Brushy Creek Characterization Report

Brushy Creek. Photo by Cameron Castilaw

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Prepared for the Texas Commission on Environmental Quality

TCEQ Project #582-23-40237

Project period ending August 31, 2025

The Texas Commission on Environmental Quality is supporting the Brushy Creek Watershed Characterization Project with funding provided by the U.S. Environmental Protection Agency through the Nonpoint Source Clean Water Act Section 319(h)

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Abbreviations/Acronyms

µg	microgram
amsl	above mean sea level
AU	Assessment Unit
AnU	Animal Unit
AVMA	American Veterinary Medical Association
BMP	Best Management Practices
CAFO	Concentrated Animal Feeding Operation
cfs	cubic feet per second
cfu	colony forming unit
CGP	Construction General Permit
DAR	Drainage Area Ratio
DEM	Digital Elevation Model
DMU	Deer Management Unit
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
ECHO	Enforcement and Compliance History Online
EF	Enhanced Fujita
ETJ	Extra-Territorial Jurisdiction
EPA	U.S. Environmental Protection Agency
FDC	Flow Duration Curve
GIS	Geographic Information System
HGS	Hydrologic Soil Group
LDC	Load Duration Curve
MCM	Minimum Control Measures
mL	milliliter
mg	milligram
MS4	Municipal Separate Storm Sewer Systems
MSGP	Multi-Sector General Permit
MRLC	Multi-Resolution Land Characteristics Consortium
MPN	Most Probable Number
MUD	Municipal Utility District
NASS	National Agricultural Statistics Service
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
NRCS	Natural Resources Conservation Service
OSSF	On-Site Sewage Facility
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SSO	Sanitary Sewer Overflow
SSURGO	Soil Survey Geographic Database
SWCD	Soil and Water Conservation District
SWMP	Stormwater Management Program
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality

TDS	Total Dissolved Solids
Texas Integrated Report	Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)
TSSWCB	Texas State Soil and Water Conservation Board
TSWQ	Texas Surface Water Quality Standards
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TWQS	Texas Water Quality Standards
TWDB	Texas Water Development Board
TPWD	Texas Parks and Wildlife Department
TWRI	Texas Water Resources Institute
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WWTF	Wastewater Treatment Facility
WWTP	Wastewater Treatment Plant

Watershed Description

The Brushy Creek watershed encompasses the entirety of Brushy Creek and its tributaries, covering an area of 331,276 acres across Milam and Williamson counties. Brushy Creek runs a total length of 68.7 miles from the confluence of South Brushy Creek to the San Gabriel River. The Texas Commission on Environmental Quality (TCEQ) has designated Brushy Creek as stream segment 1244 and has broken it and its tributaries down further into smaller assessment units (AUs) (Table 1; Figure 1; TCEQ 2024a).

These stream segments are monitored by TCEQ and assessed every two years in the Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d), hereinafter referred to as the Texas Integrated Report. In the most recent 2024 report, Brushy Creek segments 1244_01, 1244_02, and 1244_03 are designated as *Impaired* due to elevated levels of bacteria, indicated by the presence of *Escherichia coli* (*E. coli*). The impairment is based on water quality standards established for designated uses, including primary contact recreation (e.g., swimming, wading, kayaking). These same segments are also indicated to have elevated nitrate levels in the 2024 Texas Integrated Report.

Table 1. AUs in the Brushy Creek watershed

AU	Length (mi.)	Impaired	Description
1244_01	27.4	Yes	From the confluence of the San Gabriel River upstream to the confluence of Mustang Creek
1244_02	23.0	Yes	From the confluence of Mustang Creek upstream to the confluence of Cottonwood Creek
1244_03	11.9	Yes	From the confluence of Cottonwood Creek upstream to the confluence of Lake Creek
1244_04	6.3	No	From the confluence of Lake Creek upstream to the confluence of South Brushy Creek

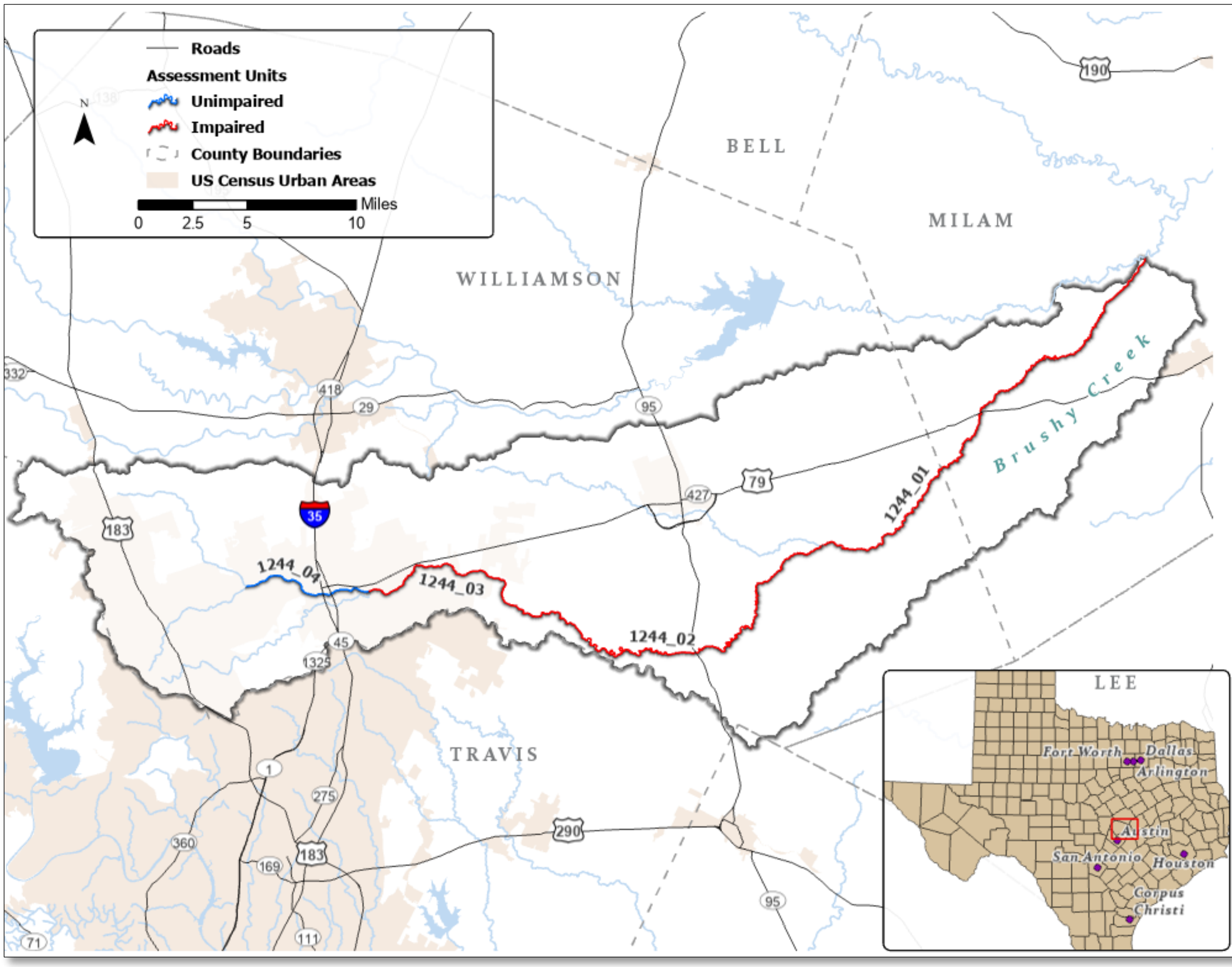

Figure 1. **Assessment units of Brushy Creek**

Topography

The topography of a watershed is not only important because it controls the direction of surface water flow, but also because of its impacts on land use that contribute to the development of the watershed over time. The elevation in the Brushy Creek watershed ranges from approximately 320 feet above mean sea level (AMSL) in the easternmost downstream section to about 1,140 feet AMSL in the westernmost portion. In Figure 2 we see how the topography drains water down from the higher elevation of the Edwards Plateau down through plains and hills of eastern Brushy Creek. This elevation data was gathered from The National Map as part of its Digital Elevation Model (DEM) collection (USGS 2024).

