Proctor Lake Watershed Characterization

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Resources Institute
make every drop count

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Cover photo: View from Sowell Creek Park on Proctor Lake. Photo by Leslie Lee, TWRI.

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Abbreviations List

AnU	Animal unit
AU	Assessment unit
AVMA	American Veterinary Medical Association
BRA	Brazos River Authority
CAFO	Concentrated Animal Facility Operation
CCN	Certificate of Convenience and Necessity
cfs	cubic feet per second
cfu	colony forming unit
CGP	Construction General Permit
CS	Screening level concern
CN	Concern near not attainment
CWA	Clean Water Act
DAR	Drainage area ratio
DMU	Deer Management Unit
DO	Dissolved oxygen
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FDC	Flow duration curve
GCD	Groundwater Conservation District
GIS	Geographic information system
LDC	Load duration curve
mg/L	milligram per liter
mL	milliliter
MGD	Million gallons per day
MS4	Municipal separate storm sewer system
MSGP	Multi-Sector General Permit
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	United States Department of Agriculture – Natural Resources Conservation Service
NS	Standard not supported
OSSF	On-site sewage facilities
PBIAS	Percent bias
PCR	Primary Contact Recreation
RUAA	Recreational Use – Attainability Analysis
SCR	Secondary Contact Recreation
SSO	Sanitary sewer overflow
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department

TSWQS	Texas surface water quality standards
TWDB	Texas Water Development Board
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WSD	Water Supply District
WWTF	Wastewater treatment facility

Executive Summary

Routine water quality monitoring indicates that several waterbodies in the Proctor Lake watershed (Duncan Creek, Rush-Copperas Creek, Sabana River, Sweetwater Creek, and Leon River below Leon Reservoir) do not meet water quality standards for recreation use because of elevated concentrations of bacteria. Leon River below Leon Reservoir is also considered impaired for aquatic life use due to depressed dissolved oxygen concentrations. Several use concerns due to depressed dissolved oxygen, elevated concentrations of chlorophyll-a, bacteria, and nitrates also exist in the watershed. With water quality impairments comes a need to plan and implement actions that restore water quality and ensure safe and healthy water.

To meet this need, the Texas Water Resources Institute, in partnership with the Texas State Soil and Water Conservation Board, is working with local stakeholders to characterize the watershed by identifying sources of pollution in the watershed contributing to water quality impairments and related concerns.

This report describes the analysis of existing data and information on water quality impairments and pollutant loading in the watershed. Existing data and information are used to the extent possible to characterize water quality conditions, watershed characteristics, and potential sources of pollution contributing to water quality impairments and concerns.

Chapter 1 – Introduction

1.1 Background

Routine water quality monitoring indicates that several waterbodies in the Proctor Lake watershed (Duncan Creek, Rush-Copperas Creek, Sabana River, Sweetwater Creek, and Leon River below Leon Reservoir) do not meet water quality standards for recreation use because of elevated bacteria concentrations. The Leon River below Leon Reservoir is also considered impaired for aquatic life use due to depressed dissolved oxygen (DO) concentrations. Several use concerns due to depressed DO, elevated concentrations of chlorophyll-a, bacteria, and nitrates also exist in waterbodies in the watershed. As the most upstream segments of the Leon River, and the main source of water for Proctor Lake, impairments in this portion of the Leon River have far-reaching downstream impacts. With water quality impairments comes a need to plan and implement actions that restore water quality and ensure safe and healthy water. A key factor in achieving water quality improvement is to have strategies that are locally developed, supported, and implemented.

1.2 Watershed-Based Water Quality Management

1.2.1 Definition of a Watershed

A watershed is the area of land that water flows across or through as it makes its way to a specific point in a stream, river, lake, or even the ocean. Flowing water can come from a variety of sources: rainfall, snowmelt, springs, and even from a water hose. All land on our planet is part of a watershed. Watersheds can contain smaller subwatersheds and can also be contained within larger watersheds. A healthy watershed, according to the United States Environmental Protection Agency (EPA), is an area that supports dynamic environmental processes and habitats of sufficient size and connectivity to support native species and meets the physical and chemical water quality standards needed to support biological communities (EPA 2012).

1.2.2 Water Quality Management

The water that flows into a waterbody directly impacts the quality of that waterbody due to the natural processes and human activities that occur within a watershed. These processes and activities may generate pollutants which end up in the waterbody. Pollutants can enter a waterbody from either a “point source,” a fixed location such as a pipe or channel, or a “nonpoint source” that is washed off the landscape by rainfall. Point sources, and some urban nonpoint sources, are regulated and require a permit to discharge to waterways. Nonpoint sources are not regulated. Instead, they are managed primarily through responsible resources stewardship and voluntary management practice implementation. Water quality management approaches aim to improve and maintain optimal water quality for a specific waterbody by preventing and reducing pollution.

1.2.3 The Watershed Approach

The watershed approach is widely accepted by state and federal water resource management agencies to facilitate water quality management. The EPA describes the watershed approach as “a flexible framework for managing water resource quality and quantity within a specified drainage area or watershed” (EPA 2008). The watershed approach requires engaging stakeholders to make management decisions supported by sound science (EPA 2008). One critical aspect of the watershed approach is that it focuses on hydrologic boundaries rather than political boundaries to address potential water quality impacts affecting all potential stakeholders (EPA 1996). Since watersheds do not follow political boundaries such as county lines or city limits, stakeholders must work together in unique ways to address water quality concerns in their watershed.

1.3 Watershed Characterization

A critical step that informs the process of determining appropriate and effective methods and locations of management strategies aimed at restoring water quality is to characterize the sources and causes of impairments in the watershed. Watershed characterization involves gathering and analyzing existing data and information on water quality impairments and pollutant loading in the watershed. By collecting and analyzing these data in tandem, a conceptual model can be developed to show the linkage between the water quality problems in the watershed, sources of impairments, and potential load reductions needed to restore water quality.

This report includes a compilation and analysis of available existing data and information in the Proctor Lake watershed. The report further documents the application of the compiled data and information to describe relevant watershed characteristics and to identify the potential causes of water quality impairments.

Chapter 2 – Watershed Properties

This chapter provides a geographic, demographic, and water quality overview of the Proctor Lake watershed. Development of the information within this chapter relied heavily on state and federal data resources as well as local stakeholder knowledge. The collection of this information is critical for the reliable assessment of potential sources of water quality impairment and the recommendation of beneficial management measures.

2.1 Watershed Description and Impairment Overview

The Proctor Lake watershed encompasses areas drained by the most upstream portion of the Leon River and tributaries draining into Proctor Lake. The watershed area spans nearly 820,705 acres of land in Comanche, Eastland, Erath, Brown, Callahan, and Stephens counties (Figure 2-1). The Texas Commission on Environmental Quality (TCEQ) divided waterbodies in the Proctor Lake watershed into segments[1] and assessment units[2] (AUs) that TCEQ uses to incrementally evaluate water quality in the watershed. The watershed is comprised of three classified segments (Proctor Lake, Leon River Below Leon Reservoir, and Leon Reservoir) and ten unclassified waterbodies (Duncan Creek, Rush-Copperas Creek, Sabana River, Sowells Creek, Sweetwater Creek, Hackberry Creek, Armstrong Creek, Cow Creek, Leon River Above Leon Reservoir, and South Fork Leon River) (Table 2-1).

In compliance with Sections 305(b) and 303(d) of the Federal Clean Water Act (CWA), TCEQ evaluates water bodies in the state and identifies those that do not meet uses and criteria defined in the Texas Surface Water Quality Standards (TSWQS). TCEQ publishes the results as the Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) (Texas Integrated Report). These reports include the support level[3] for a particular use, method, or parameter group. The 2022 Texas Integrated Report (TCEQ 2022a) lists several AUs in the watershed as impaired or as having use concerns. In TCEQ's terminology, impaired waterbodies are listed as not supporting (NS) their water

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[1] Segment – a waterbody or portion of a waterbody that is individually defined and classified in the Texas Surface Water Quality Standards (TSWQS). A segment is intended to have relatively homogeneous chemical, physical, and hydrological characteristics. Unclassified waterbodies are not defined in the TSWQS, though associated with a classified waterbody in the same watershed.

[2] Assessment Units (AU) - a sub-area of a stream segment, defined as the smallest geographic area of use support.

[3] Level of support: A range of water quality conditions and assessment status is expressed by a level of support established in each AU. Support status can be described as either fully supporting, concern for near non-attainment, concern for screening level, non-supporting, not assessed, no concern, or pending issue (TCEQ 2022a).

quality criteria, waterbodies with screening level concerns (CS) exceed screening levels established for parameters without specific criteria, and waterbodies with use concerns (CN) are near the point where they no longer support established water quality criteria (Table 2-2).

In this report, analyses of watershed properties and water quality conditions cover drainage areas for the whole waterbody, not each AU. This is because water quality monitoring occurs at a singular station on most of the waterbodies in the watershed. The terms “waterbody” and “segment” are used interchangeably in this report.

Table 2-1. TCEQ description of waterbodies in the Proctor Lake watershed

Waterbody	Segment ID	Segment description	AU ID	AU description
Proctor Lake	1222	From Proctor Dam in Comanche County to a point immediately upstream of the confluence of Mill Branch in Comanche County, up to the normal pool elevation of 1162 feet (impounds Leon River)	1222_01	Sabana River arm of the lake
			1222_02	Copperas/Duncan Creeks arm of the lake
			1222_03	Portion of waterbody near the dam
Duncan Creek	1222A	From the confluence of Proctor Lake northeast of Comanche in Comanche County to the upstream perennial portion of the stream west of Comanche in Comanche Count	1222A_01	Same as the segment description
Rush-Copperas Creek	1222B	From the confluence of Proctor Lake northeast of Comanche in Comanche County to the upstream perennial portion of the stream northwest of Comanche in Comanche County	1222B_01	Same as the segment description
Sabana River	1222C	From the confluence of Proctor Lake northeast of Comanche in Comanche County to the upstream perennial portion of the stream northwest of Rising Star in Eastland County	1222C_01	Portion of Sabana River from the confluence with Proctor Lake in Comanche County upstream to confluence with Elm Creek in Eastland County.
			1222C_02	Portion of Sabana River from the confluence with Elm Creek in Eastland upstream to headwaters in Callahan County
Sowells Creek	1222D	From its confluence with Lake Proctor, upstream to its headwaters 1.3 mi west of Dublin in Erath County	1222D_01	Same as the segment description
Sweetwater Creek	1222E	From its confluence with Copperas Creek, upstream to its headwaters, 6.3 mi west of Comanche in Comanche County	1222E_01	Same as the segment description
Hackberry Creek	1222F	From its confluence with Armstrong Creek, upstream to its headwaters approximately 9.8 mi west of Stephenville in Erath County	1222F_01	Same as the segment description

Waterbody	Segment ID	Segment description	AU ID	AU description
Leon River Below Leon Reservoir	1223	From a point immediately upstream of the confluence of Mill Branch in Comanche County to Leon Dam in Eastland County	1223_01	Same as the segment description
Armstrong Creek	1223A	From its confluence with the Leon River downstream of Leon Reservoir, upstream to its headwaters in Erath County 6.2 mi east of State Hwy 16.	1223A_01	Same as the segment description
Cow Creek	1223B	From the confluence with Armstrong Creek, upstream to its headwaters in Erath County, 5 mi north of Dublin	1223B_01	Same as the segment description
Leon Reservoir	1224	From Leon Dam in Eastland County up to the normal pool elevation of 1375 feet (impounds Leon River)	1224_01	Portion near dam
			1224_02	Headwater portion
Leon River Above Leon Reservoir	1224A	From the headwaters of Leon Reservoir up to the confluence of the North Fork Leon River and the South Fork Leon River (includes Lake Olden)	1224A_01	Same as the segment description
South Fork Leon River	1224C	From the confluence of the North Fork Leon River up to the confluence of the Middle Fork Leon River	1224C_01	Same as the segment description

Table 2-2. Waterbodies in the Proctor Lake watershed with impairments or concerns

Waterbody	Segment ID	AU ID	Parameter of impairment or concern	Level of support*
Proctor Lake	1222	1222_03	DO	CS
Duncan Creek	1222A	1222A_01	Chlorophyll-a Bacteria	CS NS
Rush-Copperas Creek	1222B	1222B_01	Bacteria	NS
Sabana River	1222C	1222C_01	Bacteria	NS
Sowells Creek	1222D	1222D_01	Bacteria	CN
Sweetwater Creek	1222E	1222E_01	Bacteria	NS
Hackberry Creek	1222F	1222F_01	DO Bacteria	CS CN
Leon River Below Leon Reservoir	1223	1223_01	DO Chlorophyll-a Bacteria	NS CS NS
Armstrong Creek	1223A	1223A_01	Nitrate	CS
Cow Creek	1223B	1223B_01	Bacteria	CN

*** Level of support: NS = Nonsupport, CS = Screening Level Concern, CN = Use Concern**

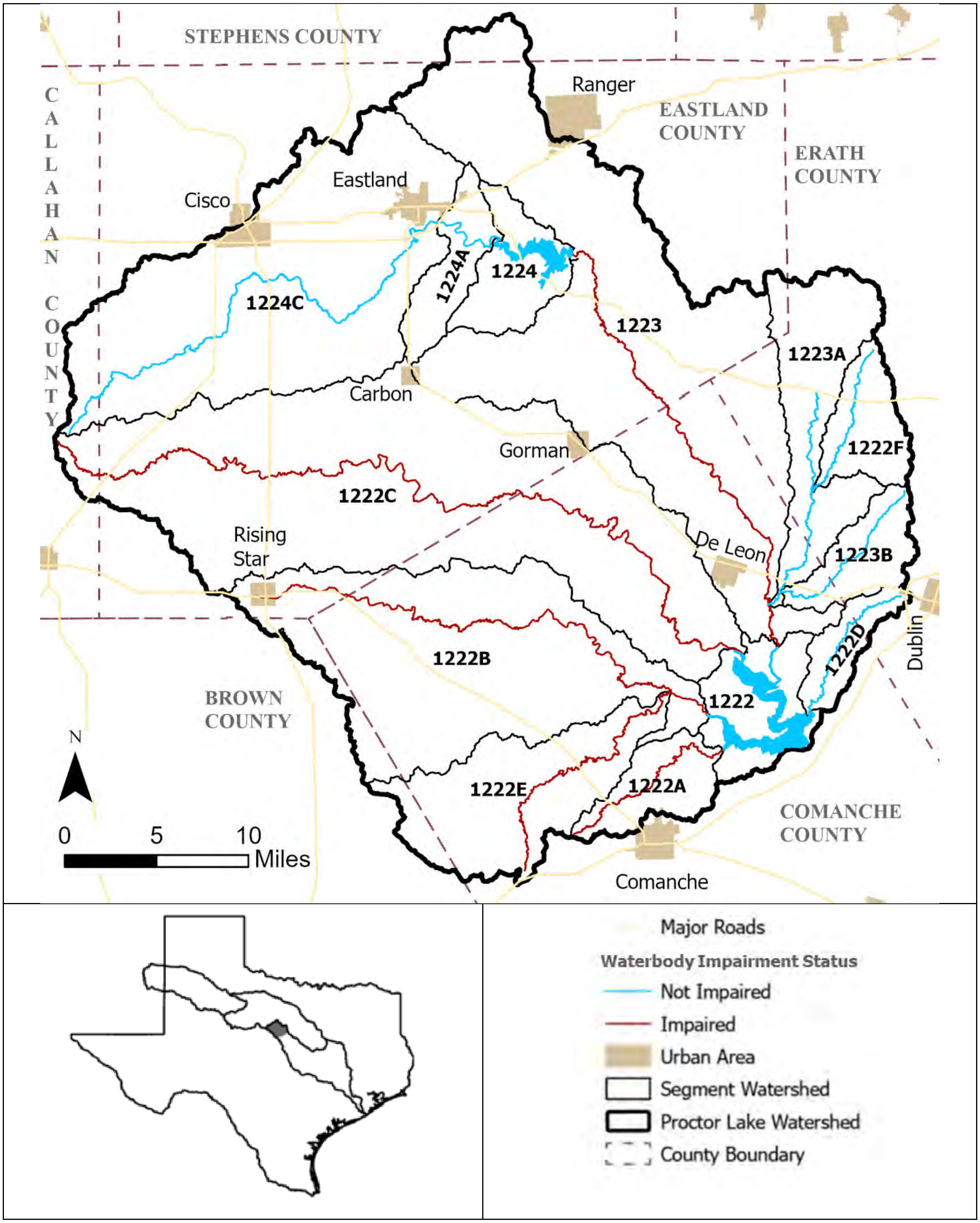


Figure 2-1. Proctor Lake watershed boundary and waterbody impairment status

2.2 Land Use and Land Cover

The National Land Cover Database (NLCD) provides nationwide data on land cover at a 30-meter (m) resolution. The database provides the ability to understand both current and historical land cover and land cover change. According to the 2021 NLCD land cover data (Dewitz 2023), the dominant land cover in the Proctor Lake watershed is rangeland (shrub and herbaceous grasslands) which cover about 60% of the watershed (Figure 2-2). Developed areas make up less than 5% of the watershed. Other significant land covers in the watershed are pasture/hay, forests, and cultivated crops.

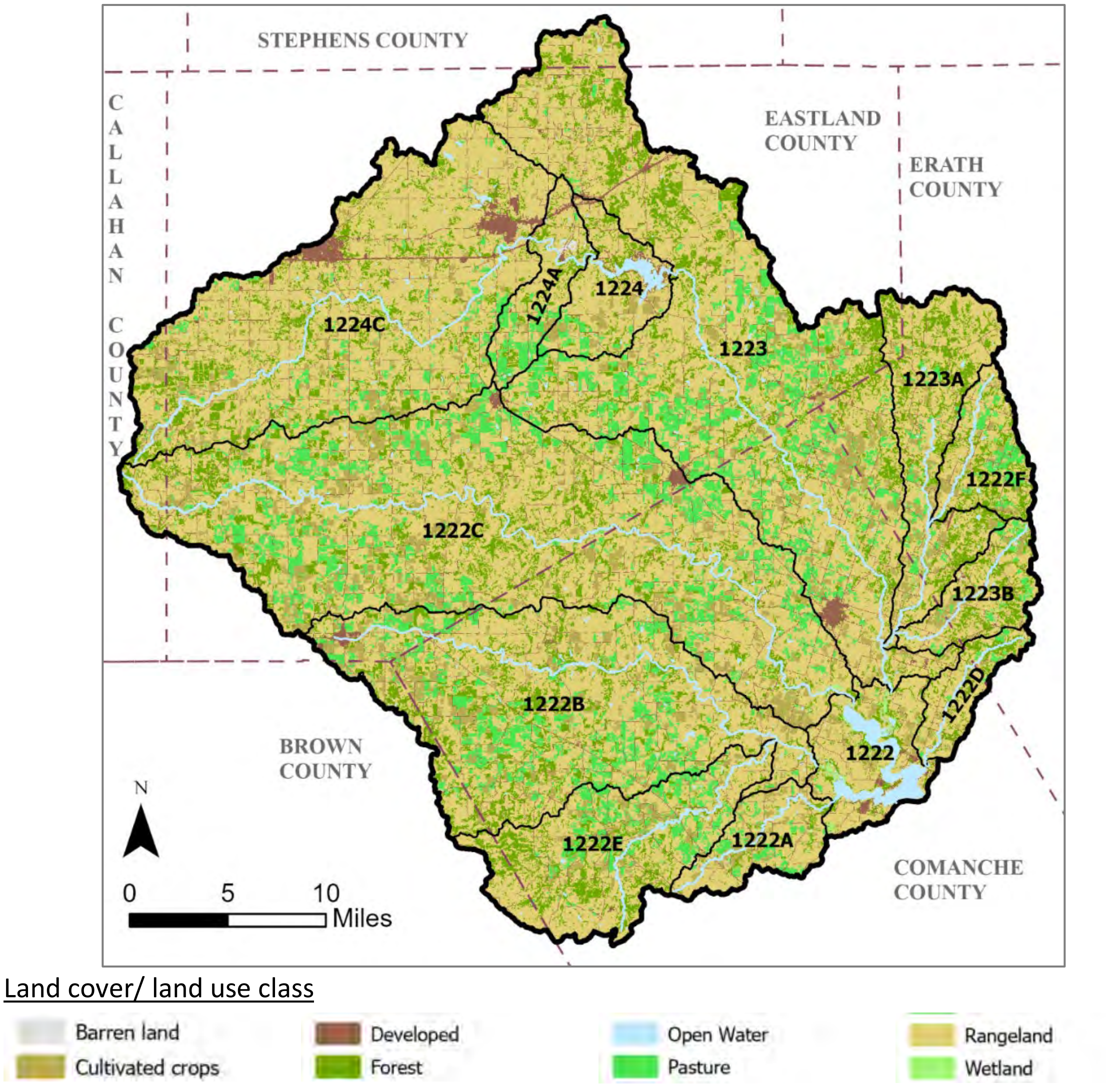
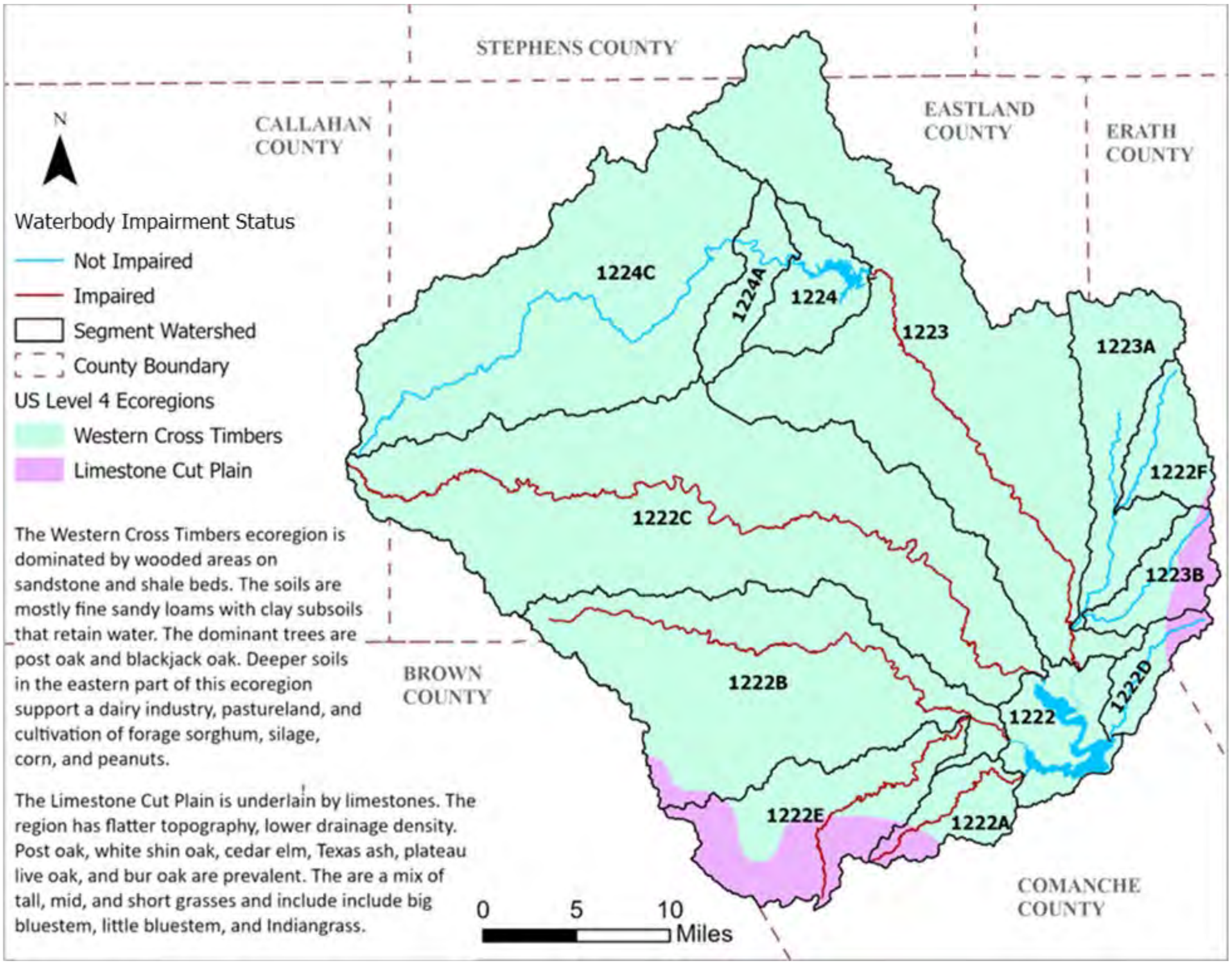


Figure 2-2. Proctor Lake watershed land cover and land use

2.3 Ecoregions

Ecoregions are land areas with ecosystems that contain similar quality and quantity of natural resources (Griffith *et al*. 2007). There are four separate delineated levels of ecoregions, with Level I being the most unrefined classification and Level IV being the most refined (EPA 2023). The Proctor Lake watershed area is within the Level III Ecoregion 29, known as the Cross Timbers, and its location within Ecoregion 29 is subdivided into two Level IV Ecoregions 29c and 29e, known as the Western Cross Timbers and the Limestone Cut Plain respectively (Figure 2-3). This region is made up of a mix of prairie, savanna, and woodland and forms part of the boundary between the more heavily forested eastern country and the almost treeless Great Plains. It also marks as the western habitat limit of many mammals and insects (Griffith et. al., 2007).



