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

Assessment Unit: 0604A_03

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Abbreviations

AU	assessment unit
AVMA	American Veterinary Medical Association
CCN	Certificate of Convenience and Necessity
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
CGP	construction general permit
DAR	drainage area ratio
DMR	discharge monitoring report
E. coli	*Escherichia coli*
EPA	(U.S.) Environmental Protection Agency
FDC	flow duration curve
FG	future growth
FC	flow category
ft^3	cubic feet
GIS	Geographic Information System
I&I	inflow and infiltration
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
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
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
TWDB	Texas Water Development Board

U.S.	United States
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WLA	wasteload allocation
WLA_{SW}	wasteload allocation from regulated stormwater
WLA_{WWTF}	wasteload allocation from wastewater treatment facilities
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 water body included on a state's 303(d) list of impaired waters. 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 applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time but may be expressed in other ways.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The 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.

TCEQ first identified the bacteria impairment within assessment unit (AU) 0604A_03 in the U.S. Environmental Protection Agency (EPA)-approved 2022 *Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report; TCEQ, 2022a)

This document will consider one bacteria impairment in one AU of Cedar Creek. The impaired AU and its identifying number are:

- Cedar Creek 0604A_03

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, TCEQ established the *Texas Surface Water Quality Standards* (TCEQ, 2022b). The Standards describe the limits for indicators that are monitored to assess the quality of available water for specific uses. TCEQ monitors and assesses water bodies based on these Standards and publishes the Texas Integrated Report list biennially.

The Standards are rules that do all of the following:

- Designate the uses, or purposes, for which the state's water bodies should be suitable.

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

Standards are established to protect uses assigned to water bodies. The primary uses assigned to water bodies are:

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

Fecal indicator bacteria are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal indicator bacteria are bacteria that are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from fecal waste may be reaching water bodies because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2018). The fecal indicator bacteria used for freshwater in Texas is *Escherichia coli* (*E. coli*), a species of fecal coliform bacteria.

On Sept. 7, 2022, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2022b) and on Nov. 7, 2022, the EPA approved the categorical levels of recreational use and their associated criteria. Recreational use consists of several categories:

- **Primary contact recreation** 1 – Activities that are presumed to involve a significant risk of ingestion of water (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and the following whitewater activities: kayaking, canoeing, and rafting). It has a geometric mean criterion for *E. coli* of 126 colony forming units (cfu) per 100 milliliters (mL) and an additional single sample criterion of 399 cfu per 100 mL.

- **Primary contact recreation 2** – Water recreation activities, such as wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and whitewater kayaking, canoeing, and rafting, that involve a significant risk of ingestion of water but that occur less frequently than for primary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 206 cfu per 100 mL.

- **Secondary contact recreation 1** – Activities that commonly occur but have limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation 1 or 2 but more than secondary contact recreation 2. The geometric mean criterion for *E. coli* is 630 cfu per 100 mL.

- **Secondary contact recreation 2** – Activities with limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating) that are presumed to pose a less significant risk of water ingestion than secondary contact recreation 1. These activities occur less frequently than secondary contact recreation 1 due to physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 1,030 cfu per 100 mL.

- **Noncontact recreation** – Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic. The geometric mean criterion for *E. coli* is 2,060 cfu per 100 mL.

Cedar Creek is a freshwater stream and has a primary contact recreation 1 use. The associated criterion for *E. coli* is a geometric mean of 126 cfu per 100 mL.

1.3. Report Purpose and Organization

The Cedar Creek TMDL project was initiated through a contract between TCEQ and TWRI. The tasks of this project were to (1) develop, have approved, and adhere to a quality assurance project plan; (2) develop a technical support document for the impaired watershed; and (3) assist TCEQ with public participation. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the impaired AU. This report contains:

- Information on historical data.
- Watershed properties and characteristics.
- Summary of historical bacteria data that confirms the Texas 303(d) listings of impairment due to concentrations of *E. coli*.
- Development of a load duration curve (LDC).
- Application of the LDC approach for developing the pollutant load allocation.

Whenever it was feasible, the data development and computations for developing the LDC and pollutant load allocation were performed in a manner to remain consistent with the previously completed *Four Total Maximum Daily Loads for Indicator Bacteria in Tributaries of the Neches River below Lake Palestine* (TCEQ, 2022c).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The Cedar Creek TMDL watershed for the impaired AU 0604A_03 is almost entirely within the City of Lufkin in Angelina County (Figure 1). The total area of the Cedar Creek watershed is approximately 2,509 acres.

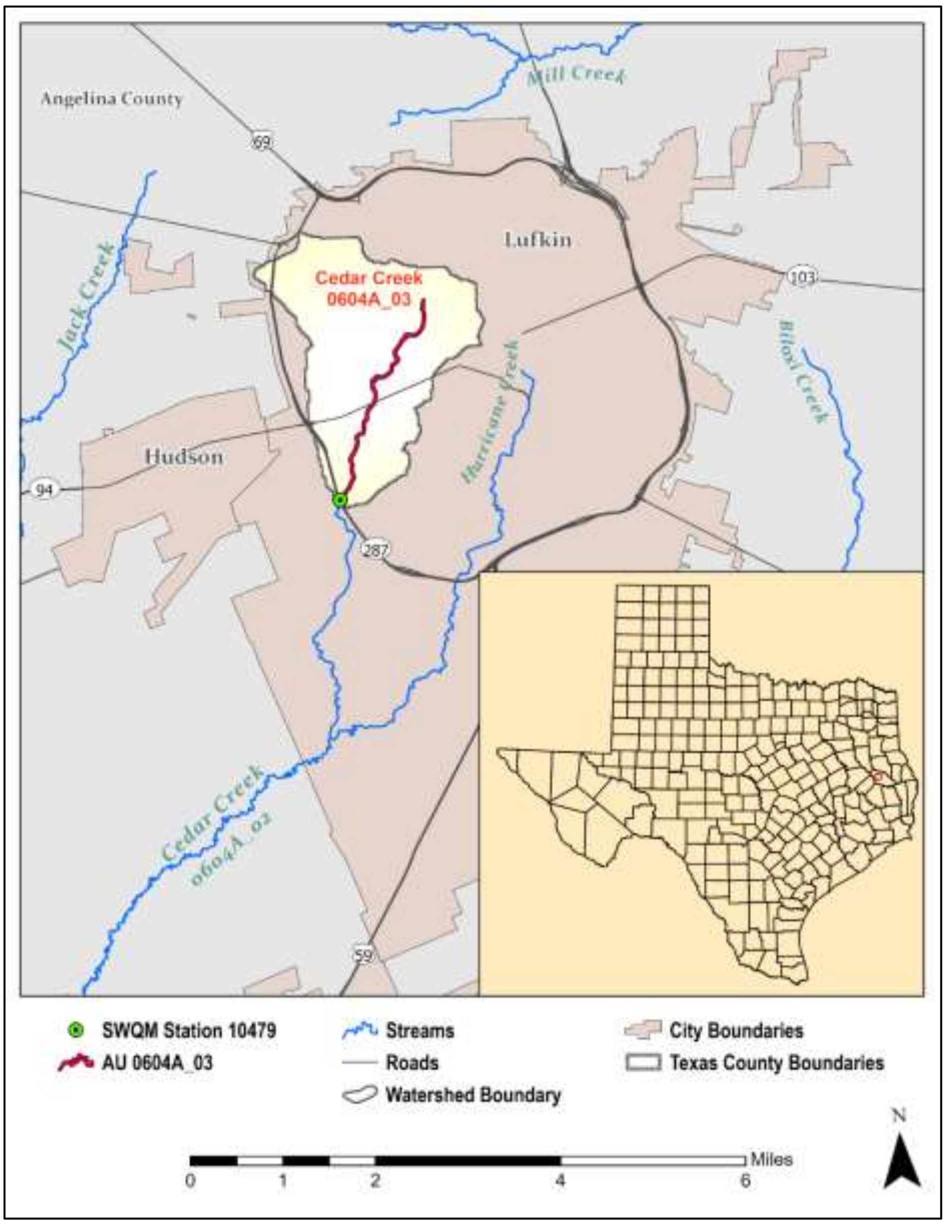

Figure 1. Map of the Cedar Creek watershed

The 2022 Texas Integrated Report (TCEQ, 2022a) has the following water body and AU descriptions:

- Cedar Creek – From the confluence of the Neches River southwest of Lufkin in Angelina County to the upstream perennial portion of the stream in Lufkin in Angelina County
    - AU 0604A_03 – From the confluence with unnamed tributary adjacent to State Highway Loop 287 upstream to headwaters near Hoo Hoo Avenue in the City of Lufkin.

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

There are two active TCEQ Surface Water Quality Monitoring (SWQM) stations with *E. coli* data within AU 0604A_03. The 2022 Texas Integrated Report (TCEQ, 2022a) found the geometric mean for *E. coli* within AU 0604A_03 to exceed the criterion of 126 cfu/100 mL.