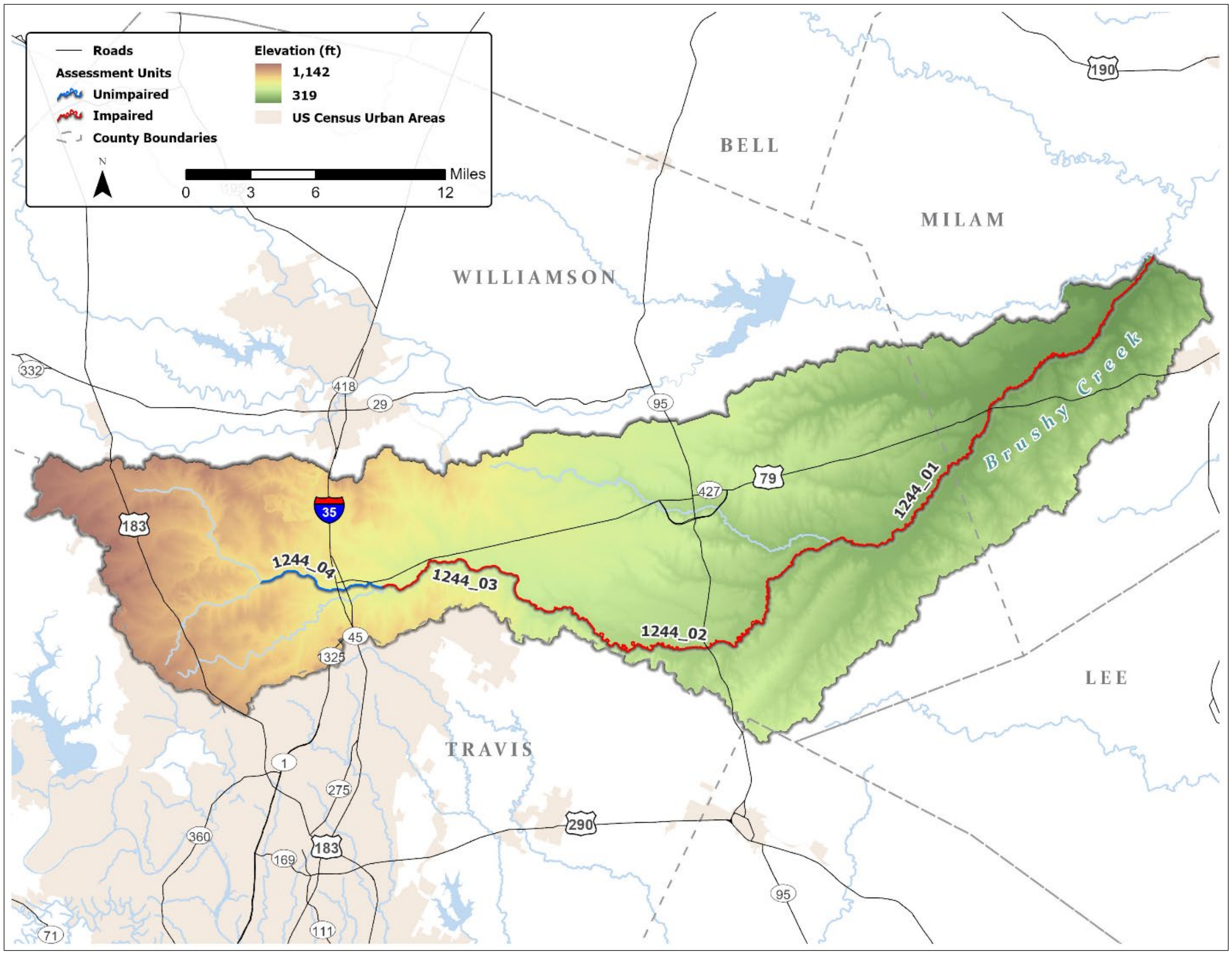

Figure 2. **Topography across the Brushy Creek watershed**

Climate

The general climate for Brushy Creek falls under a humid subtropical, with hot and humid summers and mild winters. Long-term precipitation average (1991-2020), collected from the Parameter-elevation Regressions on Independent Slopes Model (PRISM), showed that across the watershed, mean annual precipitation ranged between 34 inches and 37 inches (Figure 3; PRISM 2022). Higher precipitation occurred in the eastern half of the watershed, while less precipitation occurred westward in the higher elevation plateau. Moreover, long-term PRISM temperature data showed that the western higher elevation plateau had lower temperatures while the southern low elevation part of the watershed had higher temperatures (Figure 4).

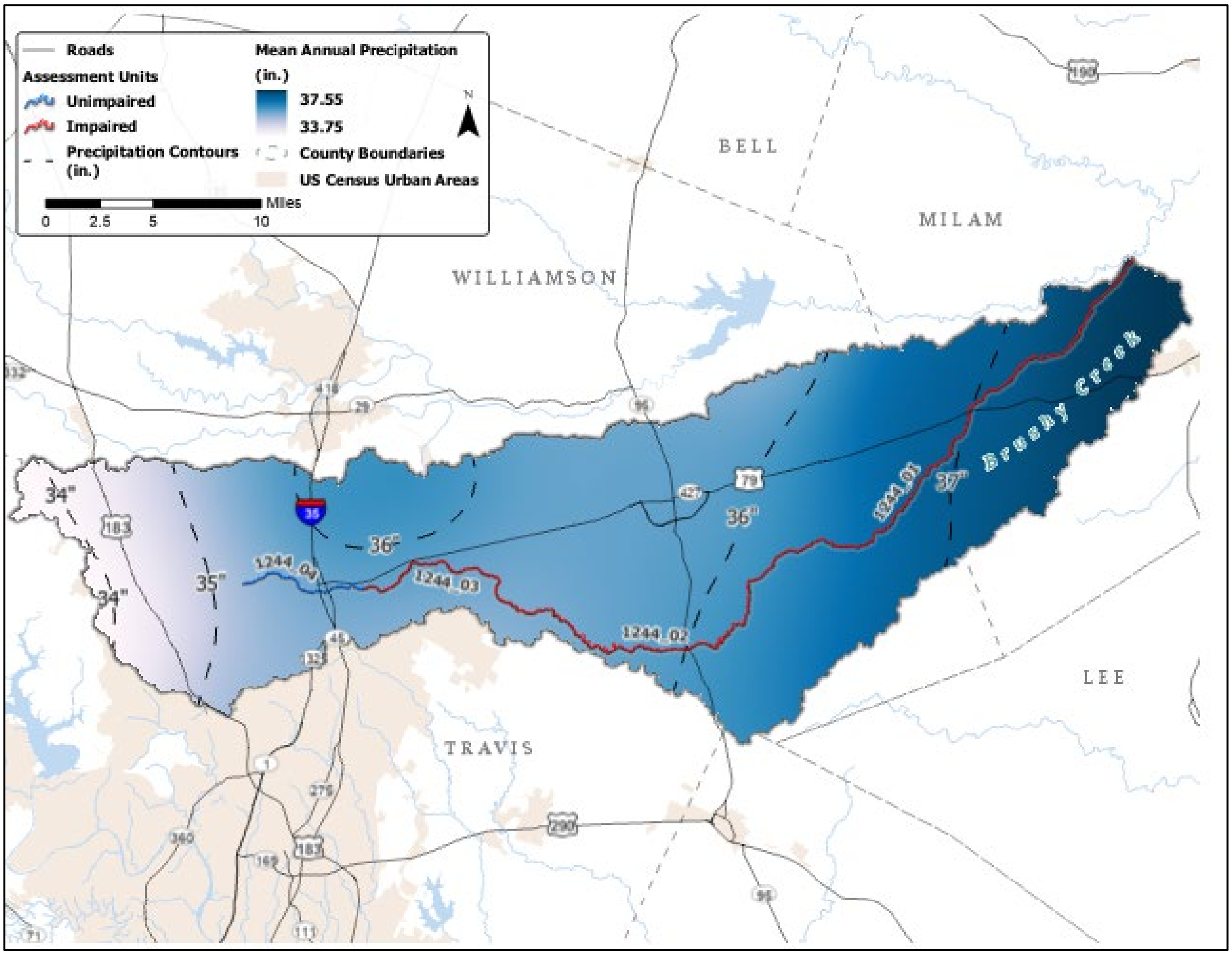

Figure 3. Average annual precipitation distribution in the watershed

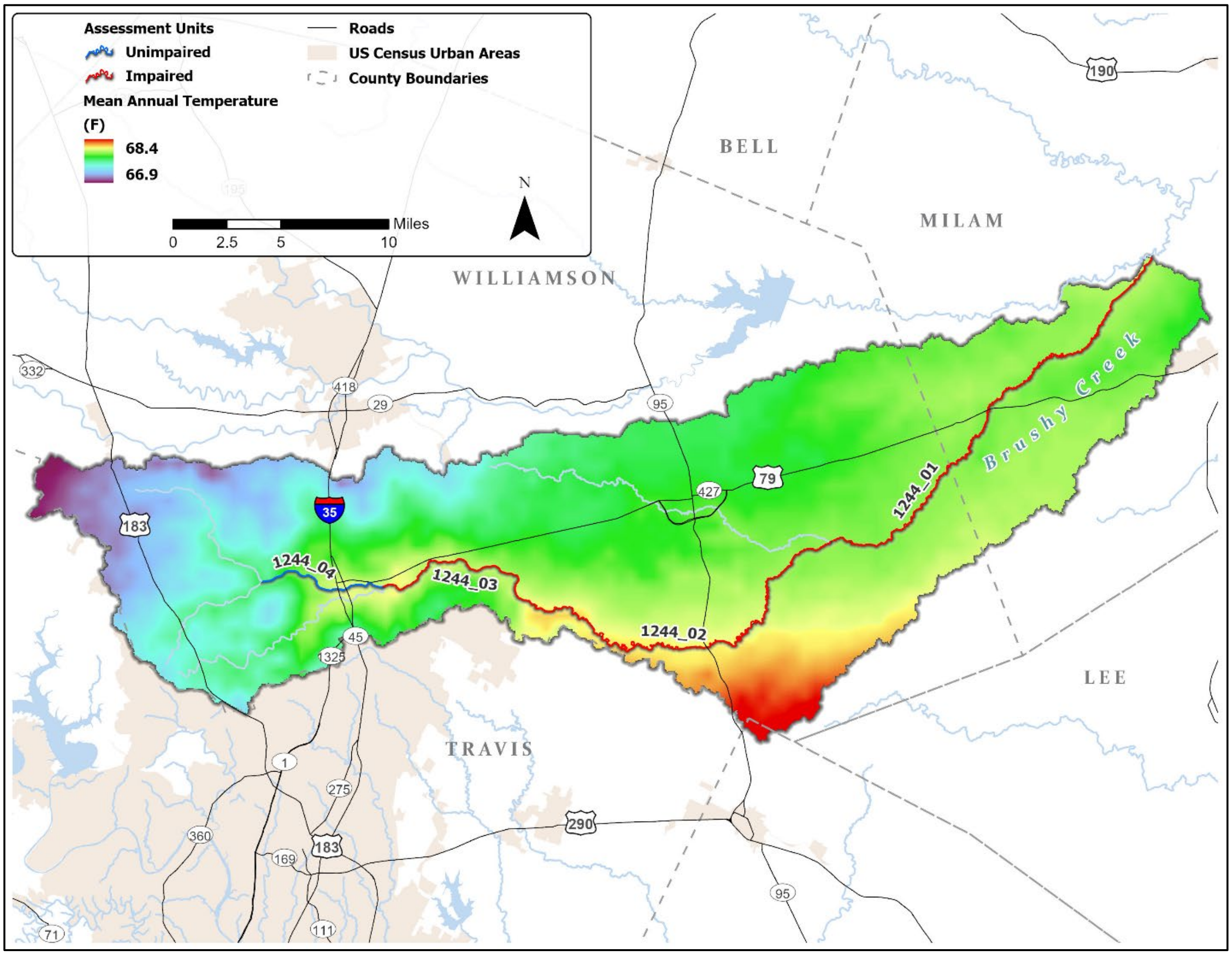

Figure 4. Mean annual temperature in the watershed

In addition to 30-year average annual precipitation, monthly precipitation and temperature data between 2003 and 2023 were retrieved from a NOAA (National Oceanic and Atmospheric Administration) weather station (USC00418862) located in the central portion of the watershed (Figure 5). These data showed that monthly total precipitation was the highest in May (4.58 inches) and the lowest in February (1.92 inches). Mean monthly temperature across the watershed was the hottest in August (high 97˚F, low 73˚F) and the coolest in January (high 61˚F, low 37˚F).