The Western Cross Timbers ecoregion is dominated by wooded areas on sandstone and shale beds. The soils are mostly fine sandy loams with clay subsoils that retain water. The dominant trees are post oak and blackjack oak. Deeper soils in the eastern part of this ecoregion support a dairy industry, pastureland, and cultivation of forage sorghum, silage, corn, and peanuts.

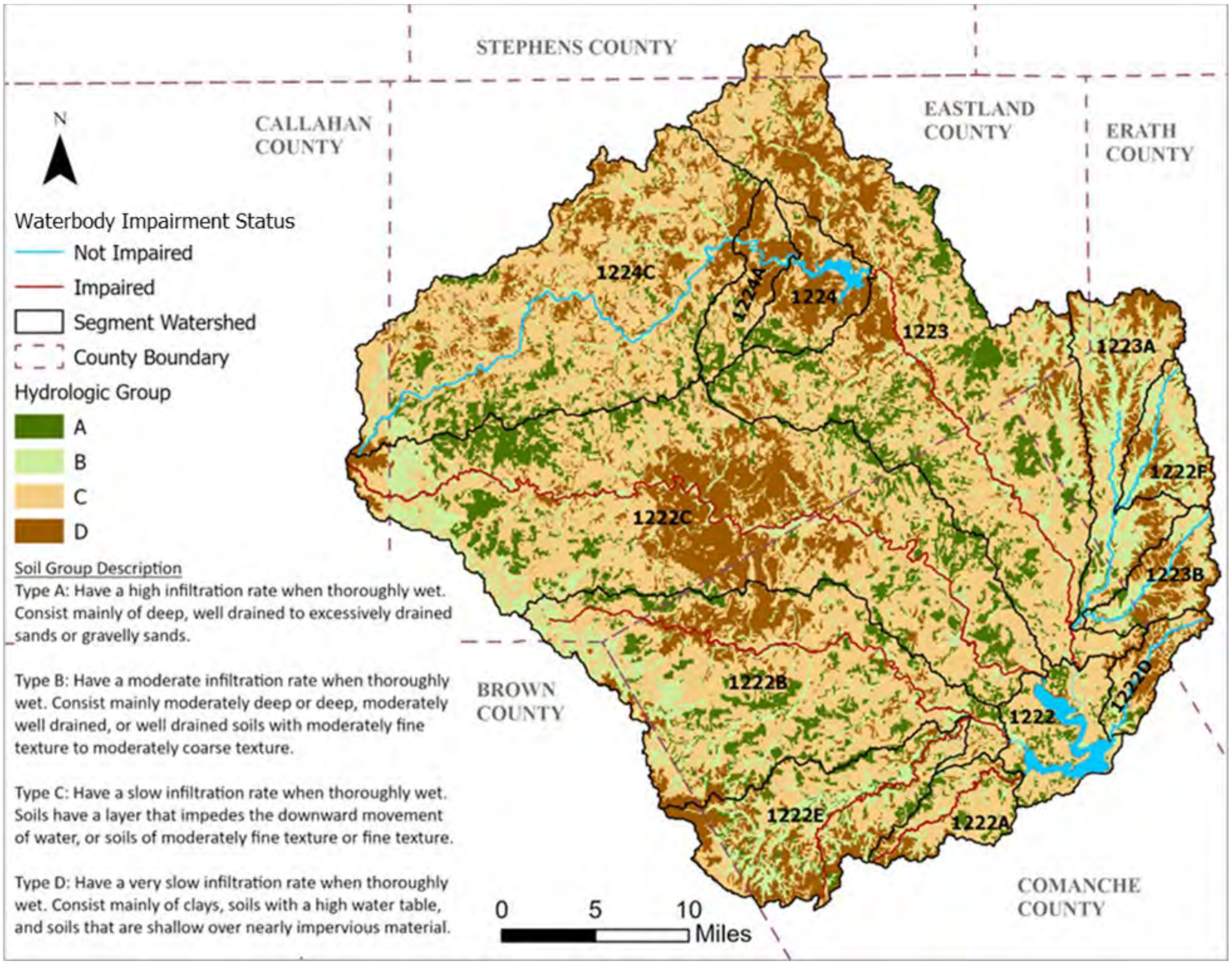
The Limestone Cut Plain is underlain by limestones. The region has flatter topography, lower drainage density. Post oak, white shin oak, cedar elm, Texas ash, plateau live oak, and bur oak are prevalent. The are a mix of tall, mid, and short grasses and include include big bluestem, little bluestem, and Indiangrass.

Figure 2-3. Proctor Lake watershed Level IV ecoregions

2.4 Soils

The United States Department of Agriculture – Natural Resources Conservation Service (NRCS) provides information about soils collected by the National Cooperative Soil Survey, which is available through the Web Soil Survey (Soil Survey Staff, 2022). This database describes soil components and properties and provides a hydrologic rating that groups soils by similar runoff properties. These ratings are useful for considering the potential for runoff from properties under consistent rainfall and cover conditions.

Soils in the Proctor Lake watershed are primarily Group D and Group C soils (Figure 2-4). When wet, these soils have a high runoff potential, and water movement is restricted in the soils. Given the high percent coverage of Group D and Group C soils in the watershed, runoff generation potential across the watershed is high.



Soil Group Description

Type A: Have a high infiltration rate when thoroughly wet. Consist mainly of deep, well drained to excessively drained sands or gravelly sands.

Type B: Have a moderate infiltration rate when thoroughly wet. Consist mainly moderately deep or deep, moderately well drained, or well drained soils with moderately fine texture to moderately coarse texture.

Type C: Have a slow infiltration rate when thoroughly wet. Soils have a layer that impedes the downward movement of water, or soils of moderately fine texture or fine texture.

Type D: Have a very slow infiltration rate when thoroughly wet. Consist mainly of clays, soils with a high water table, and soils that are shallow over nearly impervious material.

Figure 2-4. Proctor Lake watershed hydrologic soil group classifications

2.5 Climate

The Proctor Lake watershed is in a subtropical subhumid climate region characterized by hot summers and dry winters (Larkin and Bomar, 1983). Precipitation data from the Proctor Reservoir weather station (National Weather Service, 2023) located near the dam (Figure 2-5) show that May is the typically the wettest month, while December is typically the driest month. Average temperature generally peaks in August and average low temperature generally occurs in December (Figure 2-5). Generally, the upstream northwestern part of the watershed is dryer compared to the downstream positions of the watershed. Parts of the watershed in Erath County are the wettest.

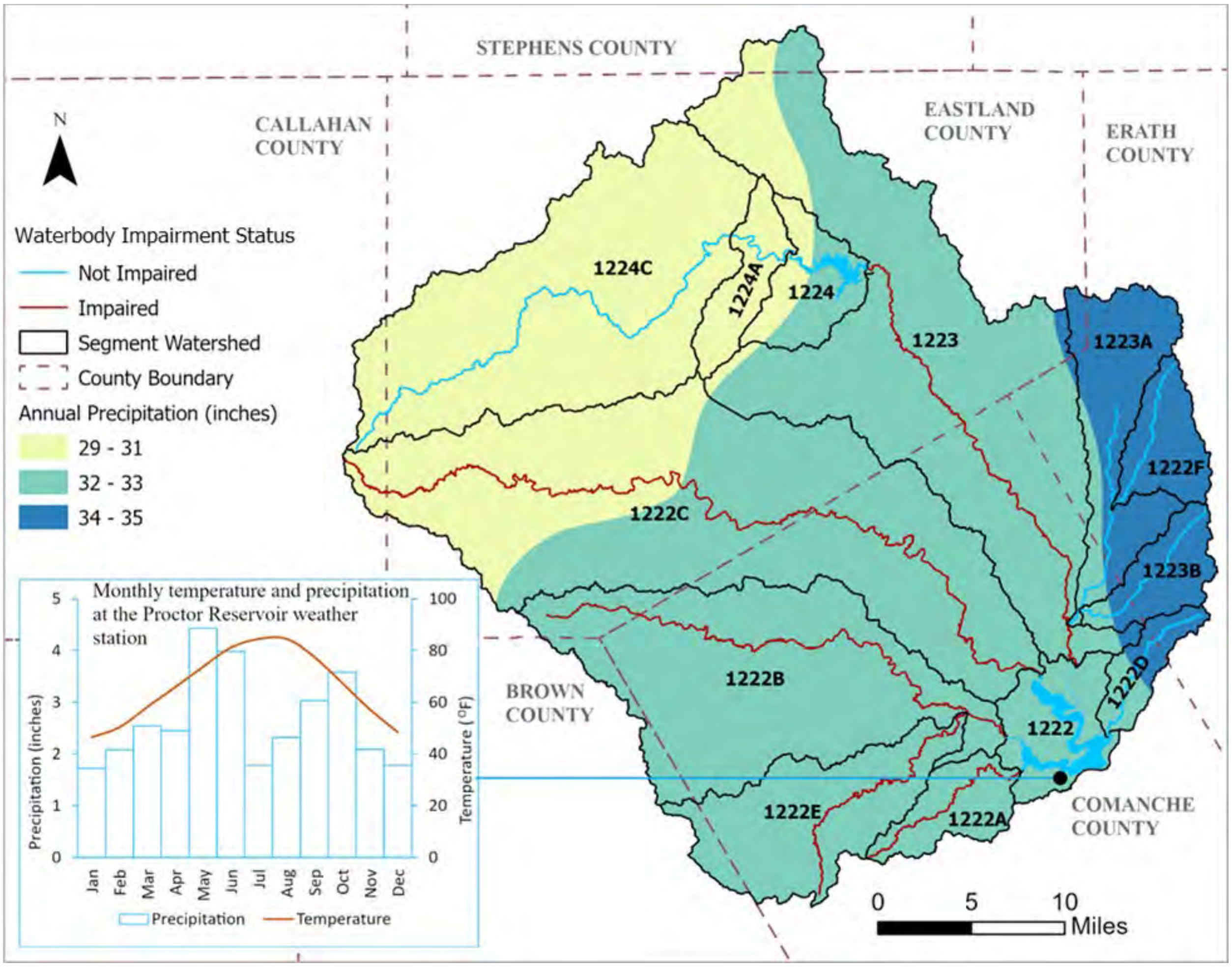


Figure 2-5. 30-year average monthly temperature and precipitation (1991-2020) for the Proctor Dam weather station, Texas.

2.6 Topography

Watershed hydrology has many key components, including soil properties and topography. Slope and elevation determine the direction of water flow, while elevation and soil properties affect the quantity and speed with which water infiltrates into, flows over, or moves through the soil into a waterbody.

The United States Geological Survey (USGS) collection of 10 m resolution Digital Elevation Models (USGS 2023a) provide the highest resolution seamless elevation dataset for the U.S. According to this dataset, elevation across the watershed ranges from a maximum of approximately 640 meters above mean sea level in the western portion of the watershed in Callahan County to a minimum of about 350 meters above mean sea level near the dam (Figure 2-6).

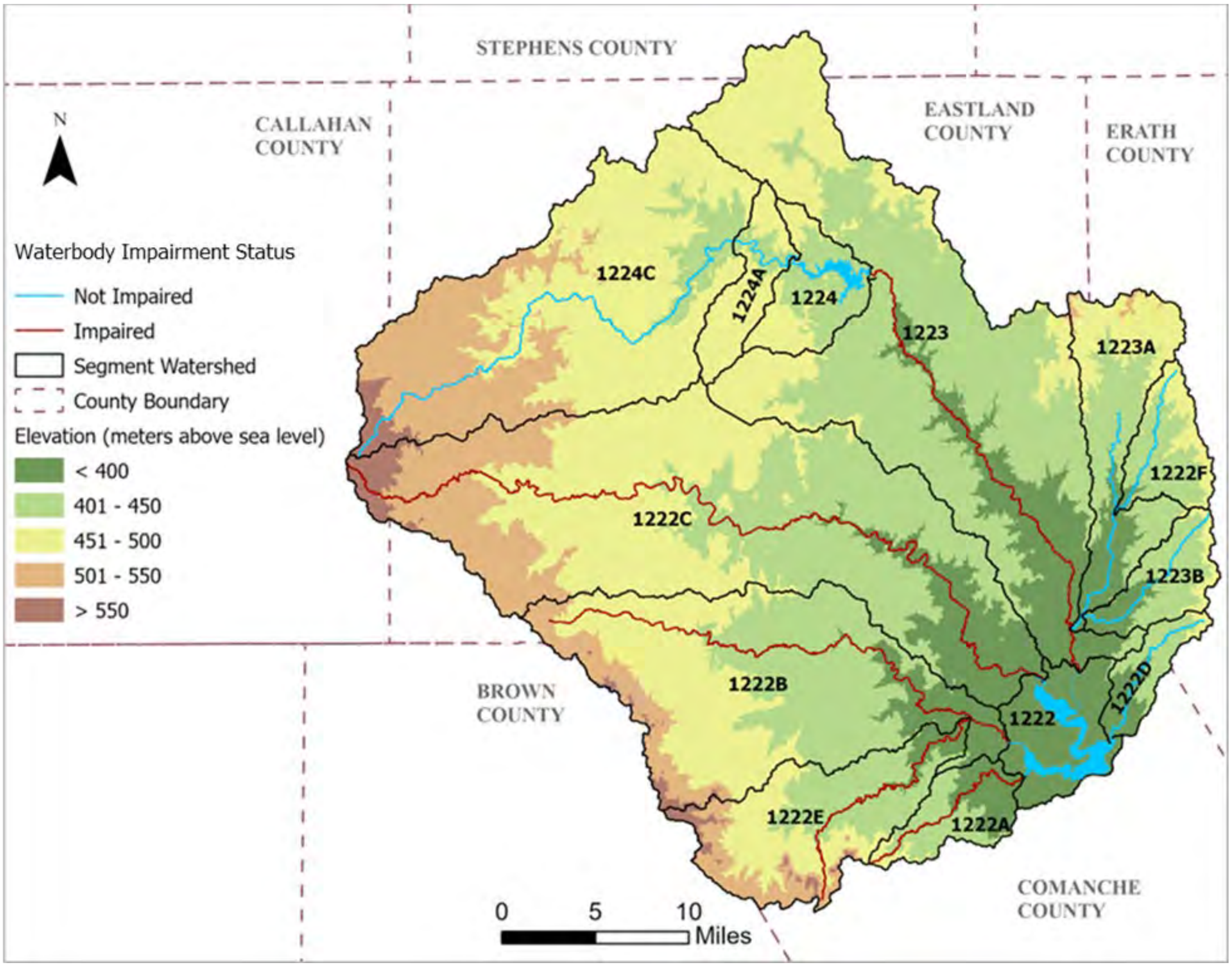


Figure 2-6. Topographical elevation of the Proctor Lake Watershed

2.7 Aquifers

Texas has numerous aquifers capable of producing groundwater. The Texas Water Development Board (TWDB) recognizes 9 major aquifers that produce large amounts of water over large areas, and 2 minor aquifers that produce minor amounts of water over large areas or large amounts of water over small areas. The Trinity aquifer, a major aquifer, and Cross Timbers aquifer, a minor aquifer underlie the Proctor Lake watershed. The Trinity Aquifer is one of the most extensive and highly used groundwater resources in Texas (TWDB 2011).

In Texas, local groundwater conservation districts (GCDs) are the state’s preferred method of groundwater management. GCDs are charged to manage groundwater by providing for the conservation, preservation, protection, recharging, and preventing groundwater waste within their jurisdictions. The Middle Trinity GCD covers parts of the watershed located in the Erath and Comanche counties and is responsible for conserving, preserving and protecting the quantity and quality of groundwater resources in the above counties. Other parts of the watershed do not have a confirmed GCD (TWDB 2023).

2.8 Population

Watershed population estimates were developed using the United States Census Bureau (USCB) 2020 census blocks[4] data (USCB 2020a) and 2020 decennial population data (USCB 2020b). Based on these data, the population of Proctor Lake watershed was estimated to be about 20,860. The watershed is generally sparsely populated with population densities less than 100 people per 10 square miles (Figure 2-7). Population density is highest in cities like De Leon, Eastland, and Cisco.

The TWDB regional water plan population and water demand projections (TWDB 2021) provide decadal population projections for counties within Texas from 2020 through 2070. County population growth rates for Brown, Callaham, Comanche, Eastland, Erath, and Stephens counties were presumed to be appropriate for estimating population projections for the watershed. Population in these counties is projected to grow by about 4% every decade (TWDB 2021). Based on TWDB’s county population

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[4] Census blocks are the smallest geographic units used by USCB to tabulate population data.

projections, the population in the Proctor Lake watershed is expected to increase by about 19% by 2070 (Table 2-3).

Table 2-3. The 2020 population and population projections for the Proctor Lake watershed.

Segment watershed	Population estimates					
	2020	2030	2040	2050	2060	2070
1222	827	875	906	934	959	983
1222A	485	513	531	548	563	576
1222B	1,655	1,751	1,812	1,868	1,920	1,967
1222C	2,528	2,675	2,768	2,854	2,933	3,004
1222D	175	185	192	198	203	208
1222E	445	471	487	502	516	529
1222F	332	351	364	375	385	395
1223	4,614	4,882	5,052	5,209	5,353	5,484
1223A	380	402	416	429	441	452
1223B	326	345	357	368	378	387
1224	846	895	926	955	981	1,005
1224A	294	311	322	332	341	349
1224C	7,952	8,414	8,707	8,978	9,226	9,451
Total	20,859	22,070	22,840	23,549	24,200	24,790

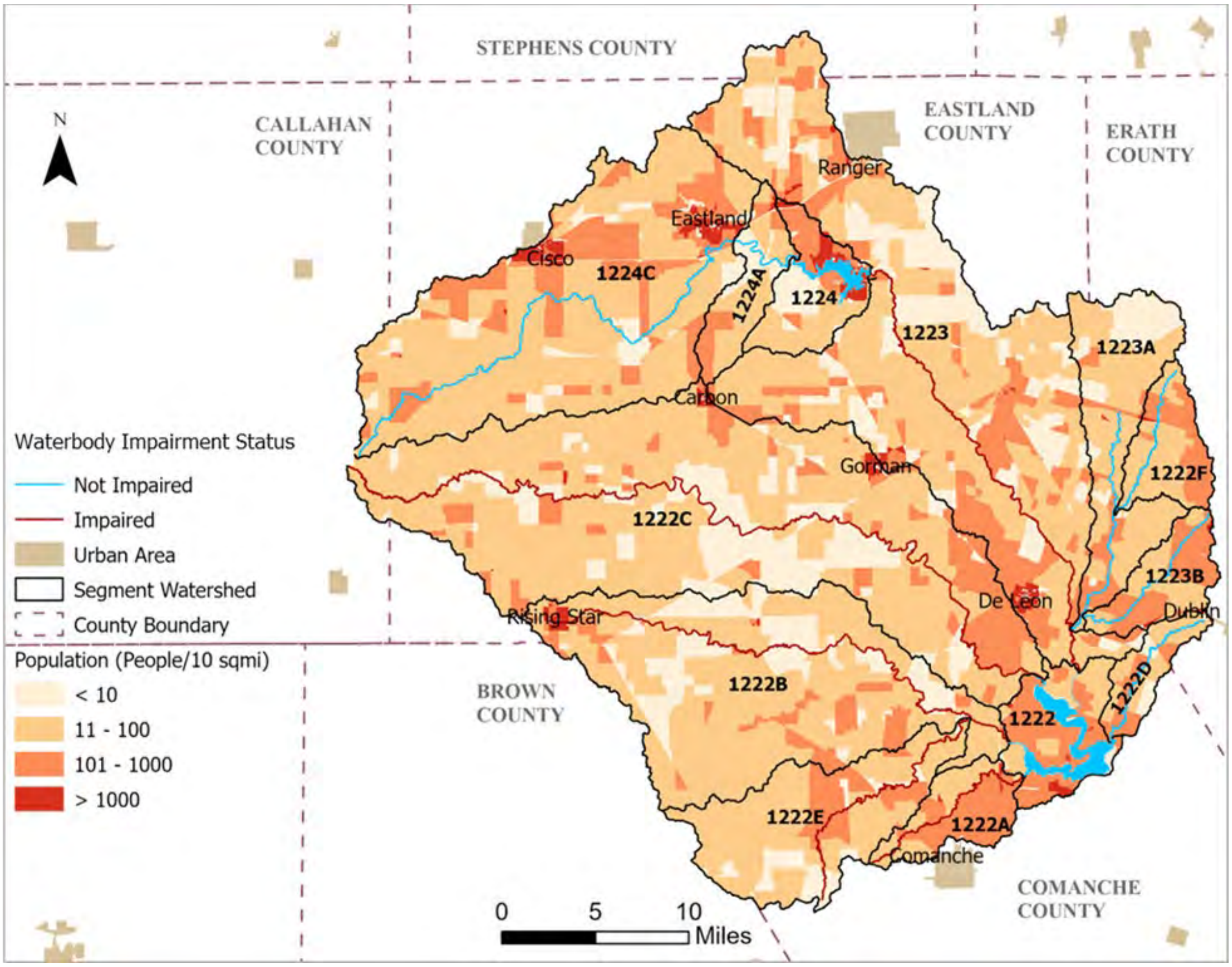

Figure 2-7. Proctor Lake watershed population density by 2020 U.S. Census Blocks

Chapter 3 – Water Quality

3.1 Texas Surface Water Quality Standards

Water quality standards are established by the state and approved by EPA to define a waterbody's ability to support its designated (beneficial) uses, which may include aquatic life use (fish, shellfish, and wildlife protection and propagation), primary contact recreation (swimming, wading, etc.), public water supply, fish consumption and general use. In the Proctor Lake watershed, only aquatic life use, general use and recreational uses are applied.

The standards are set by TCEQ in Texas under the authority of the Clean Water Act (CWA). The most recent version of the Texas Surface Water Quality standards (TSWQS, TCEQ 2022) was adopted as a state rule on September 29, 2022, and serves as the benchmark for water quality assessment in this report. The standards set general and numerical criteria/limitations expressed as acceptable levels (constituent concentrations) or as narrative statements that are aimed at protecting beneficial uses. Numeric water quality criteria specify precise measurable levels of a particular water quality indicator allowable in a waterbody.

3.1.1 Recreational Use

The recreational designated use is designed to establish relevant water quality criteria to support various levels of water recreational uses. Fecal indicator bacteria are used to determine whether a waterbody attains these use levels. The 2022 TSWQS defines the following recreational use categories:

- Primary contact recreation 1 (PCR1) – Activities presumed to involve a significant risk of ingestion of water.
- Primary Contact Recreation 2 (PCR2) – Activities presumed to involve a significant risk of ingesting water, but that occur less frequently than for primary contact recreation 1 due to physical characteristics of the waterbody or limited public access.
- Secondary Contact Recreation 1 (SCR1) - Activities that commonly occur but have limited body contact incidental to shoreline activity.
- Secondary Contact Recreation 2 (SCR2) - Activities with limited body contact incidental to shoreline activity that are presumed to pose a less significant risk of ingesting water than secondary contact recreation 1.
- Noncontact Recreation - Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity.

TCEQ conducts a Recreational Use-Attainability Analysis (RUAA) to evaluate and determine what category of recreational use is appropriate for a particular waterbody. The RUAA for several waterbodies in the watershed (Duncan Creek, Sweetwater Creek, Leon River Below Leon Reservoir, Armstrong Creek) characterized Duncan Creek and Armstrong Creek as SCR1 and SCR2 respectively (TCEQ 2022c). For waterbodies without a RUAA, PCR1 is presumed as the appropriate recreation use category. Recreation use categories and corresponding *E. coli* criteria for waterbodies in the watershed are listed in Table 3-1 and exceedances of these criteria in each waterbody are listed in Table 3-2.

3.1.2 Aquatic Life Use

The establishment of numerical criteria for aquatic life is highly dependent on desired use, sensitivities of aquatic communities, and local physical and chemical characteristics. Six subcategories of aquatic life use are established. They include minimal, limited, intermediate, high, and exceptional aquatic life and oyster waters. The categories and associated DO criteria for waterbodies in the watershed are listed in Table 3-1. DO concerns for near non-attainment and impairments are listed in Table 3-2.

3.1.3 General Use

This category of use is defined to safeguard the general water quality of Texas' waterbodies. Parameters considered for general use attainment include water temperature, pH, chloride, sulfate, total dissolved solids, and chlorophyll-a. General use water quality criteria only apply to classified waterbodies. As such, only Proctor Lake has applicable general use criteria applied. In the 2022 Texas Integrated Report, these criteria are all being met. For unclassified waterbodies, nutrient screening levels have been created to indicate whether a concern for general use attainment exists. These screening levels include: total phosphorus (0.69 mg/L), nitrate (1.95 mg/L), ammonia (0.33 mg/L), and chlorophyll-a (14.1 ug/L). Screening level concerns in the watershed are listed in Table 3-2.

Table 3-1. Recreation and Aquatic use categories and criteria for waterbodies in the watershed.

