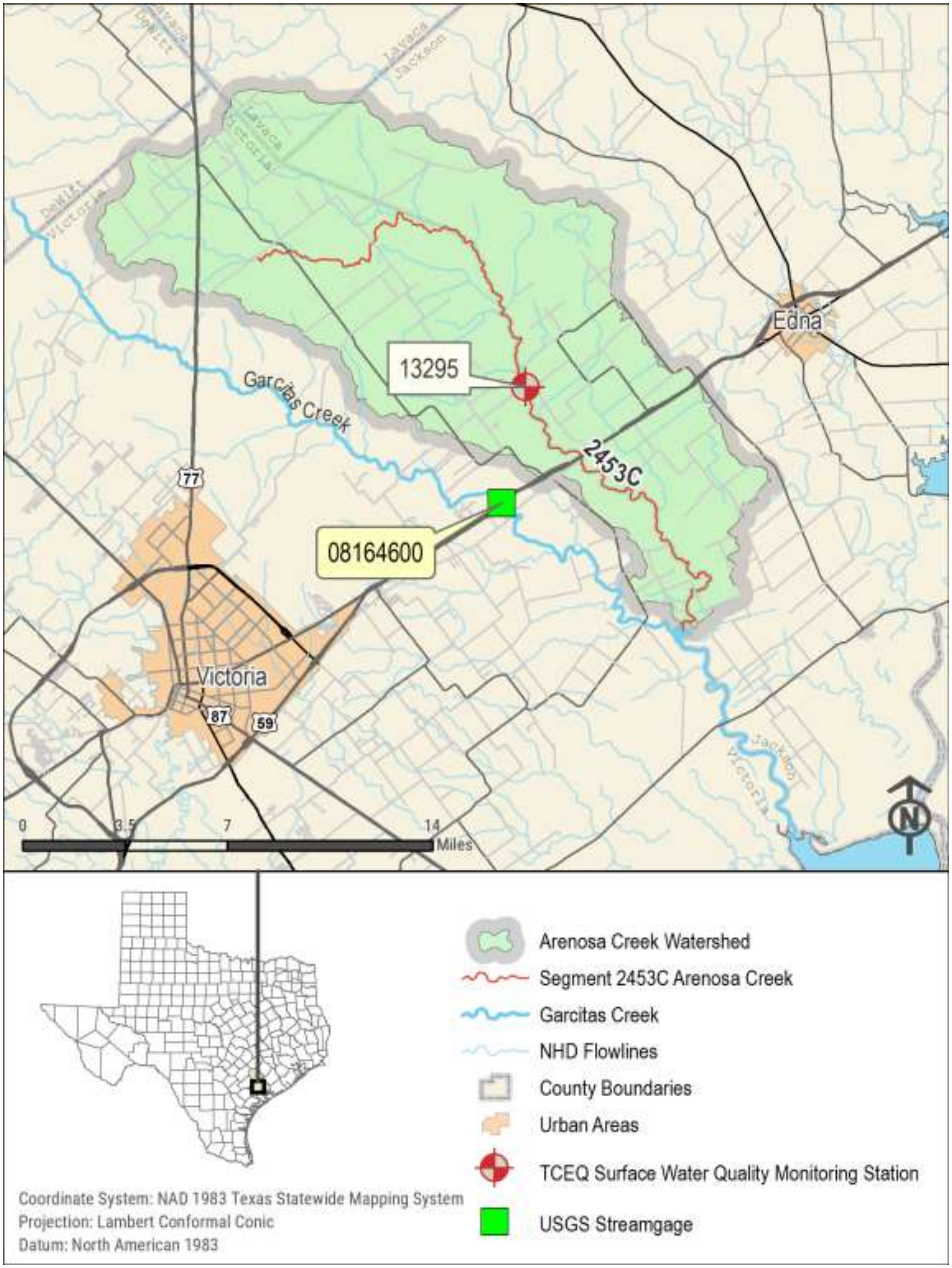

Figure 1. Overview map showing the Arenosa Creek watershed and TCEQ monitoring station

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 program's primary objective is to restore and maintain water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

This TMDL document addresses an impairment to the primary contact recreation use due to exceedance of the geometric mean criterion for *E. coli* in Arenosa Creek (AU 2453C_01). This TMDL document uses a watershed approach to address the impairment. While TMDL allocations were developed only for the impaired AU identified in this report, the entire project watershed (Figure 1) and all regulated dischargers that discharge within it are included within the scope of this TMDL. Information in this TMDL document was derived from the *Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek*[1] (Jain, Ruff, & Schramm, 2018).

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

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

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

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

[1] www.tceq.texas.gov/assets/public/waterquality/tmdl/108arenosa/108-arenosa-tsd-final.pdf

Problem Definition

TCEQ first identified the impairment to Arenosa Creek (AU 2453C_01) in the 2010 Texas Integrated Report (TCEQ, 2011). The listing was carried forward due to insufficient data in each subsequent Texas Integrated Report through the most recent EPA-approved 2020 Texas Integrated Report (TCEQ, 2020a). This document will consider the bacteria impairment in a single AU of one segment: Arenosa Creek (AU 2453C_01).

Ambient Indicator Bacteria Concentration

Routine monitoring in Arenosa Creek (AU 2453C_01) with sufficient *E. coli* samples for assessment (minimum of 20 samples) has occurred at a single surface water quality monitoring (SWQM) station (13295). *E. coli* data collected at this station indicated a geometric mean concentration of 197.6 cfu/100 mL from the assessment period of December 1, 2000, through November 30, 2008 (Table 1). The impairment listing has been carried forward through the 2012 Texas Integrated Report (TCEQ, 2013), 2014 Texas Integrated Report (TCEQ, 2015), 2016 Texas Integrated Report (TCEQ, 2019b), 2018 Texas Integrated Report (TCEQ, 2019a), and 2020 Texas Integrated Report (TCEQ, 2020a) due to insufficient data for assessment. The 2010 assessment data indicate non-support of the primary contact recreation use because of the geometric mean concentrations exceeding the geometric criterion of 126 cfu/100 mL for Arenosa Creek (AU 2453C_01).

Table 1. 2010 Integrated Report summary for Arenosa Creek (AU 2453C_01)

Water Body	AU	Parameter	SWQM Station	Data Date Range	Number of Samples	Geometric Mean (cfu/100 mL)
Arenosa Creek	2453C_01	E. coli	13295	Dec. 1, 2000 – Nov. 30, 2008	32	197.6

Watershed Overview

Arenosa Creek is located along the Texas Gulf Coast, approximately midway between the cities of Edna and Victoria (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 J-2 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% of the watershed) and Jackson County (45% of the watershed). Three percent of the watershed resides in Lavaca County.

The 2020 Texas Integrated Report (TCEQ, 2020a) provides the following segment and AU description for the water body considered in this document:

- Segment 2453C and AU 2453C_01 – From Garcitas Creek confluence upstream to J-2 Ranch Road.

This study incorporates a watershed approach, where the entire drainage area of AU 2453C_01 is considered.

Watershed Climate and Hydrology

The Arenosa Creek watershed is located along the Texas Central Gulf Coast and falls within the subtropical humid climate region (Larkin & Bomar, 1983). This regional climate is characterized as a modified marine climate including warm summers, with the occasional invasion of drier, cooler continental airflow offsetting the prevailing flow of tropical maritime air from the Gulf of Mexico (Larkin & Bomar, 1983). The nearest National Oceanic and Atmospheric Administration (NOAA) weather station with long-term air and precipitation data is located at the Victoria Regional Airport (USW00012912). From 2001-2017, the mean annual rainfall was 38.84 inches, with average annual totals ranging from 15.27 to 69.06 inches per year across the watershed (NOAA 2019; Figure 2).