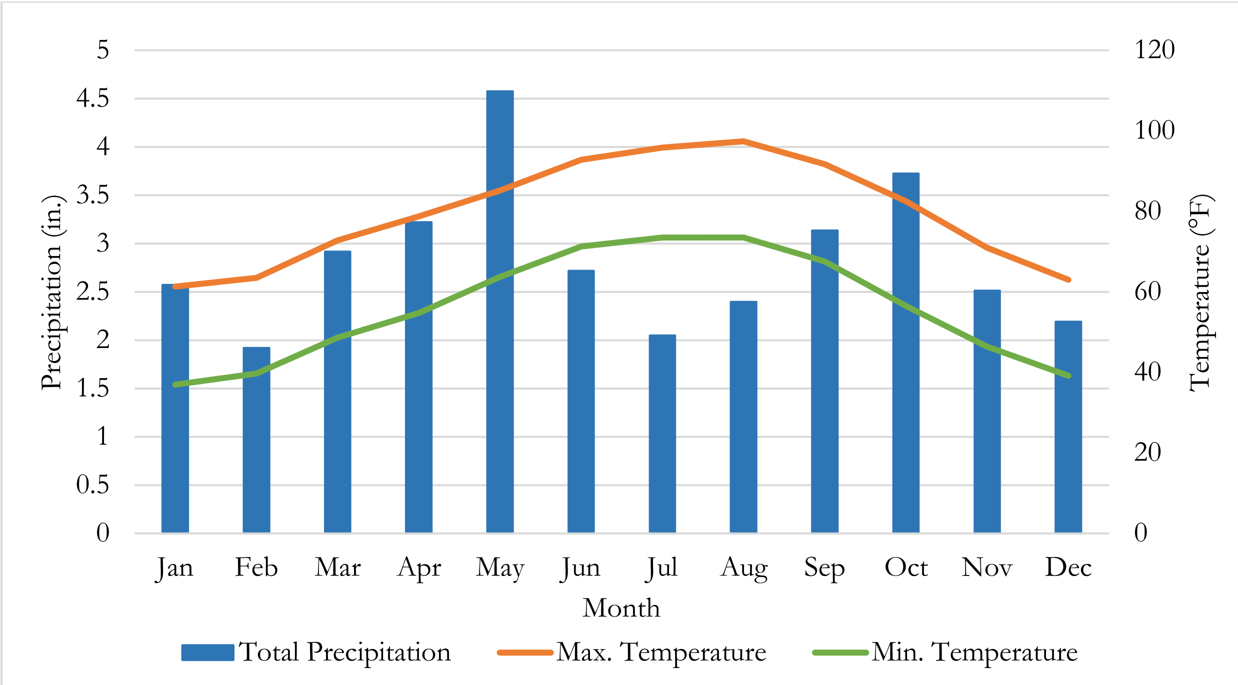

Figure 5. Mean monthly precipitation and temperature between 2003 and 2023

Brushy Creek has also experienced bouts of extreme weather. The most notable is an EF (Enhanced Fujita) – 2 tornado (wind speed between 111 mi/hr. and 135 mi/hr.) that struck near Round Rock in March 2022, causing significant damage and leaving a trail of debris across the central area of the watershed (Figure 6).

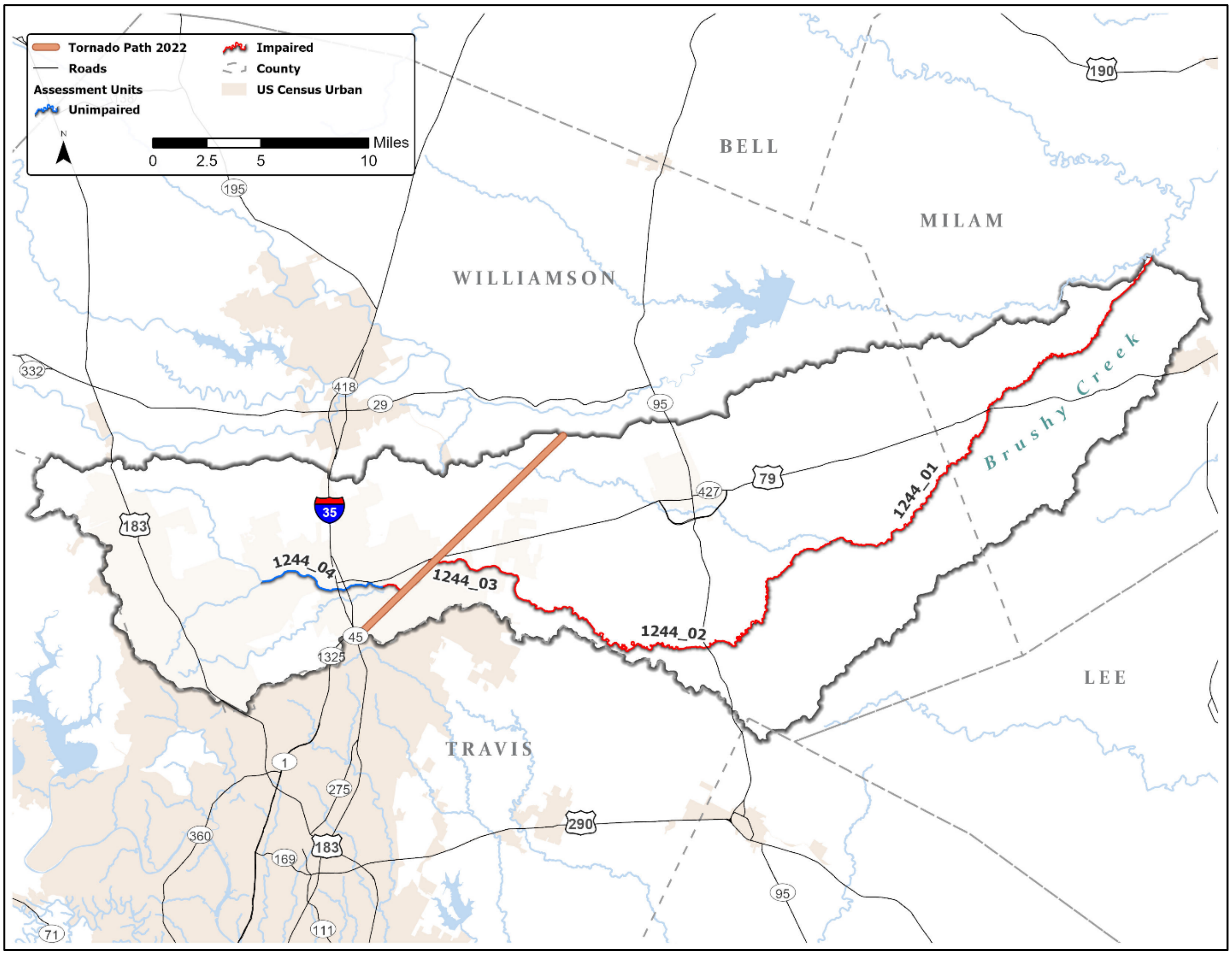

Figure 6. EF-2 tornado in March 2022.

Ecoregion

Brushy Creek is divided across three ecoregions: the East Central Plains, the Edwards Plateau, and the Blackland Prairies (Griffith et al. 2007). Figure 7 shows the distribution of ecoregions across the watershed.

The Edwards Plateau, which is seen to coincide with less precipitation, higher elevation, and land development covers the western quarter of the watershed. It is characterized by Texas hill country, where grasslands and shallow soils overlay extensive groundwater resources.

The Blackland Prairies, which make up a majority of the watershed, are known for fertile soils and rolling hills. This makes the area popular for crop production and ranching.

The East Central Plains covers a small portion of the watershed along the eastern edge and is the transitional area between forests to the east and the plains to the north and west.