Waterbody	Recreation Use	Indicator Bacteria (*E. coli*) #/100 mL	Aquatic Life Use	DO Criterion – 24hr Mean/Minimum (mg/L)
Proctor Lake	PCR1	126	High	5.0/3.0
Duncan Creek	SCR1	630	Minimal	2.0/1.5
Rush-Copperas Creek	PCR1	126	Limited	3.0/2.0
Sabana River	PCR1	126	Minimal	2.0/1.5
Sweetwater Creek	PCR1	126	Minimal	2.0/1.5
Leon River Below Leon Reservoir	PCR1	126	High	5.0/3.0
Armstrong Creek	SCR2	1030	Minimal	2.0/1.5
Leon Reservoir	PCR1	126	High	5.0/3.0
Leon River Above Leaon Reservoir	PCR1	126	High	5.0/3.0
South Fork Leon River	PCR1	126	High	5.0/3.0

3.2 Surface Water Quality Monitoring in the Watershed

The federal CWA gives states primary responsibility for implementing programs to protect and restore water quality, including monitoring and assessing the nation's waters and reporting on their quality. In Texas, TCEQ is the agency responsible for implementing the monitoring, assessment, and reporting requirements of the CWA. The TCEQ Surface Water Quality Monitoring (SWQM) program conducts and coordinates the collection of physical, chemical, and biological samples. SWQM data is stored in the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database[5].

TCEQ partners with regional water authorities through the Texas Clean Rivers Program to coordinate and conduct water quality monitoring. The Brazos River Authority (BRA) manages water resources in the Brazos River basin. TCEQ and BRA routinely collect water quality monitoring data at several stations (Figure 3-1) on stream and reservoir segments in the watershed.

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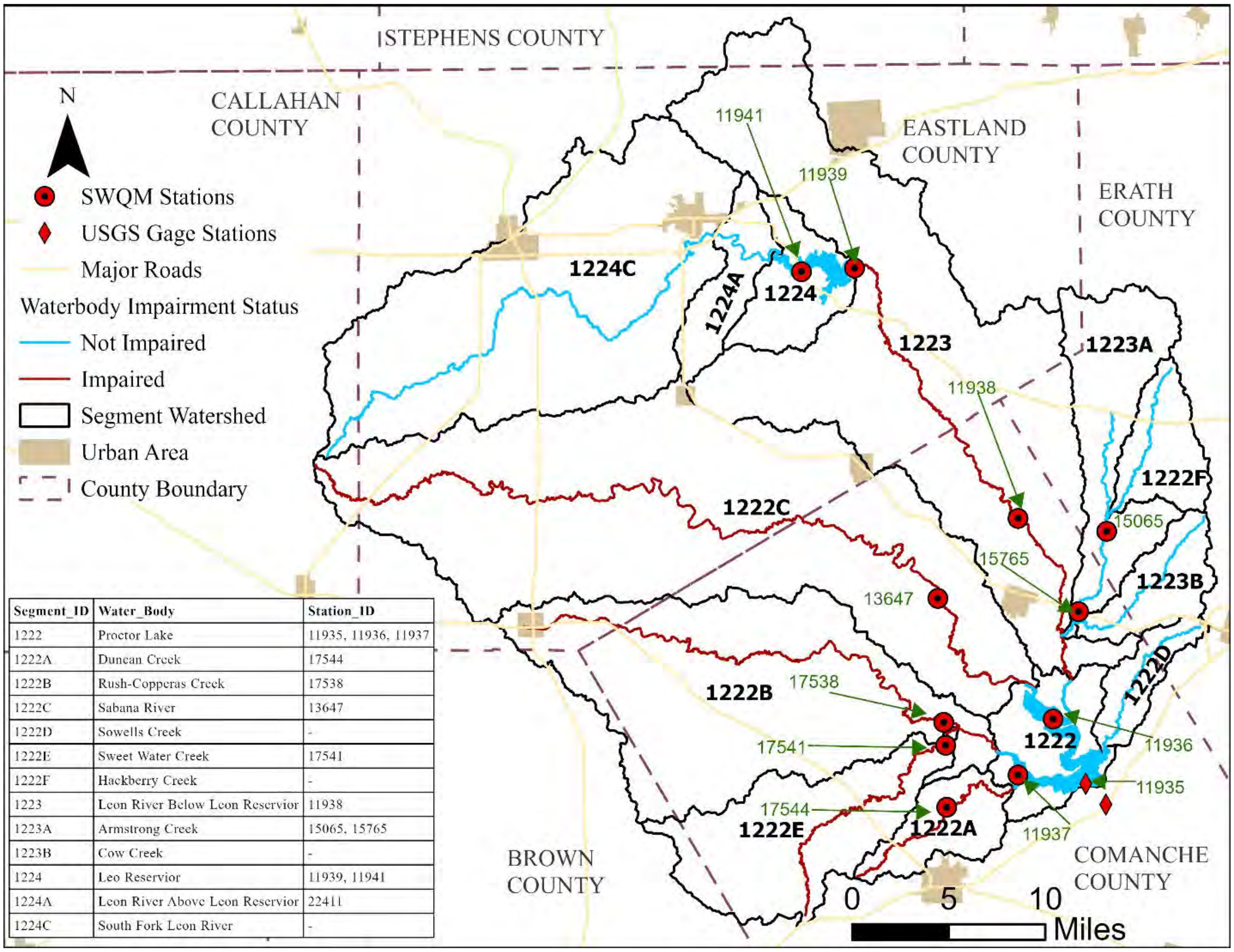
[5] Surface water quality web reporting tool (database). https://www80.tceq.texas.gov/SwqmisPublic/index.htm



Segment_ID	Water_Body	Station_ID
1222	Proctor Lake	11935, 11936, 11937
1222A	Duncan Creek	17544
1222B	Rush-Copperas Creek	17538
1222C	Sabana River	13647
1222D	Sowells Creek	-
1222E	Sweet Water Creek	17541
1222F	Hackberry Creek	-
1223	Leon River Below Leon Reservior	11938
1223A	Armstrong Creek	15065, 15765
1223B	Cow Creek	-
1224	Leo Reservior	11939, 11941
1224A	Leon River Above Leon Reservior	22411
1224C	South Fork Leon River	-

Figure 3-1. Surface water quality monitoring stations in the Proctor Lake watershed.

3.3 Waterbody Assessments

TCEQ conducts biennial waterbody assessments and publishes an assessment report that lists all impaired waterbodies not supporting their beneficial uses and those having use concerns. The most recent assessment, the 2022 Texas Integrated Report (TCEQ 2022a) includes water quality data collected from December 1, 2013 – November 30, 2020. Table 3-2 shows the impairments and concerns for water quality listed on the 2022 Texas Integrated Report.

Table 3-2. Impairments and concerns listed on the 2022 Texas Integrated Report Surface Water Quality

Parameter	AU ID	Impairment/ concern description	Impairment Category/ level of concern*
Proctor Lake	1222_03	Depressed DO	CS
Duncan Creek	1222A_01	Bacteria	5c
		Chlorophyll-a	CS
Rush-Copperas Creek	1222B_01	Bacteria	5c
Sabana River	1222C_01	Bacteria	5c
Sowells Creek	1222D_01	Bacteria	CN
Sweetwater Creek	1222E_01	Bacteria	5c
Hackberry Creek	1222F_01	Bacteria	CN
		Depressed DO	CN
Leon River Below Leon Reservoir	1223_01	Bacteria	5c
		Depressed DO	5c
		Chlorophyll-a	CS
Armstrong Creek	1223A_01	Nitrate	CS
Cow Creek	1223B_01	Bacteria	CN

* Category 5c – additional data and information will be collected or evaluated before a management strategy is selected; CS - Concern for water quality based on screening levels; CN - Concern for water quality based on use.

3.3.1 Bacteria

To assess potential risk of human illness from contact recreation, concentrations of fecal indicator bacteria such as *E. coli* in waterbodies are measured. The quantity of these bacteria can indicate increased potential for related pathogens present in the intestinal tract of warm-blooded animals to also be in surface waters. Based on monitoring results, the Rush-Copperas Creek, Sabana River, Sweetwater Creek, and Leon River Below Leon Reservoir have *E. coli* concentrations above their respective criteria (Table 3-3). Figure 3-3 shows *E. coli* geomean values for assessed waterbodies. Of all impaired waterbodies, *E. coli* concentrations are highest in the Leon River below Leon Reservoir. *E. coli* concentrations are also high in Armstrong Creek, although the creek is not considered impaired (Table 3-3). The creek is designated as an SCR2 which has an *E. coli* concentration criterion of 1030 cfu/100 mL. Generally, *E. coli* concentrations vary considerably over time with impaired waterbodies containing consistently higher concentrations (Figure 3-2).

Table 3-3. Bacteria Water quality monitoring station summary from December 2013 – November 2020

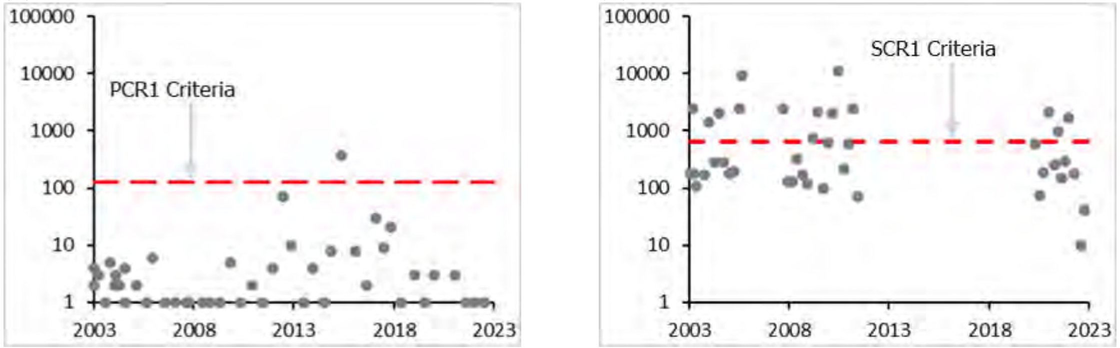
Waterbody	Segment ID	AU ID	Station ID**	# of samples	7-year *E. coli* geomean (cfu/100 mL)	*E. coli* Geomean criterion (cfu/100 mL)
Proctor Lake	1222	1222_01	11936	13	5.0	126
		1222_02	11937	13	2.8	126
		1222_03	11935	13	11.2	126
Duncan Creek*	1222A	1222A_01	17544	3	200.4	630
Rush-Copperas Creek*	1222B	1222B_01	17538	12	132.7	126
Sabana River*	1222C	1222C_01	13647	25	275.1	126
		1222C_02	NA	-	-	-
Sowells Creek	1222D	1222D_01	NA	-	-	-
Sweetwater Creek*	1222E	1222E_01	17541	6	150.6	126
Hackberry Creek	1222F	1222F_01	NA	-	-	-
Leon River Below Leon Reservoir*	1223	1223_01	11938	20	418.6	126
Armstrong Creek	1223A	1223A_01	15065, 15765	42	451.5	1030
Cow Creek	1223B	12223B_01	NA	-	-	-
Leon Reservoir	1224	1224_01	11939	20	1.6	126
		1224_02	11941	20	2.1	126
Leon River Above Leon Reservoir	1224A	1224A_01	NA	--	--	-
South Fork Leon River	1224C	1224C_01	NA	-	-	-

* Impaired waterbody

** NA = No monitoring station on the assessment unit

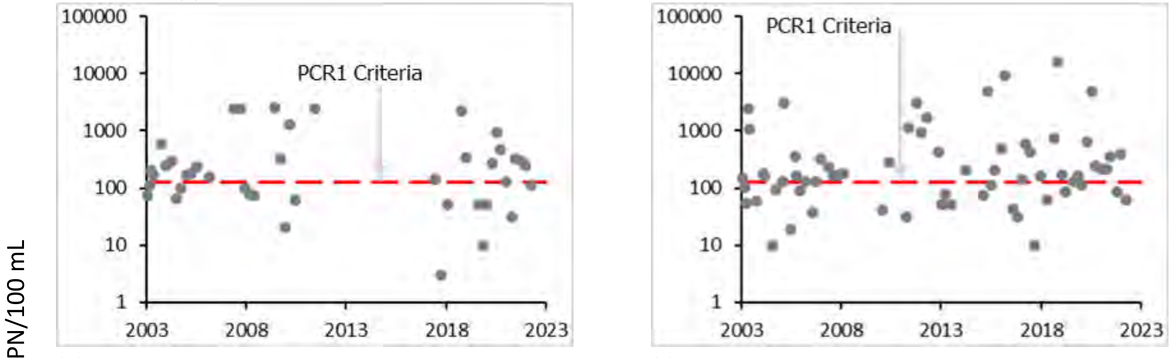
(a) Proctor Lake, Station 11936

(b) Duncan Creek, Station 17544



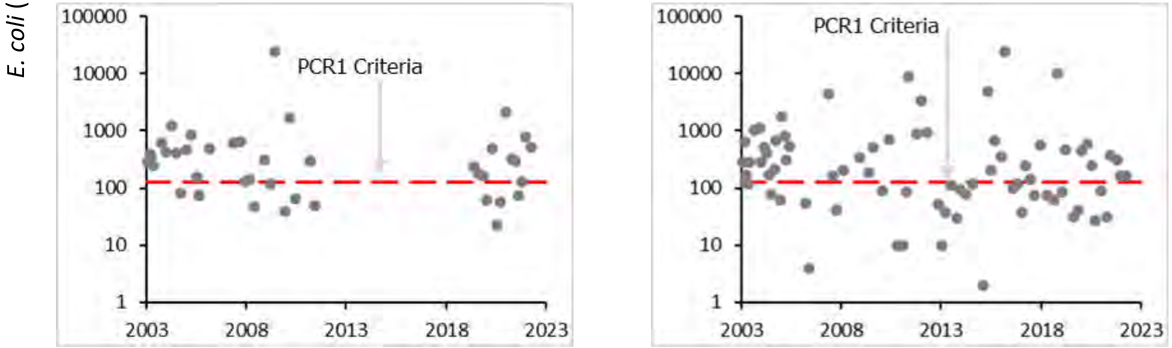
(c) Rush-Copperas Creek, Station 17538

(d) Sabana River, Station 13647



(e) Sweetwater Creek, Station 17541

(f) Leon River Below Leon Reservoir, Station 11938



(e) Armstrong Creek, Station 15765

(f) Leon Reservoir, Station 11939

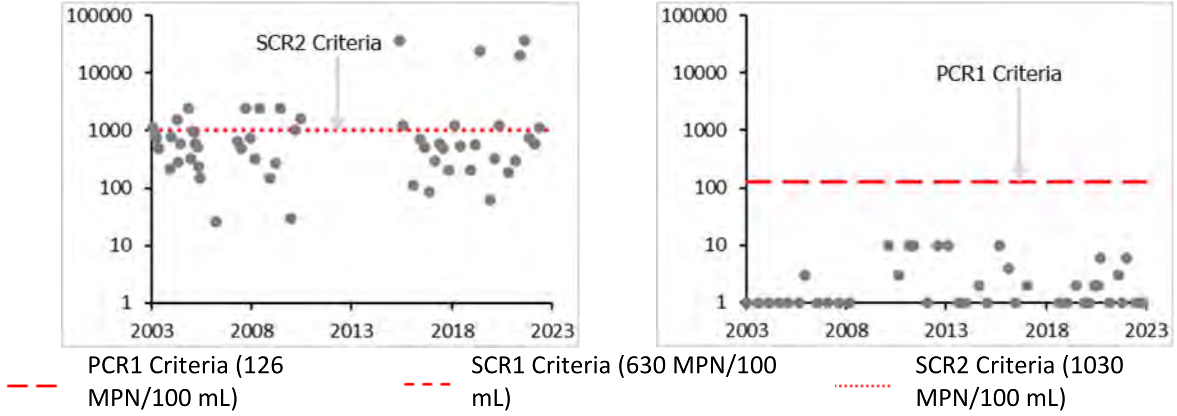


Figure 3-2. *E. coli* measurements in the Proctor Lake watershed, 2003 – 2022.

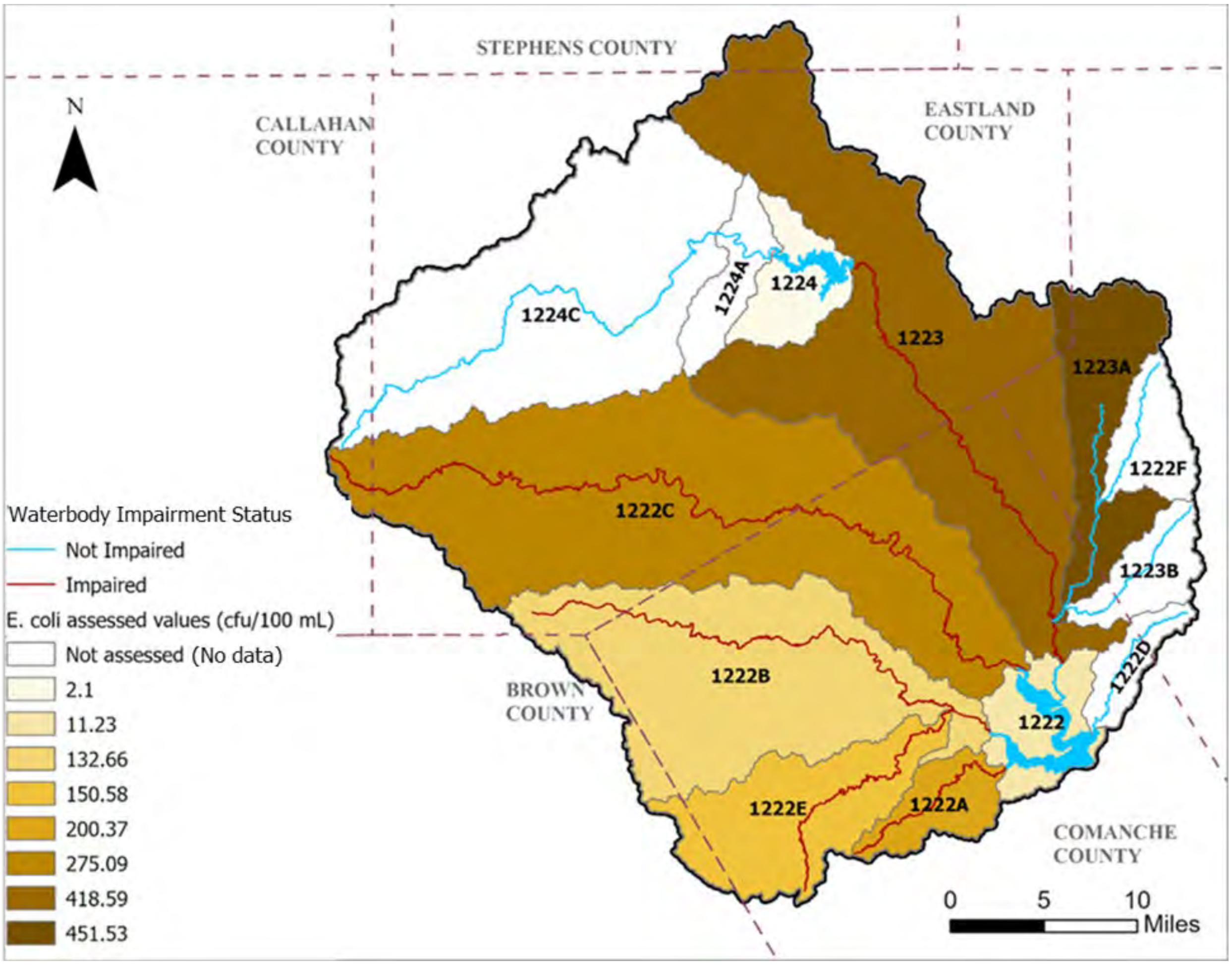


Figure 3-3. Variation of *E. coli* geomean values by segment watershed on the 2022 TCEQ Integrated Report.

3.3.2 Nutrients

Nitrogen and phosphorus are used by aquatic plants and algae to grow; however, excessive concentrations can lead to algae blooms that reduce DO concentrations and can affect fish respiration. Sources of nutrients may include wastewater treatment facility (WWTF) effluent and fertilizer application transported by rainfall into surface water. Rainfall runoff can also carry newly eroded sediment particles with nutrients bound to them, further increasing nutrient concentrations in streams.

Although Texas has not developed numeric nutrient criteria for streams, screening level concentrations were established to evaluate nutrient loading compared to similar waterbodies statewide[6]. In the

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[6] Screening level concentrations for nutrient parameters are based on the 85th percentile values of a similar waterbody type. A concern for water quality is identified if the screening level is exceeded more than 20% of the time.

Proctor Lake watershed, the most monitored indicators of nutrients are nitrate, ammonia, phosphorus, and chlorophyll-a. The 2022 integrated report uses nutrient screening level concentrations of 1.95 mg/L for nitrate, 0.33 mg/L for ammonia, 0.69 mg/L for total phosphorous, and 14.1 µg/L for chlorophyll-a to evaluate nutrient loading in the watershed.

Based on monitoring results, several chlorophyll-a concentrations exceed screening levels in several waterbodies (Table 3-4, Figure 3-4). Nitrates are a concern for Armstrong Creek whereas chlorophyll-a concerns exist in Duncan Creek and the Leon River Below Leon Reservoir (Figure 3-5).

Table 3-4. Nutrient screening level concentrations and assessment results on the 2022 Texas Integrated Report.

Parameter	Screening level concentration	Waterbody	AU ID	Number of samples assessed	Assessed samples exceeding criteria	Mean concentration Exceedances	Category
Nitrate (mg/L)	1.95	Armstrong Creek	1223A_01	42	35	6.662	CS
Chlorophyll-*a* (µg/L)	14.1	Duncan Creek	1222A_01	0	-	-	CS
		Leon River Below Leon Reservoir	1223_01	25	9	56.52	CS

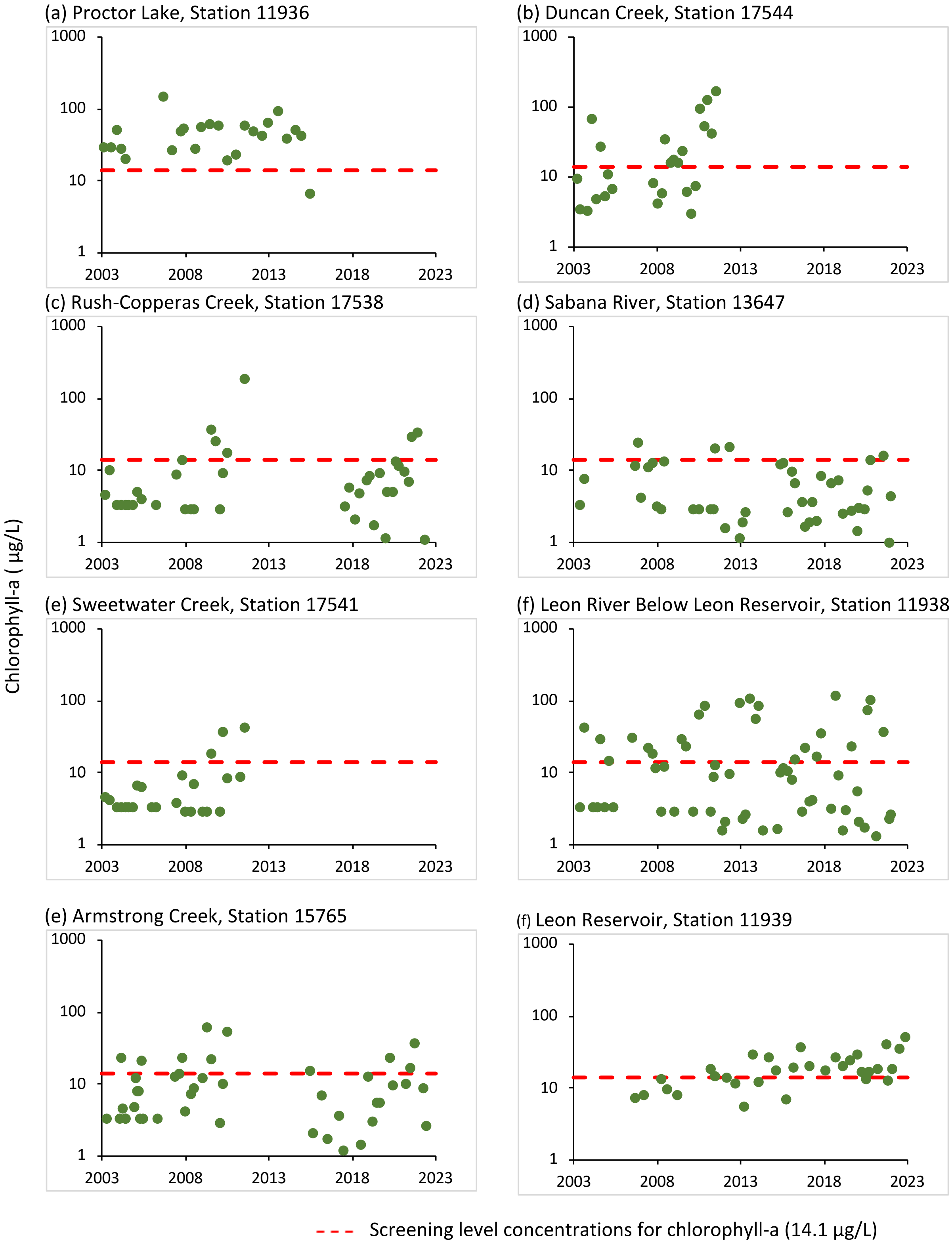


Figure 3-4. Chlorophyll-a measurements in the Proctor Lake watershed, 2003 – 2022.