Table 1. 2022 Texas Integrated Report summary for the Cedar Creek watershed

Watershed	AU	Parameter	SWQM Station	No. of Samples	Data Date Range	Geometric Mean (cfu/100 mL)
Cedar Creek	0604A_03	*E. coli*	10479 21434	56	12/01/2013 – 11/30/2020	186.67

2.3. Climate and Hydrology

The TMDL watershed is in east Texas primarily under the impact of humid subtropical with hot summers based on the Köppen–Geiger climate classification. Precipitation and temperature data were acquired from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center database for January 2002 – December 2021. The nearest weather station to the TMDL watershed is USW00093987 located in the Angelina County Airport (NOAA, 2022). As shown in Figure 2, monthly low temperatures ranged between 37.3 F (January) and 72.6 F (July); meanwhile, monthly high temperatures ranged between 60.6 F (January) and 94.5 F (August). Mean precipitation ranged between 3.53 inches (August) and 5.75 inches (May).

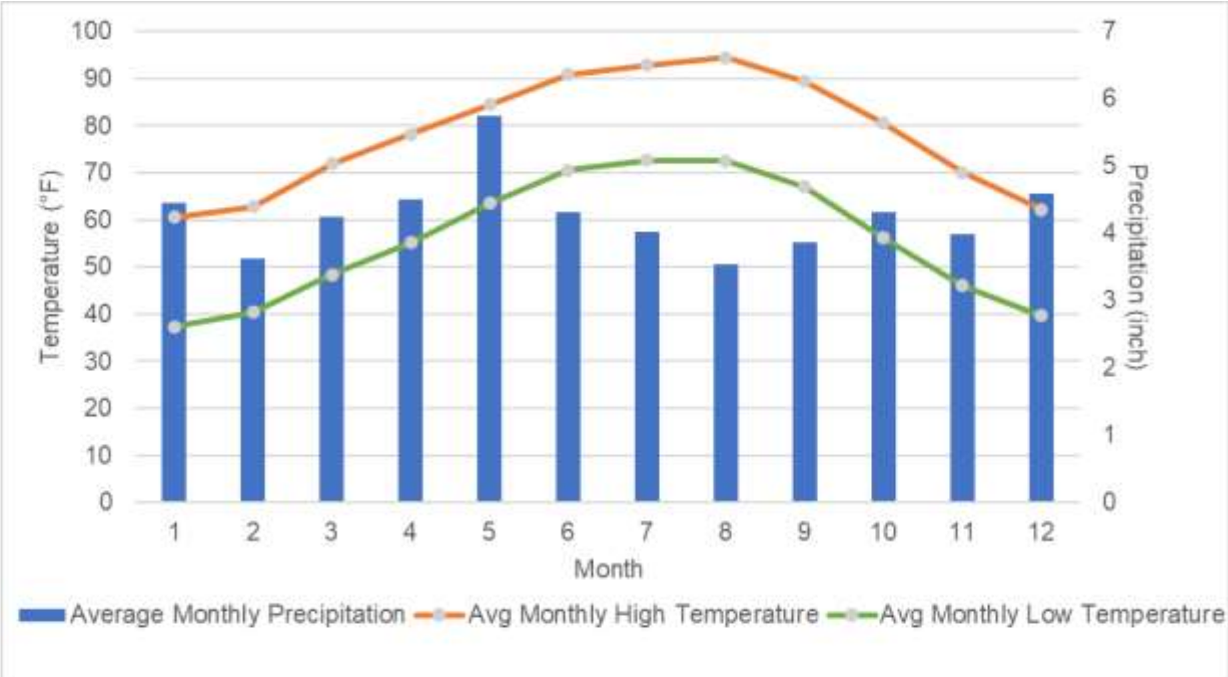

Figure 2. Maximum and minimum monthly temperatures and mean monthly precipitation (2002-2021) at weather station USW00093987

2.4. Population and Population Projections

Watershed population estimates were developed using the U.S. Census Bureau (USCB) 2020 census blocks data (USCB, 2020). Using the methodology described in Appendix A, the population of the TMDL watershed in 2020 was estimated to be 4,784. Figure 3 shows the population density by census block.

Population projections by decade for Angelina County (Table 2) and the Cedar Creek watershed (Table 3) are estimated from the Texas Water Development Board (TWDB) 2021 Regional Water Plan Population and Water Demand Projection data (TWDB, 2019).

Table 2. Population projection for Angelina County

Area	2020 Population	2030 Projected Population	2040 Projected Population	2050 Projected Population	2060 Projected Population	2070 Projected Population
Angelina County	93,316	99,848	105,329	110,332	114,808	118,772
Percent Increase	-	7.00%	5.49%	4.75%	4.06%	3.45%

Table 3. Population projection for the Cedar Creek watershed

Area	2020 Population	2030 Projected Population	2040 Projected Population	2050 Projected Population	2060 Projected Population	2070 Projected Population	2020-2070 Percent Increase
Cedar Creek Watershed	4,784	5,119	5,400	5,656	5,886	6,089	27.28%

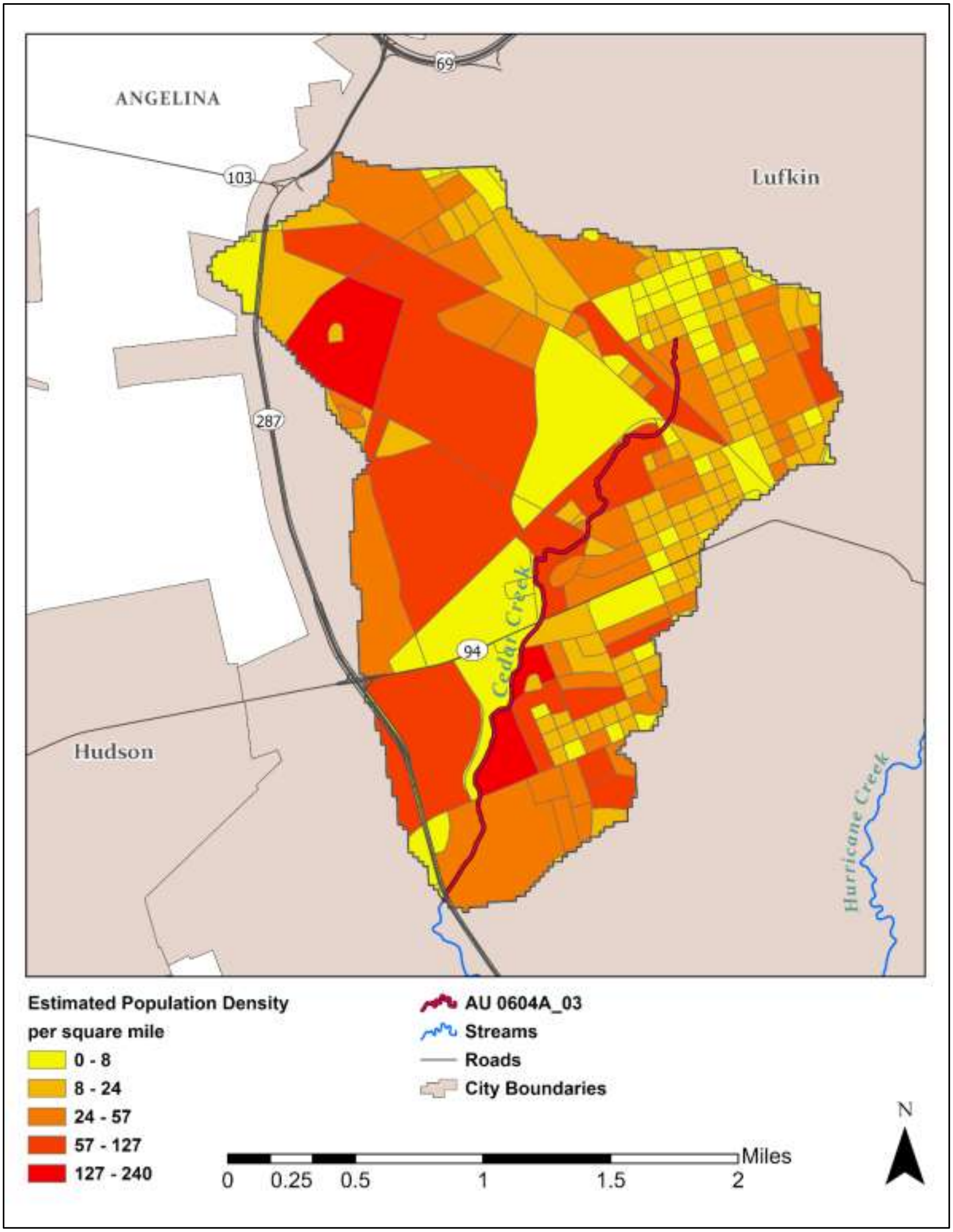

Figure 3. Population density estimated based on 2020 U.S. Census by census block data in the Cedar Creek watershed

2.5. Land Cover

The land cover data for the TMDL watershed was obtained from the 2019 National Land Cover Database (NLCD) and is displayed in Figure 4 (NLCD, 2019). The following are the land cover categories and definitions represented in the NLCD.