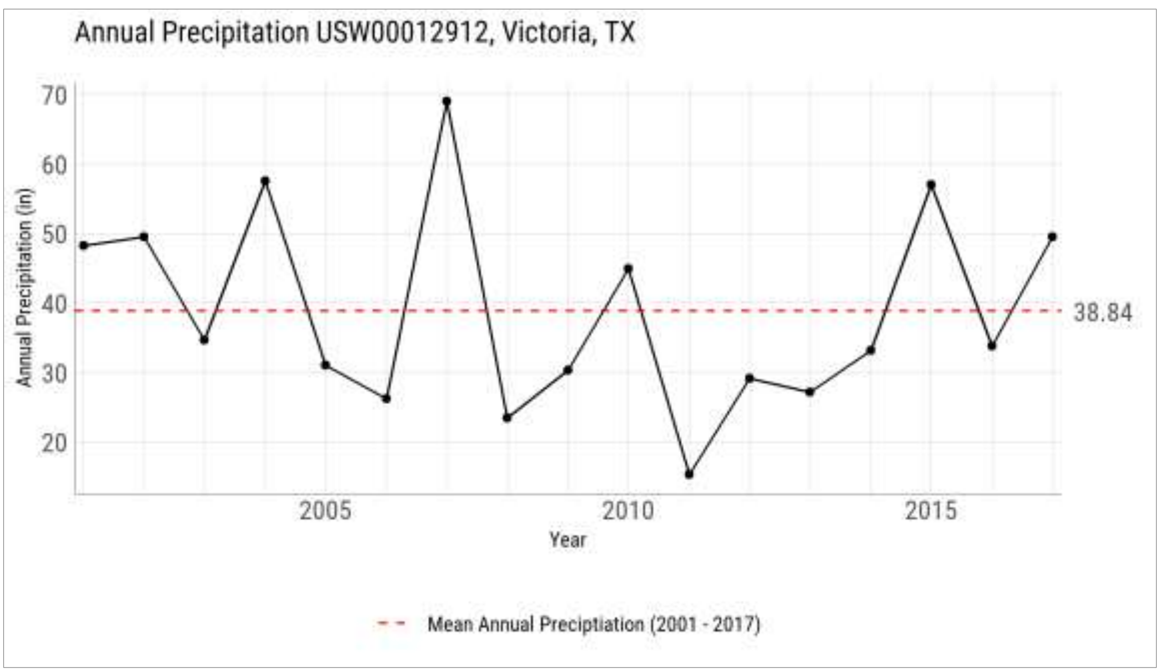

Figure 2. Annual precipitation (2001-2017) at the Victoria Regional Airport

Source: NOAA (2019)

Average monthly maximum air temperature at the Victoria Regional Airport ranged from 64.93˚F in January to 95.52˚F in August (Figure 3). Average monthly minimum air temperatures ranged from 45.07˚F in January to 75.78˚F in August. Monthly average precipitation ranged from 1.79 inches in February to 4.99 inches in September (Figure 3).

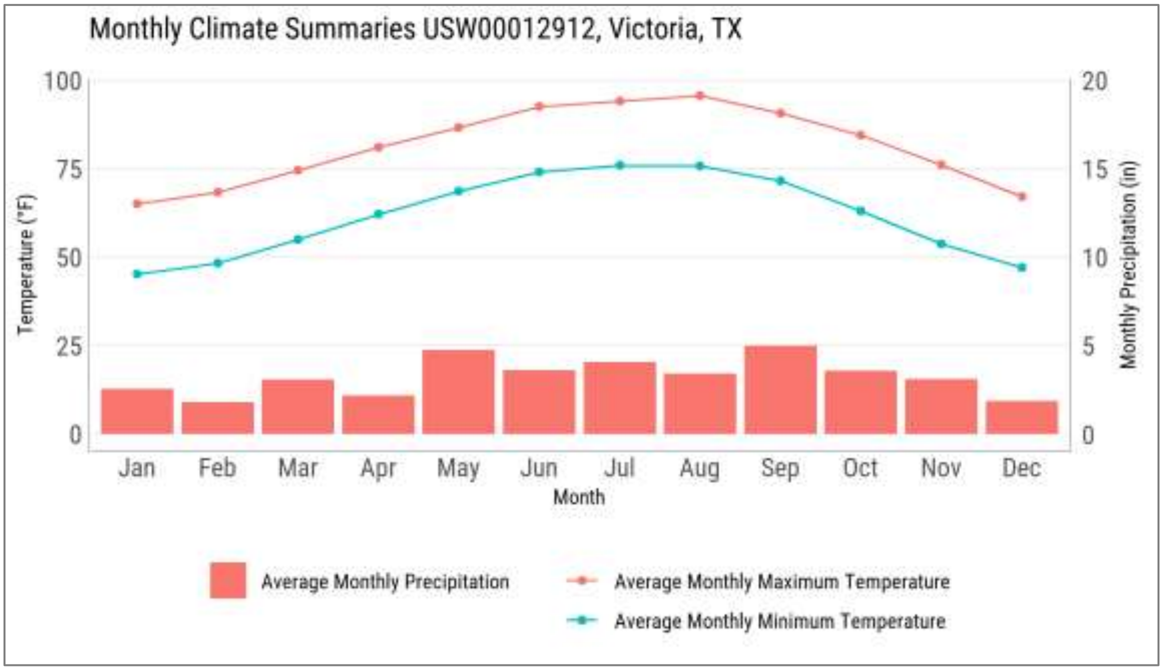

Figure 3. Monthly average precipitation, average maximum temperature, and average minimum temperature from 2001 through 2017 at the Victoria Regional Airport

Source: NOAA (2019)

Watershed Population and Population Projections

The Arenosa Creek watershed includes portions of Jackson, Lavaca, and Victoria counties. No municipal boundaries occur in the watershed. According to the United States Census Bureau (USCB) 2010 Census Block data, approximately 938 people live in the watershed (U.S. Census Bureau, 2010). The low population density indicates a largely rural watershed with no concentrated population centers (Figure 4).

Watershed population (U.S. Census Bureau, 2010) and 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 obtained by the Texas Water Resources Institute (TWRI) to complete the population projection exercise. The steps of the population projection exercise are provided in Appendix B. The exercise indicates a 29.4% population increase in the Arenosa Creek watershed by 2070. Table 2 provides a summary of 2010-2070 population estimates and projections. The largest population increases are expected in the portion of the watershed that lies within Victoria County. An additional 276 people are projected to reside in the watershed by 2070.