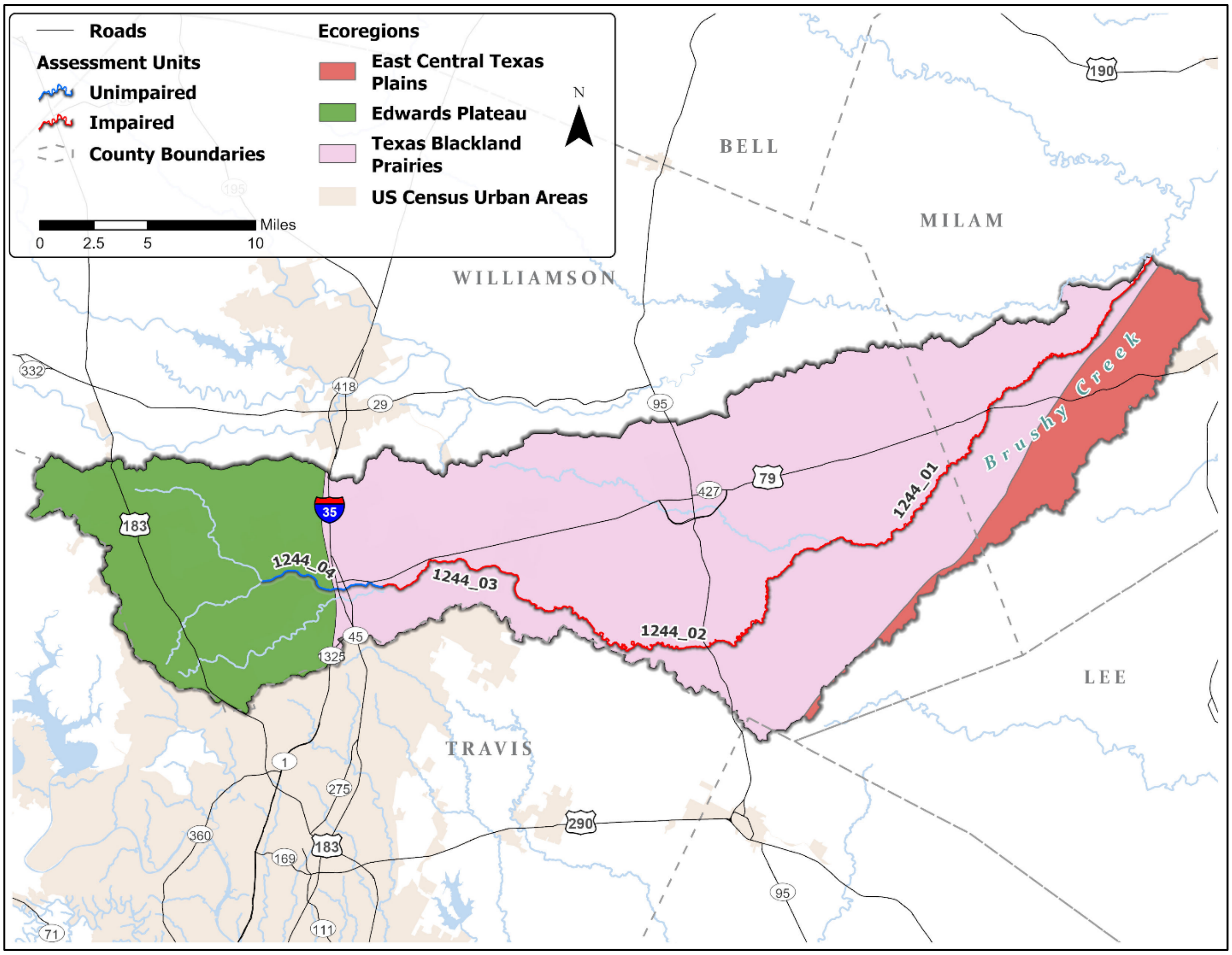

Figure 7. **Ecoregions in the Brushy Creek watershed**

Soil

Soil data were obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) (NRCS 2019). SSURGO dataset assigns different soils to one of the seven possible runoff potential classifications or hydrologic soil groups (HSGs). The SSURGO classification is based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The classes are A, B, C, D, A/D, B/D, and C/D. The "null" classification indicates areas where data is incomplete or unavailable. Four main HSGs, as well as the dual classes, are described below.

- Group A – Soils having high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
- Group B – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
- Group C – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high-water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

In large part, the soils in the Brushy Creek watershed have an HSG classification of D (85.7%) (Table 2; Figure 8).

Table 2. Hydrologic soil groups in the watershed

HSG	Acreage	Percentage of Total
A	3,462	1.0
B	12,655	3.8
C	31,467	9.5
D	285,067	85.7
Total	**332,651**	**100.0**

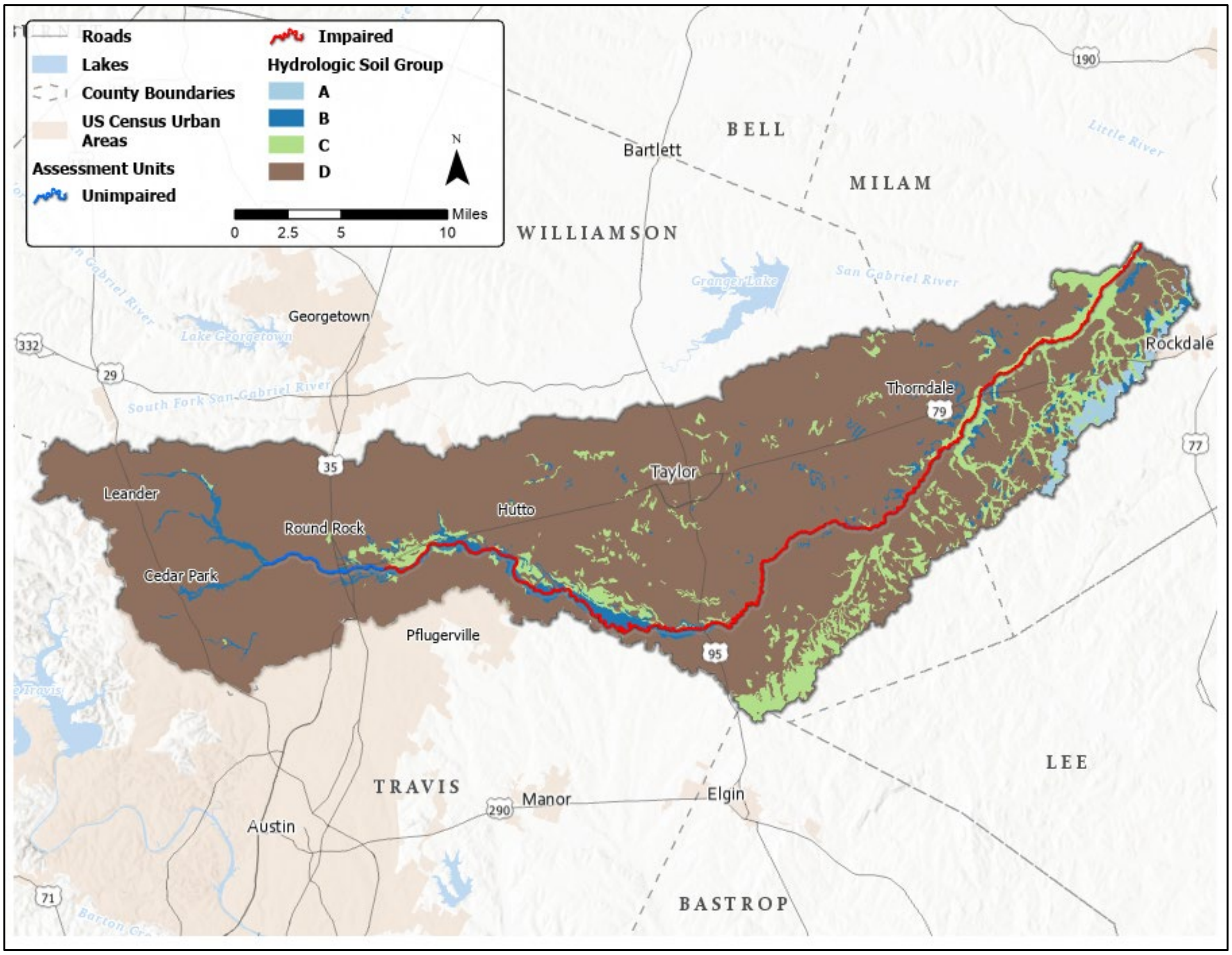

Figure 8. **Hydrologic soil groups in the Brushy Creek watershed**

Land Cover

Land cover is important to future watershed plans for multiple reasons. For example, it can show how much urban development has taken place, how much habitat is available for wildlife, or how much of the watershed is covered by surface water. Land cover data was collected from the National Land Cover Database (NLCD) in 30-meter resolution for the entire watershed (NLCD 2021). Land cover types were generally categorized into 14 classes, which are defined as the following:

- Open Water: areas of open water that are generally less than 25% vegetation or soil cover.
- Developed, Open Space: areas that have a mixture of constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. Such areas typically include large-lot single family

housing units, parks, golf courses and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

- Developed, Low Intensity: areas that consist of a mix of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas commonly include single-family housing units.
- Developed, Medium Intensity: areas that consist of a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas commonly include single-family housing units.
- Developed, High Intensity: highly developed areas where people reside or work in high numbers. Areas include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
- Barren Land: areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
- Deciduous Forest: areas generally dominated by trees greater than 5 meters tall and greater than 20% of total vegetation cover. More than 75% of tree species shed foliage simultaneously in response to seasonal change.
- Evergreen Forest: areas generally dominated by trees greater than 5 meters tall and greater than 20% total vegetation cover. More than 75% of the tree species maintain their leaves year-round. Canopy is never without green foliage.
- Mixed Forest: areas generally dominated by trees greater than 5 meters tall and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- Shrub/Scrub: areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in early successional stage or trees stunted from environmental conditions.
- Herbaceous: areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These types of areas are not subject to intensive management such as tilling but can be used for grazing.
- Pasture/Hay: areas of grass, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
- Woody Wetlands: areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- Emergent Herbaceous Wetlands: areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

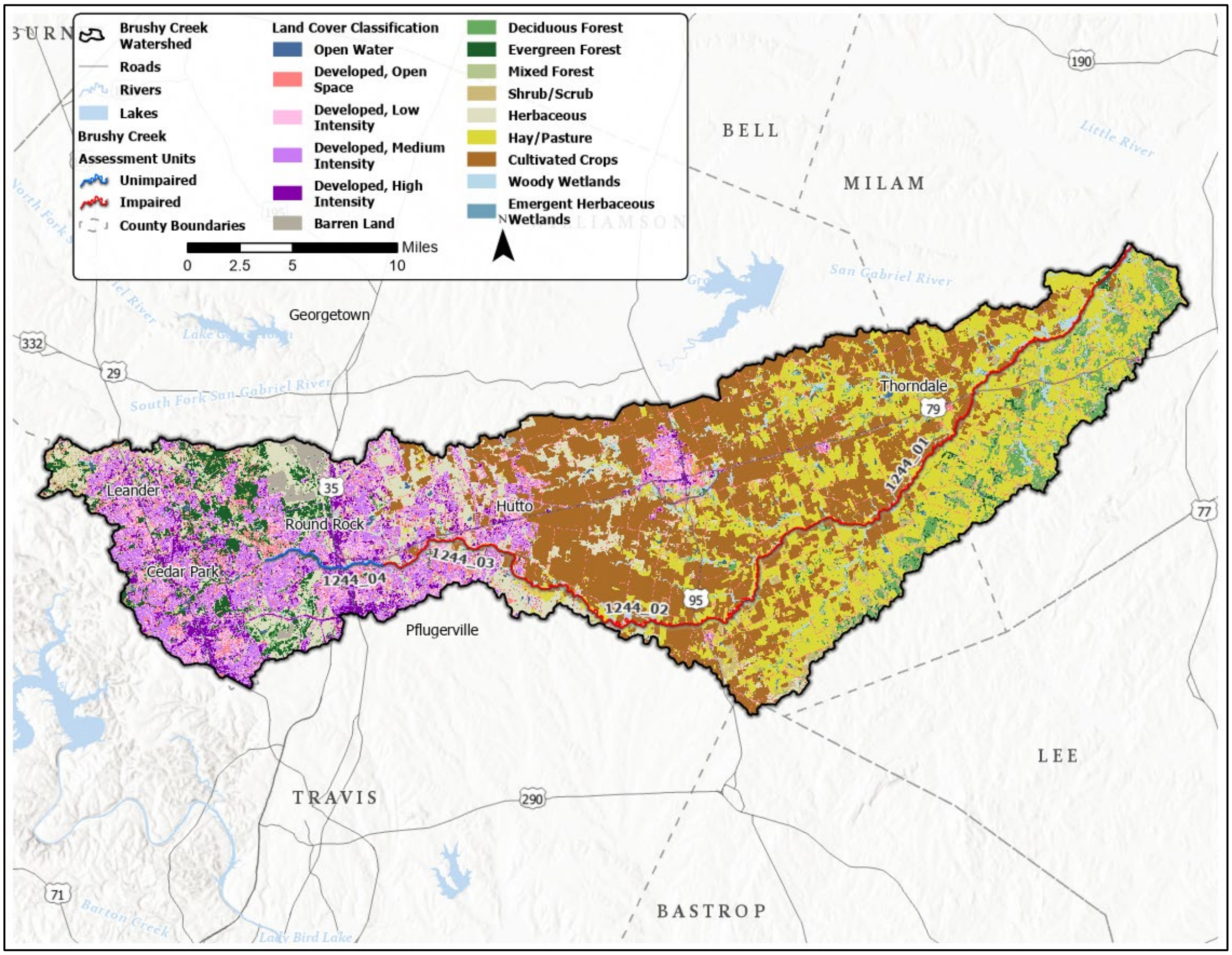

Figure 9. Land cover distribution in the Brushy Creek watershed

As shown in Figure 9, the easternmost third of the watershed was characterized by pastures with scattered forests, which transition into primarily cropland in the central section. The western portion of the watershed consisted of a much higher proportion of developed land, containing cities and suburbs of Austin.