- **Open Water** – Areas of open water, generally with less than 25% cover of vegetation or soil.
- **Developed, Open Space** – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- **Developed, Low Intensity** – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.
- **Developed, Medium Intensity** – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of total cover. These areas most commonly include single-family housing units.
- **Developed, High Intensity** – Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80% to 100% of total cover.
- **Barren Land (Rock/Sand/Clay)** – Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
- **Deciduous Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
- **Evergreen Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the species maintain their leaves all year. Canopy is never without green foliage.
- **Mixed Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% total tree cover.

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

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

- **Woody Wetlands** – Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

- **Emergent Herbaceous Wetlands** – Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil substrate is periodically saturated with or covered with water.

A summary of the land cover data is provided in Table 4. The Cedar Creek watershed predominant land covers are Developed (79.45%), Mixed Forest (8.09%), and Evergreen Forest (7.84%).

Table 4. 2019 NLCD land cover level in the Cedar Creek watershed

NLCD 2019 Classification	Area[a] (acre)	Percent Total (%)
Open Water	0.89	0.04%
Developed, Open Space	322.02	12.84%
Developed, Low Intensity	891.77	35.55%
Developed, Medium Intensity	462.34	18.43%
Developed, High Intensity	316.90	12.63%
Barren Land	2.89	0.12%
Deciduous Forest	0.89	0.04%
Evergreen Forest	196.59	7.84%
Mixed Forest	203.04	8.09%
Shrub/Scrub	18.24	0.73%
Grassland/Herbaceous	19.35	0.77%
Pasture/Hay	56.49	2.25%
Woody Wetlands	16.46	0.66%
Emergent Herbaceous Wetlands	0.89	0.04%
Total	2,508.76	100%

[a]Total area for the TMDL watershed slightly differs from the 2,508.7 acres mentioned above because the clipped NLCD 2019 raster data in the geographic information system (GIS) analysis is not completely within the watershed boundary.

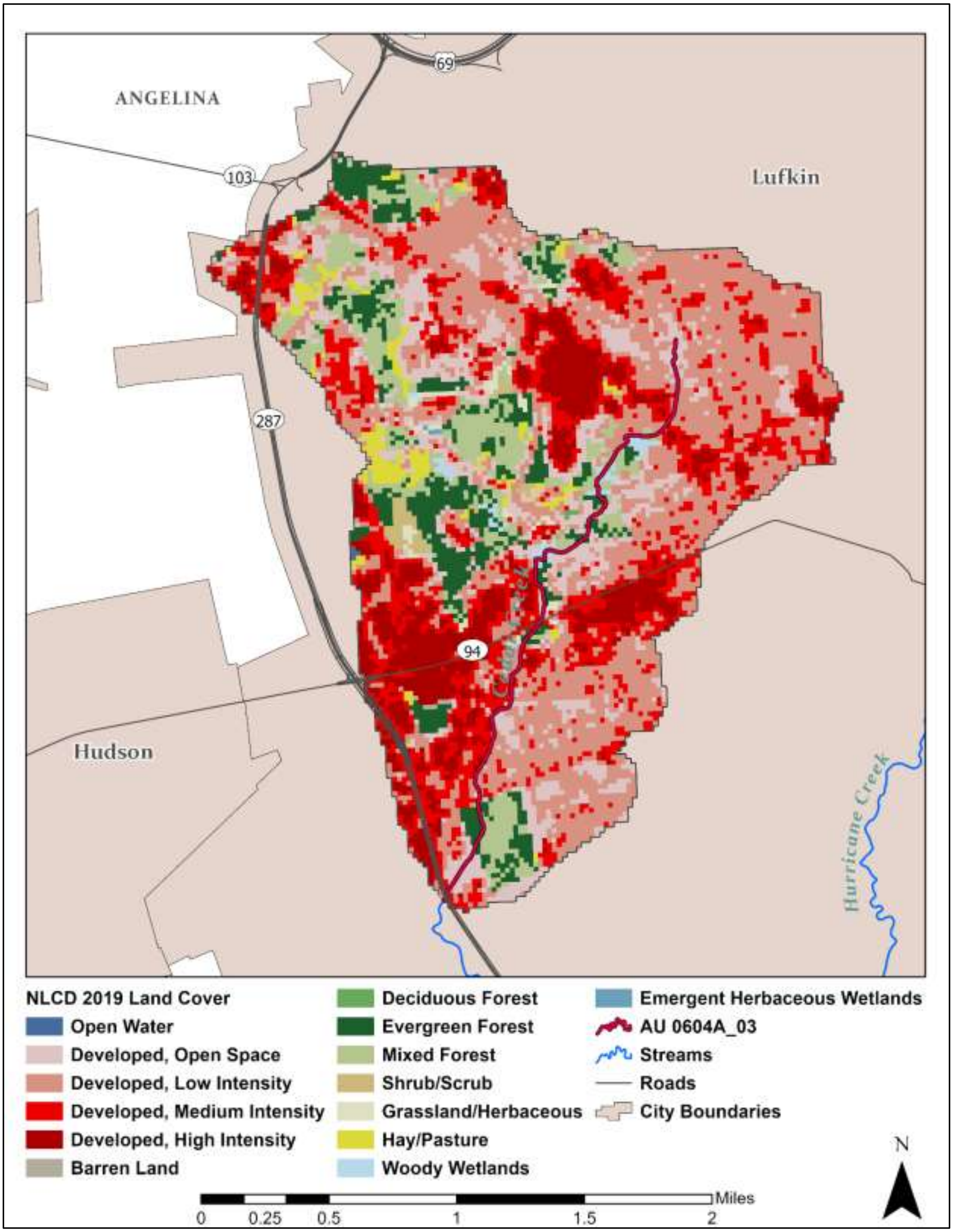

Figure 4. Land cover within the Cedar Creek watershed based on the 2019 NLCD

2.6. Soils

Soils within the Cedar Creek watershed are characterized by hydrologic groups that describe infiltration and runoff potential (Figure 5). These data are provided by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO; USDA NRCS, 2019). 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.

A summary of soil types is provided in Table 5. The Cedar Creek watershed consists of hydrologic soil groups C (44.075%) and D (55.925%).

Table 5. Hydrologic soil groups in the Cedar Creek watershed

Hydrologic Soil Group	Area (acre)	Percent Total (%)
C	1,105.848	44.075%
D	1,403.152	55.925%
Total	2,509.00	100%

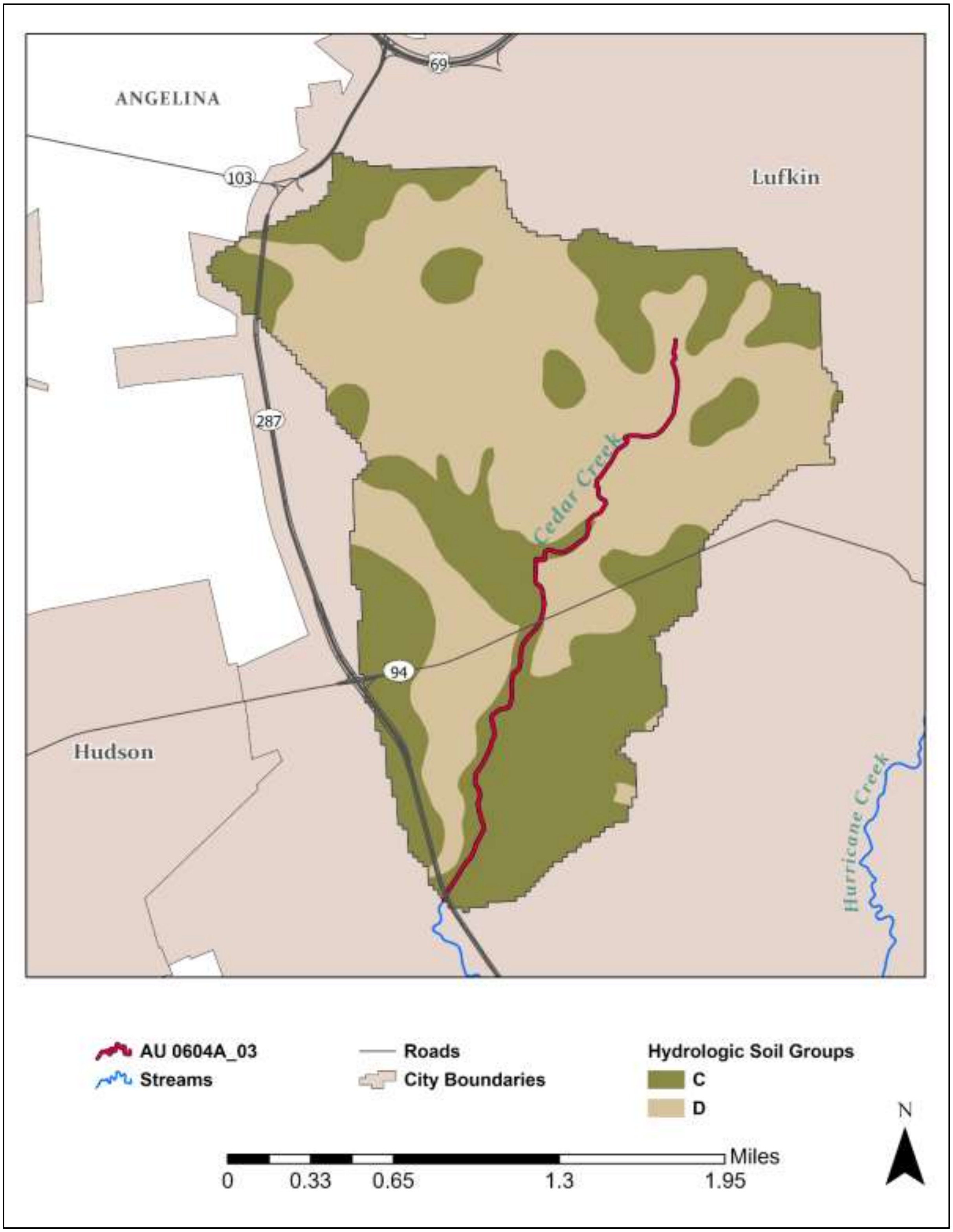

Figure 5. Hydrologic soil groups within the Cedar Creek watershed

2.7. Potential Sources of Fecal Indicator Bacteria

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 controlled by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. Wastewater treatment facility (WWTF) and stormwater discharges from industrial sites, regulated construction activities, and the separate storm sewer systems of cities 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 permits.