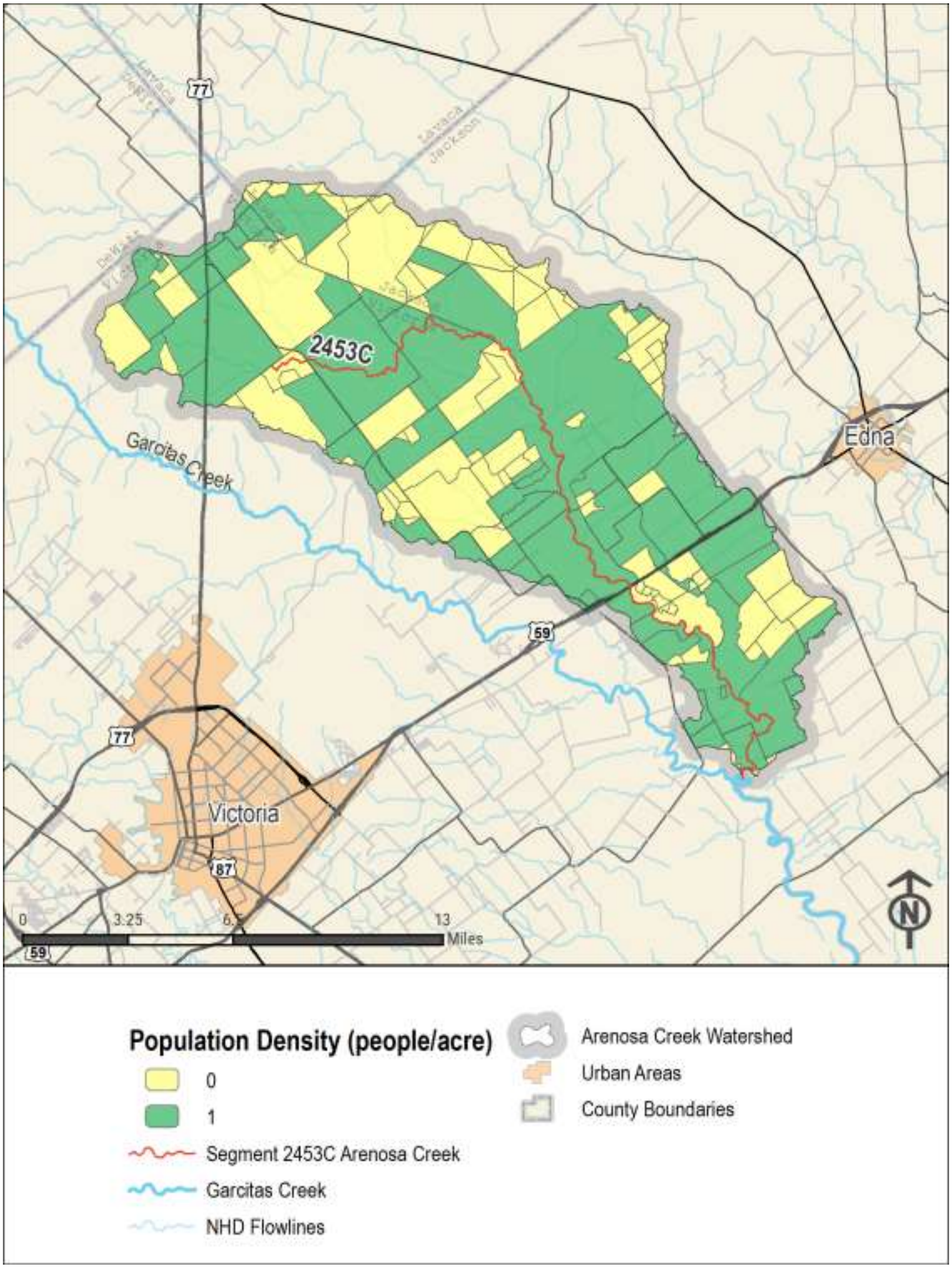

Figure 4. Population density for the Arenosa Creek watershed based on 2010 U.S. Census Block data

Table 2. Arenosa Creek watershed population estimates and population projections

Location	2010 U.S. Census	2070 Population Projection	Projected Increase (2010-2070)	Percent Increase (2010-2070)
Jackson County	203	227	24	11.8%
Lavaca County	4	4	0	0%
Victoria County	731	983	252	34.5%
Watershed Total	**938**	**1,214**	**276**	**29.4%**

Water Rights Review

Surface water rights in Texas are administered and overseen by TCEQ. A search of the TCEQ active water rights and GIS files (TCEQ, 2019c, 2019d) indicated there are water rights in the Arenosa Creek watershed; however, the South Texas Watermaster confirmed (TCEQ, 2020b) that there are currently no active surface water rights diversions within the Arenosa Creek watershed based on water use information.

Land Use

Land use/land cover data for the Arenosa Creek watershed was obtained from the 2011 National Land Cover Database (NLCD) (Homer et al., 2015). The land use/land cover is represented by the following categories and definitions:

- **Open Water** – All areas of open water, generally with less than 25% cover of vegetation or soil.
- **Developed, Open Space** – Includes 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** – Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49% of total cover. These areas most commonly include single-family housing units.
- **Developed, Medium Intensity** – Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79% of the total cover. These areas most commonly include single-family housing units.

- **Developed, High Intensity** – Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80-100% of the total cover.

- **Barren Land (Rock/Sand/Clay)** – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

- **Deciduous Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

- **Evergreen Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

- **Mixed Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

- **Shrub/Scrub** – Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

- **Grassland/Herbaceous** – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management, such as tilling, but can be utilized for grazing.

- **Pasture/Hay** – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

- **Cultivated Crops** – Areas used 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 shrub land 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.

A summary of the land use/land cover data is provided in Table 3. As depicted in Table 3 and Figure 4, the dominant land uses are Pasture/Hay (56.7%) and Cultivated Crops (15.3%), together comprising approximately 72% of total land use/land cover in the watershed. In summary, the land use data indicates a largely rural and agricultural watershed with very little urbanization.

Table 3. Land Cover within the Arenosa Creek watershed

2011 NLCD Classification	Area (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%**

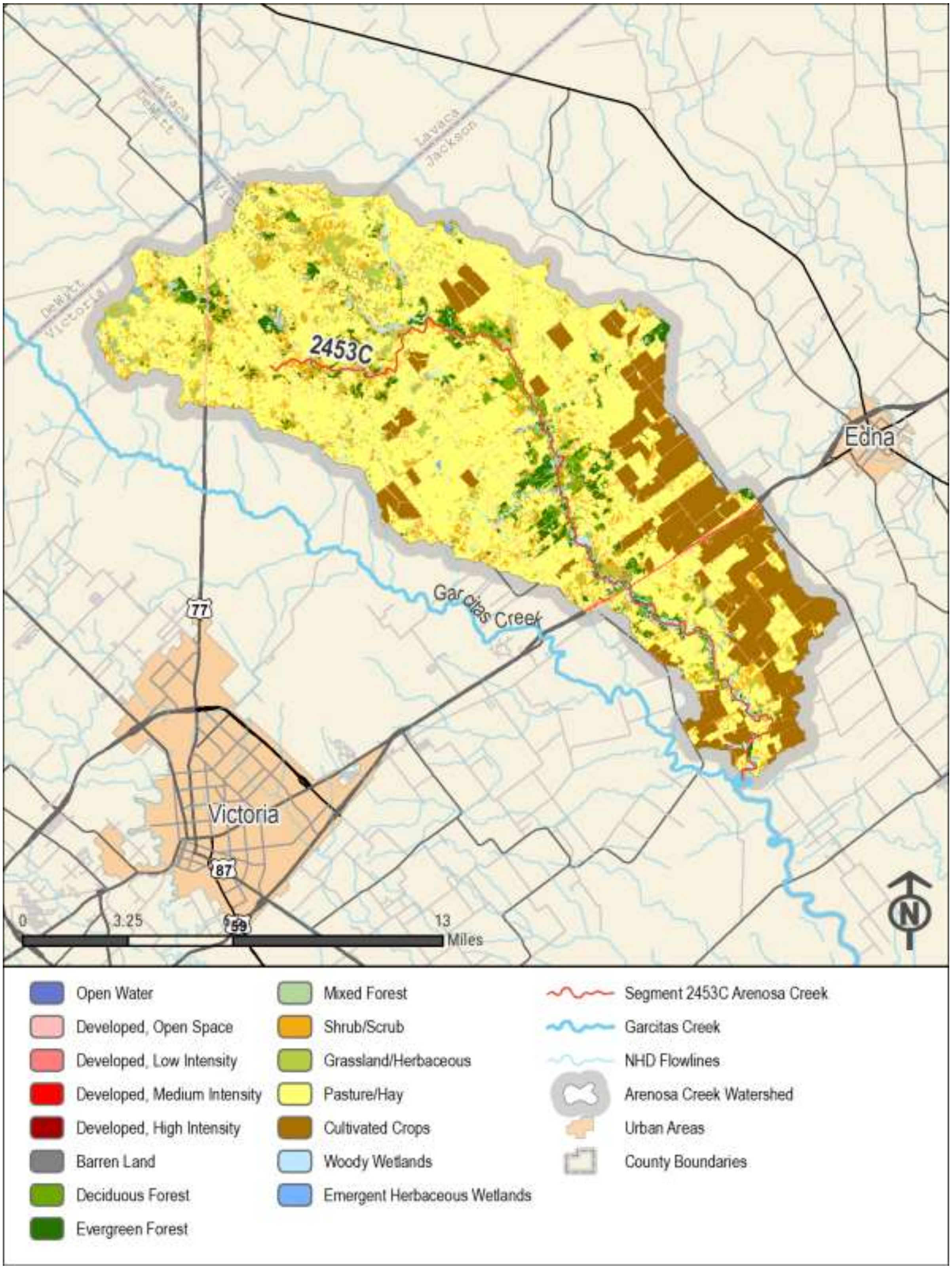

Figure 4. 2011 NLCD land use/land cover for the Arenosa Creek watershed

Soils

Soils within the Arenosa Creek watershed are characterized by hydrologic groups that describe infiltration and runoff potential. These data are provided by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) (USDA NRCS, 2015). The 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 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.

Figure 6 and Table 4 indicate that 95% of the watershed is composed of soils with slow to very slow rates of infiltration and moderately high to high runoff potential when wet (Hydrologic Soil Groups C, C/D, and D). In summary, the majority of soils in the Arenosa Creek watershed have limited capacity to move water through the soil layer and have a high potential to pond or generate runoff when wet.