The percentage of each land cover type is in Table 3. Cultivated crop land made up the highest percentage (27.09%) followed by developed land (24.12%) and hay/pasture (i.e., improved pasture) (22.04%).

Table 3. Land cover types in the watershed

Land Cover Classification	Acres	Percentage of Total Area
Cultivated Crops	90,099	27.09
Hay/Pasture	73,303	22.04
Herbaceous	33,504	10.07
Developed, Medium Intensity	29,575	8.89
Developed, Low Intensity	20,544	6.18
Developed, Open Space	19,784	5.95
Deciduous Forest	14,700	4.42
Evergreen Forest	12,256	3.68
Shrub/Scrub	11,993	3.61
Developed, High Intensity	10,324	3.10
Woody Wetlands	9,268	2.79
Barren Land	3,292	0.99
Mixed Forest	1,850	0.56
Open Water	1,733	0.52
Emergent Herbaceous Wetlands	428	0.13
Total	**332,651**	**100.00**

Population and Population Projection

Population within the Brushy Creek watershed was estimated using the U.S. Census Bureau (USCB) population data by census block (the finest geographic area for which census data are collected) (USCB 2020). The Brushy Creek watershed had an estimated total population of 457,064, with higher population density around the cities of Leander, Cedar Park, Round Rock, and Hutto.

The Texas Water Development Board (TWDB) publishes the population projection every five years for each county in a Regional Water Plan (TWDB 2021). Table 4 shows the most recent projected population within the watershed by county and year. Between 2020 and 2070, the population of Bastrop County was expected to increase by over 300%, followed by Willamson County with an increase of 160%; while the populations of Lee and Milam counties were expected to increase by around 25%. According to this projection, the population within the Brushy Creek watershed was projected to reach 619,593 by 2070.

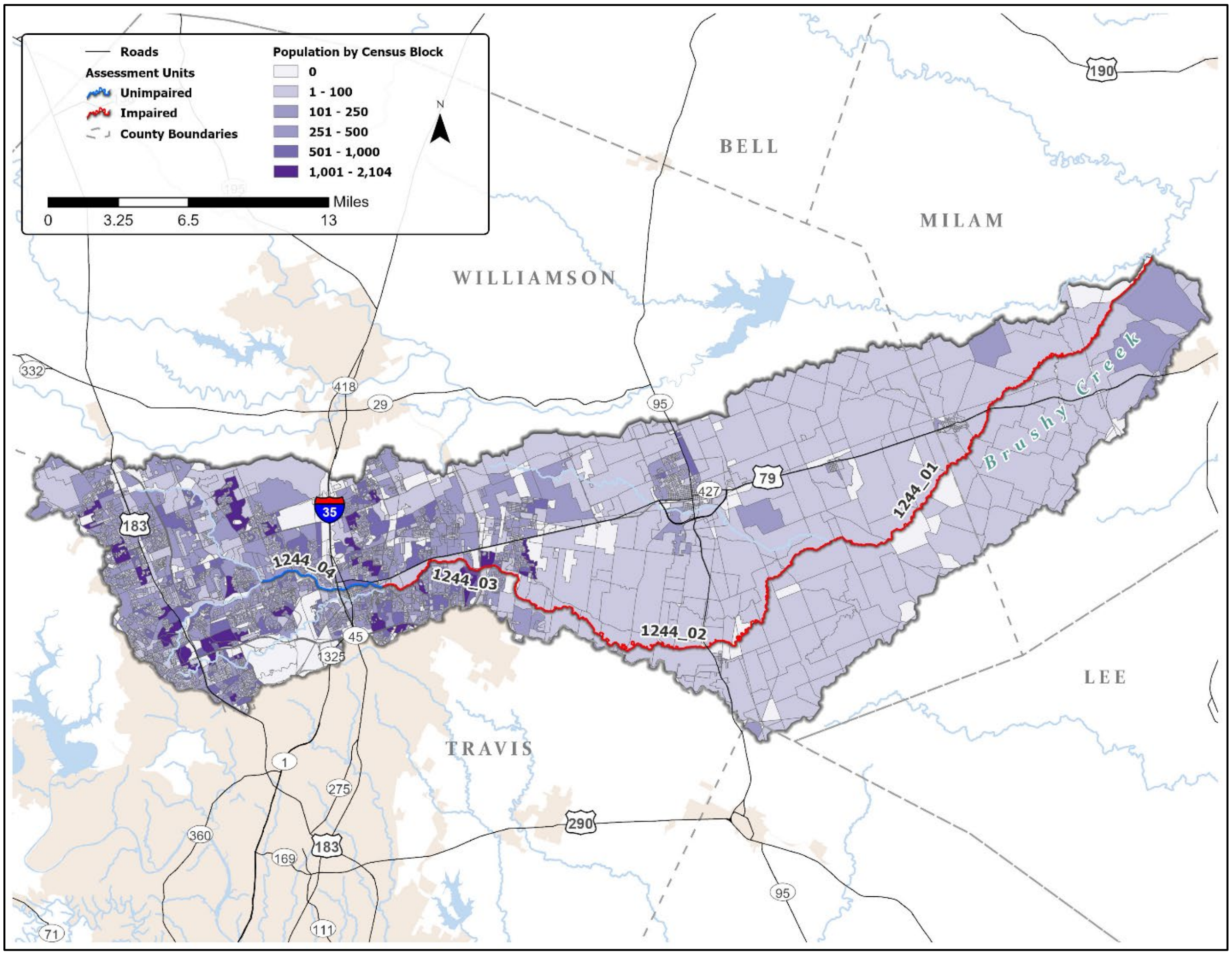

Figure 10. **Population distribution in the watershed**

Table 4. 2021 Regional Water Plan population projection by county for 2020-2070

County	Projected Population by Year						
	2020	2030	2040	2050	2060	2070	Percent Increase
Milam	26,234	27,793	28,896	30,300	31,501	32,629	24.4
Williamson	631,097	771,834	941,827	1,141,301	1,394,412	1,643,646	160.4

Table 5. 2021 Regional Water Plan population projection in the watershed for 2020-2070

County	Projected Population in the Watershed by Year						
	2020	2030	2040	2050	2060	2070	Percent Increase
Milam	2,363	2,503	2,602	2,729	2,837	2,938	24.4
Williamson	236,772	289,573	353,350	428,188	523,149	616,655	160.4

Groundwater

The Brushy Creek watershed overlies portions of three major aquifers: the Carrizo-Wilcox, Edwards, and Trinity (Figure 11). Within the watershed, groundwater quality and characteristics vary by aquifer and location. In the confined zones of the Carrizo-Wilcox Aquifer—primarily underlying the eastern portion of the watershed—groundwater is generally softer, with total dissolved solids (TDS) typically less than 1,000 milligrams per liter (mg/L). However, TDS levels tend to increase in the deeper southern and western extents of the aquifer, which lie mostly outside the Brushy Creek watershed.

Groundwater in the Trinity Aquifer, which underlies much of the central and western parts of the watershed, is generally considered fresh (containing less than 1,000 mg/L of TDS), making it suitable for most domestic and agricultural uses without extensive treatment. In areas where the aquifer reaches the land surface—known as the outcrop—groundwater can be very hard due to elevated mineral content. Within the watershed, TDS in the Trinity Aquifer ranges from less than 1,000 mg/L in the east and southeast to between 1,000 and 5,000 mg/L in western portions and at greater depths, where groundwater becomes more mineralized. Sulfate and chloride concentrations also tend to increase with depth.

The Edwards Aquifer, a karst system formed in soluble limestone, occurs in the western half of the Brushy Creek watershed. From the Kyle to Belton area, groundwater in this aquifer generally contains less than 1,000 mg/L of dissolved solids. Water from the recharge zone, an area where surface water can refill an aquifer, typically contains between 200 and 400 mg/L of TDS (TWDB 2024).