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see the "WLA" section), the regulated and unregulated sources in this section are presented to give a general account of the various 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.

2.7.1. Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed include sanitary sewer overflows (SSOs), stormwater discharges from industrial and regulated sites and other miscellaneous sources.

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

As of November 2022, there are no domestic or industrial wastewater facilities with a TPDES permit that discharge within the watershed (TCEQ, 2022d; EPA, 2022).

2.7.1.2 TCEQ/TPDES General Wastewater Permits

Certain types of activities must be covered by one of several TCEQ/TPDES wastewater general permits:

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

Discharges related to the following general permit authorizations are not expected to affect the bacteria loading in the TMDL watershed and were excluded from this investigation:

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

A review of active general permits (TCEQ, 2022e) in the Cedar Creek watershed, as of November 2022, found one general permit authorization for a concrete production facility. This facility, however, does not have bacteria reporting requirements or limits in its permit; therefore, it is assumed to contain inconsequential amounts of indicator bacteria in the effluent. It is thus considered unnecessary to allocate bacteria loads to this facility. There is no other active general wastewater permit authorization found in the Cedar Creek watershed.

2.7.1.3. 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 municipal separate storm sewer system (MS4) entities, stormwater discharges associated with regulated industrial activities, and construction activities.
2. Stormwater runoff not subject to regulation.

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, while the Phase II General Permit regulates other MS4s within a USCB defined urbanized area.

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 the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices 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 (only required for MS4s serving a population of 100,000 people or more in the urban area).
- Authorization for construction activities where the small MS4 is the site operator (*optional*).

Phase I MS4 individual permits have their own set of MCMs that are similar to the Phase II MCMs, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program.

Discharges of stormwater from a Phase II MS4 area, regulated industrial facility, construction area, or other facility involved in certain activities must be authorized under one of the following general permits:

- TXR040000 – Phase II MS4 General Permit for MS4s located in urbanized areas (discussed above)
- TXR050000 – Multi-Sector General Permit (MSGP) for industrial facilities
- TXR150000 – Construction General Permit (CGP) for construction activities disturbing more than one acre or are part of a common plan of development disturbing more than one acre

TCEQ Central Registry includes no Phase I or II MS4 permits for the Cedar Creek watershed. Nonetheless, several MSGP-regulated facilities were found within the watershed. Areas authorized under the MSGP were not specified in the Summary of Authorization in TCEQ Central Registry. Therefore, areas were estimated based on records available in the Angelina County Appraisal District database (2023).

The total area of regulated stormwater is approximately 41.645 acres or 1.66% of the Cedar Creek watershed. Due to the short-term nature of construction permits, a search of active, terminated, and expired CGPs was done from January 2002 to December 2021, and two construction permits were found, which together occupy 11.3 acres or 0.45% of the watershed.

Table 6. Active stormwater general permits in the Cedar Creek watershed

Permittee	Authorization Type	TPDES Permit No.	Location	Area of Regulated Stormwater (acres)
Prince Energy, LLC-Lufkin Plant	MSGP	TXR05FO17	515 Industrial Blvd Lufkin	2.079
Jewell Hudgens, Inc.	MSGP	TXR05DJ51	1114 N Raguet St, Lufkin	2.534
Pilgrim's Pride Corporation	MSGP	TXR05ED54	1508 Webber St, Lufkin	7.632
Pilgrim's Pride Corporation	MSGP	TXR05EH01	1710 W Frank Ave, Lufkin	6.600
Sun Coast Resources, Inc.	MSGP	TXR05EN77	2509 W Frank Ave, Lufkin	11.500

Table 7. Summary of land area covered by TPDES regulated stormwater permits in the Cedar Creek Watershed

AU	MSGP (count)	MSGP (acres)	CGP (count)	CGP (acres)	Total area of TPDES regulated stormwater (acres)
0604A_03	5	30.345	2	11.300	41.645

2.7.1.4. 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 worsen the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

TCEQ Central Office in Austin provided statewide data on SSO incidents from January 2016 through August 2022 (TCEQ, 2022f). Table 8 summarizes the number of estimated SSO incidents based on the records reported by regulated entities operating within the watershed.

Table 8. Summary of reported SSO events (from 2016 through 2022) in the Cedar Creek watershed (in gallons)

AU	Estimated Incidents	Total Volume (Gallon)	Minimum Volume (Gallon)	Maximum Volume (Gallon)
0604A_03	4	2,501	1	1,500

2.7.1.5. Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies 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 TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer system 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 included in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Direct Illicit Discharges:

- Sanitary wastewater piping that is directly connected from a home to the storm sewer.
- Materials 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.

2.7.2. 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. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, urban runoff not covered by a permit, and domestic pets.

2.7.2.1. Wildlife and Unmanaged Animals

Fecal bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife and feral hogs. Wildlife and feral hogs are attracted naturally to riparian corridors of water bodies. With direct access to the stream channel, the direct deposition of wildlife and feral hog waste can be a concentrated source of bacteria loading to a water body. Wildlife and feral hogs also leave feces on land, where they may be washed into nearby water bodies by rainfall runoff.

Texas Parks and Wildlife Department (TPWD) provided deer population density estimates by Resource Management Unit (RMU) and Ecoregion in the state (TPWD, 2020). The Cedar Creek watershed lies entirely in RMU 14 with an average deer density of 20.98 deer per 1,000 acres over the period 2005 through 2018 (TPWD, 2020). Applying this value to the suitable habitat area of the TMDL watershed estimates that there are approximately 11 deer within the watershed. Suitable land cover types for both deer and feral hog habitat include the following: Hay/Pasture, Shrub/Scrub, Grassland/ Herbaceous, Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, and Emergent Herbaceous Wetlands, as defined in the NLCD (2019).

For feral hogs, AgriLife Extension estimates one hog per 39 acres as a statewide average density for feral hogs (Timmons et.al., 2012). Using the same suitable land cover types within the TMDL watershed, the estimated feral hog density was applied to the area suitable for feral hog habitat which estimated that there are about 13 feral hogs in the watershed.

Both the suitable land cover area and estimated deer and feral hog populations are shown in Table 9 for the Cedar Creek watershed. The *E. coli* contribution from feral hogs and wildlife could not be determined based on existing information.

Table 9. Estimated feral hog and white-tailed deer populations

AU	Acres of Suitable Land Cover	Estimated Number of Feral Hogs	Estimated Number of White-tailed Deer
0604A_03	511.95	13	11

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Activities such as livestock grazing close to water bodies and the use of manure as fertilizer can contribute *E. coli* to water bodies.

Table 10 shows estimated numbers of livestock in the TMDL watershed based on the 2017 Census of Agriculture (USDA, 2019). Livestock populations in the TMDL watershed were estimated based on the ratio of the suitable habitat in the TMDL watershed to that in Angelina County. Suitable habitat is composed of land cover classified as Pasture/Hay or Grassland/Herbaceous in the 2019 NLCD. The ratio of suitable habitat (0.000803) was then multiplied by the county-level livestock populations to generate the TMDL watershed-level livestock population estimates.

Table 10. Estimated livestock populations

Area	Acres of Suitable Land Cover	Cattle and Calves	Hogs and Pigs	Goats and Sheep	Horses
Angelina County	94,468.29	19,274	147	1,885	2,031
0604A_03	75.83	15	0	2	2

Fecal matter from dogs and cats is transported to water bodies by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 11 summarizes the estimated number of dogs and cats in the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association (AVMA) 2017–2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the watershed was estimated using 2020 Census data (USCB, 2020). The actual contribution and significance of bacteria loads from pets reaching the water bodies is unknown.

Table 11. Estimated households and pet populations

AU	Estimated Households	Estimated Dog Population	Estimated Cat Population
0604A_03	2,136	1,312	976

2.7.2.3. On-Site Sewage Facilities

Private residential on-site sewage facility (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 contribute virtually no fecal bacteria to surface waters. For example, Weiskel et al. (1996) 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. Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The Cedar Creek watershed is located within the Region 5 area, which has a reported failure rate of about 19%, providing insights into expected failure rates for the area.