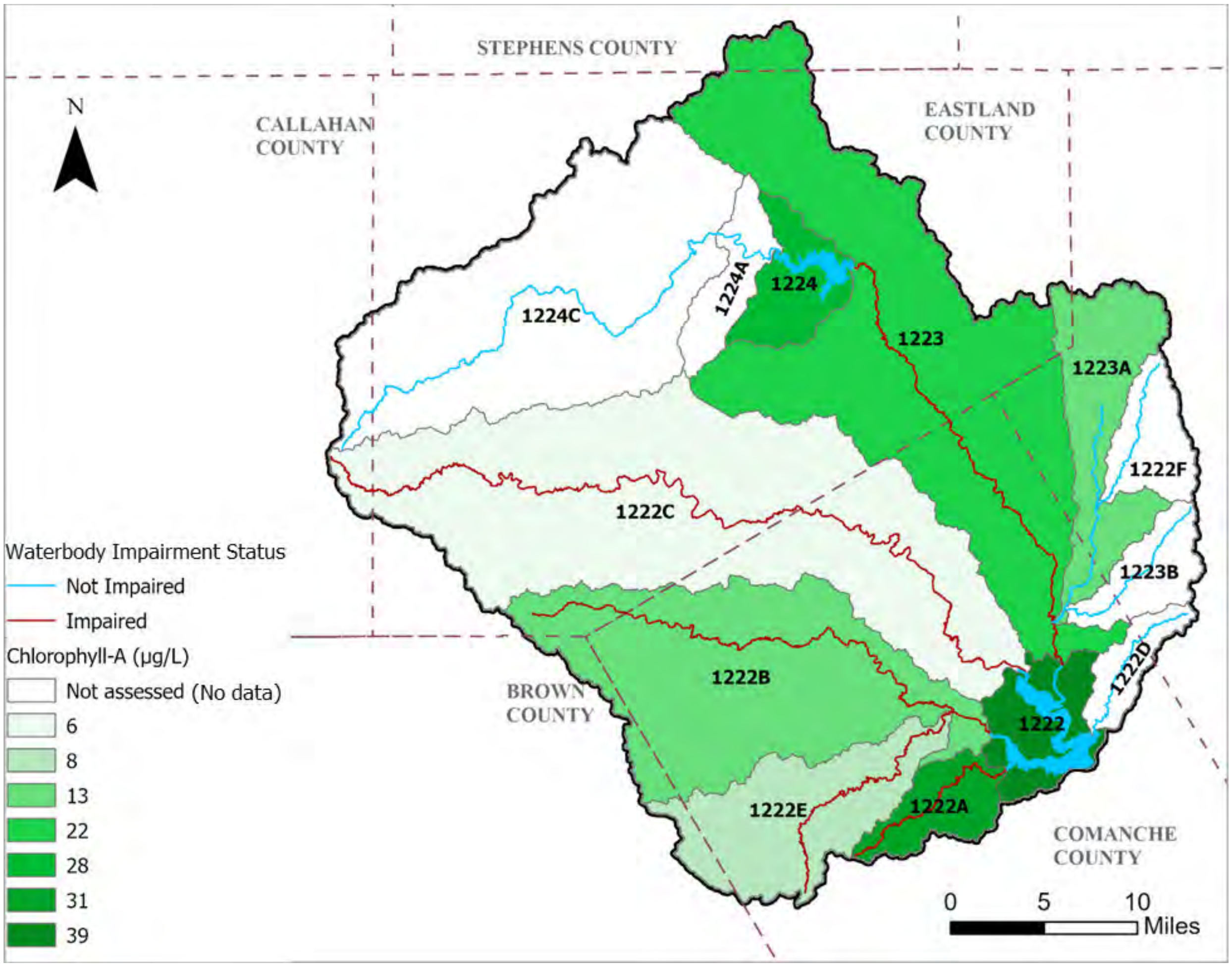


Figure 3-5. Variation of average chlorophyll-a concentrations by segment watershed from 2003 through 2020.

3.3.3 Dissolved Oxygen

DO is the primary measurement used to determine a waterbody's ability to support and maintain aquatic life. If DO concentrations in a waterbody drop too low (or are "depressed"), fish and other aquatic species will not have enough oxygen to survive.

DO concentrations fluctuate throughout the day depending on environmental factors. The lowest concentrations of DO occur just before dawn as both plants and animals in the water consume oxygen through respiration, while the highest concentrations of DO occur in mid to late afternoon, due to increased photosynthesis. Similarly, seasonal fluctuations in DO are common due to decreased oxygen solubility in water as temperature increases and it is common to see lower DO concentrations during the summer.

While DO does fluctuate naturally, human activities can also impact concentrations. Excess nutrients in the water can lower DO as aquatic plants and algae increase growth in response to the greater nutrient concentrations, which causes increased respiration and DO consumption. In addition, decaying organic matter from plant die-off can reduce DO concentrations as bacteria break down the materials and, subsequently, consume oxygen.

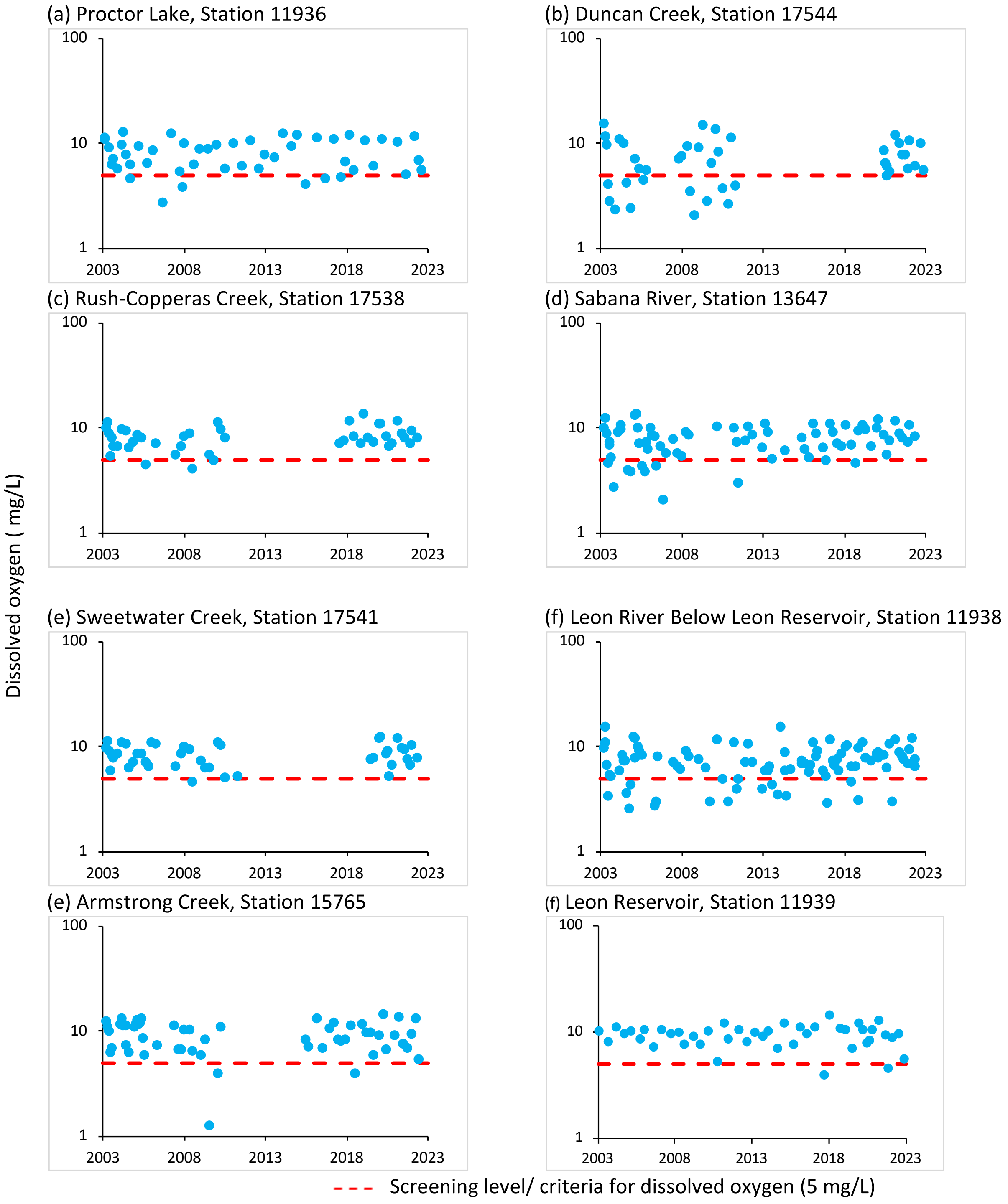
Monitoring results show that depressed DO concentrations are a concern in Proctor Lake (Table 3-5). The Leon River Below Leon Reservoir has depressed DO concentrations (Figure 3-6) and is listed as impaired for depressed DO on the 2022 Texas Integrated Report. Measurements of DO indicate that low DO conditions have existed for the past two decades (2003-2022) in the watershed (Figure 3-7).

Table 3-5. Dissolved oxygen assessment results for waterbodies in the Proctor Lake watershed

Parameter	Screening level/ Criteria (mg/L)		Assessment results from the Texas 2022 Integrated Report			
		Waterbody Name	AU ID	Number of samples assessed	Samples exceeding criteria /screening level	Level of support**
Dissolved Oxygen – grab minimum	3	Proctor Lake	1222_02	14	1	FS
Dissolved Oxygen – grab screening level	5	Proctor Lake	1222_01	14	2	NC
	5		1222_02	14	1	NC
	5		1222_03	14	3	CS
	5	Leon River Below Leon Reservoir	1223_01	29	5	NA
	5	Leon Reservoir	1224_01	17	1	NC
Dissolved Oxygen – 24hr average	5	Leon River Below Leon Reservoir	1223_01	16	4	NS
Dissolved Oxygen – 24hr minimum	3		1223_01	16	5	NS

* Grab sampling involves collecting a single water sample at a specific point in time. Continuous or 24-hour monitoring involves collecting samples over an extended period (usually 24 hours) to assess average conditions.

** FS= Fully supporting; NC= No concern; NS= Not supporting


(a) Proctor Lake, Station 11936

(b) Duncan Creek, Station 17544

(c) Rush-Copperas Creek, Station 17538

(d) Sabana River, Station 13647

(e) Sweetwater Creek, Station 17541

(f) Leon River Below Leon Reservoir, Station 11938

(e) Armstrong Creek, Station 15765

(f) Leon Reservoir, Station 11939

- - - Screening level/ criteria for dissolved oxygen (5 mg/L)

Figure 3-6. Dissolved oxygen measurements in the Proctor Lake watershed, 2003 – 2022.

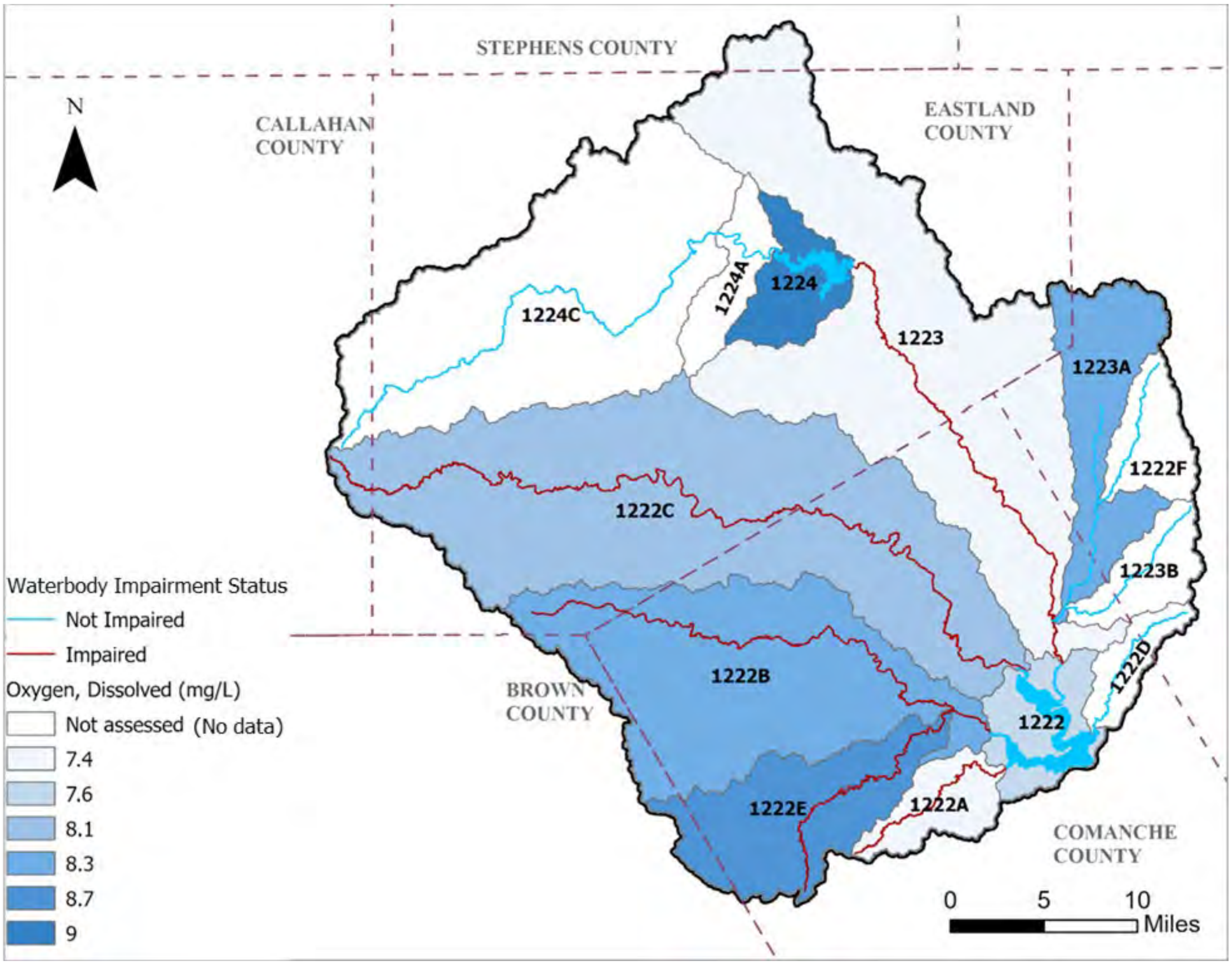


Figure 3-7. Variation of mean dissolved oxygen concentrations by segment watershed from 2003 through 2020.

3.4 Streamflow

Continuous streamflow data are essential to watershed projects that focus on pollutant load analysis. Streamflow records are required to estimate loads of pollutants and other constituents, and for determining parameter variability due to seasonal or daily variations in flow, point-source discharges, or other variables. In water quality analyses, load concentration variations across different flow regimes can be expressed graphically on a load duration curve (LDC). Using the LDC framework, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions can succinctly be presented. Because the load is the product of the flow and pollutant/constituent concentration, the development of an LDC requires first developing a flow duration curve (FDC).

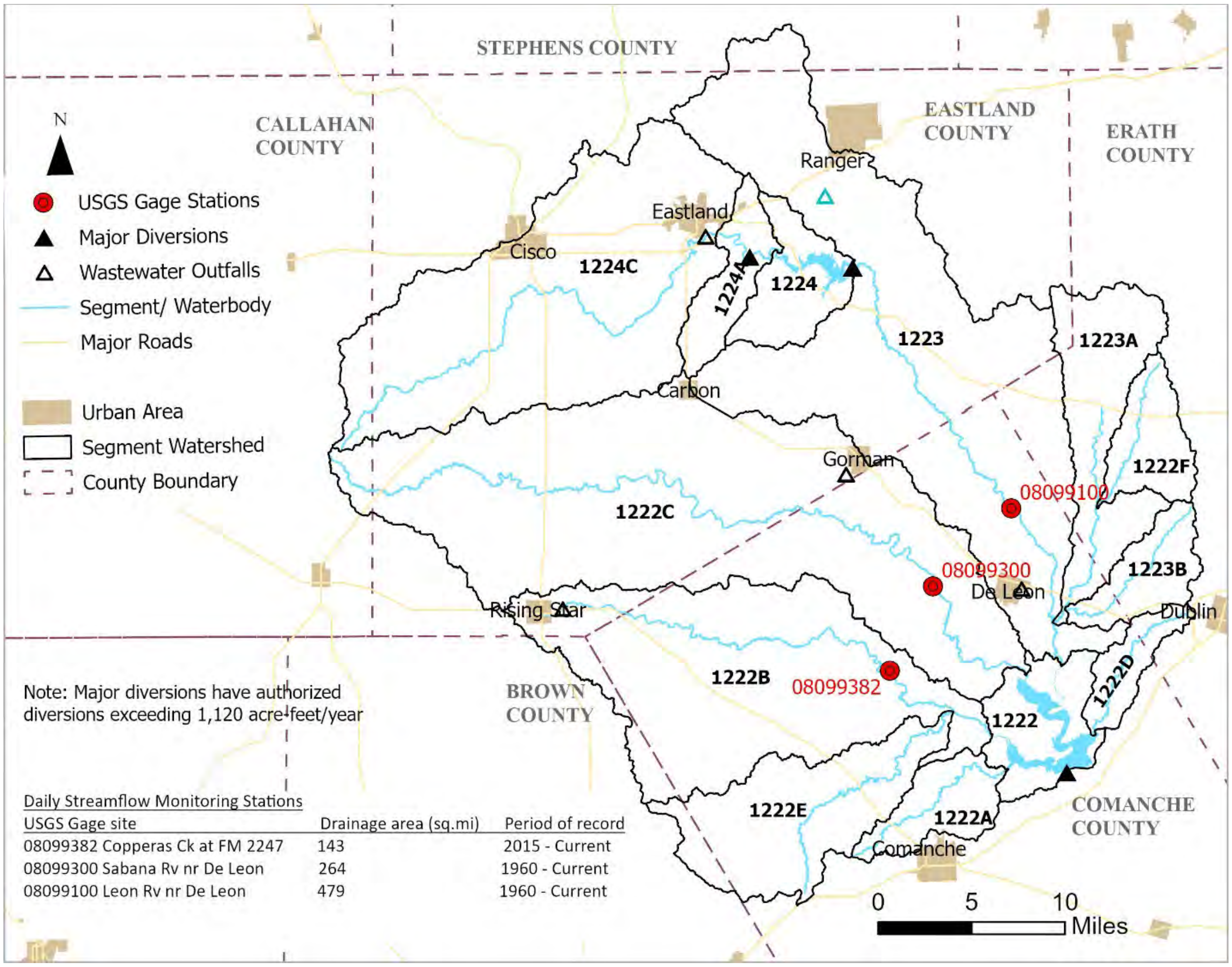
FDCs are used for many purposes in which the analysis of the frequency of flows of various magnitudes is required. FDCs show the percentage of time specified flows are equaled or exceeded during a given period. For example, a 5% exceedance probability represents a high flow that is exceeded by only 5% of all days of the flow record. Conversely, a 95% exceedance probability would characterize low-flow conditions in a stream, because 95% of all daily mean flows in the record are greater than that amount. For flow-duration statistics to be reliable indicators of probable future conditions, a minimum of 10 years of record typically is used (Searcy, 1959).

This section summarizes available flow data and evaluates whether sufficient data and information are available for developing FDCs necessary to analyze water quality across the watershed. Without recorded data, other approaches are necessary to estimate stream flow – pollutant load relationships.

3.4.1 Streamflow Monitoring in the Watershed

The nationwide streamflow-gaging network operated by the USGS in cooperation with State agencies and other cooperators provides stream flow data that are valuable for developing FDCs. Recorded data is published in the National Water Information System (USGS 2023b). Within the Proctor Lake watershed, the USGS currently operates three streamflow monitoring stations (Figure 3-8). Measurements at USGS gages 08099100 and 08099300 started in the 1960s and in 2015 at USGS 08099382.

Water diversions from stream and large additions to flow (WWTF discharges, etc.) are also measured or estimated in the watershed. These inputs and withdrawals can also influence load estimates. Diversions and outfalls present in the watershed are discussed in Appendix A.



Daily Streamflow Monitoring Stations

USGS Gage site	Drainage area (sq.mi)	Period of record
08099382 Copperas Ck at FM 2247	143	2015 - Current
08099300 Sabana Rv nr De Leon	264	1960 - Current
08099100 Leon Rv nr De Leon	479	1960 - Current

Figure 3-8. Streamflow gages, permitted discharges, and major diversions in the Proctor Lake watershed.

3.4.2 Construction of flow duration curves

Streamflow monitoring records greater than 10 years exist at USGS gages 08099100 and 08099300 while only 8 years of stream flow data are available at USGS gage 08099382. These records are considered sufficient for the development of FDCs at these sites. Continuous daily streamflow data collected at USGS gages 08099100 (2009-2023), 08099300 (2004-2023), and 08099382 (2016-2023) were used for FDC construction (Appendix A). Flows and FDCs at other water quality monitoring sites that do not have records of continuous streamflow data and are located on impaired waterbodies (Sweetwater Creek and Duncan Creek) were estimated using the drainage area ratio (DAR) method which is described in detail in Appendix A.

Chapter 4 – Potential Sources of Pollution

Pollutants originate from various sources and can have differing effects on water quality. Pollutants enter the environment from a *point source*, such as a pipe or channel, or from a *nonpoint source* with widespread origins. Both source types can reach a waterbody and contribute pollutants and water to the natural system. Point and nonpoint sources are present in the Proctor Lake watershed and were identified and estimated using publicly available databases.

4.1 Point Sources

Point sources are regulated and require a permit to discharge to land and waterways. Point sources in Texas are regulated and managed through the Texas Pollutant Discharge Elimination Systems (TPDES)[7], administered by the TCEQ. Permits issued under the program identify and limit the amount of water and specific pollutants each facility may discharge directly to the landscape or to a particular waterbody. Examples of point sources include municipal or industrial WWTF, sanitary sewer overflows (SSO), construction site runoff, and municipal separate storm sewer systems (MS4) of urbanized areas.

4.1.1 Domestic and Industrial Wastewater

WWTFs treat sewage and wastewater so that they can be returned to the environment. Wastewater discharge into or adjacent to water in the state is authorized by TCEQ through its permitting process. Data on permitted facilities in the state can be accessed from TCEQ's geographic information system (GIS) data hub[8] and Central Registry Query[9]. Permit compliance history data can be accessed through the EPA's Enforcement and Compliance History Online website[10].

A review of these databases identified four WWTFs (Figure 4-1, Table 4-1) and one water treatment facility with discharge permits in the Proctor Lake watershed. The Eastland County Water Supply District (WSD) Water Treatment Facility discharges potable water treatment system backwash which does not have *E. coli* discharge limitations.

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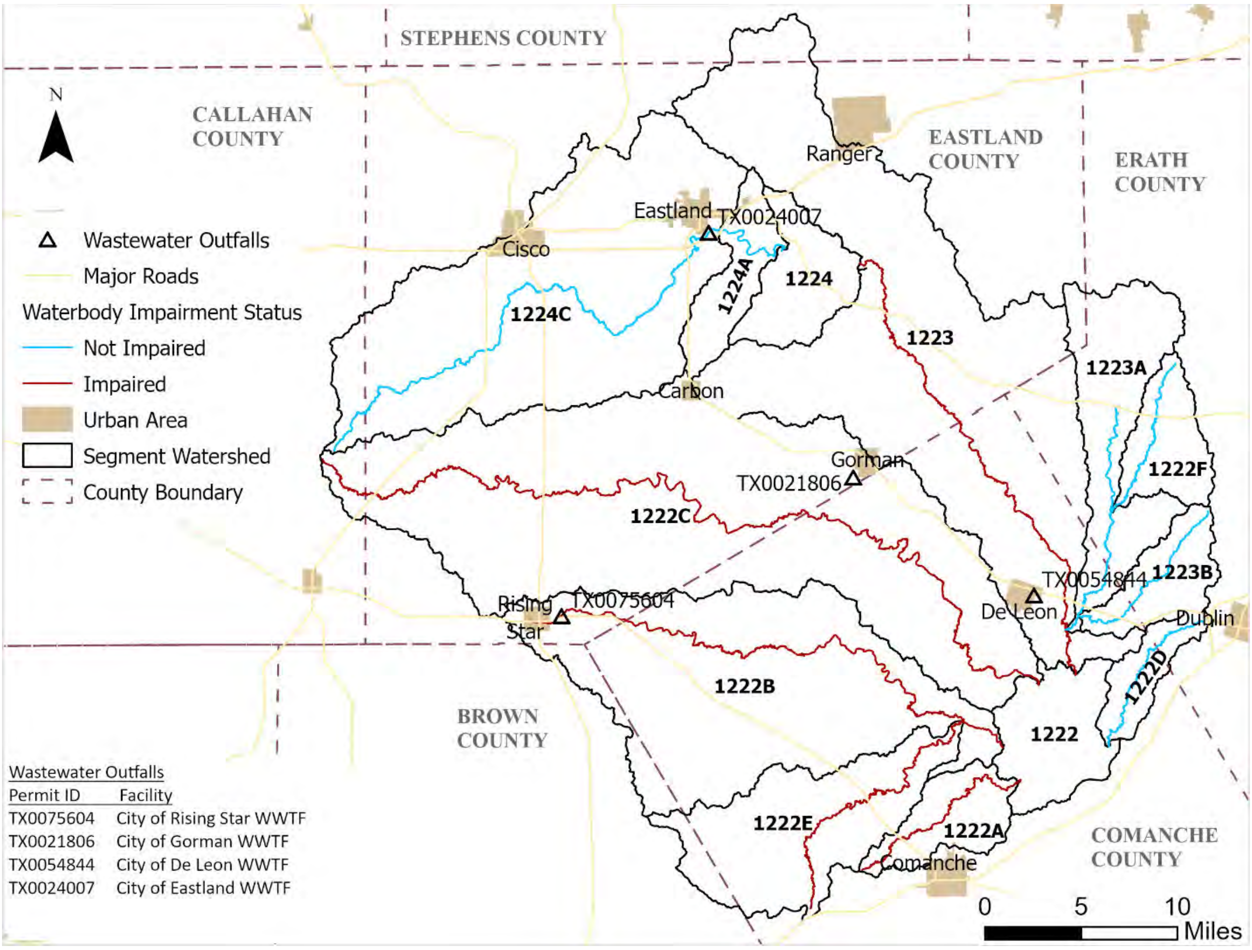
[7] Regulatory program to control discharges of pollutants to surface waters in Texas. Additional information about the program is available at https://www.tceq.texas.gov/permitting/wastewater/pretreatment/tpdes_definition.html

[8] TCEQ Wastewater Outfalls data. Available at https://gis-tceq.opendata.arcgis.com/

[9] TCEQ Central Registry Query. Available at https://www15.tceq.texas.gov/crpub/index.cfm?fuseaction=home.welcome

[10] EPA Enforcement and Compliance History Online website. Available at https://echo.epa.gov/

WWTFs in the watershed have a daily average *E. coli* discharge limit of 126 cfu/100mL. The review of permit compliance history showed that all WWTF permits had non-conformances during the 2020-2023 reporting period (Table 4-1).