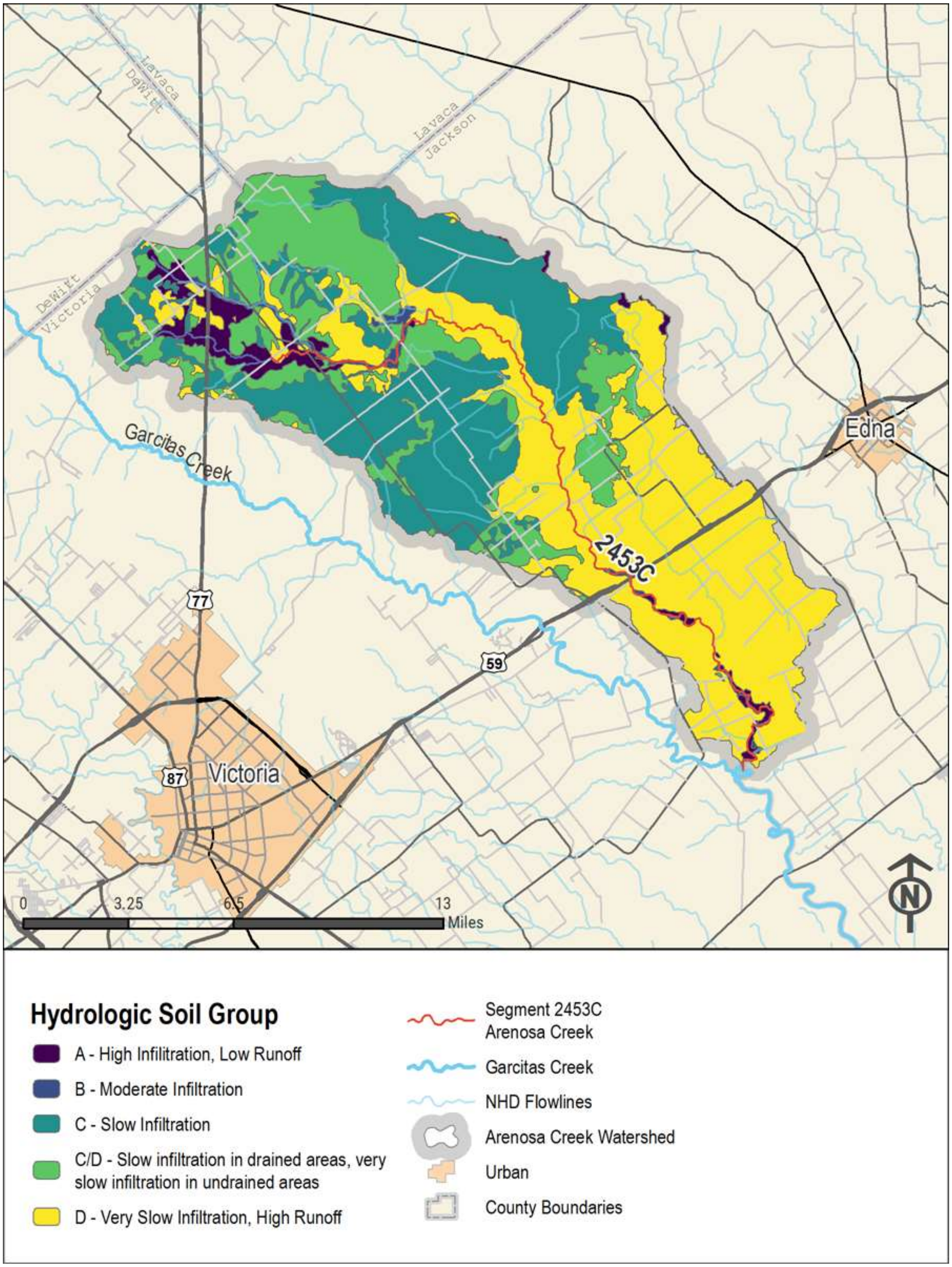

Figure 5. Hydrologic soil groups in the Arenosa Creek watershed

Table 4. Arenosa Creek watershed hydrologic soil groups

Hydrologic Soil 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%**

Endpoint Identification

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

The endpoint for the TMDL in this report is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 cfu/100 mL, identified in the 2018 Texas Surface Water Quality Standards (TCEQ, 2018).

Source Analysis

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

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

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

Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed include stormwater discharges from construction activities. There are no TPDES WWTFs, industrial stormwater, or MS4 discharge permits in the watershed.

Domestic and Industrial WWTFs

As of October 28, 2019, no facilities with a TPDES discharge permit were operating in the watershed (TCEQ, 2019e). One facility was issued a permit for the land application of sewage sludge on 726.1 acres of land in the watershed. However, the permit does not allow for discharge.

TCEQ/TPDES Water Quality General Permits

In addition to individual wastewater discharge permits, certain types of activities are required to be covered by one of several TPDES general permits:

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

A review of active general permit coverage in the Arenosa Creek (AU 2453C_01) watershed, revealed that there are currently no active general permits in the area.

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. These overflows in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I&I) are typical causes of overflows 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 SSOs reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. A search of the database revealed no reported overflows within the watershed, because at the time this report was completed, there was no collection system infrastructure in the watershed.

TPDES-Regulated Stormwater

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

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

The TPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, whereas the Phase II general permit regulates smaller communities within a USCB defined urbanized area (UAs). The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the MS4. The permits require that the SWMPs specify the best management practices (BMPs) to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include all of the following:

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

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

Phase I MS4 permits are associated with large urban areas. No permits of this nature occur for the Arenosa Creek AU 2453C_01 watershed. Discharges of stormwater from areas involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 - Phase II MS4 general permit for small MS4s located in UAs.
- TXR050000 - multi-sector general permit (MSGP) for industrial facilities.
- TXR150000 - construction general permit from construction activities disturbing one acre or more.

Phase II MS4 permits are associated with areas located within USCB UAs. The Arenosa Creek AU 2453C_01 watershed is not located in a UA and therefore not subject to Phase II MS4 permitting requirements. In the absence of areas regulated by Phase I and Phase II MS4 areas, a review of other stormwater permits is conducted. The area of the watershed with regulated stormwater is estimated by determining coverage by individual industrial stormwater WWTFs, multi-sector, and construction permits.

A Central Registry query of stormwater general permits in the Arenosa Creek watershed from 2014 through 2018 found that construction activities were not common in the watershed. Two authorizations were identified in this period, and an estimated 163 acres is disturbed during a construction activity in any given year. There are currently no Phase II MS4s, or industrial facilities regulated under the MSGP, in the watershed. Based on the active stormwater general permits, regulated stormwater currently comprises less than 1% of the watershed area.

Illicit Discharges

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

Direct Illicit Discharges:

- Sanitary wastewater piping that is directly connected from a home to the storm sewer.
- Materials that have been dumped illegally into a storm drain catch basin.
- A shop floor drain that is connected to the storm sewer.
- A cross-connection between the sanitary sewer and storm sewer systems.

Indirect Illicit Discharges:

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

Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit, wildlife, various agricultural activities, agricultural animals, land application fields, failing OSSFs, unmanaged and feral animals, and domestic pets.

Unregulated Agricultural Activities and Domesticated Animals

A number of agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Livestock are present throughout the Arenosa Creek watershed. The number of cattle and calves in the watershed was estimated based on stakeholder-estimated typical stocking densities. Local stakeholders estimate that cattle are stocked at a rate of one animal unit per four acres of pasture and one animal unit per 11 acres of unimproved rangeland on average.

Other livestock in the Arenosa Creek watershed were estimated from county-level data obtained from the 2012 Census of Agriculture (USDA National Agriculture Statistics Service, 2014). The county-level data were refined to reflect acres of un-urbanized land within the TMDL watershed. The refinement was determined by the total area of each county and the 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.

Activities such as livestock grazing close to water bodies and the use of manure as fertilizer can contribute bacteria loading to nearby water bodies. Table 5 provides estimated numbers of selected livestock in the watershed based on the 2012 Census of Agriculture conducted by U.S. Department of Agriculture (USDA National Agriculture Statistics Service, 2014). The county-level estimated livestock populations were reviewed by Texas State Soil and Water Conservation Board (TSSWCB) staff and were distributed based on geographic information systems calculations of pastureland in the watershed, based on the Texas 2011 Land Cover Data (Homer et al., 2015). These livestock numbers, however, were not used to develop an allocation.