Estimates of the number of OSSFs in the Cedar Creek watershed were determined using GIS datasets, including 911 addresses (TNRIS, 2021), city boundaries, Certificates of Convenience and Necessity (CCN) boundaries (PUC, 2017), and aerial imagery. Address data points located outside of the city and CCN boundaries were manually examined on the aerial imagery to determine whether they were located on residential buildings or businesses, which were assumed to have been equipped with OSSFs. Data from these sources indicated that there may not be any OSSFs within the TMDL watershed, as the watershed completely lies within the City of Lufkin and is almost completely in the CCN boundary except for its northwestern corner near State Loop 287, which is approximately 11 acres or 0.4% of the watershed.

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

Section 3. Bacteria Tool Development

This section describes the rationale for selecting the bacteria tool used 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 0604A_03 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 (Jones et al., 2009). Mechanistic models and empirically derived LDCs are the two approaches commonly used for bacteria TMDLs in Texas.

The LDC method allows for estimation of existing and allowable loads by using 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, often associated with bacteria TMDLs that constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by TCEQ, and the Texas State Soil and Water Conservation Board supports application of the LDC method within their three-tiered approach to TMDL development (Jones et al., 2009). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion and can give indications of broad sources of the bacteria, that is, point source and nonpoint source.

3.2. Data Resources

Daily streamflow data were unavailable for the TMDL watershed; however, streamflow records are available at a nearby U.S. Geological Survey (USGS) gaging station 08066200 at Long King Creek in Livingston County. This gage was selected to develop naturalized historical daily streamflow data for Cedar Creek at SWQM station 10479. The selection of this USGS gage was also in consistent with that in the original TMDL (TCEQ, 2022c), where historical daily streamflow records were extrapolated from USGS gage 08066200 to develop an FDC at the downstream AU 0604A_02 of the Cedar Creek segment.

3.3. Methodology for Flow Duration and Load Duration Curve Development

To develop the flow duration curve (FDC) and LDC, the previously discussed data resources were used in the following sequential steps.

- Step 1: Determine the hydrologic period of record to be used in developing the FDC.
- Step 2: Determine the stream location for which FDC and LDC development is desired.
- Step 3: Develop daily streamflow record at desired location.
- 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.

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

3.3.1. Step 1: Determine Hydrologic Period

Daily streamflow data were estimated at SWQM station 10479 by extrapolating streamflow records from USGS gage 08066200. Ideally, the period of record used for developing an FDC should be long term so that the curve can be regarded as a probability curve and used to infer the percent of time that a specific streamflow is exceeded. Meanwhile, the hydrologic period should also be selected according to the *E. coli* data availability. Table 12 shows the available *E. coli* data for AU 0604A_03 upon development of this document. To be consistent with the period of *E. coli* measurements, as well as to make the FDC function as a probability curve, a ten-year hydrologic period of Oct. 1, 2012 through Sept. 30, 2022 was selected.

Table 12. Hydrologic periods of historical *E. coli* and estimated daily streamflow data at SWQM stations in the Cedar Creek watershed

SWQM Station	Assessment Unit	Period of *E. coli* Measurements
10479	0604A_03	09/19/2013 – 05/12/2021
21434	0604A_03	09/19/2013 – 05/17/2021

3.3.2. Step 2: Determine Desired Stream Location

There are two active SWQM stations located within the AU 0604A_03 watershed. SWQM station 10479 was considered a more appropriate location rather than SWQM station 21434 because station 10479 is the furthest downstream station and is more representative of the impaired watershed. The station also meets the 24 minimum sample suggestion when developing LDCs (Jones et al., 2009).

3.3.3. Step 3: Develop Daily Streamflow Record at Desired Location

Once the hydrologic period of record and the SWQM station location were determined, long-term daily streamflow data in the TMDL watershed were estimated using the drainage area ratio (DAR) approach.

To this end, the mean daily streamflow observed at USGS gage 08066200 (**Error! Reference source not found.**) was scaled using a factor to estimate the streamflow record at SWQM station 10479 as shown in Equation 1. The factor is determined using the drainage area above the ungaged SWQM station, the drainage area above the USGS gage, and a streamflow percentile exponent factor.

$$Y = X * (A_y \div A_x)^{\phi} \quad \text{(Equation 1)}$$

Where:

Y = streamflow for the ungaged location

X = streamflow for the gaged location

A_y = drainage area for the ungaged location

A_x = drainage area for the gaged location

ϕ = exponent based on percentile streamflow (Asquith et al., 2006)

Conventionally, $\phi = 1$ is used in the DAR approach. However, empirical analysis of the streamflow in Texas indicates that using $\phi = 1$ may result in substantial bias in streamflow estimates at very low and very high streamflow percentiles (Asquith et al., 2006). For this reason, a range of values (i.e., 0.7 – 0.935) for ϕ was used for different percentiles of streamflow based on the suggestions in Asquith et al (2006).

Identifying a gaged watershed, from which streamflow record is extrapolated to an ungaged watershed, requires considering several factors, such as the separation distance, relative drainage area, and hydrologic similarity. Furthermore, discharges and diversions in watersheds may complicate the application of the DAR approach.

A general understanding about the actual streamflow characteristics at the ungaged watershed is uncertain and relies upon local knowledge. Cedar Creek (AU 0604A_03) is described as a perennial stream in Appendix D of the Texas Surface Water Quality Standards (TCEQ, 2022b). To minimize complications from regulated discharges and diversions, a surrogate stream gage with minimal diversions and discharges was desired. Furthermore, Asquith et al. (2006) suggest a 100-mile maximum separation distance between the gage watershed and the ungaged one. Given the above, USGS gage 08066200 on Long King Creek at Livingston was selected as the donor gage (Figure 6).

This USGS station is around 43.4 miles southwest of SWQM Station 10479, and the corresponding drainage watershed, encompassing 38,482 acres, has no diversions and minimal upstream discharges from three WWTFs. On the other hand, the Long King Creek watershed is highly rural which is significantly different from the Cedar Creek watershed, which is more urban.

The streamflow measured at USGS gage 08066200 (USGS, 2019) was first “naturalized,” which refers to the process of removing hydrologic alterations, including additions of permitted discharges and withdrawals based on water rights. That said, the resulting “naturalized” flow is the flow that would occur in response to precipitation, evapotranspiration, near surface geology, soils, land covers of the watershed, and other hydrological processes. Since there are no withdrawals based on water rights within the Long King Creek watershed, naturalized flows were estimated by subtracting the additions, which were discharges in the Discharge Monitoring Reports (DMRs), from the USGS daily streamflow data. It is worth mentioning that DMRs report monthly mean discharge for WWTFs, and the daily discharge was, therefore, assumed to be the same across the entire month.

The Texas Water Rights Viewer showed no active water right holders or diversions in the gaged and ungaged watersheds (TCEQ, 2022g). A search for active TPDES wastewater permits indicated that three permitted entities discharge above USGS gage 08066200 in Long King Creek (Figure 6). To naturalize the gaged streamflow, DMRs were retrieved from the Enforcement and Compliance History Online (EPA, 2022). Monthly mean daily DMR discharges were removed from the USGS daily streamflow records for Oct. 1, 2012 through Sept. 30, 2022.

After applying the DAR to daily naturalized gaged streamflow values, the output is the estimated naturalized streamflow at the specific SWQM station. For the purposes of TMDL development, a final adjustment to the naturalized streamflow involves adding the full permitted discharge and future growth (FG) calculations of all upstream WWTFs. In this case, there are no upstream WWTFs so only the FG component was added to the naturalized streamflow record. The FG term which was estimated to be 0.1305 MGD (or 0.2019 cfs) to account for the growing population. The calculation of the FG term is described in 4.7.4.

Figure 7 shows the hydrograph of the daily mean streamflow estimated for SWQM station 10479 between Oct. 1, 2012 and Sept. 30, 2022.