Wastewater Outfalls

Permit ID	Facility
TX0075604	City of Rising Star WWTF
TX0021806	City of Gorman WWTF
TX0054844	City of De Leon WWTF
TX0024007	City of Eastland WWTF

Figure 4-1. Permitted wastewater outfalls in the watershed.

Table 4-1. Permitted wastewater treatment facilities in the Proctor Lake watershed.

Watershed/ Segment ID	Wastewater Treatment Facility	Daily Average Discharge Limitations				Quarters with nonconformances (of 12) 10/2020-09/2023
		Flow (MGD)	*E. coli,* cfu/100 mL	BOD (5-day), mg/l	Ammonia Nitrogen, mg/l	
1222B	City of Rising Star WWTF	0.14	126	20	-	7
1222C	City of Gorman WWTF	0.12	126	30	-	1
1223	City of De Leon WWTF	0.295	126	10	3	6
1224C	City of Eastland WWTF	0.9	126	5	1.5	11

General Permits

In addition to WWTFs, certain types of activities such as concrete production facilities and livestock concentrated animal feeding operations (CAFOs) must be covered by one of several TCEQ/TPDES wastewater general permits. A review of active wastewater general permits using TCEQ'S water quality general permits search application[11] in the Proctor Lake watershed found:

- 3 general authorizations for concrete production facilities, and
- 22 distinct permits for livestock CAFOs.

Based on their permit information, the 22 CAFOs are permitted to house up to 74,913 cattle and are estimated to generate 189,982 tons of solid waste and 1,727 ac-ft of wastewater annually. The concrete production facility general permit authorizes the discharge of facility wastewater and stormwater and does not authorize the discharge of domestic sewage[12].

4.1.2 Permitted Stormwater

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.

Stormwater discharges 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 small MS4s located in urbanized areas (discussed above).
- TXR050000 – Multi-Sector General Permit (MSGP) for industrial facilities.

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[11] TCEQ Water Quality General Permits Search application. https://www2.tceq.texas.gov/wq_dpa/index.cfm

[12] Concrete Production Facility Discharges: Obtaining Coverage Under General Permit No. TXG110000. https://www.tceq.texas.gov/permitting/wastewater/general/TXG11_steps.html

- 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.

A review of active stormwater general permits using TCEQ's water quality general permits search application[13] found no active Phase I or Phase II MS4 general permit in the watershed in 2023. Due to the relatively low population density and low anticipated population growth, no MS4 permit is expected to be issued in the watershed. The review identified active 11 MSGPs and 23 CGPs located in the watershed.

Based on property appraisal parcel data for Comanche County[14], Eastland County[15] , and Erath County[16] where these MSGP and CGP facilities are located, about 906.29 acres of land were under MSGP permits and the total disturbed area based on permit data for CGPs was about 117 acres. Permits for these facilities authorize the discharge of facility stormwater only.

4.1.3 Sanitary Sewer Overflows

Sanitary sewers are systems that collect and transport wastewater to appropriate treatment facilities. Raw sewage releases from these lines, known as a SSO event, happens when sewer lines fail due to age, lack of maintenance, or are overloaded during rain events. 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. Stormwater permit violation information is provided by TCEQ upon request.

The TCEQ Central Office in Austin provided statewide and regional data on SSO incidents from 2020 through 2023. No SSO events were reported in the watershed during this period.

4.2 Nonpoint Sources

Pollutants entering the environment from sources without a single point of origin are referred to as nonpoint source (NPS) pollution. These pollutants are eventually carried across the landscape and into water bodies by rainfall runoff. Nonpoint sources are not regulated and are controlled primarily through

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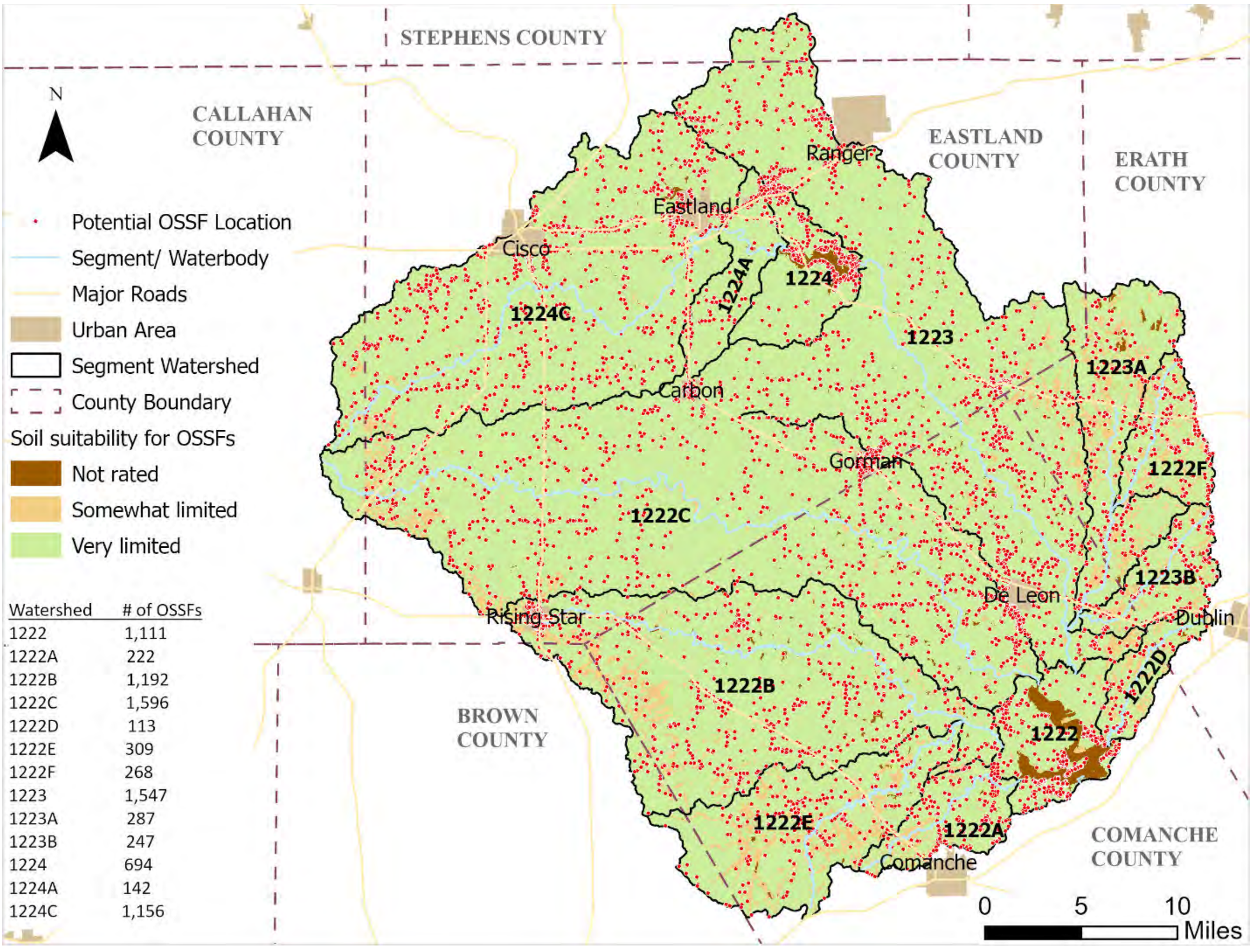
[13] TCEQ Water Quality General Permits Search application. https://www2.tceq.texas.gov/wq_dpa/index.cfm
[14] Comanche County Appraisal District. https://comanchecad.org/
[15] Eastland County Appraisal District. https://eastlandcad.org/
[16] Erath County Appraisal District https://erath-cad.com/

responsible land stewardship and voluntary land management practices. Examples of nonpoint sources include on-site sewage facilities (OSSF), pets, livestock, wildlife, and feral hogs.

4.2.1 On-site Sewage Facilities

OSSFs provide wastewater treatment for households unable to connect to municipal sewer systems. If OSSFs are properly designed, installed, routinely inspected, and effectively managed, they provide an adequate level of waste treatment and disinfection. However, failing OSSFs can lead to nonpoint source bacterial and nutrient contamination within a watershed. Improper site design, age, and lack of maintenance like regular pumping and proper chlorination can cause OSSFs to inadequately treat waste before it enters the environment. The ability of the soil to absorb wastewater affects the ability of a conventional OSSF to function as well.

Soil suitability rankings for OSSF design were developed by NRCS based on topography, saturated hydraulic conductivity, depth to the water table, ponding, flooding, etc. (Soil Survey Staff, 2022), and soils were divided into three categories: not limited, somewhat limited, and very limited. If an OSSF is not properly designed, systems in a somewhat limited or very limited soil type have an increased risk of failure. The soil in the Proctor Lake watershed are generally rated as very limited (Figure 4-2).



Watershed	# of OSSFs
1222	1,111
1222A	222
1222B	1,192
1222C	1,596
1222D	113
1222E	309
1222F	268
1223	1,547
1223A	287
1223B	247
1224	694
1224A	142
1224C	1,156

Figure 4-2. Estimated OSSF locations and NRCS soil suitability ratings for the Proctor Lake watershed

OSSF location estimates in the Proctor Lake watershed were determined using 911 address data and visually validated with aerial imagery. Residential and business addresses found outside of city boundaries, areas covered by Certificates of Convenience and Necessity[17], and outside of city sewer system boundaries were assumed to have an OSSF. Data from these sources indicate that the highest number of OSSFs are in the Sabana River and the Leon River below Leon Reservoir watersheds (Figure 4-2). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The Proctor Lake watershed is located within the Region 1 area, which has a reported failure rate of about 8%, providing insights into expected failure rates for the area.

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[17] A Certificate of Convenience and Necessity (CCN) gives a retail public utility the exclusive right to provide retail water or sewer utility service to an identified geographic area. Information on CCNs in Texas is available at https://www.puc.texas.gov/industry/water/utilities/gis.aspx.

4.2.2 Stormwater Runoff

Rainfall-generated stormwater is a vehicle for almost all pollutant types that impact surface waterbodies. Debris, dissolved pollutants, fecal matter, nutrients, sediment, and more are transported overland and into waterbodies when rainfall generates runoff. This is a natural and important process, but excess quantities of any of these constituents can be detrimental to instream water quality. Runoff occurs on all land cover and soil types when rainfall rates exceed the soil's infiltration capacity. Impervious surfaces common in developed areas (roof tops, parking lots, roads, etc.) land uses increase runoff to volumes above natural levels. In developed areas, the timing when water arrives in the stream is also altered and generally leads to increased peak flows which increase flooding potential. Combined, these factors can have adverse effects on instream water quality.

4.2.3 Livestock

Domestic livestock and/or the use of land-applied manure can introduce *E. coli* into waterbodies via runoff. Timing between when manure is deposited on the landscape and when runoff occurs significantly influences the amount of *E. coli* and some nutrients present in water leaving a given field. Natural die-off of bacteria and attenuation of some nutrients (nitrogen) occur over time. As the amount of time between deposition and runoff increases, concentrations of these constituents decrease.

Livestock populations in the Proctor Lake watershed were estimated using the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) agriculture census data (USDA 2022). Since NASS data are county-based (Table 4-2), populations for cattle, horses, hogs, sheep, and goats were estimated based on the fraction of each county's grazable area (Shrub/Scrub, Herbaceous, and Hay/Pasture) (Bigelow and Borchers, 2017) located in the watershed (Table 4-3). The NASS report indicates the most prevalent livestock in the watershed were cattle (all cattle types) followed by sheep (Table 4-2). About 60% of the cattle were reported to reside in the Sweetwater Creek (1222B), Sabana River (1222C), and Leon River Below Leon Reservoir (1223) watersheds (Table 4-4).

Table 4-2. Estimated livestock populations in counties in the Proctor Lake watershed (not all animals documented here reside in the watershed).

County	Cattle*				Hogs and Pigs	Sheep and Lamb	Goats	Equine	Poultry**
	All Cattle and Calves	Beef Cows	Milk Cows	Other Cattle					
Brown	34,968	D	D	14,616	530	10,528	5,910	1,028	6,025
Callahan	33,909	17,302	0	16,607	171	4,067	2,426	1,113	4,423
Comanche	117,228	40,702	30,843	45,683	95	11,713	6,526	1,901	3,021
Eastland	37,464	D	D	17,048	398	2,220	4,205	1,338	5,786
Erath	171,459	37,211	57,418	76,830	1,025	5,273	13,035	5,001	5,400
Stephens	18,280	D	D	7,177	26	310	648	271	2,845

* All cattle and calves = Sum of beef and milk cows and other cattle; Other cattle = Data include heifers that had not calved, steers, calves, and bulls; D = Data not published due to only one operation being present

** Data includes layers, pullets, broilers and other meat-type chickens, and turkeys

Table 4-3. Proportion of the county's grazable area within each segment watershed.

<table>
<tr><td colspan="2">County</td><td>Brown</td><td>Callahan</td><td>Comanche</td><td>Eastland</td><td>Erath</td><td>Stephens</td></tr>
<tr><td colspan="2">County area (acres)</td><td>609,984</td><td>574,242</td><td>607,121</td><td>592,881</td><td>693,045</td><td>587,804</td></tr>
<tr><td colspan="2">Grazable area (acres)</td><td>439,492</td><td>441,527</td><td>406,459</td><td>463,158</td><td>442,186</td><td>442,186</td></tr>
<tr><td>Watershed</td><td>Segment ID</td><td colspan="6">Total grazable area(acres) withing each segment</td></tr>
<tr><td>Proctor Lake</td><td>1222</td><td colspan="6">12428.65</td></tr>
<tr><td>Duncan Creek</td><td>1222A</td><td colspan="6">12005.50</td></tr>
<tr><td>Rush-Copperas Creek</td><td>1222B</td><td colspan="6">80204.28</td></tr>
<tr><td>Sabana River</td><td>1222C</td><td colspan="6">141117.82</td></tr>
<tr><td>Sowells Creek</td><td>1222D</td><td colspan="6">7106.82</td></tr>
<tr><td>Sweet Water Creek</td><td>1222E</td><td colspan="6">33779.62</td></tr>
<tr><td>Hackberry Creek</td><td>1222F</td><td colspan="6">10462.98</td></tr>
<tr><td>Leon River Below Leon Reservoir</td><td>1223</td><td colspan="6">128018.75</td></tr>
<tr><td>Armstrong Creek</td><td>1223A</td><td colspan="6">24481.74</td></tr>
<tr><td>Cow Creek</td><td>1223B</td><td colspan="6">10204.84</td></tr>
<tr><td>Leon Reservoir</td><td>1224</td><td colspan="6">12690.90</td></tr>
<tr><td>Leon River Above Leon Reservoir</td><td>1224A</td><td colspan="6">11195.58</td></tr>
<tr><td>South Fork Leon River</td><td>1224C</td><td colspan="6">95378.42</td></tr>
</table>

Table 4-4. Estimated livestock populations in the Proctor Lake watershed

Watershed	Segment ID	Cattle	Hogs and Pigs	Sheep and Lamb	Goats	Equine	Poultry
Proctor Lake	1222	3,273	3	327	182	53	130
Duncan Creek	1222A	3,178	3	318	177	52	126
Rush-Copperas Creek	1222B	19,223	27	1,972	1,146	327	879
Sabana River	1222C	20,846	100	1,741	1,643	506	1,820
Sowells Creek	1222D	2,060	5	162	128	41	77
Sweet Water Creek	1222E	8,305	10	883	493	139	365
Hackberry Creek	1222F	3,883	23	119	295	113	122
Leon River Below Leon Reservoir	1223	19,313	107	1,406	1,569	502	1,651
Armstrong Creek	1223A	8,417	47	304	631	238	284
Cow Creek	1223B	3,546	18	148	258	96	116
Leon Reservoir	1224	1,165	12	69	131	42	180
Leon River Above Leon Reservoir	1224A	1,028	11	61	115	37	159
South Fork Leon River	1224C	8,707	90	534	966	310	1,338
Total		102,944	456	8,044	7,734	2,456	7,247

4.2.4 Wildlife and Feral Hogs

Wildlife and feral hogs tend to concentrate near or within riparian corridors that are not barren or developed. Pollutants from wild animals can enter the waterbody through direct deposition when wading and through runoff from nearby areas during a storm event. Feral hogs tend to be particularly destructive to riparian vegetation which also reduces the riparian area’s capacity to filter runoff and potential pollutants from other sources. Estimates of most wildlife including raccoons, opossums, and birds are difficult to ascertain; therefore, management measures commonly focus on two species with practical management options: white-tailed deer and feral hogs.

The Texas Parks and Wildlife Department (TPWD) provides deer population-density estimates by Deer Management Unit (DMU). The largest portion of the Proctor Lake watershed area lies in the DMU 24 located in the Cross Timbers ecoregion. Estimates of deer density in DMU 24 were 51.27 deer/1000 acres in 2019 (TPWD 2020). Texas A&M AgriLife Extension (2012) estimates one hog per 39 acres as a statewide average density for feral hogs.

Both species prefer similar land cover classes: forest, pasture, shrub, and wetlands. While they mostly travel through riparian corridors, they can also be found in the pastures, croplands, and rangelands, especially at night. Feral hogs can be significant contributors of fecal bacteria to waterbodies as they spend much of their time wallowing in and around the water. These non-native, invasive hogs also cause erosion and soil loss issues due to their rooting and wallowing habits.

White-tailed deer and feral hog density estimates were applied to appropriate NLCD classes (all but barren land, developed, and open water) in the watershed to estimate their populations. Being a rural watershed, over 90 percent of the watershed provides a suitable habitat for wildlife. In total, nearly 18,200 feral hogs and 36,400 white-tailed deer are estimated to live in the watershed (Table 4-5). These estimates are based on historical data and current actual populations may be different.

Table 4-5. Wildlife population estimates in the Proctor Lake watershed.

Watershed	Segment ID	Feral hogs	White-tailed deer
Proctor Lake	1222	395	790
Duncan Creek	1222A	352	705
Rush-Copperas Creek	1222B	2,514	5,029
Sabana River	1222C	4,345	8,691
Sowells Creek	1222D	245	490
Sweet Water Creek	1222E	1,102	2,205
Hackberry Creek	1222F	367	734
Leon River Below Leon Reservoir	1223	3,995	7,989
Armstrong Creek	1223A	878	1,755
Cow Creek	1223B	350	699
Leon Reservoir	1224	382	763
Leon River Above Leon Reservoir	1224A	343	686
South Fork Leon River	1224C	2,932	5,864
Total		18,200	36,400

4.2.5 Pets

Dogs can be a contributor to *E. coli* in a watershed if pet waste is not properly discarded. Table 4-6 summarizes the estimated number of dogs in the watershed. Dog population estimates were calculated using the average number of dogs per household (1.46 dogs per household) multiplied by the percentage of households owning dogs (44.6%) according to data from the American Veterinary Medical Association (AVMA) U.S. Pet Statistics (AVMA 2022) multiplied by the number of households in the watershed. The number of households in the watershed was estimated using 2020 census data (Table 4-6). Based on these data, about 7,086 dogs live in the watershed (Table 4-6).

Table 4-6. Pet populations in the Proctor Lake watershed

Watershed	Segment ID	Number of households	Number of Dogs
Proctor Lake	1222	485	316
Duncan Creek	1222A	225	147
Rush-Copperas Creek	1222B	955	622
Sabana River	1222C	1,390	905
Sowells Creek	1222D	95	62
Sweet Water Creek	1222E	252	164
Hackberry Creek	1222F	140	91
Leon River Below Leon Reservoir	1223	2,308	1,504
Armstrong Creek	1223A	165	107
Cow Creek	1223B	140	91
Leon Reservoir	1224	597	389
Leon River Above Leon Reservoir	1224A	152	99
South Fork Leon River	1224C	3,977	2,589
Total		10,881	7,086

4.2.6 Illegal Dumping

Although most trash items dumped are not major bacteria or nutrient sources, areas that are littered tend to accumulate additional litter. Commonly dumped items, like animal carcasses and household chemical containers, can contribute additional bacteria and nutrients to the watershed.

Chapter 5 – Pollution Source Assessment

Once potential pollution sources have been identified, water quality data is used to estimate pollutant load reductions needed to achieve water quality standards. A pollutant load is the volume of a contaminant flowing through a specific part of a waterbody at a specific point in time.

Bacteria load capacities for impaired waterbodies in the Proctor Lake watershed were calculated using the LDC method with data from the TCEQ SWQMIS database. This chapter describes the relative bacteria load contributions and potential areas for targeted load reductions from the various potential pollutant sources.

Nutrient load reductions were not developed because there are no nutrient criteria for freshwater streams in Texas. DO levels in water are influenced by several parameters including nutrients, temperature and instream flow conditions. Calculating precise load reductions for DO is challenging due to the intricate dynamics involved. For this reason, load reductions for DO were not developed. However, nutrient and DO management is still an important consideration, and practices implemented to reduce bacteria in the watershed typically also mitigate nutrient and DO concerns.

5.1 Bacteria Load Duration Curve Analysis

LDCs are a widely accepted methodology used to characterize water quality data across different flow conditions in a watershed. A LDC provides a visual display of the relationship between stream flow and loading capacity. Measurements above the LDC line exceed the water quality criterion for that parameter while measurements below the line do not. A percent reduction can be calculated based on the difference between the current measured load and the allowable load. The process for developing LDCs is detailed in Appendix B.

Results of LDC analysis show that the *E. coli* loads generally exceed allowable amounts by a greater margin during high flow conditions than during other flow conditions (Figure 5-1). The fact that bacteria loads for impaired waterbodies were generally above allowable levels during high flow conditions indicates that sources contributing to bacteria loads are mostly NPS.