Table 5. Estimated livestock populations within the Arenosa Creek watershed

AU	Cattle and Calves	Hogs and Pigs	Poultry	Goats and Sheep	Horses
2453C_01	16,693	53	6,970	187	116

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 6 summarizes the estimated number of dogs and cats for the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (American Veterinary Medical Association, 2012). The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 6. Estimated households and pet populations in the Arenosa Creek watershed

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

Wildlife and Unmanaged Animals

Fecal indicator bacteria, such as *E. coli*, inhabit the intestines of all warm-blooded animals, including wildlife such as mammals and birds. To develop bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to the riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff.

Unfortunately, quantitative estimates of wildlife are inexact and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire. This holds true especially when considering potential wildlife bacteria contributors such as birds. However, population estimates for feral hogs and deer are readily available for the impaired watershed.

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. Applying this value to the area of the entire watershed returns an estimate of 6,086 deer in the Arenosa Creek watershed.

For feral hogs, a study conducted by Wagner & Moench (2009) estimated densities in the proximate Copano Bay watershed to be one hog per 33.3 acres. The local stakeholder group estimated a much higher density in the area due to the high proportion of habitat and food. Therefore, a density of one feral hog per 8.325 acres of available habitat was applied in the watershed. Habitat deemed suitable for feral hogs followed as closely as possible to land use selections used in the study and include these categories from the 2011 NLCD: Pasture/Hay, Cultivated Crops, Shrub/Scrub, Grasslands/Herbaceous, Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, and Emergent Herbaceous Wetlands. Using this methodology, there are an estimated 12,738 feral hogs.

On-Site Sewage Facilities

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

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel et al., 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. Arenosa Creek watershed is located within the Region IV area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

Estimates of the number of OSSFs in the Arenosa Creek watershed were based on 911 address data, visually validated with aerial imagery data to remove non-residential locations (Gregory et al., 2014). OSSFs were estimated to be households that were outside of either a sewered area or a city boundary. The total estimate is shown in Table 7, and the OSSF density is shown in Figure 6.

Bacteria Survival and Die-off

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

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. This relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources and direct fecal material deposition into the water body. During 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 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 bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Table 7. OSSF estimate for the Arenosa Creek watershed

AU	Estimated OSSFs
2453C_01	322

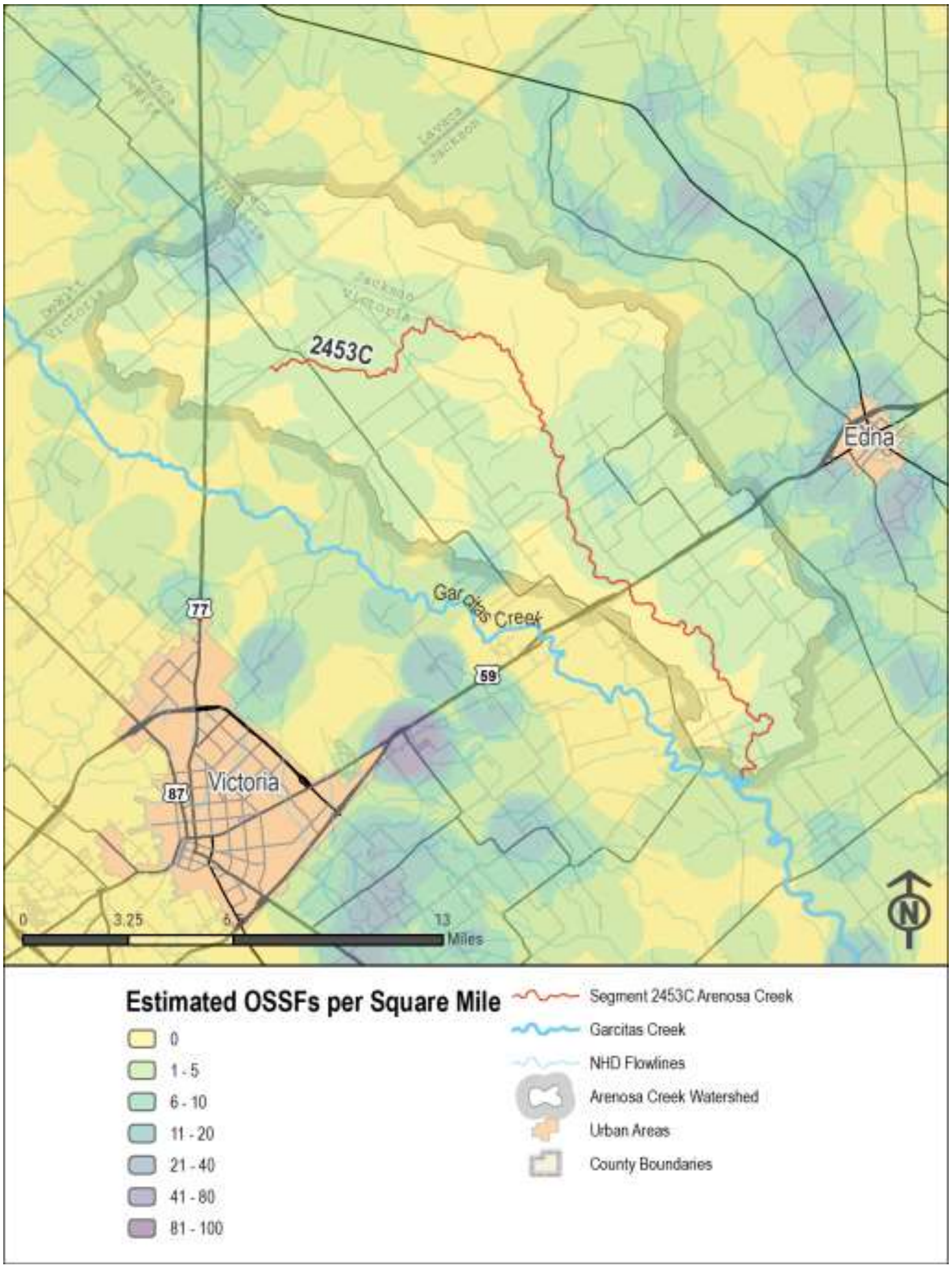

Figure 6. Estimated OSSF density in the Arenosa Creek watershed

Load Duration Curve Analysis

LDCs are graphs of the frequency distribution of loads of pollutants in a stream. In the case of this TMDL, the loads shown are of *E. coli* bacteria in cfu/day. LDCs are derived from flow duration curves (FDCs). A detailed discussion of the methodology used to develop FDCs and LDCs in the Arenosa Creek watershed is included in the *Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Arenosa Creek*[2] (Jain, Ruff, & Schramm, 2018) and Appendix A.

Load Duration Curve Results

For developing the TMDL allocation, an LDC was constructed using data obtained from SWQM station 13295. Geometric mean loadings for the data points within each flow regime have also been distinguished on Figure 7 to aid interpretation. The LDC provides a means of identifying the streamflow conditions under which exceedances in *E. coli* concentrations have occurred. The LDC depicts the allowable loadings at the station under the geometric mean criterion (126 cfu/100 mL) and shows that existing loadings often exceed the criterion. In addition, the LDC also presents the allowable loading at the station under the single sample criterion (399 cfu/100 mL).

Based on the LDC for SWQM station 13295 with historical *E. coli* data added to the graph (Figure 7), the following broad linkage statements can be made for the Arenosa Creek watershed. The historical *E. coli* data indicate that elevated bacteria loadings occur under all flow conditions but become most elevated under high flows and only fall below the single sample criterion under the mid-range and lowest flows. Regulated stormwater comprises a minor portion of the Arenosa Creek watershed (less than 1%) and must be considered only a minor contributor. It is therefore likely that unregulated stormwater comprises the majority of high-flow related loadings. Other sources of bacteria loadings under lower flows and in the absence of overland-flow contributions (i.e., without stormwater contribution) are most likely contributing bacteria directly to the water, and could occur through direct deposition of fecal material from such sources as wildlife (avian and non-avian), feral hogs, and livestock. The actual contribution of bacteria loadings attributable to these direct sources of fecal material deposition cannot be determined using LDCs.

Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the

[2] www.tceq.texas.gov/assets/public/waterquality/tmdl/108arenosa/108-arenosa-tsd-final.pdf

goal of the TMDL will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated into the TMDL using two methods:

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

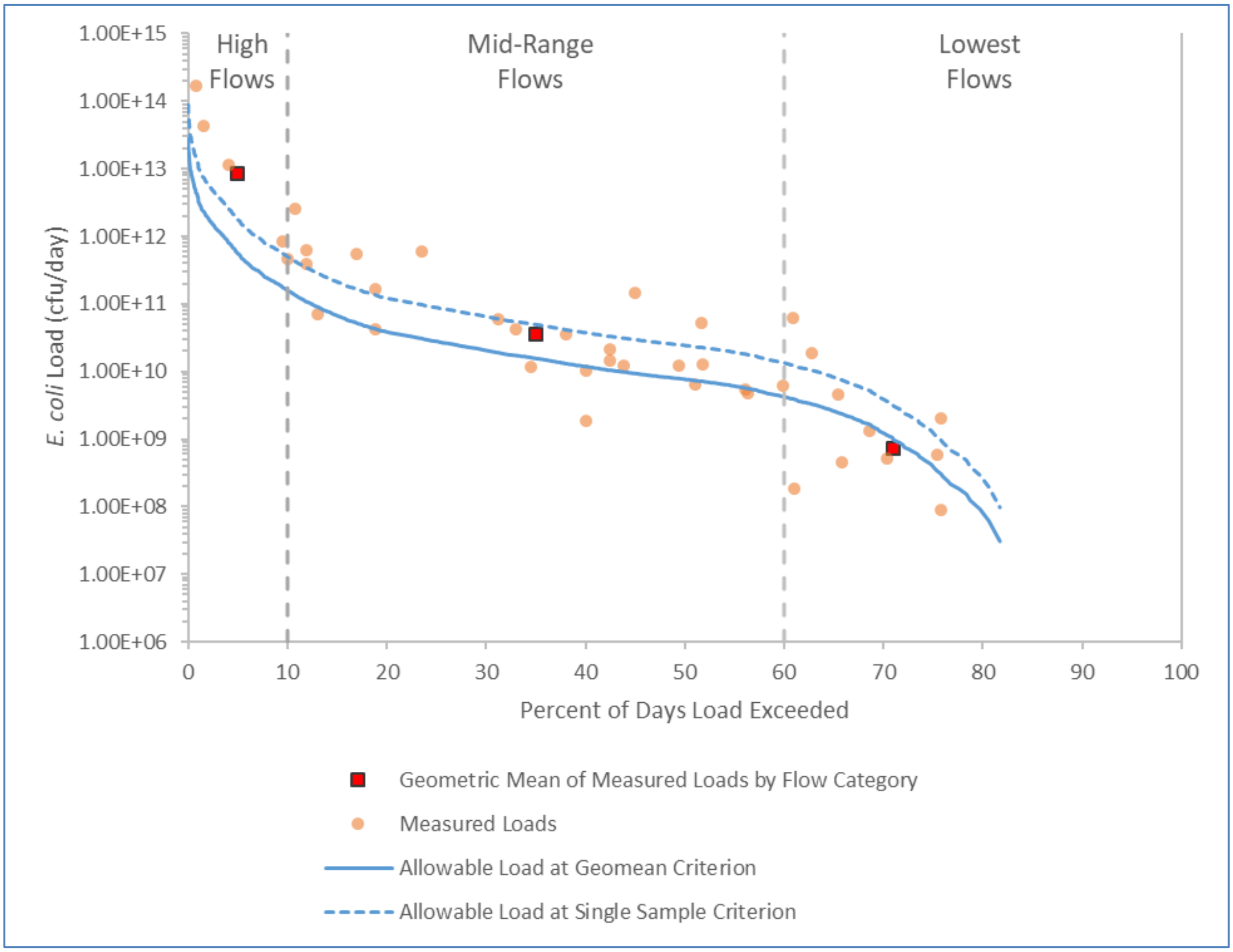

Figure 7. Load duration curve at SWQM station 13295 on Arenosa Creek for the period September 1, 2000, through August 31, 2015

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

Pollutant Load Allocation

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

TMDL = WLA + LA + FG + MOS

Where:

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures [40 CFR 130.2(i)].

The TMDL components for the Arenosa Creek AU 2453C_01 watershed covered in this report are derived using the median flow within the high-flow regime (or 5% flow) of the LDC developed for SWQM station 13295. The following sections will present an explanation of the TMDL component, followed by the results of the calculation for that component.

AU-Level TMDL Computations

The bacteria TMDL for Arenosa Creek AU 2453C_01 watershed was developed as a pollutant load allocation based on information from the LDC for SWQM station 13295 (Figure 8). The bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* geometric mean criterion (126 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the "Allowable Load" displayed in the LDC at 5% exceedance (the median value of the high-flow regime) is the TMDL:

TMDL (cfu/day) = criterion * flow * conversion factor

Where:

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

Flow = cubic feet per second (cfs) at 5% exceedance

Conversion factor (to billion cfu/day) = 28,316.8 mL/cubic feet × 86,400 seconds/day

At 5% load duration exceedance, the TMDL value is provided in Table 8.

Table 8. Summary of allowable loading calculation for Arenosa Creek AU 2453C_01 watershed

Indicator Bacteria	5% Exceedance Flow (cfs)	5% Exceedance Load (Billion cfu/day)	TMDL (Billion cfu/day)
E. coli	181.29	558.859	558.859

Margin of Safety Formula

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

MOS = 0.05 * TMDL

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

The MOS is presented in Table 9.

Table 9. Summary of the MOS calculation for Arenosa Creek AU 2453C_01 watershed

Indicator Bacteria	TMDL (Billion cfu/day)	MOS (Billion cfu/day)
E. coli	558.859	27.943

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}).

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

Wastewater Treatment Facilities

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. The *E. coli* primary contact recreation geometric mean criterion of 126 cfu/100 mL is used as the WWTF target. This is expressed in the following equation as:

$$WLA_{WWTF} = criterion * flow * conversion\ factor$$

Where:

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

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

Conversion factor (to cfu/day) = 1.54723 cfs/MGD * 28,316.8 mL/ft^3 * 86,400 sec/day

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 permitted flow from any WWTF.

Regulated Stormwater

Stormwater discharges from MS4s, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA was used in the development of this 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 that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load to be allocated as the stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint source runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

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

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

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

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

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 "TPDES-Regulated Stormwater," a search of stormwater general permits was performed. The results are displayed in Table 10.

No MS4 Phase I or Phase II permits are held in the Arenosa Creek AU 2453C_01 watershed. For construction permits, the average acreages associated with permits was calculated to be 163 acres. No MSGPs were located within the watershed.

Table 10. Regulated stormwater FDA_{SWP} basis for the Arenosa Creek AU 2453C_01 watershed

AU	MS4 General Permit (acres)	Construction General Permit (acres)	Multi-Sector General Permit (acres)	Concrete Production Facilities (acres)	Petroleum Bulk Stations (acres)	Total Area of Permits (acres)	Watershed Area (acres)	FDA_{SWP}
2453C_01	0	163	0	0	0	163	110,165.5	0.148%

In order to calculate WLA_{SW}, the FG term must be known. The calculation for the FG term is presented in a later section, but the results will be included here for continuity. Table 11 provides the information needed to compute WLA_{SW}.

Once the WLA_{SW} and WLA_{WWTF} terms are known, the WLA term can be calculated as the sum of the two parts, as shown in Table 12.