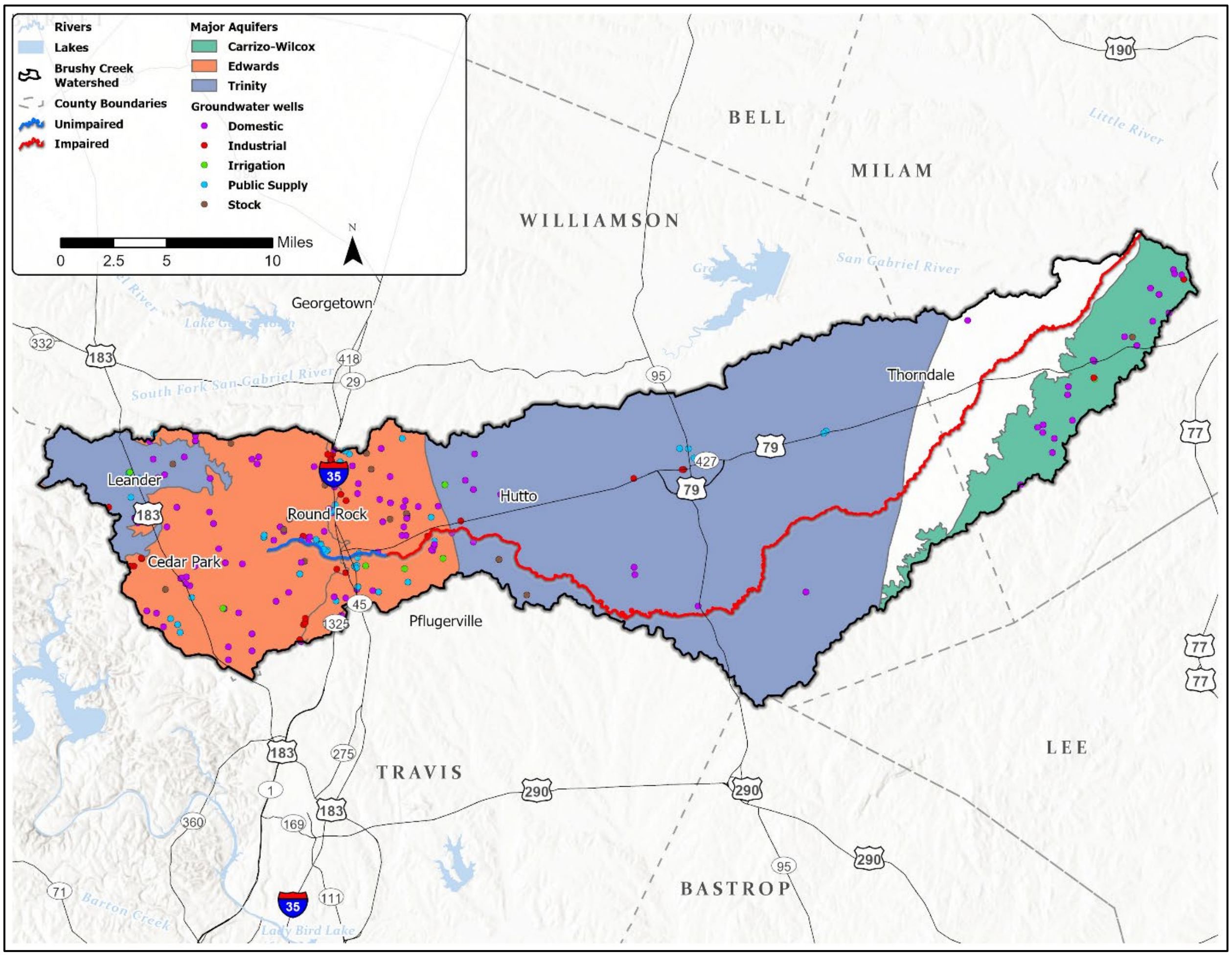

Figure 11. **Aquifers and groundwater wells in the watershed**

Water Quality

Surface waters are monitored in Texas to ensure that their quality supports designated uses defined in the Texas Surface Water Quality Standards (TSWQS) (TCEQ 2022). Designated uses and associated standards are developed by TCEQ to fulfill requirements of the federal Clean Water Act (CWA). Texas is required to set standards that: (1) maintain and restore biological integrity in the waters, (2) protect fish, wildlife, and recreation in and on the water (fishable/swimmable), and (3) consider the use and value of state waters for public supplies, wildlife, recreation, agricultural and industrial purposes.

Under the CWA (33 U.S. Code § 1251.303), administered by the U.S. Environmental Protection Agency (EPA) (40 Code of Federal Regulations § 130.7), Texas is required to develop a list that describes all water bodies that are impaired and are not within established water quality standards. This list is commonly known as the "303(d) list" in reference to the *Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)* (EPA 2005). Furthermore, TCEQ conducts assessment on water bodies every two years and publishes the findings in the "305(b) report" in reference to the *Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)*, which is hereinafter referred to as the *Texas Integrated Report* (EPA 2005).

In the *2024 Texas Integrated Report,* the main stem of Brushy Creek (Segment 1244) is composed of AUs 1244_01 through 1244_04 (Figure 12) and its assessment results were based on water quality data collected between December 1, 2015 and November 30, 2022 (TCEQ 2024a).

Historically, water quality was monitored along Brushy Creek by different entities at six surface water quality monitoring (SWQM) stations: 12068, 12060, 12059, 22395, 22392, and 12054. (Figure 12; TCEQ 2024a). The Texas Water Resources Institute (TWRI), funded by the Texas State Soil and Water Conservation Board (TSSWCB), conducted monthly routine water quality monitoring at SWQM stations 12059 and 22392. The data available for the creek include instantaneous streamflow, bacteria, and field parameters, such as Secchi depth (water clarity), water temperature, dissolved oxygen (DO), specific conductivity, and pH.

Historical water quality data between October 1, 2004, and September 30, 2024, were retrieved from the SWQM Information System (SWQMIS; TCEQ 2024b).

Table 6. Monitoring stations and segments reviewed

AU ID	Station ID	Description
1244_01	12054	Brushy Creek at FM 908
1244_02	12059	Brushy Creek at CR 129
	22392	Brushy Creek at FM 619
	22395	Brushy Creek at immediately upstream of FM 973
1244_03	12060	Brushy Creek at FM 685
1244_04	12068	Brushy Creek at Chisholm Trail

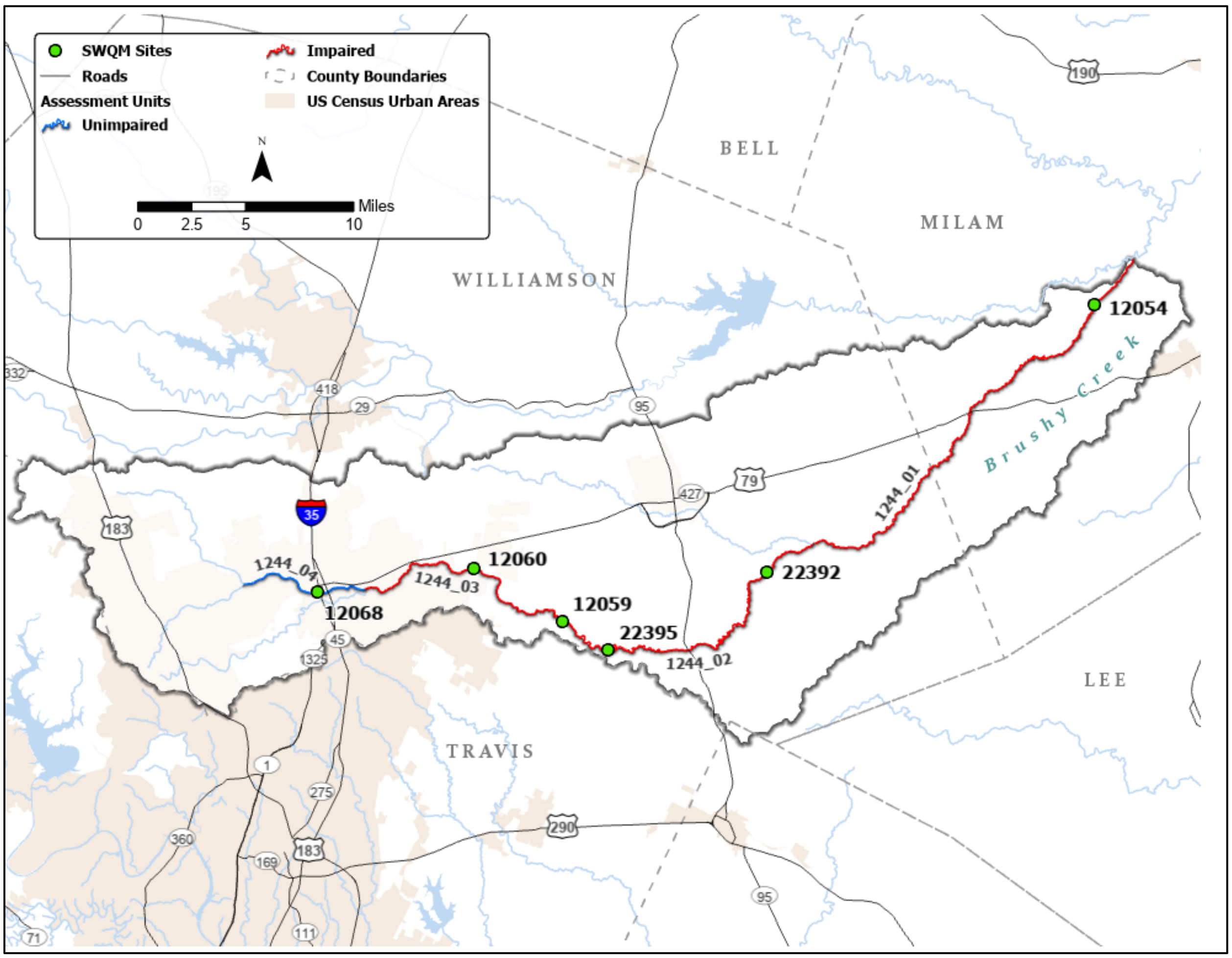

Figure 12. Locations of TCEQ SWQM stations on Brushy Creek

TSWQS are implemented to ensure a water body's ability to support its designated use(s). For Brushy Creek, standards for primary contact recreation use, aquatic life use, general use, and domestic water supply are all applicable (Table 7 – Table 10).

E. coli levels are used to determine whether a freshwater body supports primary contact recreation. The seven-year geometric mean concentration of *E. coli* should be below 126 MPN per 100 mL (most probable numbers per 100 milliliters) based on at least 20 samples (TCEQ 2021).

Dissolved oxygen (DO) levels and habitat quality are used to assess support for aquatic life. Grab screening level is used to identify potential concerns and to indicate if further assessment is needed to determine if conditions consistently pose risks to aquatic life. Meanwhile, grab minimum refers to the lowest acceptable DO concentration measured in an instantaneous sampling event, and when an instantaneous measurement of DO falls below the grab minimum threshold, it could indicate adverse conditions to aquatic life.

Screening levels for total phosphorus, nitrate, chlorophyll-*a*, and ammonia are used to assess general use support (Table 7 - Table 10; TCEQ 2021).

It is also worth noting that while the *E. coli* and DO grab minimum are EPA-approved criteria for CWA purposes, the DO grab screening level and nutrient screening level methods are provisions of the State (TCEQ 2022).

The *2024 Texas Integrated Report* identifies that AU 1244_01 does not support primary contact recreation use because the *E. coli* levels measured at SWQM station 12054 exceeded EPA-approved bacteria criterion of 126 MPN per 100 mL for freshwater (Table 7). In addition, AU 1244_01 has concerns for elevated nitrate concentration in water (TCEQ 2024a).