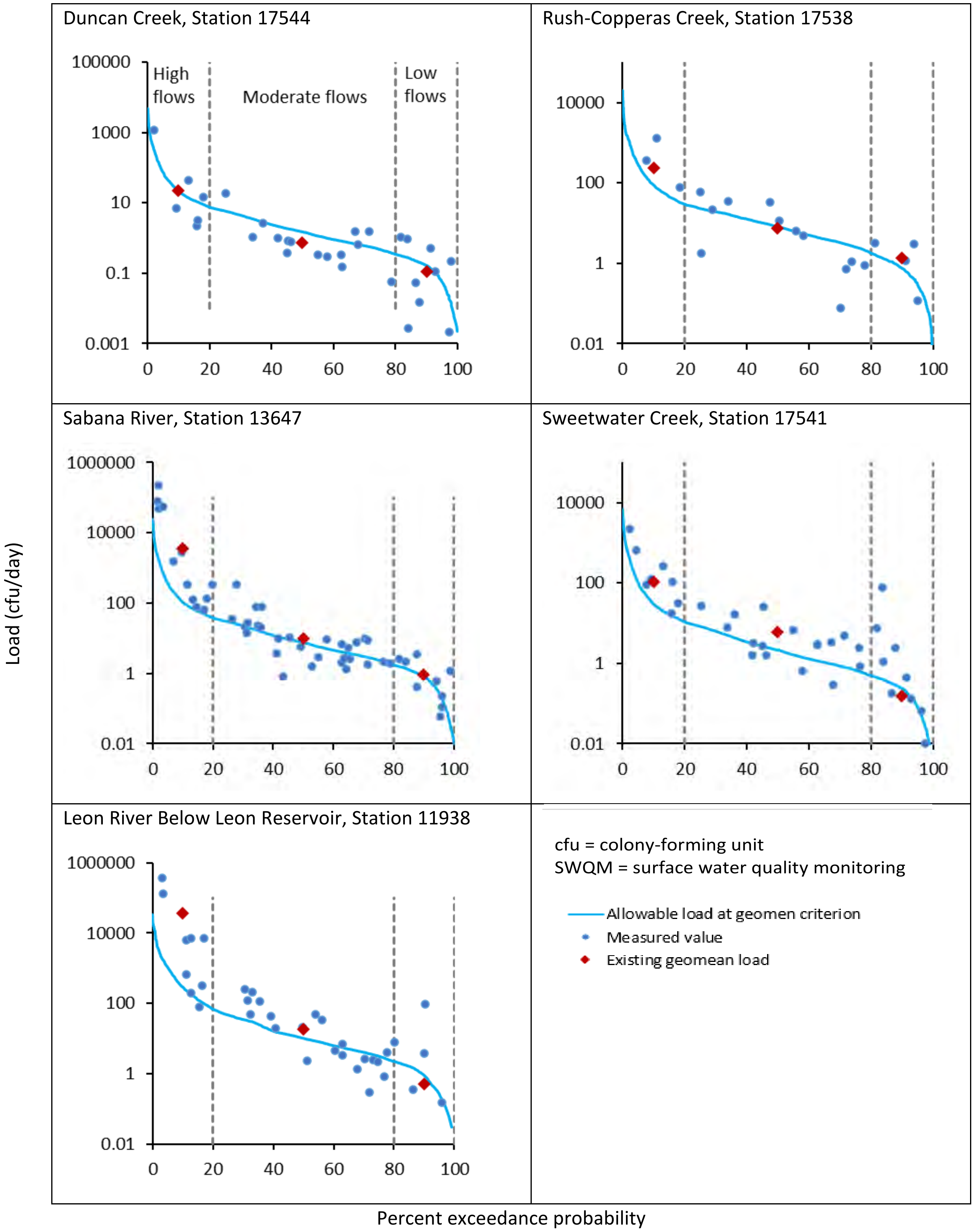

Figure 5-1. Bacteria load duration curves at monitoring stations on impaired waterbodies in the watershed.

5.2 Load Reduction Needed for Bacteria

LDC results indicate daily bacteria loads waterbodies in the watershed can have and still support water quality standards. Using the current daily load, the load reduction needed to keep the current geomean load from exceeding the water quality geomean criterion under different flow conditions was determined for each impaired waterbody. These *E. coli* load reductions can serve as the basis to determine goals for recommended management measures. Estimates of loads and load reductions are summarized in Table 5-1. The methodology for calculating loads and load reductions is described in Appendix B.

Table 5-1. Estimated *E. coli* loads, and load reductions needed to meet water quality criteria in the watershed.

Segment	Flow condition	Median flow (cfs)	Estimated geometric mean concentration (cfu/100 mL)	Estimated daily load (Billion cfu)	*E. coli* criterion (cfu/100 mL)	Allowable daily load (Billion cfu)	Reduction needed (%)
1222A	High	1.37	655	8,031	630	7,720	4
	Mid-range	0.10	315	276	630	553	-
	Low	0.01	422	40	630	60	-
1222B	High	29.09	340	88,322	126	32,731	63
	Mid-range	2.67	112	2,672	126	3,002	-
	Low	0.24	226	492	126	275	44
1222C	High	34.50	4,284	1,319,744	126	38,819	97
	Mid-range	2.47	159	3,514	126	2,779	21
	Low	0.27	137	331	126	304	8
1222E	High	9.74	453	39,368	126	10,955	72
	Mid-range	0.70	348	2,167	126	784	64
	Low	0.08	84	57	126	86	-
1223	High	94.30	15,492	13,045,743	126	106,104	99
	Mid-range	3.34	231	6,880	126	3,758	45
	Low	0.29	70	182	126	326	-

5.3 Pollutant Source Loading Analysis

To facilitate potential pollutant source identification spatially, the Proctor Lake watershed was delineated into smaller subwatersheds (Table 5-2, Figure 5-2). Using the best available data, a GIS analysis was performed to determine relative potential load contributions within each subwatershed. Spatial analyses assist with prioritizing where management measures should be implemented for the greatest need and highest potential impact. The following estimates show the relative potential for bacteria to enter waterbodies in any particular subwatershed, and is a conservative overestimate compared to the actual amounts expected to enter waterbodies. Unlike LDC analysis, which is limited to impaired waterbodies, the GIS analysis shows potential loading from the entire watershed. The methodology for calculating load estimates from each potential source is described in Appendix D

Table 5-2. Subwatersheds in the Proctor Lake watershed.

Subwatershed ID	Subwatershed Description	Segment ID	Area (acres)
1	Proctor Lake	1222	23,167.65
2	Duncan Creek	1222A	16,086.36
3	Copperas Creek-Proctor Lake	1222B	3,968.79
4	Martins Creek-Copperas Creek	1222B	33112.42
5	South Copperas Creek	1222B	25,147.31
6	Sipe Springs Creek-Copperas Creek	1222B	16,477.75
7	Nanny Branch-Copperas Creek	1222B	34,841.75
8	Sabana River-Proctor Lake	1222C	24,226.01
9	Nabors Lake-Sabana River	1222C	27,875.42
10	Currycomb Branch-Sabana River	1222C	35,736.96
11	Elm Creek	1222C	20,640.29
12	Hunting Shirt Creek-Sabana River	1222C	21,757.84
13	Long Branch-Sabana River	1222C	19064.59
14	Yellow Branch	1222C	10,361.12
15	Mexican Hat Hill-Sabana River	1222C	36,716.45
16	Sowells Creek	1222D	10,437.41
17	Round Mountain-Sweetwater Creek	1222E	21,777.18
18	Jimmys Creek	1222E	26,305.59
19	Henning Creek-Hackberry Creek	1222F	16,257.15
20	Walker Creek-Leon River	1223	6,384.05
21	City of De Leon-Leon River	1223	12,414.64
22	Flat Creek-Leon River	1223	33,973.17
23	Jameson Peaks-Hog Creek	1223	14,922.20
24	Salt Branch-Leon River	1223	30,680.40
25	Nash Creek-Leon River	1223	37,472.33
26	Lower Colony Creek	1223	17,161.49
27	Upper Colony Creek	1223	24,204.31
28	Lower Armstrong Creek	1223A	12,596.04
29	Upper Armstrong Creek	1223A	26,112.99
30	Cow Creek	1223B	15,727.29
31	Leon Reservoir	1224	19,278.50
32	Leon River above Leon Reservoir	1224A	15,134.90
33	North Fork Leon River	1224C	29,541.68
34	Lower South Fork Leon River	1224C	30,379.65
35	Dead Horse Creek	1224C	15,907.16
36	Middle South Fork Leon River	1224C	26,805.11
37	Upper South Fork Leon River	1224C	28,051.88

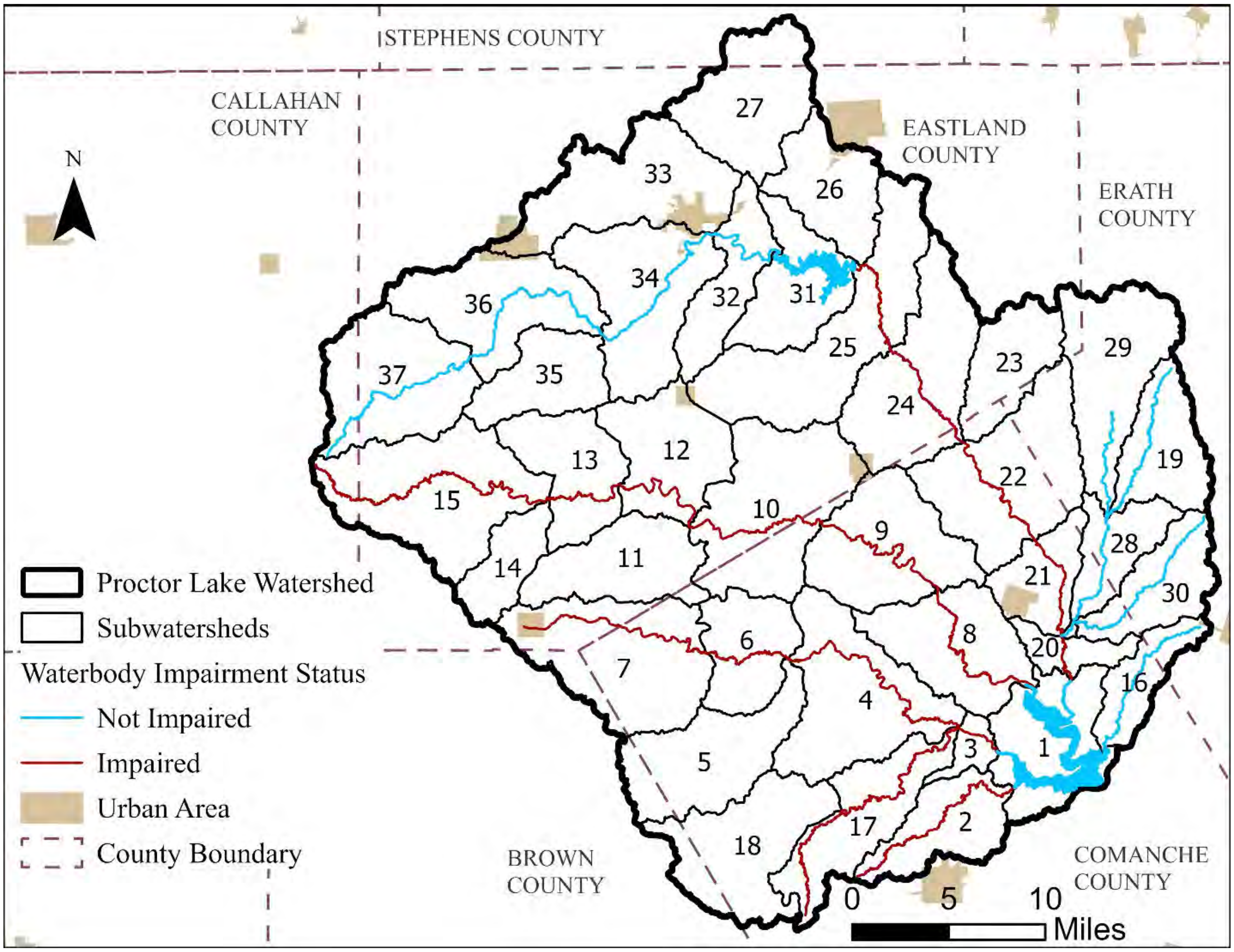

Figure 5-2. Subwatersheds in the Proctor Lake watershed

5.3.1 Bacteria Load Estimates from Wastewater Treatment Facilities

Based on allowable *E. coli* discharges from WWTFs in the watershed, the estimated daily bacteria load from WWTFs in the Proctor Lake watershed is summarized in Table 5-3. Potential loading from WWTFs is highest in the South Fork Leon River and Leon River Below Leon Reservoir. About 38% of potential bacteria loading from WWTFs is in watersheds with impaired waterbodies.

Table 5-3. Potential bacteria loading estimates from wastewater treatment plants in the Proctor Lake watershed

Waterbody	Segment ID	Daily *E. coli* loading (Billion cfu) estimates
Proctor Lake	1222	-
Duncan Creek	1222A*	-
Rush-Copperas Creek	1222B*	0.7
Sabana River	1222C*	0.6
Sowells Creek	1222D	-
Sweet Water Creek	1222E*	-
Hackberry Creek	1222F	-
Leon River Below Leon Reservoir	1223*	1.4
Armstrong Creek	1223A	-
Cow Creek	1223B	-
Leon Reservoir	1224	-
Leon River Above Leon Reservoir	1224A	-
South Fork Leon River	1224C	4.3

* Impaired waterbody

Figure 5-3 shows the spatial distribution of potential loading from WWTFs in the Proctor Lake watershed. Potential loading for bacteria from WWTFs is highest in the Lower South Fork Leon River (subwatershed 34) and City of De Leon-Leon River (subwatershed 21).

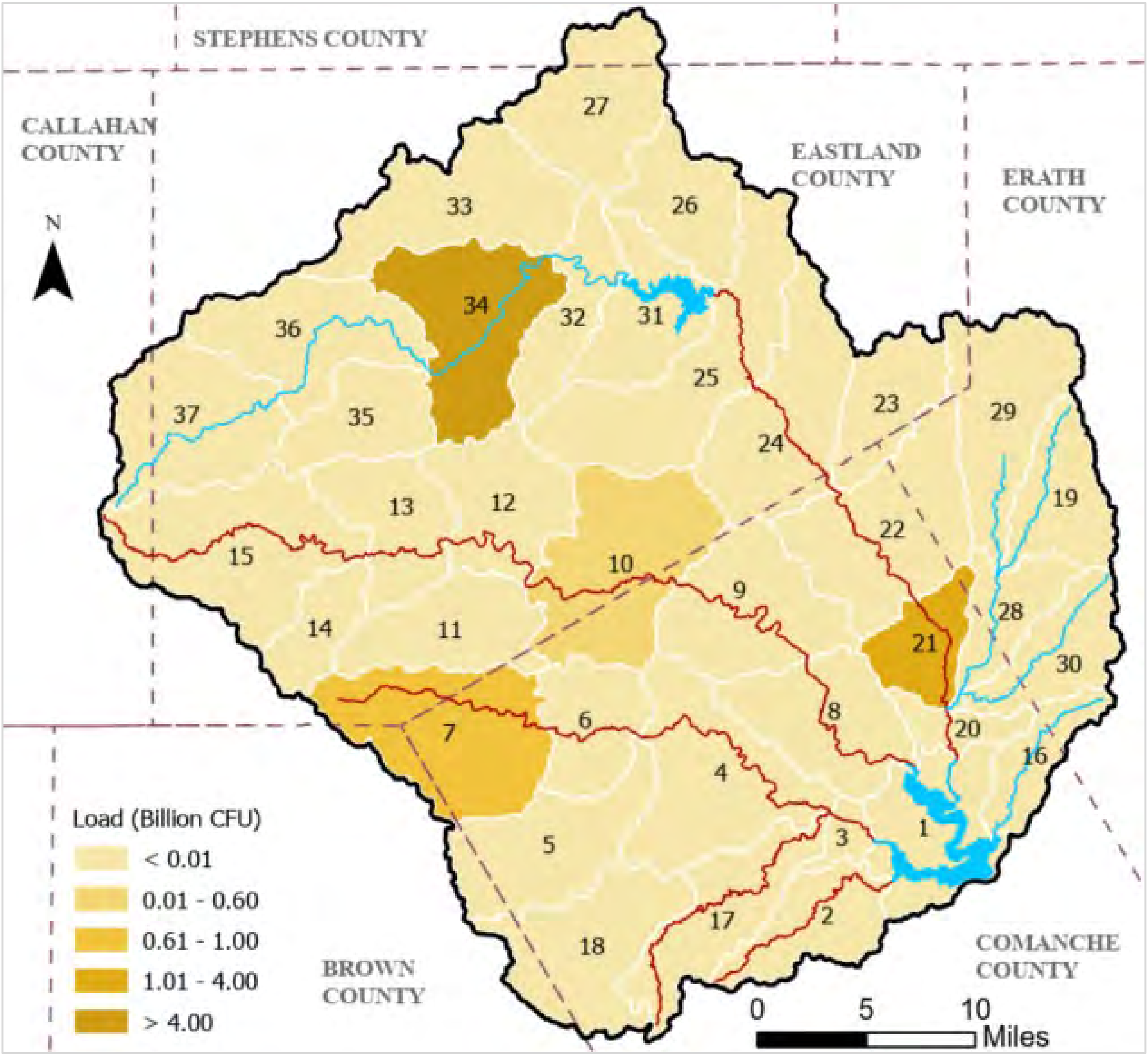

Figure 5-3. Estimated daily load contribution from WWTFs.

5.3.2 Bacteria Load Estimates from On-site Sewage Facilities

Based on the number of OSSFs in the watersheds, the estimated daily bacteria load from OSSFs are summarized in Table 5-4. Potential loading for bacteria loading from OSSFs is highest in the Sabana River and Leon River Below Leon Reservoir watersheds. About 55% of estimated bacteria loading from OSSFs is from watersheds with impaired waterbodies.

Figure 5-4 shows the spatial distribution of potential loading from OSSFs in the Proctor Lake watershed. Potential loading for bacteria from OSSFs is highest in Proctor Lake (subwatershed 1), Nanny Branch-Copperas Creek (subwatershed 7), and Leon Reservoir (subwatershed 31).

Table 5-4. Bacteria loading estimates from OSSFs in the Proctor Lake watershed.

Waterbody	Segment ID	Daily *E. coli* loading (Billion cfu) estimates
Proctor Lake	1222	284
Duncan Creek	1222A*	57
Rush-Copperas Creek	1222B*	305
Sabana River	1222C*	409
Sowells Creek	1222D	29
Sweet Water Creek	1222E*	79
Hackberry Creek	1222F	69
Leon River Below Leon Reservoir	1223*	396
Armstrong Creek	1223A	73
Cow Creek	1223B	63
Leon Reservoir	1224	179
Leon River Above Leon Reservoir	1224A	36
South Fork Leon River	1224C	296

* Impaired waterbody

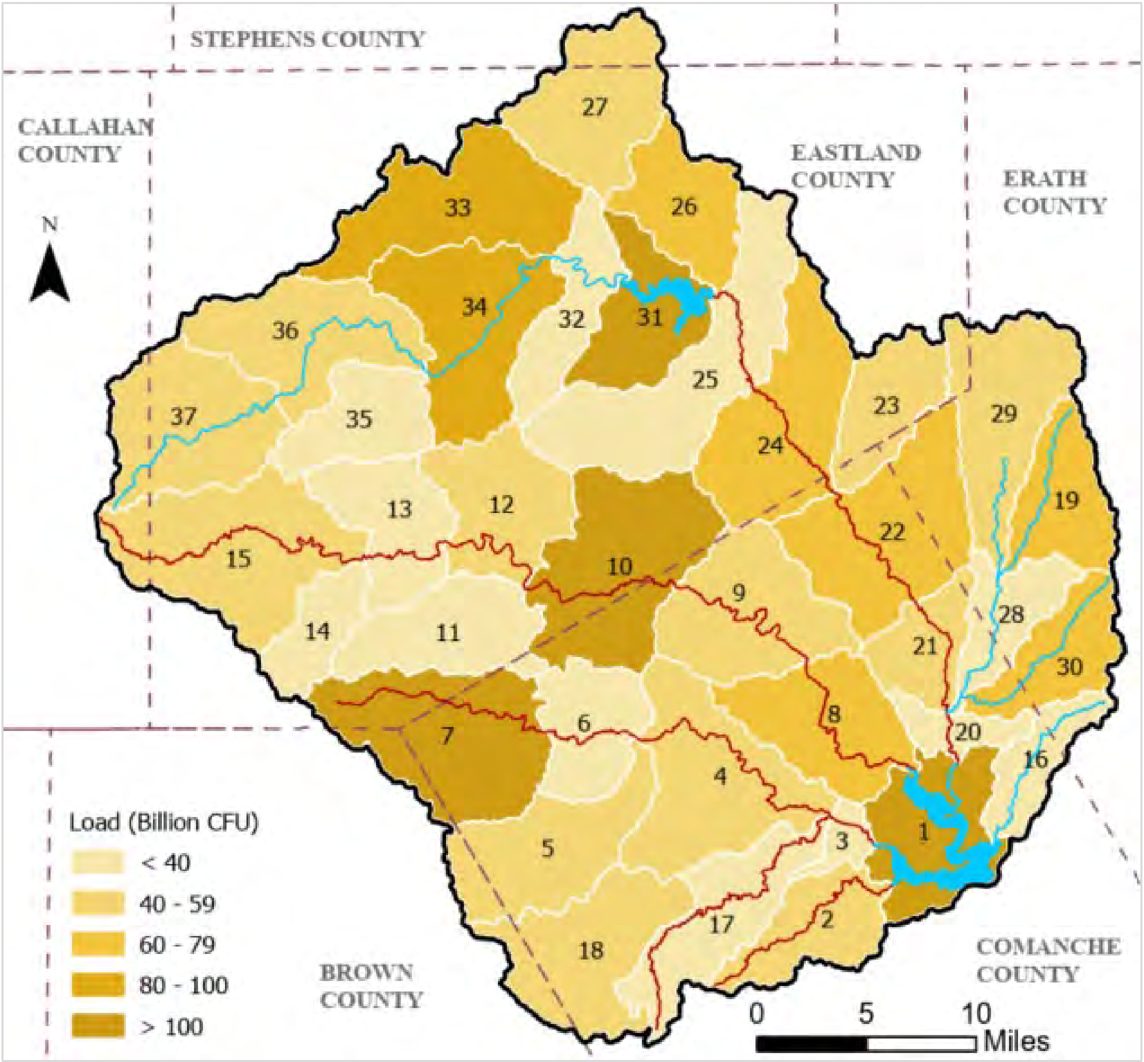

Figure 5-4. Estimated load contribution from OSSFs.

5.3.3 Bacteria Load Estimates from Livestock

The impact of livestock on water quality can vary significantly based on management practices like open (unconfined) grazing and CAFOs. When livestock graze openly, manure is deposited over the grazed area. When runoff occurs, bacteria from manure may be transported into nearby water bodies, especially if the land is overgrazed. Livestock with access to streams can also directly deposit manure in the stream. Manure from confined livestock is generally accumulated and then land applied. Timing in relation to runoff events and location of these land applications can influence potential for bacteria to be carried to downstream water bodies.

A review of TCEQ permits identified 22 CAFOs in the Proctor Lake watershed (Table 5-5). Based on permit information these 22 CAFOs are permitted to house up to 74,913 cattle. Assuming the actual quantity of livestock kept in CAFOs is close to the total permitted number, a significant number of the cattle in the watershed (about 74%) are estimated to be managed in CAFOs (Table 5-5).

Table 5-5. Estimated cattle population and CAFO permits in the Proctor Lake watershed.

Watershed	Segment ID	Total Cattle Estimates based on USDA NASS Statistics	CAFO Permit Authorization Details			
			Number of CAFOs	Number of Cattle	Estimated Solids Generated Annually (Tons)	Estimated Wastewater Generated annually (acre-feet)
Proctor Lake	1222	3,273	-	-	-	-
Duncan Creek	1222A	3,178	1	5,005	5,116	22.63
Rush-Copperas Creek	1222B	19,223	1	10,000	8,760	37.56
Sabana River	1222C	20,846	-	-	-	-
Sowells Creek	1222D	2,060	1	1,600	4,600	46.38
Sweet Water Creek	1222E	8,305	3	8,000 1,213 999	27,363 3,254 3,376	269.89 7.69 23.36
Hackberry Creek	1222F	3,883	6	999 400 1,485 4,500 7,335 3,000	3,752 1,502 1,815.78 16,425 9,745 9,658	30.68 15.21 19.48 151.8 28.76 70.83
Leon River Below Leon Reservoir	1223	19,313	-	-	-	-
Armstrong Creek	1223A	8,417	6	600 5,000 2,660 10,000 5,070 699	2,254 1,022 6,990 33,557 13,324 2,625	21.69 15.46 42.82 363.83 154.94 1.74
Cow Creek	1223B	3,546	4	4,000 2,249 999 700	19,688 8,774 3,752 2,629	97.46 63.73 40.05 201.09
Leon Reservoir	1224	1,165	-	-	-	-
Leon River Above Leon Reservoir	1224A	1,028	-	-	-	-
South Fork Leon River	1224C	8,707	-	-	-	-
Total		102,944	-	76,513	189,982	1,727

The CAFO general permit[18] provides authorization for facilities defined or designated as CAFOs to discharge manure, sludge, and wastewater into or adjacent to surface water in the State, only when chronic or catastrophic rainfall causes an overflow from the properly designed, constructed, operated, and maintained facility. The general permit also provides requirements for the retention and beneficial land application of manure, sludge, and wastewater generated by a CAFO. Permits contains additional requirements or prohibitions of coverage for CAFOs located in an impaired segment. Generally, permits include stringent discharge restrictions and effluent limitations to mitigate water pollution impacts from CAFOs. Nonetheless, land application of manure, sludge or wastewater generated by CAFOs can be potential significant source of both bacteria and nutrients in the watershed.

Potential loading from cattle managed in CAFOs was not developed largely due to lack of information on where solids and lagoon effluents are applied. For the purpose of assessing potential loads from cattle, watershed load calculations in this report are based on the estimated unconfined cattle population derived from USDA livestock census data. Milk cows (dairy cattle) included in the census statistics (Table 4-2) were considered to be managed in CAFOs and are thus excluded when calculating potential load estimates. The number of pigs kept as livestock and poultry in the watershed are small, rendering their potential contribution to bacteria load insignificant.

Table 5-6 shows potential loading estimates by watershed from livestock. Potential bacteria loading from livestock is highest in the Sabana River, Rush-Copperas Creek, and Leon River Below Leon Reservoir watersheds, largely due to the estimated high number of sheep and unconfined cattle in these watersheds. Figure 5-5 shows the spatial distribution of potential loading from livestock in the Proctor Lake watershed. The highest potential loads are in the southern portion of the watershed, in the Martins Creek – Copperas Creek (subwatershed 4), Flat Creek-Leon River (subwatershed 22), and Nabors Lake - Sabana River (subwatershed 9) subwatersheds.