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

Table 11. Regulated stormwater calculations for the Arenosa Creek AU 2453C_01 watershed

Indicator Bacteria	TMDL	WLA_{WWTF}	FG	MOS	FDA_{SWP}	WLA_{SW}
E. coli	558.859	0	0.290	27.943	0.148%	0.785

Load units expressed as billion cfu/day

Table 12. Wasteload allocation calculations for the Arenosa Creek AU 2453C_01 watershed

WLA_{WWTF}	WLA_{SW}	WLA
0	0.785	0.785

Load units expressed as billion cfu/day

Implementation of Wasteload Allocations

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

As there are no regulated sources discharging into Arenosa Creek at this time, TCEQ will plan to implement individual WLAs for any future sources through the permitting process as monitoring requirements and/or effluent limitations as required by 30 Texas Administrative Code (TAC) Chapter 319, which became effective November 26, 2009. Any future WWTFs discharging to the TMDL segments will be assigned an effluent limit based on the TMDL. Monitoring requirements will be based on permitted flow rates and are listed in 30 TAC Section 319.9.

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

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

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

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

> "Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality concerns, permits would be modified in subsequent terms to include "more specific conditions or limitations [which] may include an integrated suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric WQBELs, action levels, etc."

Using this iterative adaptive BMP approach to the maximum extent practicable is appropriate to address the stormwater component of this TMDL.

Updates to Wasteload Allocations

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

Load Allocation

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

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

Where:

LA = allowable load from unregulated sources

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 13

Table 13. Load allocation calculations for the Arenosa Creek AU 2453C_01 watershed

Indicator Bacteria	TMDL	WLA_{WWTF}	WLA_{SW}	FG	MOS	LA
E. coli	558.859	0	0.785	0.290	27.943	529.841

Load units expressed as billion cfu/day

Allowance for Future Growth

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

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

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 (see the WWTF section). 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).

$$FG = criterion * (\%POP_{2010\text{-}2070} * WWTF_{FP}) * conversion\ factor$$

Where:

FG = future growth from WWTFs

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

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

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

Conversion factor (to billion cfu/day) = 1.54723 cfs/MGD * 28,316.8 mL/ft^3 * 86,400 s/d

For this TMDL, conventional FG calculations are hampered by the $WWTF_{FP}$ being zero. While there are no plans for WWTFs 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 watershed to accommodate the potential of a WWTF to serve residents within the watershed.

Discharge flow for potential WWTFs was determined by first estimating the population served. The FG of the Arenosa Creek 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 WWTFs. Title 30, Rule Section 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 as hypothetical potential plants were calculated as:

$$FG = criterion * (0.5 * POP_{2070}) * design\ standard * conversion\ factor$$

Where:

FG = future growth for potential WWTFs

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

POP_{2070} = estimated watershed population in 2070

Design standard = 1 * 10^{-7} million gallons per capita per day

Conversion factor (to billion cfu/day) = 1.54723 cfs/MGD * 28,316.8 mL/ft^3 * 86,400 s/d

Table 14. Future growth calculations for the Arenosa Creek AU 2453C_01 watershed

AU	Est. 2070 Watershed Population	Potential WWTF Service Population	Potential WWTF Discharge (MGD)	FG
2453C_01	1,214	607	0.0607	0.290

Load units expressed as billion cfu/day

Compliance with this TMDL is based on keeping the bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. FG of existing or new point sources is not limited by this TMDL as long as the sources do not cause bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Consequently, increases in flow allow for increased loadings. The LDC and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including FG.

Summary of TMDL Calculations

Table 15 summarizes the TMDL calculations for the Arenosa Creek AU 2453C_01 watershed. The TMDL was calculated based on median flow in the 0-10 percentile range (5% exceedance, high-flow regime) for flow exceedance from the LDC developed at SWQM station 13295. Allocations are based on the current geometric mean criterion for *E. coli* of 126 cfu/100 mL for each component of the TMDL.

Table 15. TMDL allocation summary for the Arenosa Creek AU 2453C_01 watershed

AU	TMDL	WLA_{WWTF}	WLA_{SW}	LA	FG	MOS
2453C_01	558.859	0	0.785	529.841	0.290	27.943

Load units expressed as billion cfu/day

The final TMDL allocations (

Table 16) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 16. Final TMDL allocations for the Arenosa Creek AU 2453C_01 watershed

AU	TMDL	WLA_{WWTF}[a]	WLA_{SW}	LA	MOS
2453C_01	558.859	0.290	0.785	529.841	27.943

Load units expressed as billion cfu/day

[a]WLA_{WWTF} includes the FG component

Seasonal Variation

Seasonal variations (or seasonality) occur then there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations require that TMDLs account for seasonal variation in watershed conditions and pollutant loading [40 CFR 130.7(c)(1)].

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations obtained from routine monitoring collected in the 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 *E. coli* concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test. 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.

Public Participation

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

TCEQ and TWRI are jointly providing coordination of public participation for development of both the TMDL and implementation plan (I-Plan). A series of public meetings have been held since 2018 to keep the public aware of the TMDL and to engage public participation in the development of the I-Plan.

The first public meeting to discuss watershed-based plans was held in Victoria on August 16, 2018, and stakeholder meetings have continued every couple of months through 2019. Stakeholders provided input on the documents associated with both the TMDL and the I-Plan. Notices of meetings were posted on the project webpages for both TWRI and TCEQ, and on TCEQ’s TMDL program’s online calendar. At least two weeks prior to scheduled meetings, the

TWRI issued media releases through Texas A&M AgriLife and local AgriLife Extension Offices, and formally invited stakeholders to attend. To ensure that absent or new stakeholders could get information about past meetings and pertinent material, the TWRI project webpage[3] provides meeting summaries, presentations, and documents produced for review.

Implementation and Reasonable Assurance

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

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

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, TCEQ certifies additional elements to the WQMP after the I-Plan is approved by the commission. Based on the TMDL and I-Plan, TCEQ will propose and certify WQMP updates to establish required WQBELs necessary for specific TPDES wastewater discharge permits.

Currently, there are no Phase II MS4 permit authorizations or Phase I MS4 individual permits held in the TMDL watershed. However, future population growth in the watershed may require some entities to obtain authorizations under the Phase II MS4 general permit. Where numeric effluent limitations are infeasible for MS4 entities, TCEQ normally establishes BMPs, which are a substitute for effluent limitations, as allowed by federal rules. When such practices are established in Phase II MS4 permit authorizations, TCEQ will not identify specific implementation requirements applicable to a specific TPDES stormwater permit or permit authorization through an effluent limitation update. Rather, TCEQ will revise its Phase II MS4 general permit during the renewal process to require a revised SWMP, or to require the implementation of other specific revisions in accordance with an approved I-Plan.

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

[3] matagordabasin.tamu.edu/arenosa-garcitas-creeks

committed to supporting implementation of all TMDLs adopted by the commission.

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

Key Elements of an I-Plan

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

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to an impairment.

TCEQ works with stakeholders and interested governmental agencies to develop and support I-Plans and track their progress. Work on the I-Plan begins during development of the TMDL. Because this TMDL addresses agricultural sources of pollution, TCEQ worked in close partnership with TSSWCB staff when developing the I-Plan. TSSWCB is the lead agency in Texas responsible for planning, implementing, and managing programs and practices for preventing and abating agricultural and silvicultural nonpoint sources of water pollution. The cooperation required to develop an I-Plan will become a cornerstone for the shared responsibility necessary to carry it out.

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

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

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Appendix A.
Load Duration Curve

The LDC method was used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, which 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 EPA supports the use of the basic LDC method to characterize pollutant sources including the modifications to include tidal influences. In addition, many other states are using this basic method to develop TMDLs, though the modified LDC method is more limited in its application.

Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a one-to-one relationship between instream loadings and loadings originating from point sources and the landscape as regulated and unregulated sources. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant LA. The allocation of pollutant loads was based on apportioning the loadings based on flows assigned to WWTFs, a fractional proportioning of the remaining flow based on the area of the watershed under stormwater regulation and assigning the remaining portion to unregulated stormwater.

The LDC method allows for estimation of existing loads 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.

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.

Data requirements for the LDC method are minimal, consisting of continuous daily streamflow records and historical bacteria data. A 15-year period of record from September 1, 2000, through August 31, 2015, was selected for LDC development, and this period included all available *E. coli* data at the time of the study. A 15-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent and current conditions in the watershed.

SWQM station 13295 was selected as the location for application of the LDC method. Forty-four *E. coli* samples were available and obtained from the Surface Water Quality Monitoring Information System (SWQMIS) for the sample period, meeting the 24-sample minimum suggested for LDC development (Bacteria TMDL Task Force, 2007).