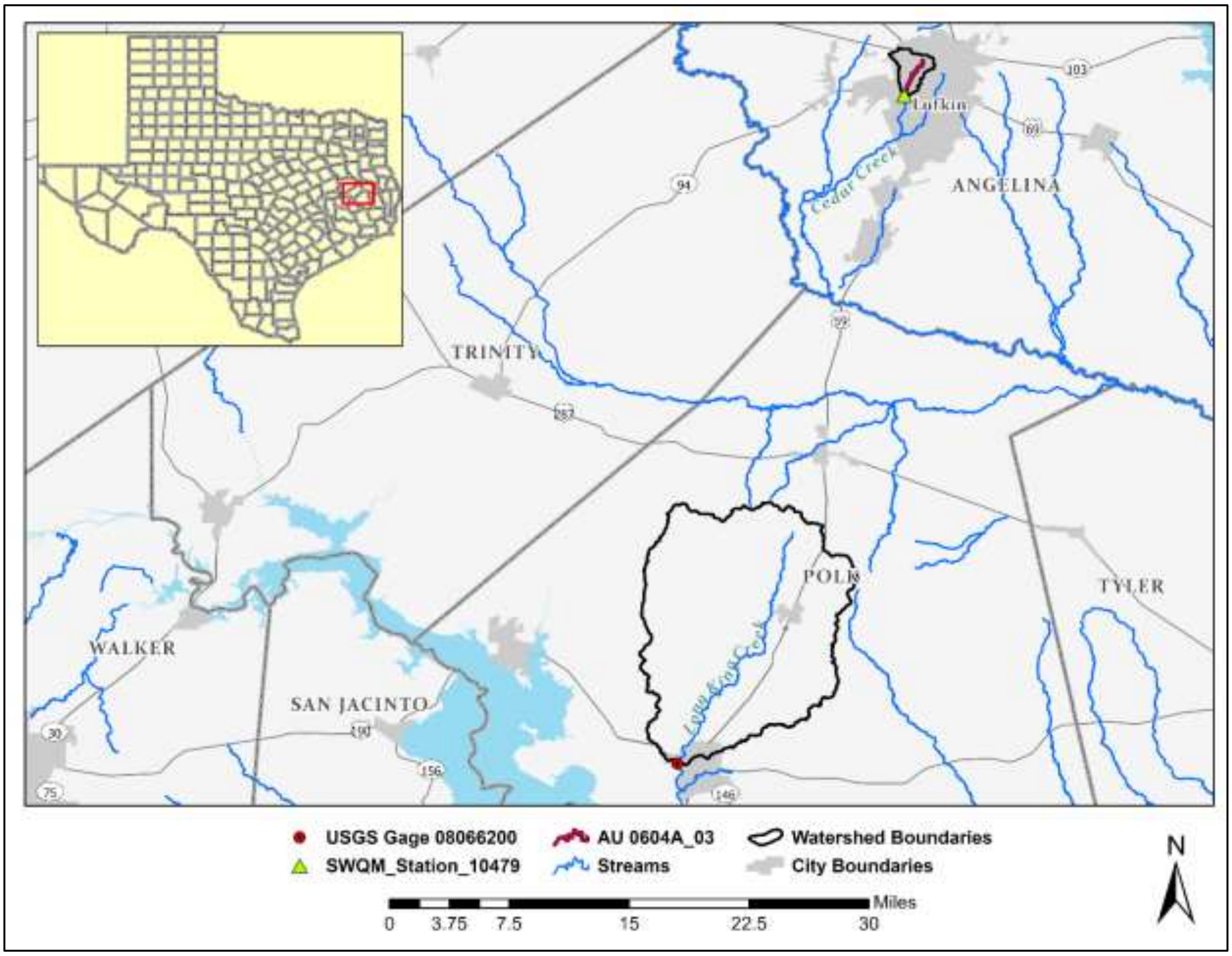

Figure 6. Locations of the gaged watershed and the TMDL watershed

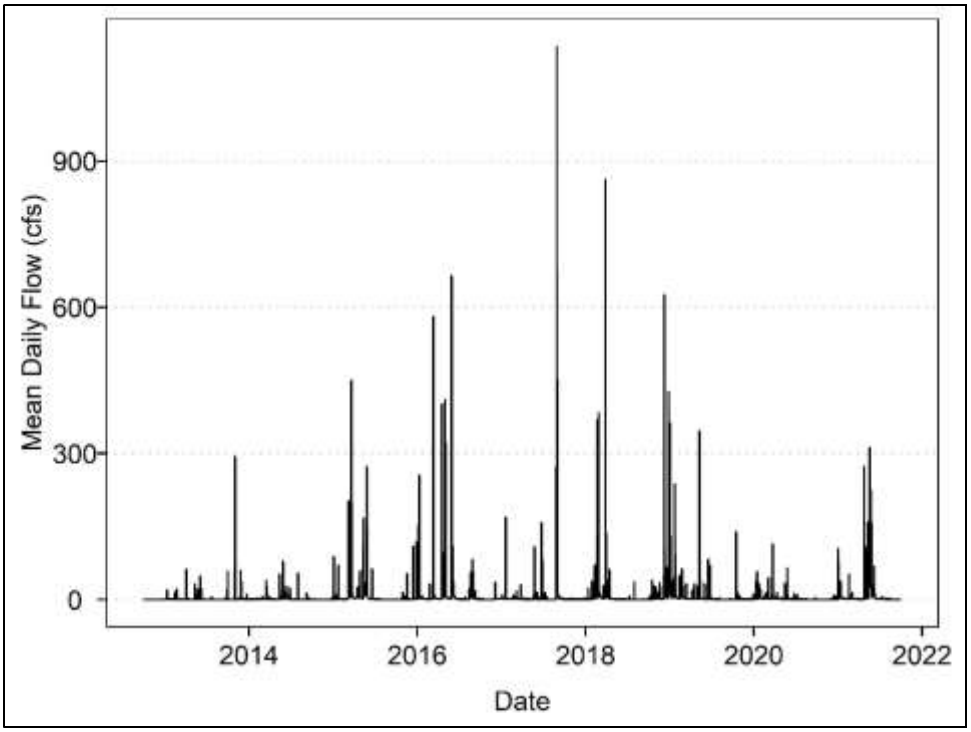

Figure 7. Time series of estimated historical daily streamflows at SWQM station 10479 on AU 0604A_03

3.3.4. Steps 4–6: Flow Duration and Load Duration Curves

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, all the following steps were taken in the order shown:

- Order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (one for the highest flow, two for the second highest flow, and so on).
- Compute the percentage of days each flow was exceeded by dividing each rank by the total number of data points plus one.
- 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 cfu/100 mL or 1.26 cfu/mL) and by a conversion factor (2.44658×10^7 or 2.44658×10^9), which gives you a loading unit of cfu/day.
- Plot the exceedance percentages, which are identical to the value for the 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 (2.44658×10^9).
- Plot on the LDC for the chosen SWQM station the load for each measurement at the exceedance percentage for its corresponding streamflow.

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

3.4. Flow Duration Curves

An FDC was developed for AU 0604A_03 watershed at SWQM station 10479 (Figure 8). In this document, the FDC was developed by scaling mean daily streamflow data from USGS gage 08066200 for Oct. 1, 2012 through Sept. 30, 2022 to the ungaged TMDL watershed using the DAR approach.

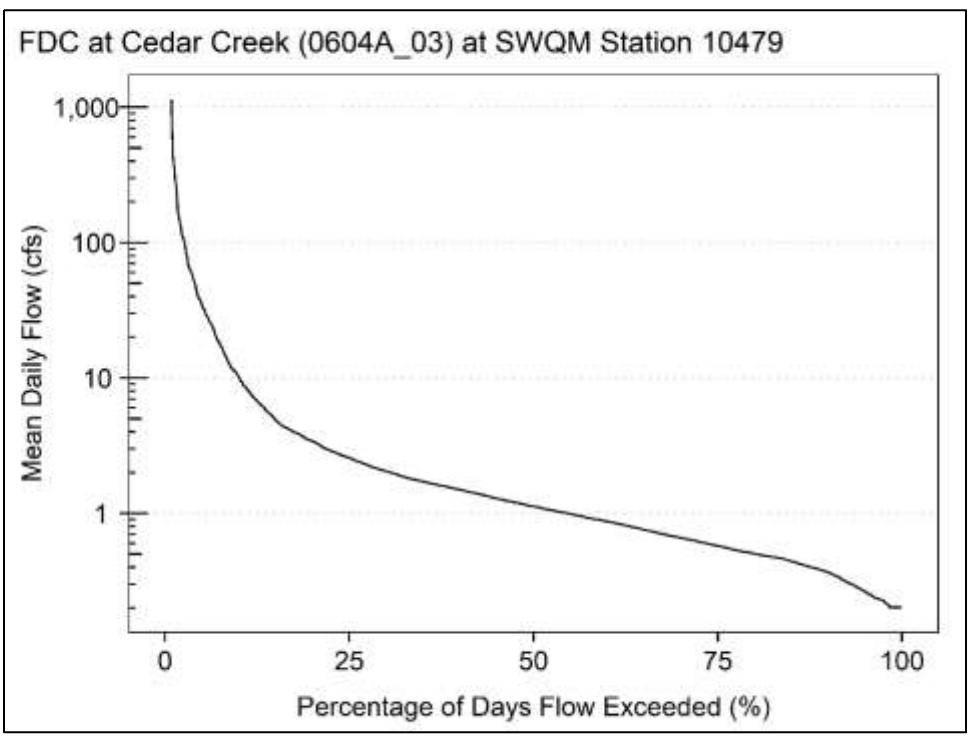

Figure 8. FDC for AU 0604A_03 at SWQM station 10479

3.5. Load Duration Curves

An LDC was developed for AU 0604A_03 at SWQM station 10479. A useful refinement of the LDC approach is to analyze the exceedance patterns in smaller portions by flow condition. A commonly used set of regimes, provided by Cleland (2003), is based on the following five segments: 0–10% (high flows); 10–40% (moist conditions); 40–60% (mid-range flows); 60–90% (dry conditions); and 90–100% (low flows). The LDC developed for the TMDL watershed is shown in Figure 9.