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[18] Concentrated Animal Feeding Operations (CAFO) Water Quality General Permit. https://www.tceq.texas.gov/permitting/wastewater/cafo/cafo.html

Table 5-6. Bacteria load estimates from livestock in the Proctor Lake watershed.

Waterbody	Segment ID	Daily *E. coli* loading (Billion cfu)				
		Cattle	Goats	Sheep	Equine	Total
Proctor Lake	1222	12,992	495	11,949	12	25,448
Duncan Creek	1222A*	12,615	482	11,620	12	24,728
Rush-Copperas Creek	1222B*	76,246	3,118	72,057	75	151,495
Sabana River	1222C*	74,280	4,470	63,616	116	142,481
Sowells Creek	1222D	7,934	348	5,919	9	14,211
Sweet Water Creek	1222E*	33,342	1,341	32,265	32	66,980
Hackberry Creek	1222F	13,908	803	4,348	26	19,085
Leon River Below Leon Reservoir	1223*	67,746	4,268	51,375	115	123,505
Armstrong Creek	1223A	30,321	1,717	11,108	55	43,200
Cow Creek	1223B	12,922	702	5,408	22	19,054
Leon Reservoir	1224	3,420	356	2,521	10	6,308
Leon River Above Leon Reservoir	1224A	3,016	313	2,229	8	5,567
South Fork Leon River	1224C	26,275	2,628	19,512	71	48,487

* Impaired waterbody

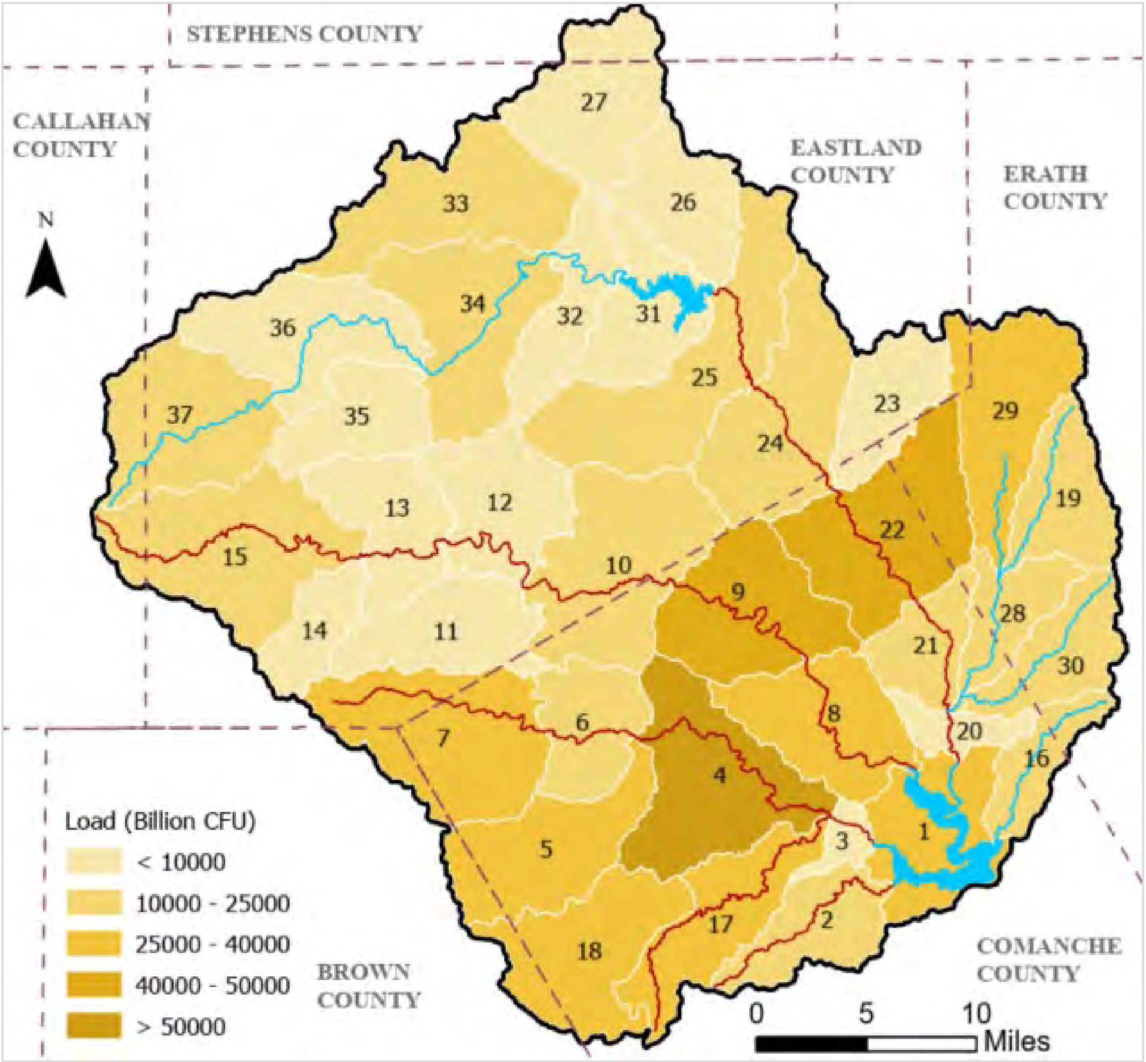


Figure 5-5. Estimated daily load contribution from livestock.

5.3.4 Bacteria Load Estimates from Feral Hogs and White-tailed Deer

Based on the number of deer and feral hogs in the watershed, the estimated daily bacteria load attributed to wildlife is summarized in Table 5-7. The table shows that potential loading for bacteria from wildlife is highest in the Sabana River, Leon River Below Leon Reservoir, and South Fork Leon River watersheds. About 68% of estimated bacteria loading from wildlife is in watersheds with impaired waterbodies.

Table 5-7. Bacteria loading estimates from wildlife in the Proctor Lake watershed.

		Daily *E. coli* loading (Billion cfu)		
Waterbody	Segment ID	Feral Hogs	White-tailed Deer	Total
Proctor Lake	1222	38	836	874
Duncan Creek	1222A*	34	746	780
Rush-Copperas Creek	1222B*	240	5,323	5,563
Sabana River	1222C*	414	9,199	9,613
Sowells Creek	1222D	23	519	542
Sweet Water Creek	1222E*	105	2,334	2,439
Hackberry Creek	1222F	35	777	812
Leon River Below Leon Reservoir	1223*	381	8,456	8,837
Armstrong Creek	1223A	84	1,857	1,941
Cow Creek	1223B	33	740	773
Leon Reservoir	1224	36	808	844
Leon River Above Leon Reservoir	1224A	33	726	759
South Fork Leon River	1224C	279	6,206	6,485

* Impaired waterbody

Figure 5-7 shows the spatial distribution of potential loading from deer and feral hogs in the Proctor Lake watershed. Potential bacteria loading is generally evenly distributed across the watershed. Potential loading is highest in Nash Creek – Leon River (subwatershed 25), Mexican Hat Hill-Sabana River (subwatershed 15), and Currycomb Branch-Sabana River (subwatershed 10), while parts of the watershed in Erath County and the downstream portion of the watershed appear to have less potential.

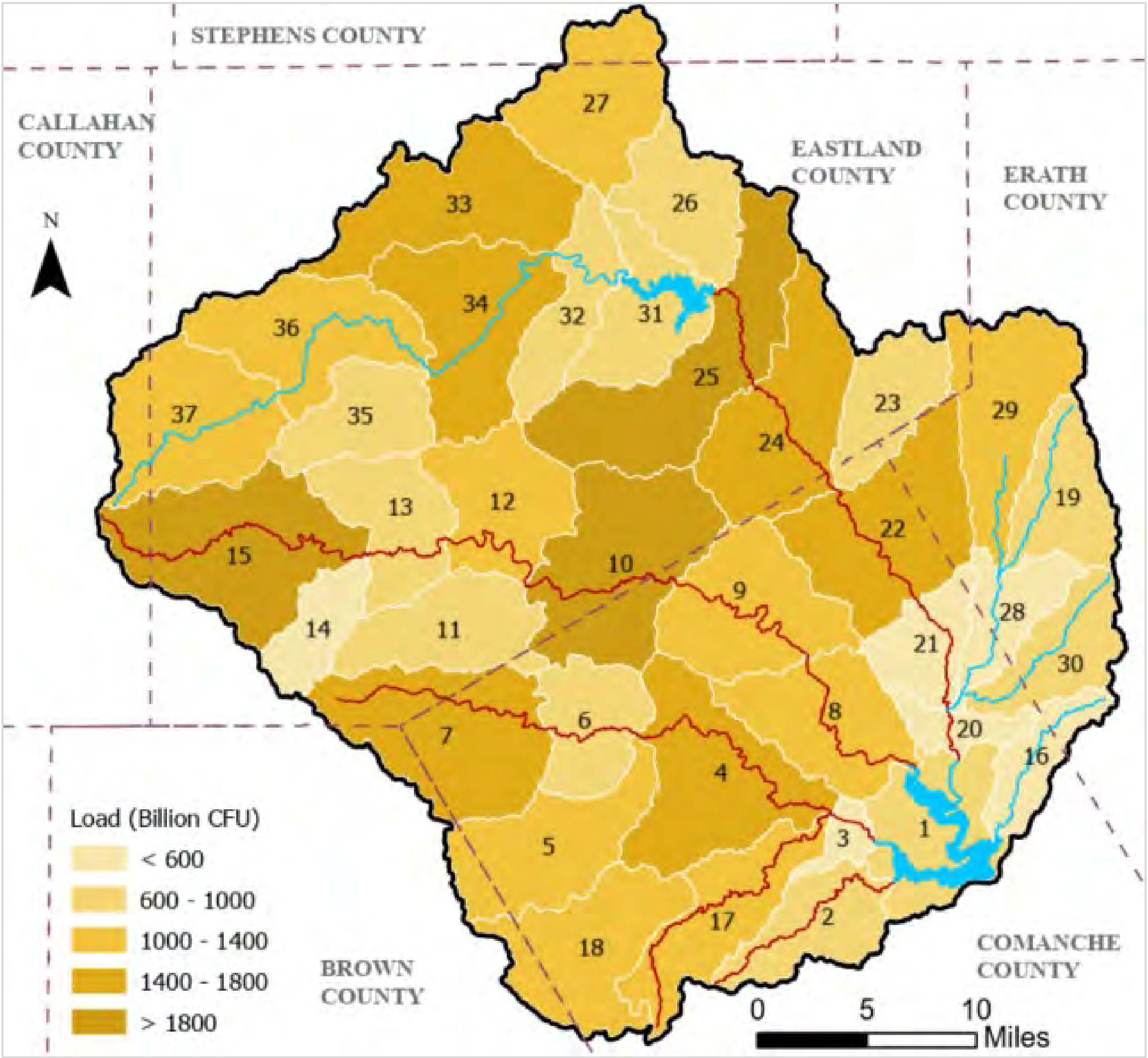


Figure 5-6. Estimated daily load contribution from deer and feral hogs.

5.3.5 Bacteria Load Estimates from Dogs

Based on the number of dogs in the watershed, the estimated daily bacteria load attributed to dogs are summarized in Table 5-8. The estimation of bacterial loading from cats is not typically conducted, given that cats are more often indoors compared to dogs. Outdoor cats also bury their waste thus reducing potential for it to be carried by runoff. Potential loading for bacteria from dogs is highest in the South Fork Leon River, Leon River Below Leon Reservoir, and Sabana River watersheds. About 47% of estimated potential bacteria loading from dogs is from watersheds with impaired waterbodies.

Table 5-8. Bacteria loading estimates from pet waste in the Proctor Lake watershed.

Waterbody	Segment ID	Dogs
Proctor Lake	1222	995
Duncan Creek	1222A*	463
Rush-Copperas Creek	1222B*	1,959
Sabana River	1222C*	2,851
Sowells Creek	1222D	195
Sweet Water Creek	1222E*	517
Hackberry Creek	1222F	287
Leon River Below Leon Reservoir	1223*	4,738
Armstrong Creek	1223A	337
Cow Creek	1223B	287
Leon Reservoir	1224	1,225
Leon River Above Leon Reservoir	1224A	312
South Fork Leon River	1224C	8,155

* Impaired waterbody

Figure 5-7 shows the spatial distribution of potential loading from dogs in the Proctor Lake watershed. Potential loading for bacteria from dogs is generally evenly distributed across the watershed. However, as expected, the more urbanized subwatersheds of North Fork Leon River (subwatershed 33), City of De Leon – Leon River (subwatershed 21), and the Nanny Branch-Copperas Creek (subwatershed 7) that encompass the cities of Eastland, De Leon, and the Rising Star respectively experience potentially higher bacterial loads from pets.

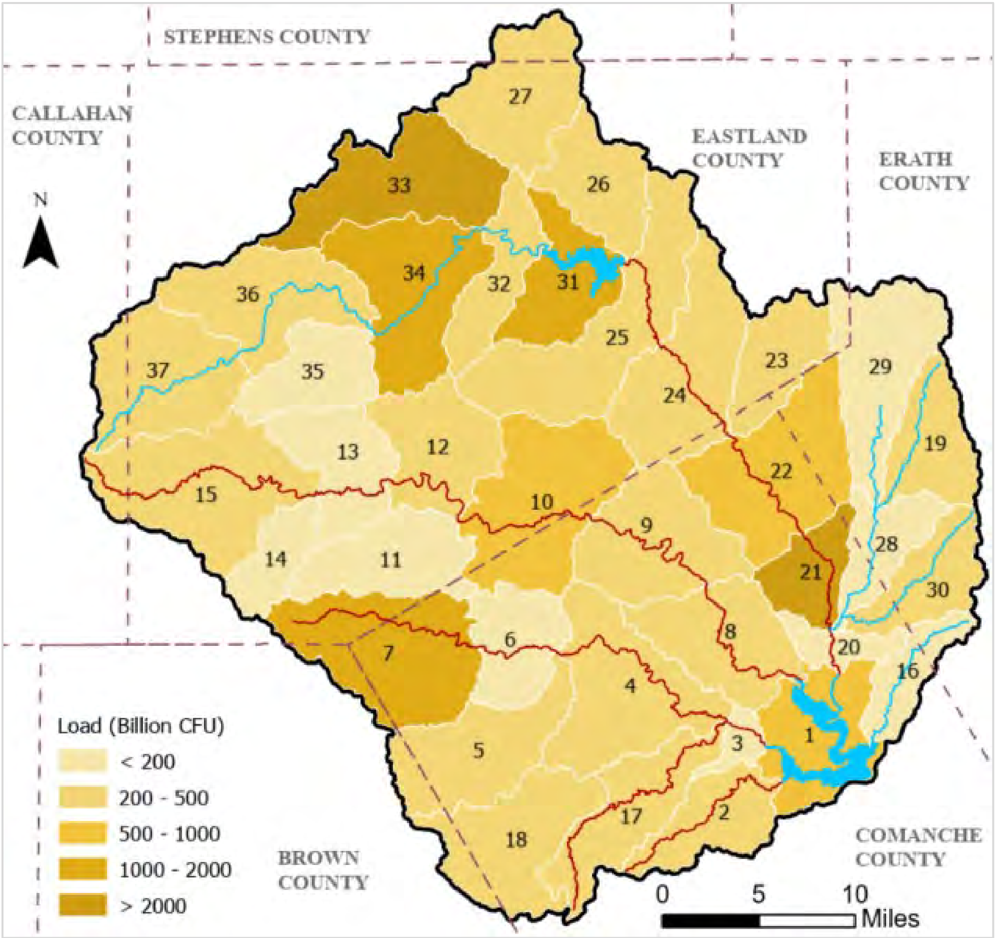


Figure 5-7. Estimated load contribution from pets.

5.4 Summary

Results of the LDC analysis show that the contact recreation water quality criterion for *E. coli* bacteria is generally exceeded by a greater margin during high flow conditions than during other flow conditions. The fact that bacteria geomeans for impaired waterbodies were generally above the water quality criterion during high flow conditions indicates that sources contributing to bacteria loads may be primarily NPS. This is because high flow conditions, such as during or shortly after rainfall, can cause runoff from various diffuse sources across the landscape. This runoff can carry bacteria and other pollutants into waterbodies. Compared to NPS, point sources and direct deposition become more pronounced during low flow because their discharges remain relatively constant, whereas the contribution of NPS sources decrease due to reduced runoff.

Among all analyzed pollutant sources, livestock, particularly cattle and sheep, appeared to be the most significant potential contributor of *E. coli* loading (Figure 5-8). Conversely, WWTFs appeared to have the least potential of contributing to *E. coli* loading. Because a substantial number of livestock in the watershed are managed in CAFOs and were not considered in spatial loading analysis, the total potential load contribution from cattle may be larger than estimated. The Rush-Copperas Creek, Sabana River, Leon River Below Leon Reservoir, and Sweetwater Creek (all impaired) watersheds potentially receive the most bacteria loads into their waters (Figure 5-9).

Combined, these findings provide useful information that can inform potential efforts to develop watershed-based plans to restore water quality. Information provided can aid in understanding watershed conditions and identify priorities for future management recommendations. It should be noted that data presented here are from readily available county, state, or national level sources. No vetting of these numbers has been conducted at the local level.

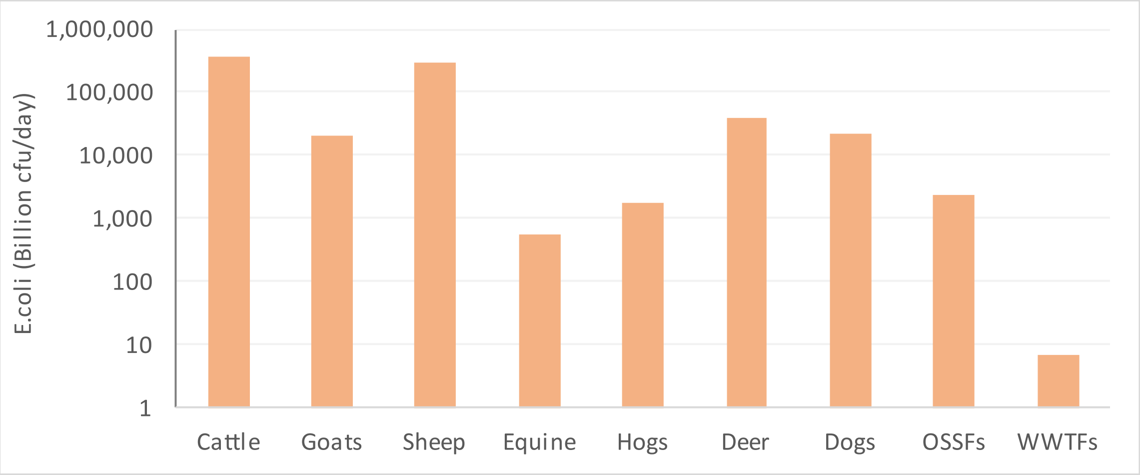


Figure 5-8. Estimated total daily *E. coli* load contribution from potential sources.

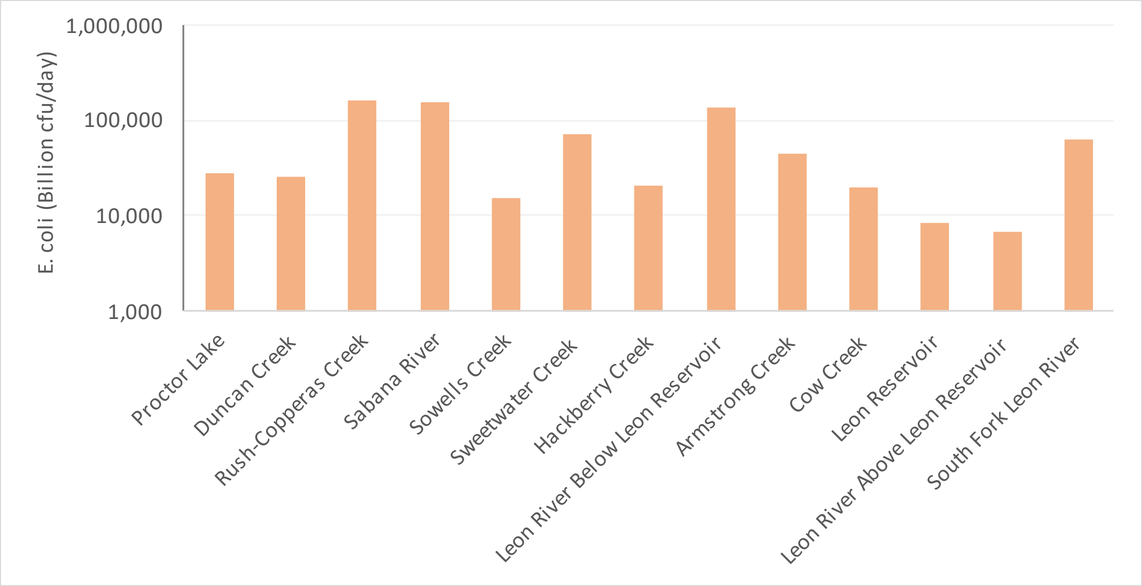


Figure 5-9. Estimated daily *E. coli* daily load from each segment watershed.

References

American Veterinary Medical Association, 2022. American Veterinary Medical Association U.S. Pet Ownership Statistics. https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics

Asquith, W.H., Roussel, M.C., and Vrabel, Joseph, 2006. Statewide analysis of the drainage-area ratio method for 34 streamflow percentile ranges in Texas: U.S. Geological Survey Scientific Investigations Report 2006–5286, 34 p. https://pubs.usgs.gov/sir/2006/5286/

Bigelow, D.P., and Borchers, A., 2017. Major uses of land in the United States, 2012. U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/publications/pub-details/?pubid=84879

Borel, K., Karthikeyan, R., Berthold, A. T., Wagner, K., 2015. Estimating *E. coli* and Enterococcus loads in a coastal Texas watershed. Texas Water Journal. 6 (1):33-44. https://doi.org/10.21423/twj.v6i1.7008.

Dewitz, J., 2023. National Land Cover Database (NLCD) 2021 Products: U.S. Geological Survey data release [Dataset]. https://doi.org/10.5066/P9JZ7AO3

Griffith, G., Bryce, S., Omernik, J., & Rogers, A. 2007. Ecoregions of Texas. Texas Commission on Environmental Quality. http://ecologicalregions.info/htm/pubs/TXeco_Jan08_v8_Cmprsd.pdf

Kikoyo, D., Oker, T., 2023. Comparative Evaluation of the Performance of SWAT, SWAT+, and APEX Models in Simulating Edge of Field Hydrological Processes. Open Journal of Modelling and Simulation. Scientific Research Publishing. 11, 37-49. https://doi.org/10.4236/ojmsi.2023.112003

Larkin, T.J. and Bomar, G.W., 1983. Climatic Atlas of Texas: Texas Water Development Board Limited Publication 192. https://www.twdb.texas.gov/publications/reports/limited_printing/doc/LP192.pdf

National Weather Service, 2023. NOWData – NOAA Online Weather Data. https://www.weather.gov/wrh/climate

Reed, Stowe, and Yanke, LLC., 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas.

https://www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/StudyToDetermine.pdf

Searcy, J.K., 1959. Flow-duration curves (No. 1542). US Government Printing Office. https://pubs.usgs.gov/wsp/1542a/report.pdf

Soil Survey Staff, 2022. Web Soil Survey. Available online at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Texas A&M AgriLife Extension Service, 2012. Feral Hog Population Growth, Density, and Harvest in Texas. SP-472. College Station. https://wildpigs.nri.tamu.edu/media/1155/sp- 472-feral-hog-population-growth-density-and-harvest-in-texas-edited.pdf.

Texas Commission on Environmental Quality (TCEQ), 2022a. 2022 Texas Integrated Report of Surface Water Quality. https://www.tceq.texas.gov/waterquality/assessment/22twqi

TCEQ. 2022b, 2022 Texas Surface Water Quality Standards. https://www.tceq.texas.gov/waterquality/standards

TCEQ. 2022c, Brazos River Basin Recreational Use-Attainability Analysis, Part 2. https://www.tceq.texas.gov/waterquality/standards/ruaas/ruaasbrazos

Texas Parks and Wildlife Department, 2020. Statewide white-tailed deer density data request (pdf files). Personal communication received January 01, 2023.

Texas Water Development Board (TWDB), 2011. Aquifers of Texas. https://www.twdb.texas.gov/groundwater/aquifer/majors/trinity.asp

TWDB, 2021. Regional Water Plan County Population Projections. https://www3.twdb.texas.gov/apps/reports/Projections/2022%20Reports/pop_county

TWDB, 2023. Groundwater Conservation Districts. https://www.twdb.texas.gov/groundwater/conservation_districts/index.asp

United States Census Bureau (USCB), 2020a. 2020 TIGER/Line Shapefiles. https://www.census.gov/geographies/mapping-files.html

USCB, 2020b. Decennial Census of Population and Housing Data. https://data.census.gov/

United States Department of Agriculture, 2022. Census of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2022/index.php

U.S. Geological Survey (USGS), 2023a. 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection: U.S. Geological Survey. Available online. https://www.sciencebase.gov/catalog/item/4f70aa9fe4b058caae3f8de5

USGS 2023b. National Water Information System: Web interface (database). Available online. https://waterdata.usgs.gov/nwis

U.S. Environmental Protection Agency (EPA), 2001. Protocol for Developing Pathogen TMDLs: Source Assessment. 1st Edition. Washington, DC: U.S. Environmental Protection Agency. EPA 841-R-00-002. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2005107536.xhtml

EPA, 2008. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. https://www.epa.gov/nps/handbook-developing-watershed-plans-restore-and-protect-our-waters

EPA, 2012. Identifying and Protecting Healthy Watersheds. https://www.epa.gov/sites/default/files/2015-10/documents/hwi-watersheds-complete.pdf

EPA, 2023. Ecoregions of North America [Dataset]. Available online. https://www.epa.gov/eco-research/ecoregions-north-america

Wagner, K. L. and Moench, E., 2009. Education Program for Improved Water Quality in Copano Bay. Task Two Report. College Station, TX: Texas Water Resources Institute. TR-347. https://oaktrust.library.tamu.edu/handle/1969.1/93181.