Meanwhile, based on data collected at SWQM station 12059, AU 1244_02 does not support primary contact recreation due to elevated bacteria levels exceeding 126 MPN per 100 mL (Table 8). This AU also has concerns for elevated nitrate in water.

Moreover, AU 1244_03 also does not support primary contact use due to bacteria levels based on data collected at SWQM station 12060 (Table 9). This AU also has nitrate concerns and a fish kill reported between Dec 2013 and Nov 2020.

Finally, AU 1244_04 supports the primary contact recreation use as the seven-year geometric mean *E. coli* concentration was below 126 MPN per 100 mL (Table 10).

Table 7. Designated use for AU 1244_01

Use	Method / Parameter	Criteria / Screening Level	# Data Assessed	Mean Data Assessed	# Exceedance	Mean Exceedance
Contact Recreation	Bacteria Geomean / *E. coli*	126 MPN/100 mL	23	147.54	1	-
Aquatic Life Use	DO grab screening level	3 mg/L	24	-	1	4.9
	DO grab minimum	5 mg/L	24	-	0	-
General Use	Total dissolved solids	800 mg/L	108	418	0	-
	Sulfate	150 mg/L	102	45.5	0	-
	Chloride	200 mg/L	102	70.37	0	-
	High pH	9	24	-	0	-
	Low pH	6.5	24	-	0	-
	Screening Levels / Total phosphorus	0.69 mg/L	23	-	3	5.39
	Screening Levels / Nitrate	1.95 mg/L	24	-	22	6.19
	Screening Levels / Chlorophyll-a	14.1 mg/L	24	-	3	17.53
	Screening Levels / Ammonia	0.33 mg/L	22	-	1	0.45
	Water temperature	32.8°	23	-	0	-

Table 8. Designated use for AU 1244_02

Use	Method	Criteria / Screening Level	# Data Assessed	Mean Data Assessed	# Exceedance	Mean Exceedance
Contact Recreation	Bacteria Geomean / *E. coli*	126 MPN/100 mL	29	322.69	1	-
Aquatic Life	DO grab screening level	3 mg/L	32	-	1	3.1
	DO grab minimum	5 mg/L	32	-	0	-
General Use	Total dissolved solids	800 mg/L	108	418	0	-
	Sulfate	150 mg/L	102	45.5	0	-
	Chloride	200 mg/L	102	70.37	0	-
	High pH	9	32	-	0	-
	Low pH	6.5	32	-	0	-
	Screening Levels / Total phosphorus	0.69 mg/L	23	-	4	0.84
	Screening Levels / Nitrate	1.95 mg/L	25	-	21	6.88
	Screening Levels / Chlorophyll-*a*	14.1 µg/L	25	-	1	16.2
	Screening Levels / Ammonia	0.33 mg/L	25	-	5	2.83
	Water temperature	32.8°C	32	-	0	-

Table 9. Designated use for AU 1244_03

Use	Method / Parameter	Criteria / Screening Level	# Data Assessed	Mean Data Assessed	# Exceedance	Mean Exceedance
Contact Recreation	Bacteria Geomean / *E. coli*	126 MPN/100 mL	22	515.4	1	-
Aquatic Life	DO grab screening level	3 mg/L	5	-	1	-
	DO grab minimum	5 mg/L	3	-	-	-
General Use	Total dissolved solids	800 mg/L	108	418	0	-
	Sulfate	150 mg/L	102	45.5	0	-
	Chloride	200 mg/L	102	70.37	0	-
	Fish Kill Reports	-	-	-	0	-
	High pH	9	25	-	0	-
	Low pH	6.5	25	-	0	-
	Screening Levels / Total phosphorus	0.69 mg/L	21	-	3	0.75
	Screening Levels / Nitrate	1.95 mg/L	22	-	18	7.21
	Screening Levels / Chlorophyll-*a*	14.1 µg/L	22	-	1	24.1
	Screening Levels / Ammonia	0.33 mg/L	22	-	5	3.6
	Water temperature	32.8°C	25	-	0	-

Table 10. Designated use for AU 1244_04

Use	Method	Criteria / Screening Level	# Data Assessed	Mean Data Assessed	# Exceedance	Mean Exceedance
Contact Recreation	Bacteria Geomean / *E. coli*	126 MPN/100 mL	25	89.32	0	-
Aquatic Life	DO grab screening level	3 mg/L	28	-	0	-
	DO grab minimum	5 mg/L	28	-	0	-
Domestic Water Supply	Nitrate	10 mg/L	25	1.32	0	-
General Use	Total dissolved solids	800	108	418	0	-
	Sulfate	150	102	45.5	0	-
	Chloride	200	102	70.37	0	-
	High pH	9	28	-	0	-
	Low pH	6.5	28	-	0	-
	Screening Levels / Total phosphorus	0.69 mg/L	24	-	0	-
	Screening Levels / Nitrate	1.95 mg/L	25	-	5	2.31
	Screening Levels / Chlorophyll-*a*	14.1 µg/L	25	-	1	42.8
	Screening Levels / Ammonia	0.33 mg/L	25	-	1	0.5
	Water temperature	32.8°C	28	-	0	-

Bacteria

Concentrations of fecal indicator bacteria are evaluated to assess the risk of illness during contact recreation. In freshwater, concentrations of *E. coli* bacteria are measured to evaluate the presence of fecal contamination from warm-blooded animals in water bodies. The presence of these fecal indicator bacteria may indicate that associated pathogens from the intestinal tracts of warm-blooded animals or other sources could be reaching water bodies and could cause illness in people that recreate in them. Common sources include wildlife, domestic livestock, pets, malfunctioning on-site sewage facilities (OSSFs), urban and agricultural runoff, sewage system overflows (SSOs), and direct discharges from wastewater treatment facilities (WWTFs).

Table 11 summarizes the bacteria data collected in the Brushy Creek watershed by monitoring station (TCEQ 2024b). Figure 13 shows the *E. coli* measurements collected in the past 20 years, as well as their seven-year rolling geometric mean trends. The black solid line indicates seven-year rolling geometric mean and the red dashed line indicates the criterion (126 MPN per 100 mL).

The data showed that bacteria levels in AU 1244_01 decreased over time, while bacteria levels in AU 1244_03 started to increase circa 2021. Additionally, bacteria levels in AU 1244_04 decreased over time, and bacteria levels in AU 1244_02 were overall above the criterion without a notable trend, partly due to lacking long-term data.

Table 11. Summary of available *E. coli* data

Station ID	AU ID	Begin Date	End Date	Geometric Mean (MPN/100 mL)	# Data Assessed
12068	1244_04	2001-09-13	2024-10-30	88.64	93
12060	1244_03	2001-09-13	2024-10-30	465.83	88
12059	1244_02	2015-11-09	2024-12-04	229.63	50
22392	1244_02	2022-10-31	2024-10-30	227.39	25
12054	1244_01	2008-10-15	2024-12-11	131.39	54

AU – assessment unit; MPN – most probable number; mL – milliliter

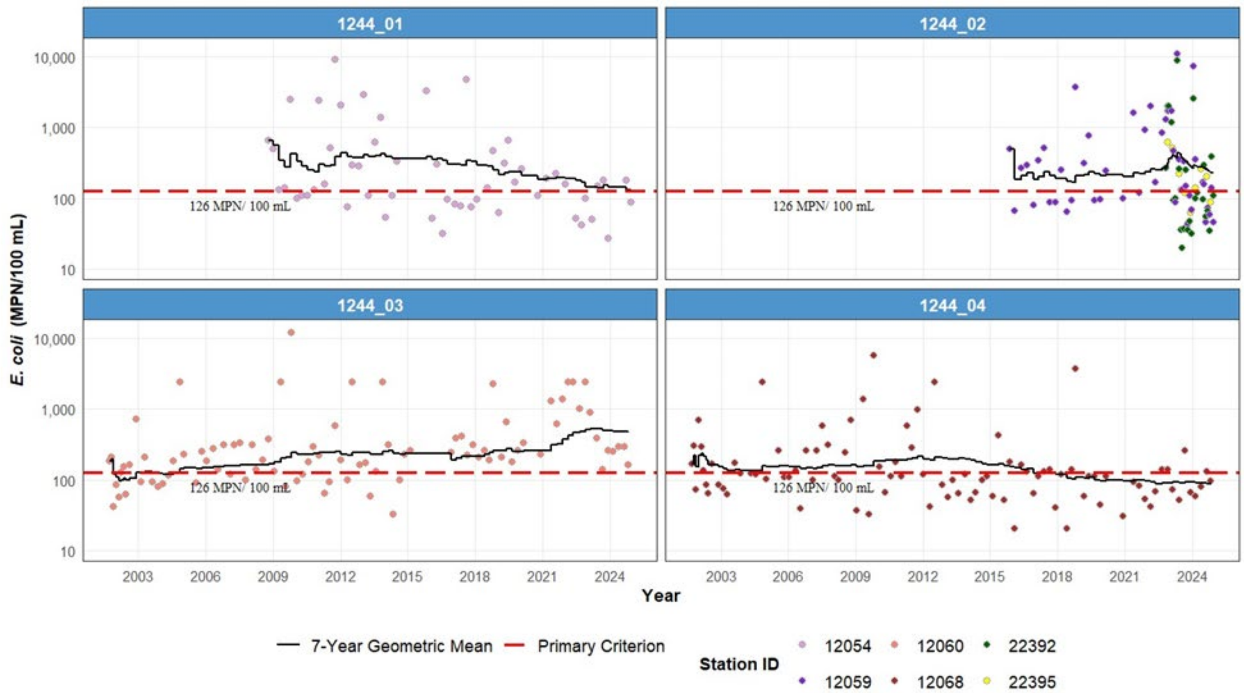

Figure 13. **Historical *E. coli* concentrations between 2001 and 2024**

Dissolved Oxygen

DO is the main parameter used to determine a water body's ability to support and maintain aquatic life uses. If DO levels in a water body drop too low, fish and other aquatic species will not survive.