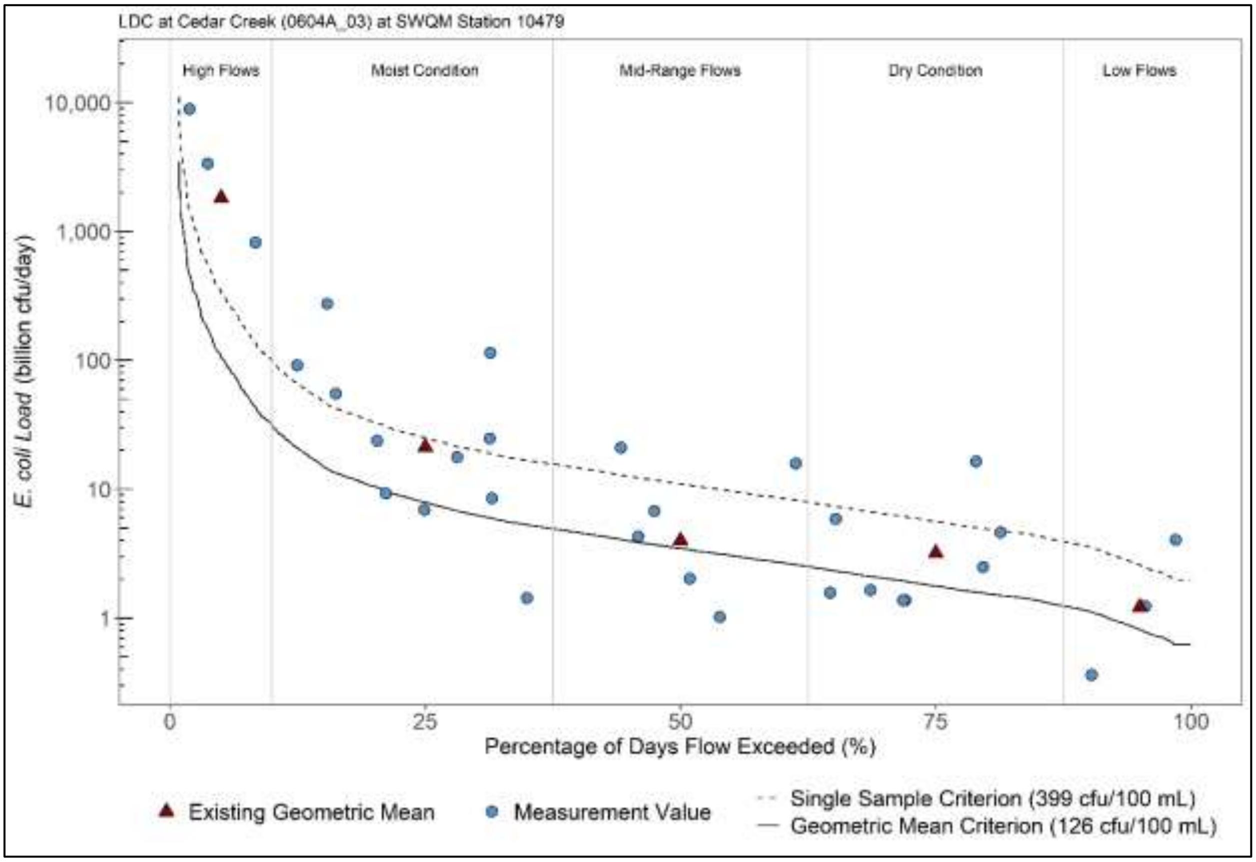

Figure 9. LDC for AU 0604A_03 at SWQM station 10479

Section 4. TMDL Allocation Analysis

4.1. 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 needed and as a criterion against which to evaluate future conditions. Please note that some calculations completed in this section have been rounded and may not lead to the exact final amounts listed in the text, tables, or figures.

The endpoint for the TMDL is to maintain the concentration of *E. coli* below the geometric mean criterion of 126 cfu/100 mL, which is protective of the primary contact recreation 1 use in freshwater.

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations, Chapter 1, Part 130, Section 130.7(c)(1)—or 40 CFR 130.7(c)(1)].

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing available *E. coli* concentrations obtained from routine monitoring at SWQM station 10479. Differences in *E. coli* concentrations were evaluated by performing a Wilcoxon Rank Sum test. *E. coli* concentrations during warmer months (May – September) were compared against those during the cooler months (November – March). April and October are considered transitional periods between warm and cool seasons and therefore were excluded from the analysis. This analysis of *E. coli* data indicated that there was no significant difference ($\alpha = 0.05$) in the concentration of indicator bacteria between cool and warm weather seasons in the TMDL watershed (Figure 10).

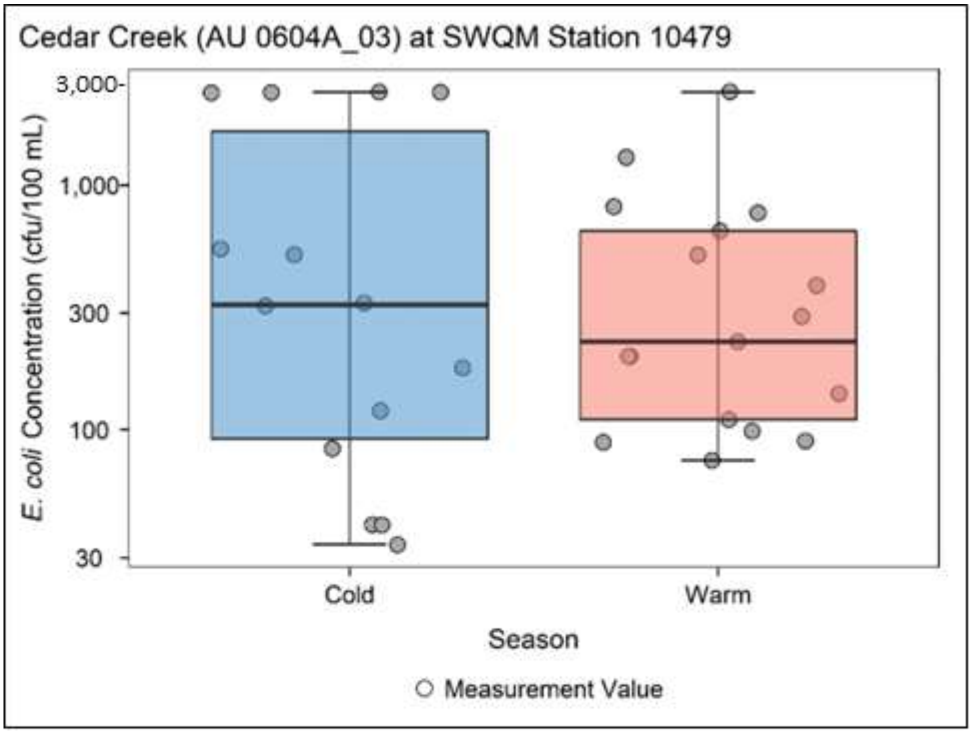

Figure 10. Distribution of *E. coli* concentrations by season in the AU 0604A_03 watershed

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 and direct deposition (such as 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 size, the impact of point sources 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, can carry bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline as runoff washes fecal bacteria from the land surface and the volume of runoff decreases following the rain event.

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

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and 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. An LDC is 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 about loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA 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 about the magnitude or specific origin of the various sources. Information gathered about point and nonpoint sources in the watershed is limited. 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 using 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.

For Cedar Creek AU 0604A_03 watershed, historical *E. coli* data indicate that elevated bacteria loads occur under all flow conditions. However, bacteria loads were the most elevated under high-flow and the upper end of moist conditions. Meanwhile, under other flow conditions, most bacteria loads were not significantly above the geometric mean criterion and some loads were below the criterion.

The AU 0604A_03 watershed is almost entirely urban, meaning most of the high-flow loads are likely related to regulated and unregulated stormwater. Over time, the concentrations of bacteria decline due to the decrease in overland runoff, which carries bacteria from land surface to water bodies. Since there are no WWTFs located within the TMDL watershed to contribute to point source loads under low to median flow conditions, elevated loads during lower flow conditions are likely related to periodic events, such as SSOs and direct deposition (direct fecal deposition into the water body). Over time, the concentrations would decline as point sources get diluted.

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 EPA guidance (EPA, 1991), the MOS can be incorporated in the TMDL using either of the following two methods:

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

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

The TMDL in this report incorporates an explicit MOS of 5%.