Hydrologic data in the form of daily streamflow records were unavailable for the Arenosa Creek watershed. However, streamflow records were available for the adjacent Garcitas Creek watershed of similar land cover characteristics, e.g., limited urbanized area and significant agricultural influences). Due to the absence of flow records within the impaired watershed, the streamflow record was constructed using the drainage-area ratio (DAR) approach. With this basic approach, each United States Geological Survey (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, $\phi = 1$ is used in the DAR approach. However, empirical analysis of streamflows in Texas indicates that $\phi = 1$ results in substantial bias in streamflow estimates at very low and very high streamflow percentiles (Asquith et al., 2006). Based on these observations, 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 A-1 provides the DAR used to develop streamflows at SWQM station 13295 (Figure A-1). 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 A-1. Drainage area ratios used to develop daily streamflow records

Watershed	Drainage Area (square miles)	DAR
Garcitas Creek above USGS Gage 08164600	91.7	NA
SWQM Station 13295[1]	109.1	1.2

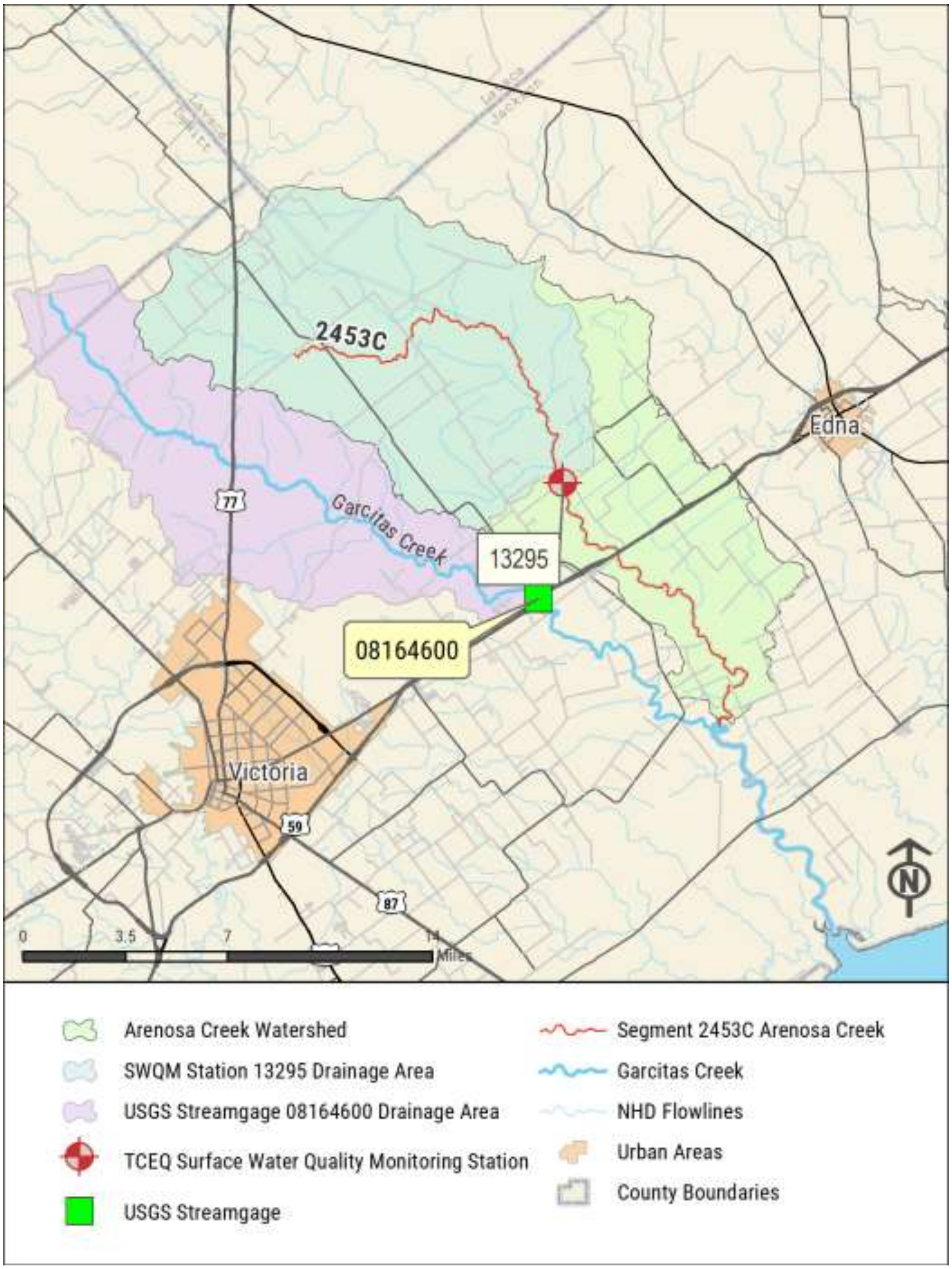

Figure A-1. Drainage areas used to develop daily flow record

The FDC at SWQM station 13295 was developed by:

1. Ordering the daily streamflow data for the location from highest to lowest and assigning a rank to each data point (one for the highest flow, two for the second highest flow, and so on).

2. Computing the percent of days each flow was exceeded by dividing each rank by the total number of data points plus one.

3. Plotting the corresponding flow data against exceedance percentages.

Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100% occur during low-flow or drought conditions while values approaching 0% occur during periods of high-flow or flood conditions.

The bacteria LDC was developed by:

1. Multiplying the stream flow in cfs by the appropriate water quality criterion for *E. coli* (geometric mean of 126 cfu/100 mL or 1.26 cfu/mL) and by a conversion factor (2.44658×10^9), which gives a loading unit of cfu/day.

2. Plotting the exceedance percentages, which are identical to the value for streamflow data points, against the geometric mean criterion for *E. coli*.

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

For the LDC at SWQM station 13295, historical bacteria data obtained from TCEQ SWQMIS database were superimposed on the allowable bacteria LDC. Each historical *E. coli* measurement was associated with the streamflow on the day of measurement and converted to a bacteria load. The associated streamflow for each bacteria loading was compared to the FDC data to determine its value for "percent days flow exceeded," which becomes the "percent of days load exceeded" value for purposes of plotting the *E. coli* loading. Each load was then plotted on the LDC at its percent exceedance. This process was repeated for each *E. coli* measurement. Points above the LDC represent exceedances of the bacteria criterion and its associated allowable loadings.

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of the FDC and LDC. For this TMDL, three flow regimes were identified following recommendations in Cleland (2003). These three intervals along the x-axis of the FDCs and LDCs are (1) 0-10% (high flows); (2) 10-60% (mid-range conditions); and (3) 60-100% (lowest flows). The FDC indicates, as with Garcitas Creek, no in-stream flow occurs approximately 19% of the time, which is anticipated to be reflective of actual conditions in the creek. Additional information explaining the LDC method may be found in Cleland (2003).

The median loading of the high-flow regime (0-10% exceedance) is used for the TMDL calculations. The median loading of the very high-flow regime (5% exceedance) is used for the TMDL calculations, because it represents a reasonable yet high value for the allowable pollutant LA.

More details on the specific methods used to develop the Arenosa Creek LDC may be found in Jain et al. (2018).

Appendix B.
Population Projections

TWRI took the following series of steps to complete the population projection exercise:

1) Census block level population data for Jackson, Victoria and Lavaca counties for the year 2010 was obtained from U.S. Census Bureau.

2) The watershed population was estimated by adding the total population of the Census blocks that lie entirely within the watershed.

3) Population for blocks that do not lie entirely in the watershed was determined by multiplying the proportion of the block area within the watershed.

4) County wide decadal population projections for 2020 - 2070 were obtained from the 2016 Regional Water Plan information for Regions L (Victoria County) and P (Jackson and Lavaca Counties).

5) As there are no municipalities within the Arenosa Creek watershed, city population projections could not be used for the population projections.

6) The projected population percentage increase in each decade from 2010 to 2070 was calculated from the 2016 Regional Water Plan information for Regions L (Victoria County) and P (Jackson and Lavaca Counties).

7) The obtained percentage increase for each decade was applied to the 2010 Census block population of each county in the watershed. County-wide watershed population projections are shown in Table 2.