Ziegeweid, J.R., Lorenz, D.L., Sanocki, C.A. and Czuba, C.R., 2015. Methods for estimating flow-duration curve and low-flow frequency statistics for ungaged locations on small streams in Minnesota (No. 2015-5170). US Geological Survey. https://doi.org/10.3133/sir20155170

Appendix A– Flow Duration Curves

Flow duration curves (FDCs) are used for many purposes in which the analyses of the frequency of flows of various magnitudes are required. Their use is widespread in hydrology, water resources research, water quality analysis, and hydraulic engineering. FDCs show the percent of time specified discharges are equalled or exceeded during a given period, and can be constructed from daily, weekly, or monthly flow records. However, they are highly dependent upon the temporal references chosen for the analysis. When FDCs are constructed from flows averaged over an extended period (e.g., mean monthly flows), the resulting FDC will be flatter due to averaging of short-term peaks with intervening smaller flows. Searcy (1959) and Vogel and Fennessey (1995) note that records of daily discharges are the most applicable for flow duration analyses. Additionally, the longer the period of observation on which FDCs rely, the better the reliability of statistical information gathered from them. For example, if only records collected in one year are used, extreme climatic conditions (e.g., significantly wetter, or drier conditions) in other years may not be captured by the FDC. Consequently, for most studies, the availability of long-term historical daily streamflow data is a prerequisite for FDC construction. About 10 years of record of daily flows is recommended for FDC construction (Searcy, 1959).

A.1 Construction of flow duration curves at gaged sites

Streamflow monitoring records greater than 10 years exist at USGS gages 08099100 and 08099300 and 8 years of data are available at USGS gage 08099382. These records are considered sufficient for the development of FDCs at these sites. Continuous daily streamflow data collected at USGS gages 08099100 (2009-2023), 08099300 (2004-2023), and 08099382 (2016-2023) were used for FDC construction.

FDC graphs were developed by plotting compiled daily flow vs the percentage of the time that a particular flow was equaled or exceeded. The procedure involves constructing FDCs from ordered observations of daily streamflow. The ordered observations are then plotted against their corresponding plotting positions P given as:

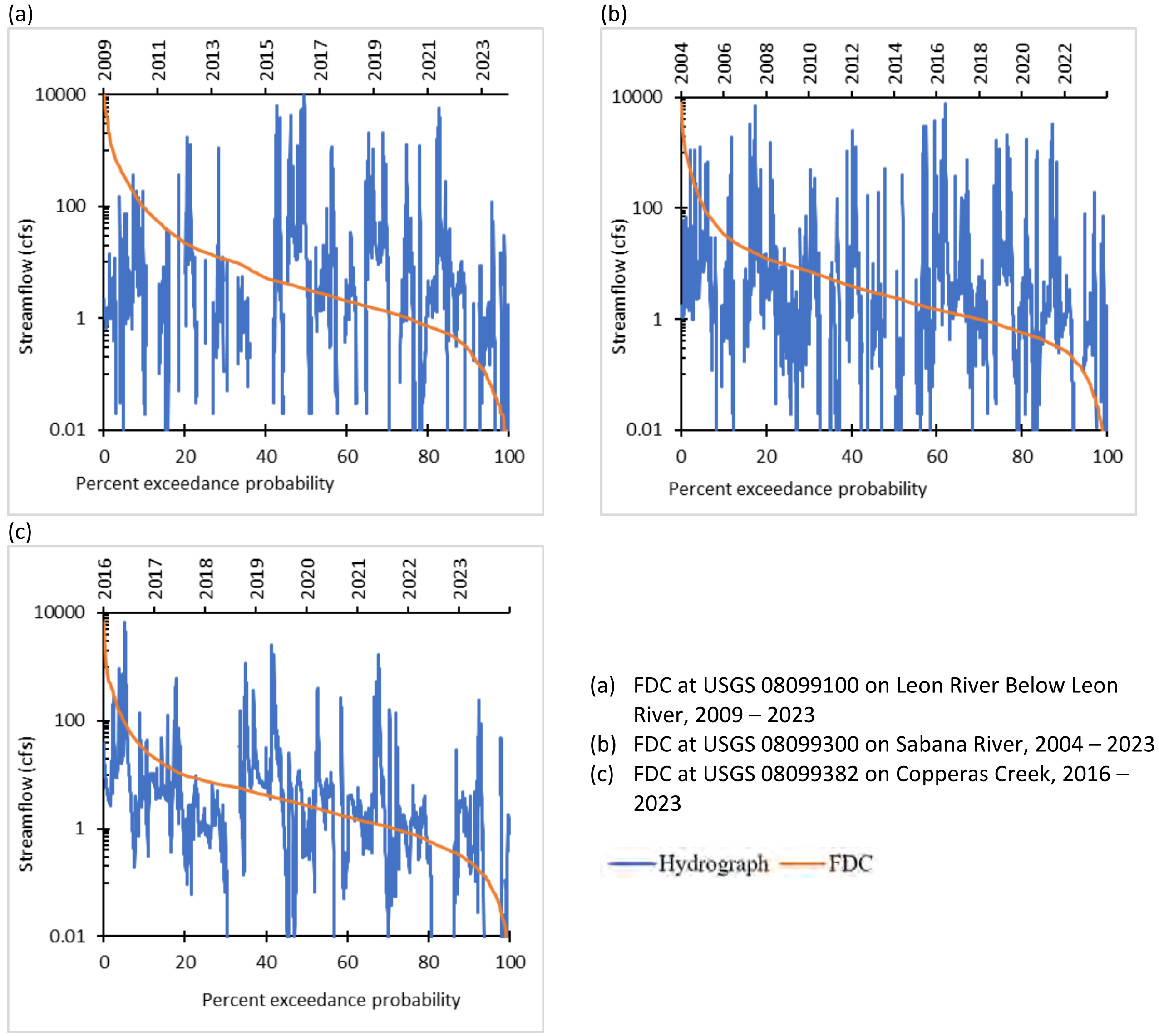
$$P = 100\left(\frac{m}{n+1}\right)$$

where;

P is the exceedance probability,

m is the ranking, from highest to lowest, of all daily mean flows for the specified period of record, and *n* is the total number of daily mean flows.

Figure A-1 shows plots of FDCs and streamflow hydrographs at gaged sites in the watershed.



(a) FDC at USGS 08099100 on Leon River Below Leon River, 2009 – 2023
(b) FDC at USGS 08099300 on Sabana River, 2004 – 2023
(c) FDC at USGS 08099382 on Copperas Creek, 2016 – 2023

Figure A- 1. Flow duration curves at gaged sites in the Proctor Lake watershed.

A.2 Methodology for estimation of flow duration curves at ungaged sites

FDCs at sites with no or inadequate streamflow data can be estimated using a variety of techniques. These include the drainage area ratio (DAR) method, the use of regional regression models, and models developed from rainfall-runoff relationships (Asquith et al., 2006; Ziegeweid et al., 2015). Generally, because of the simplicity and ease associated with the use of the DAR method, where practical, the DAR approach is preferred for deriving FDCs.

A.2.1 The Drainage Area Ratio Method.

The DAR method estimates flow and/or FDCs at a location of interest by multiplying the measured flow at the nearby reference gage by the area ratio of the ungaged to gaged watersheds.

$$Q_T = Q_D \left(\frac{A_T}{A_D}\right)$$

Where;

Q_T is streamflow for the ungaged (target) location,

Q_D is streamflow at a gaged (donor) station, and

A_T and A_D are the drainage areas for the ungaged location and the donor station, respectively.

A major assumption of the area ratio method is that flow scales directly with the watershed area. That is, as watershed area increases, flow rate increases at some fixed rate per unit area. This means that the flow per unit area is expected to be the same at both the ungaged location and gaged reference location.

A.2.2 Flow Naturalization

Diversion of surface water from a stream reduces the amount of water available at downstream sites. Conversely, discharges such as those from wastewater treatment facilities can increase the amount of water available at downstream sites. Significant water diversions and discharges must be considered when deriving FDCs.

Historical stream gage data were adjusted where applicable if authorized diversions and return flows greater than 1 million gallons per day (MGD), equivalent to 1120 acre-feet/year were identified upstream of monitoring sites. The update to the water availability model input files report for the Brazos River Basin available on TCEQ's website[19] used similar adjustment criteria when selecting diversions/ return flows to consider when deriving naturalized flows in the basin.

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[19] Water Availability Models. https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html

Information on the location of water rights points/diversions is available through the Texas Water Rights Viewer[20]. Additional water rights and water use data including water rights ownership, and the amount of water authorized for active water rights are available on TCEQ's water rights permitting webpage[21]. Discharge points (outfalls) and NPDES permit records can be accessed using TCEQ's Wastewater Outfalls Viewer[22] and Central Registry query tool[23] respectively.

As of December 2023, there are only three surface water rights permits within the Proctor Lake watershed authorized to divert more than 1 MGD (Figure 4-1). The authorized diversion on Proctor Lake is downstream of all streamflow monitoring sites in the watershed. There are no large diversions upstream of USGS 08099300 and USGS 08099382. The rest of the diversion intakes are upstream of USGS 08099100.

As of December 2023, there are no facilities with TPDES permits operating within the Proctor Lake watershed with the authorized daily average flow of effluent exceeding 1 MGD.

Because USGS 08099300 does not have large diversions, discharges, and upstream reservoirs, no adjustments were made to its FDC. This gage was identified as the donor station for estimating FDCs at ungaged sites because it has the longest record of continuous daily data, has no large upstream reservoirs, in addition to having no major upstream diversions and discharges.

A.2.3 Performance of the Drainage Area Ratio Method in Estimating FDCs in the Watershed.

The applicability of the DAR method for estimating flows in the watershed was evaluated by comparing the observed FDC at 08099382 (target site) and the DAR method derived FDC at the same site, generated using flows at USGS 08099300 (Donor site).

FDCs at USGS gages 08099300 and 08099382 were constructed using daily flow data recorded from 2016 through 2023. During this period, all gages have records of continuous streamflow data. Streamflow data at the donor site was then used to estimate flows and the FDC at the target site using

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[20] Water Rights Viewer. https://www.tceq.texas.gov/gis/water-rights-viewer

[21] Water Rights: Permits. https://www.tceq.texas.gov/permitting/water_rights/wr-permitting

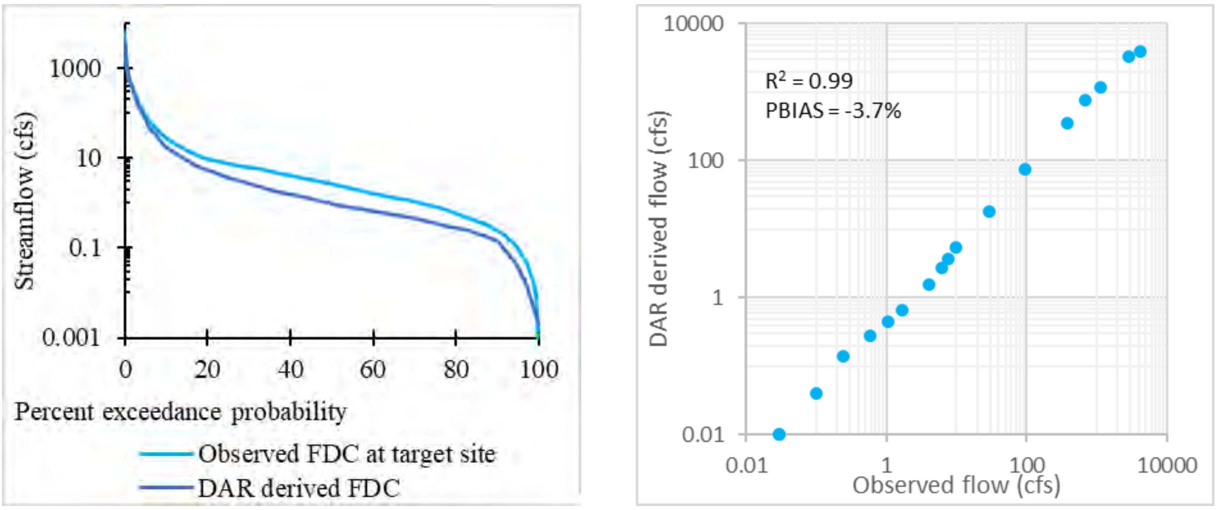
[22] Wastewater Outfalls Viewer. https://www.tceq.texas.gov/gis/wastewater-outfalls-viewer

[23] Central Registry. https://www.tceq.texas.gov/permitting/central_registry

the DAR method. The estimated FDC was compared with the observed FDC to establish the accuracy of the DAR method using goodness of fit measures.

The goodness of FDC prediction by the DAR method was evaluated using measures that show how well the observed FDC is replicated by estimated FDC, and how the observed FDC values are far from the estimated FDC values. This involved calculating the coefficient of determination (R^2) and the percent bias (PBIAS). These measures are widely used in the field of hydrology and performance evaluation and have been employed in various studies (Kikoyo and Oker, 2023).

The relationship between the observed and estimated FDCs at USGS 08099382 is illustrated in Figure A-2. The FDCs show strong similarities between the observed and DAR-derived FDC, indicating that the drainage area ratio method provides an adequate visual fit to the shapes and slopes of empirical FDCs in the watershed. Computed goodness of fit metrics (R^2 = 0.99, PBIAS = -3.7%) were all close to optimal values. The near-optimal metrics further demonstrate that the DAR method approximates well actual FDCs in the watershed.


(a) Observed and Drainage Area Ratio (DAR) derrived flow duration curves.

(b) Plot of observed versus DAR derrived streamflows

Figure A- 2. Comparison of observed and estimated flows at USGS 08099382 from 2016 through 2023.

A.2.4 Flow duration curves at ungaged sites

Flows and FDCs at other water quality monitoring sites that do not have records of continuous streamflow data and are located on impaired waterbodies (Sweetwater Creek and Duncan Creek) were estimated using the DAR method. The FDCs were estimated using streamflow recorded at USGS 08099300 from January 2004 through December 2023 and are shown in Figure A-3.

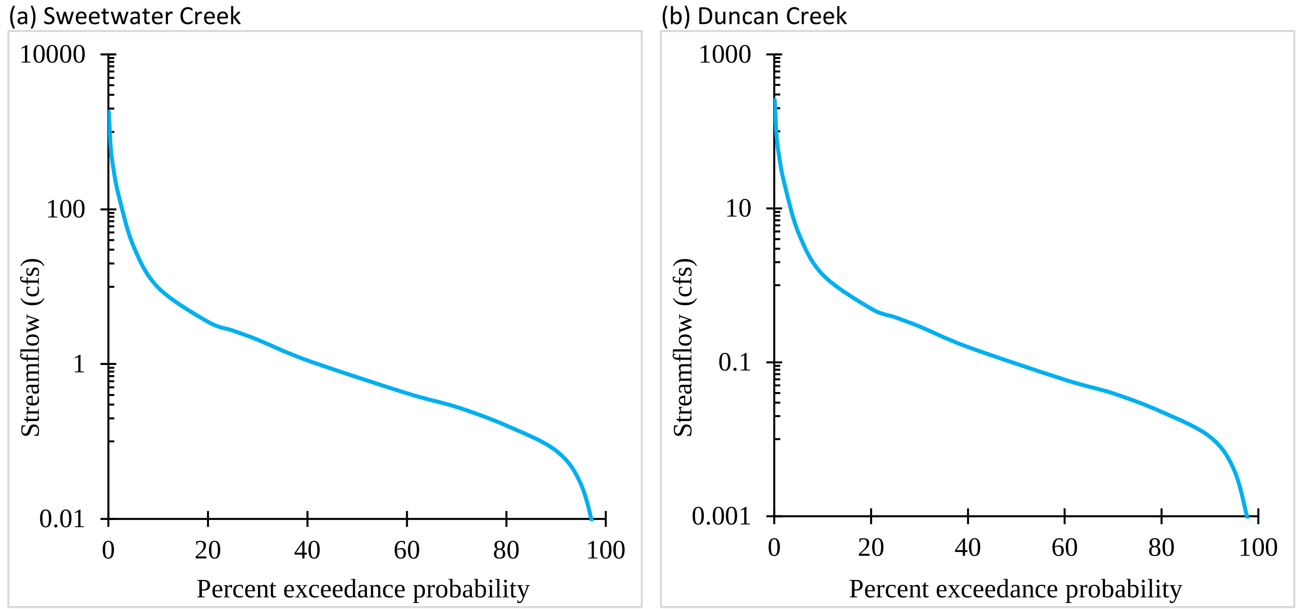


Figure A- 3. Flow duration curves at monitoring station 17541 on Sweetwater Creek and 17544 on Duncan Creek.

Appendix B– Load Duration Curves and Load Analysis

B.1 Load Duration Curves

The LDC approach is a simple method for visualizing and characterizing water quality concentrations at different flow regimes. The LDC approach is most appropriate in water bodies where there is some type of correlation between flow condition and concentration (typically rivers and streams where loading is tied to runoff and there are not strong accumulation processes).

The LDC is developed by constructing an FDC first, using historical streamflow data. The FDC is converted to an LDC by converting each streamflow value to an allowable bacteria load at the given streamflow value. Plotting the allowable load against the percent of days flow exceeded (now percent of days load exceeded) results in a LDC that indicates the allowable load at each exceedance percentile.

LDCs for bacteria were developed from the first available data collected at each station through December 2023 for impaired waterbodies. The following equation was used to estimate allowable bacteria loads in the watershed:

$$Load_p = Q_p \times E_c \times C_f$$

Where:

$Load_p$ = Allowable bacteria load (in units of billion cfu/day) at exceedance percentile p

Q_p = mean daily streamflow (in units of cfs) at exceedance percentile p

E_C = Geometric mean criterion (in units of cfu/mL, e.g. 1.26 cfu/mL for PCR1 category waterbodies)

C_f = Conversion factor; cfs to mL/day = 2.446×10^9

Instream *E. coli* measurements are also converted to daily loads by multiplying the concentration and appropriate conversion factors by the estimated mean daily streamflow on the day of the sample. The loads may then be overlaid on the LDC.

The LDC (and FDC) may further be refined by dividing the curve into flow regimes regions. In this report. the LDC (and FDC) loads (and flows) with exceedance probabilities less than 20% are classified as high flows, and those greater than 80% as low flows in this report. The geometric mean of bacteria loads within each flow regime is added to each LDC to indicate if the average bacteria load within each flow regime is above or below the LDC (geometric mean criteria).

Figure B-1 illustrates the LDC for Duncan Creek at Station 17544. It includes both the measured daily loads (blue dots), the calculated load corresponding to bacteria geomean criterion of 630 cfu/100 mL (blue curve), and calculated geomean loads for high, moderate, and low flow categories (red diamonds). The LDC provides an overview of the waterbody's load capacity under varying flow conditions.

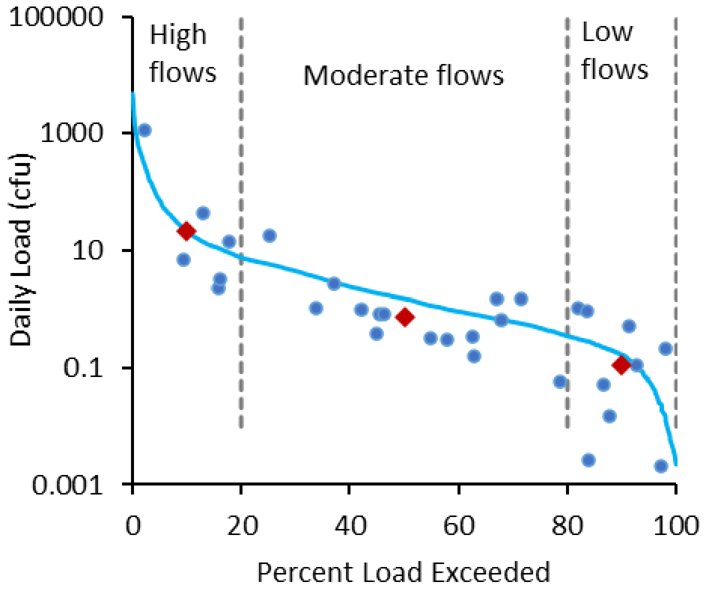


Figure B- 1. Load Duration Curve for Duncan Creek at Station 17544

B.2 Load Reduction

Total and percent bacteria load reductions can be calculated from the LDC. Within each flow regime, the difference between the geometric mean load and the allowable load at the median flow value represents the load reduction required (see equation LL_{FC} below). The following equations were used to estimate bacteria load reductions in the watershed:

$$EL_{FC} = Q_{FC} \times E_{FC} \times C_f$$

$$AL_{FC} = Q_{FC} \times A_{FC} \times C_f$$

$$LL_{FC} = \frac{EL_{FC} - AL_{FC}}{EL_{FC}}$$

Where:

EL_{FC} = Existing load at the median flow for flow category (cfu/day)

Q_{FC} = Median flow for flow category (cfs)

E_{FC} = Geometric mean of bacteria samples for flow category (cfu/ mL)

C_f = Conversion factor; cfs to mL/day = 2.446×10^9

AL_{FC} = Allowable load at the median flow frequency for flow category

A_{FC} = Geometric mean criterion

LL_{FC} = Percent load reduction for the flow category

B.3 Pollutant Source Loading Equations

The following equations were used to estimate daily bacteria loads attributed to potential bacteria sources in the watershed.

Table B- 1. Equations used for calculating bacteria load estimates from potential sources.

Potential source	Equation	Description of terms
Livestock	$L_{ls} = N_{ls} \times AnU_{ls} \times FC_{ls} \times E_f$	L_{ls} = Potential load of *E. coli* attributed to livestock (e.g., cattle) waste (in units of cfu per day) N_{ls} = Estimated number of livestock in the watershed AnU_{ls} = Animal unit (AnU) conversion factor (Table B-2, Wagner & Moench 2009) FC_{ls} = Assumed fecal coliform production rate (Table B-2 Wagner & Moench 2009) E_f = Conversion rate from fecal coliform to E. coli; 0.63 (Wagner & Moench 2009)
Deer and Feral Hogs	$L_{wl} = N_{wl} \times AnU_{wl} \times FC_{wl} \times E_f$	L_{wl} = Potential load of *E. coli* attributed to deer and feral hog waste (in units of cfu per day) N_{wl} = Estimated number of deer and feral hogs in the watershed AnU_{wl} = AnU conversion factor (Table B-2; Wagner & Moench, 2009) FC_{wl} = Assumed fecal coliform production rate (Table B-2; Wagner & Moench, 2009) E_f = Conversion rate from fecal coliform to E. coli; 0.63 (Wagner & Moench, 2009)
Pets	$L_{dog} = N_{dog} \times FC_{dog} \times E_f$	L_{dog} = Potential load of *E. coli* from dog waste (in units of cfu per day) N_{dog} = Estimated number of dogs in the watershed FC_{dog} = Assumed fecal coliform production rate for dogs; 5.0×10^9 per animal per day (EPA 2001) E_f = Conversion rate from fecal coliform to E. coli; 0.63 (Wagner & Moench, 2009)
On-site Sewage Facilities	$L_{ossf} = N_{ossf} \times N_f \times N_{hh} \times P_s \times FC_s \times E_f$	L_{ossf} = Potential load of *E. coli* attributed to failing OSSFs (in units of cfu per day) N_{ossf} = Estimated number of OSSFs in the watershed N_f = Estimated OSSF failure rate in the region; 8% (Reed, Stowe, and Yanke LLC 2001) N_{hh} = Average number of people per household P_s = Assumed sewage discharge rate; 264,979 mL per person per day (Borel et al. 2015) F_{Cs} = Fecal coliform concentration in sewage; 1.0×10^6 cfu/100 mL (EPA 2001) E_f = Conversion rate from fecal coliform to E. coli; 0.63 (Wagner & Moench 2009)
Wastewater Treatment Facilities	$L_{wwtf} = D_{wwtf} \times E_c$	L_{wwtf} = Potential load of *E. coli* attributed to WWTF (in units of cfu per day) D_{wwtf} = Maximum permitted daily discharge (in units of milliliter per day) E_c = Permitted *E. coli* concentration of effluent (in units of cfu per milliliter)

Table B- 2. Bacteria loading assumptions used for calculating load estimates from livestock and wildlife.

Assumptions	Cattle	Goats	Sheep	Equine	Feral Hogs	White-tailed Deer
Animal unit conversion factor (AnU)	1	0.17	0.2	1.25	0.125	0.112
Fecal coliform production rate (Billion cfu/AnU-day)	8.55	25.4	290	0.291	1.21	15