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 (FC) and the median flow in each flow category (excluding days with zero flow), as estimated in Section 3.3 (Equation 1).

$$\text{Existing Load}_{FC} = Q_{FC} * G_{FC} * \text{Conversion Factor} \qquad \text{(Equation 2)}$$

Where:

$\text{Existing Load}_{FC}$ = Existing *E. coli* load at the median flow in each FC

FC = Respective flow category

Q_{FC} = Median Flow for FC

G_{FC} = Geometric mean of bacteria (cfu *E. coli*/100 mL) samples for FC

Conversion Factor (to billion cfu/day) = 28,316.846 mL/cubic feet (ft^3) * 86,400 seconds/day ÷ 1,000,000,000

The allowable load was calculated (Equation 2) as:

$\text{Allowable Load}_{FC} = Q_{FC} * \text{Criterion} * \text{Conversion Factor}$ (Equation 3)

Where:

$\text{Allowable Load}_{FC}$ = Allowable *E. coli* load at the median flow in each FC

FC = Respective flow category

Q_{FC} = Median Flow for FC

Criterion = 126 cfu/100 mL

Conversion Factor (to billion cfu/day) = 28,316.846 mL/ft^3) * 86,400 seconds/day ÷ 1,000,000,000

Percent reduction for each flow category (PR_{FC}) (Equation. 3) was then calculated as:

$PR_{FC} = (\text{Existing Load}_{FC} - \text{Allowable Load}_{FC}) \div \text{Existing Load}_{FC}$ (Equation 4)

Table 13. Daily load reductions needed to meet *E. coli* standard by flow category

Flow Regime	Simulated Flow (cfs)	Geomean Concentration (cfu/100 mL)	Existing Load (billion cfu/day)	Allowable Load (billion cfu/day)	Percent Reduction Required
High Flows	31.046	2,400	1,822.953	95.705	94.750%
Moist Conditions	2.575	338	21.294	7.938	62.722%
Mid-Range Flows	1.126	145	3.995	3.471	13.116%
Dry Conditions	0.575	228	3.207	1.773	44.715%
Low Flows	0.264	189	1.221	0.814	33.333%

4.7. Pollutant Load Allocations

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

$\text{TMDL} = \text{WLA} + \text{LA} + \text{FG} + \text{MOS}$ (Equation 5)

Where:

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

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

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDL for the water body was developed as a pollutant load allocation based on information from the LDC for the SWQM station located within the watershed (Figure 9). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* 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 (cfs) * Conversion Factor (Equation 6)

Where:

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

Conversion Factor (to billion cfu/day) = 28,316.846 mL/cubic feet (ft^3) * 86,400 seconds/day (s/d) ÷ 1,000,000,000

The allowable loading of *E. coli* that the impaired water body can receive on a daily basis was determined using Equation 5 based on the median value within the high-flow regime of the FDC (or 5% flow exceedance value) for SWQM station 10479 (Table 14).

Table 14. Summary of allowable loading calculation

Water Body Name	AU	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/Day)	TMDL (Billion cfu/Day)
Cedar Creek	0604A_03	31.046	95,710,000,000	95.705

4.7.2. Margin of Safety Allocation

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

MOS = 0.05 * TMDL (Equation 7)

Using the value of TMDL for the AU provided in Table 14, the MOS may be readily computed by proper substitution in Equation 6 (Table 15).

Table 15. MOS calculations

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS
Cedar Creek	0604A_03	95.705	4.785

[a] TMDL from Table 14.

4.7.3. Wasteload Allocations

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}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{(Equation 8)}$$

4.7.3.1. Wastewater

TPDES-permitted WWTFs are allocated a daily wasteload calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. The water quality criterion (126 cfu/100mL) is used as the WWTF target to provide instream and downstream load capacity. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \qquad \text{(Equation 9)}$$

Where:

Target= 126 cfu/100 mL

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

Conversion Factor (to billion cfu/day) = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

There are not any TPDES-permitted WWTFs in the AU 0604A_03 watershed, therefore, the daily allowable loading of *E. coli* for the WLA_{WWTF} is zero. Table 16 presents the WLA_{WWTF} for the TMDL watershed.

Table 16. WLAs for TPDES-permitted facilities

Load units expressed as billion cfu/day *E. coli*

Watershed (AU)	TPDES Permit No.	Permittee	Full Permitted Flow (MGD)	*E. coli* WLA_{WWTF}
0604A_03	N/A[a]	N/A	0	0
Total:	N/A	N/A	0	0

[a] N/A = not applicable

4.7.3.2. Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges. A simplified approach for estimating the WLA for these areas 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 the land area that is under the jurisdiction of stormwater permits in the TMDL watershed was used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \qquad \text{(Equation 10)}$$

Where:

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

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order to estimate the amount of overall 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 2.7.1.3, the AU 0604A_03 watershed is not covered by any MS4 permits. The facilities with authorized general stormwater permits and construction general permits were thus used to compute an area of regulated stormwater contribution (Table 17).

Table 17. Basis of regulated stormwater area and computation of FDA_{SWP} term

Watershed	AU	Total Area (acres)	Area Under Stormwater Regulation (acres)	FDA_{SWP}
Cedar Creek	0604A_03	2,509	41.645	0.017

The daily allowable loading of *E. coli* assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. To calculate the WLA_{SW} (Equation 9), the FG term must be known. The calculation for that term is presented in the next section, but the results are included here for continuity. Table 18 provides the information needed to compute WLA_{SW}.

Table 18. Regulated stormwater WLA_{SW} calculations

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{SWP}[e]	WLA_{SW}[f]
Cedar Creek	0604A_03	95.705	4.785	0	0.622	0.017	1.499

a TMDL from Table 14

b MOS from Table 15

c WLA_{WWTF} from Table 16

d FG from Table 19

e FDA_{SWP} from Table 17

f $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Equation 10)

4.7.4. 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. Due to the absence of WWTFs within the TMDL watershed, here the FG component considers the projected increase in population between 2020 and 2070 (Table 2).

A new WWTF must accommodate daily wastewater flow of 75–100 gallons per capita per day (gpcd) as required under Title 30, Texas Administrative Code, Chapter 217, Subchapter B, Section 217.32 (30 TAC 217.32) (TCEQ, 2015). Using the upper value of 100 gallons per day and multiplying it by the estimated population change (an extra 1,305 individuals) would produce a conservative FG value. The calculation based on FG = Target * Flow * Conversion Factor (Equation 11) results for the TMDL watershed are shown in Table 19.

$$FG = Target * Flow * Conversion\ Factor \qquad \text{(Equation 11)}$$

Where:

Target= 126 cfu/100 mL

Flow = estimated population growth-induced flow (MGD), which in AU 0604A_03 was calculated using 1,305 * 100 gallons per person/day ÷ 1,000,000 = 0.1305 MGD

Conversion Factor (to billion cfu/day) = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

Table 19. FG calculation

Water Body Name	AU	Population Increase (2020–2070)	FG (MGD)	FG (*E. coli* Billion cfu/Day)
Cedar Creek	0604A_03	1,305	0.131	0.622

4.7.5. Load Allocations

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

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \qquad \text{(Equation 12)}$$

Where:

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 20.

Table 20. LA calculation

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG[e]	LA[f]
Cedar Creek	0604A_03	95.705	4.785	0	1.499	0.622	88.799

[a] TMDL from Table 14

[b] MOS from Table 15

[c] WLA_{WWTF} from Table 16

[d] WLA_{SW} from Table 18

[e] FG from Table 19

[f] $LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$ (Equation 12)

4.8. Summary of TMDL Calculations

Table 21 summarizes the TMDL calculation for the TMDL watershed. The TMDL was calculated based on the median flow in the 90-percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for SWQM station 10479. Allocations are based on the current geometric mean criterion for *E. coli* of 126 cfu/100 mL for each component of the TMDL. The TMDL allocation summary for the AU 0604A_03 watershed is summarized in Table 21.

Table 21. TMDL allocation summary

Load units expressed as billion cfu/day *E. coli*

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
0604A_03	95.705	4.785	0	1.499	88.799	0.622

[a] TMDL from Table 14

[b] MOS from Table 15

[c] WLA_{WWTF} from Table 16

[d] WLA_{SW} from Table 18

[e] LA from Table 20

[f] FG from Table 19

The final TMDL allocation (Table 22) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the $WLA_{WWTF.}$

Table 22. Final TMDL allocation

Load units expressed as billion cfu/day *E. coli*

AU	TMDL	MOS	WLA_{WWTF}[a]	WLA_{SW}	LA
0604A_03	95.705	4.785	0.622	1.499	88.799

[a] WLA_{WWTF} includes the FG component

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Appendix A. Population Estimation and Projections

Estimate 2020 watershed population

There are 251 census blocks either entirely or partially located in the Cedar Creek watershed. For census blocks that are entirely in the watershed, the 2020 Census estimates were directly summed. Meanwhile, for census blocks that are partially in the watershed, the population was estimated using the Equation (A-1)

Watershed Population =

Σ Area of a Census Block within the Watershed * (Census Block Population/Area of the Census Block) (Equation A- 1)

The underlying assumption is that within each census block, the population density is evenly distributed across space.

It is worth noting that the same method was also applied to estimate the house units within the Cedar Creek watershed and the estimated house units number was used to estimate the number of domesticated animals in the watershed.

Estimate 2020–2070 watershed population

Angelina County decadal population projections for 2020 through 2070 were obtained from the 2021 Regional Water Plan Population and Water Demand Projection data (TWDB, 2019) for Region I.

The percentage increase in population at the county level was calculated for each decade and then applied to estimate the decadal population increase at the watershed level. The underlying assumption is that the rate of population growth is the same throughout the county.