Typically, DO levels fluctuate throughout the day, with the highest levels of DO occurring in mid to late afternoon, due to plant photosynthesis. Meanwhile, DO levels are typically lowest just before dawn as both plants and animals in the water consume oxygen through respiration. Furthermore, seasonal fluctuations in DO are common because oxygen solubility decreases in water as temperature increases; therefore, it is common to see lower DO levels during the summer. While DO can fluctuate naturally, human activities can also cause abnormally low DO levels. Excessive organic matter (vegetative material, untreated wastewater, etc.) can result in depressed DO levels as bacteria break down the materials and subsequently consume oxygen. Excessive nutrients from fertilizers and manures can also depress DO as aquatic plant and algae growth increase in response to nutrients. The increased respiration from plants and decay of organic matter as plants die off can also drive down DO concentrations.

Fresh water DO levels are protected to support aquatic life use based on screening levels, which are determined based on streamflow type (perennial, intermittent with pools, or intermittent). For Brushy Creek the screening level is 5 mg per liter and the grab minimum threshold is 3 mg per liter. According to the *2024 Texas Integrated Report*, based on the data collected between December 2015 and November 2022, no AU within the watershed is impaired for depressed DO (TCEQ 2024a). All segments in the Brushy Creek watershed are assumed to support a subcategory of aquatic life use. DO screening levels and measurements are plotted in Figure 14.

Figure 14. Historical DO concentrations in Brushy Creek between 2004 and 2024

Nutrients

Nutrients, specifically nitrogen and phosphorous, are used by aquatic plants and algae. However, excessive nutrients can lead to plant and algal blooms, which would result in reduced DO levels. Sources of nutrients include effluents from WWTFs and OSSFs, direct deposition of animal fecal matter, illegal dumping, groundwater return flows, and fertilizer runoff from yards and agricultural fields. Additionally, nutrients bind to soil and sediment particles, and as a result, runoff and erosion events that result in heavy sediment loads can increase nutrient levels in receiving water bodies.

Nutrient screening levels were designated for total phosphorus, nitrate, ammonia, and chlorophyll-*a* to protect freshwater streams and support general use (Table 7 – Table 10; TCEQ 2024a). These levels are statistically derived from the SWQM monitoring data, and they are based on the 85th percentile values for each parameter in freshwater streams (TCEQ 2021). TCEQ identifies a "concern", which is not an impairment listing, for water quality if the screening level was exceeded more than 20 percent of the time based on the number of exceedances for a given number of samples collected (TCEQ 2021). In the *2024 Texas Integrated Report*, data collected between December 2015 and November 2022 were used for this assessment.

Nutrient data collected within the Brushy Creek watershed included nitrogen (Figure 15) and total phosphorus (Figure 16). The data conformed with the concerns indicated in Table 7 – Table 10, that is, AUs 1244_01, 1244_02, and 1244_03 had elevated nitrate and total phosphorous concentrations.

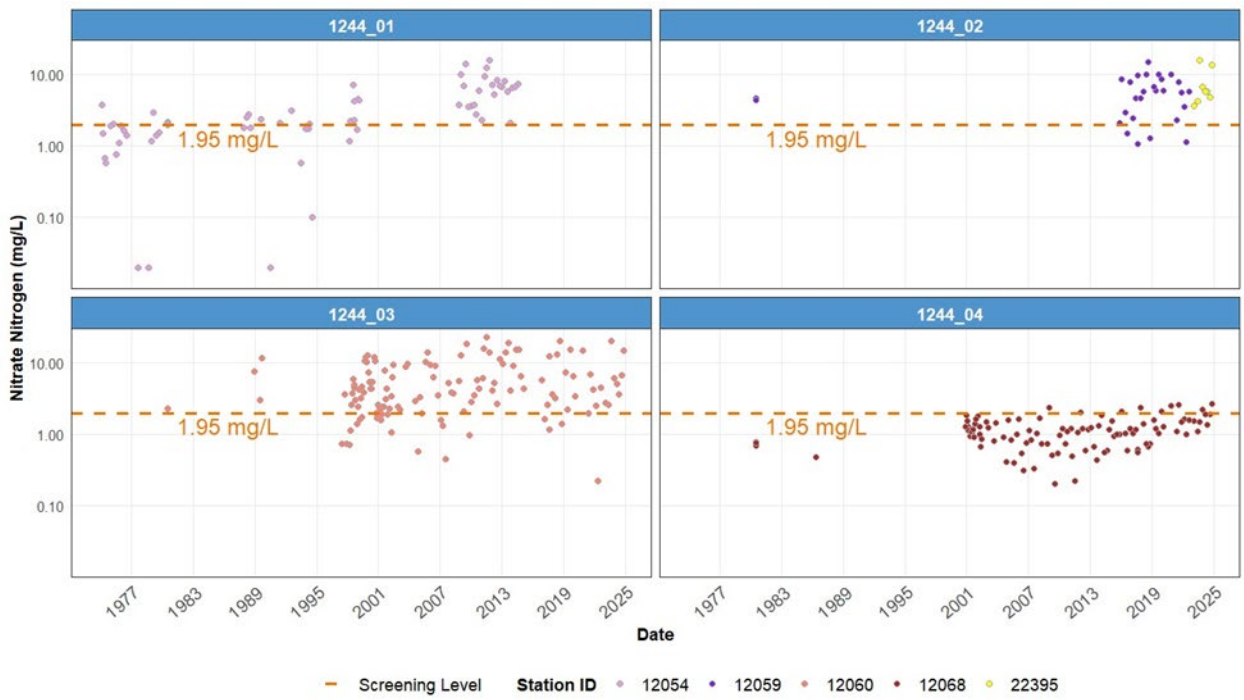

Figure 15. Historical nitrate nitrogen concentrations in Brushy Creek

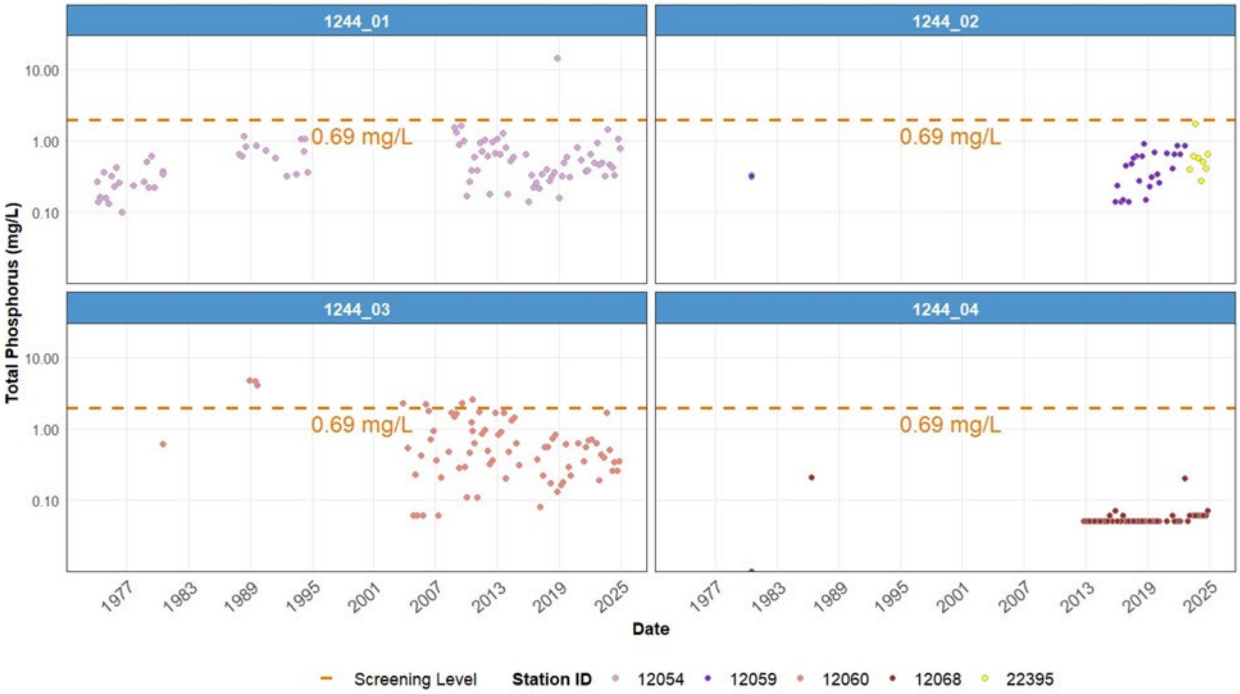

Figure 16. Historical total phosphorus concentrations in Brushy Creek, 1974 through 2024.

Potential Sources of Pollutants

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as “point sources,” come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). Wastewater treatment facilities (WWTFs) and stormwater from industries, construction, concentrated animal feeding operations (CAFOs), and municipal separate storm sewer systems (MS4s) are considered point sources of pollution.

Unregulated sources are typically nonpoint sources (NPS) in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permit, and include failing OSSFs, livestock, wildlife, feral hogs, pets, and illicit/illegal dumping (Table 12).

Table 12. Summary of potential pollutant sources and their potential impacts and causes

Type	Pollutant Sources	Potential Impacts	Potential Causes
Point sources	- WWTFs - SSOs - CAFOs	Contributing to bacteria and nutrient loads	- Overflow during severe storm events - Systematic failures
	- TPDES-permitted stormwater	Contributing to bacteria and nutrient loads, litter, oils, etc.	- Excessive surface runoff due to impervious pavements
	- Livestock - Wildlife - Feral hogs	Contributing to bacteria loads	- Animals defecating directly in water - Animals spending time in riparian areas, causing soil erosion and degradation
NPSs	- Pets	Contributing to bacteria loads	- Improper disposal of pet waste
	- OSSFs	Contributing to bacteria and nutrient loads	- System not properly designed for site-specific conditions - Improper function due to age or lack of maintenance/sludge removal
	- Illegal dumping	Contributing to bacteria and nutrient loads	- Decaying animal carcasses and trash dumped near water bodies

CAFO – concentrated animal feeding operation; OSSF – on-site sewage facility; SSO – sanitary sewer overflow; TPDES – Texas Pollutant Discharge Elimination System.

Livestock

Livestock is a potential source of NPS pollution as animals graze over pastures and deposit fecal matter onto the land as well directly into accessible water bodies. Fecal matter deposited within the watershed is likely to be transported to adjacent creeks during rainfall events and can contribute to increased bacteria loads in water. Since watershed-level livestock populations are not available, the numbers of hogs/pigs, sheep/lambs, goats, horses, and poultry (layers and broilers) in the Brushy Creek watershed were estimated using the 2022 USDA National Agricultural Statistics Service (NASS) county-level livestock populations (Table 13; NASS 2024) and land cover data (NLCD 2021). The county-level NASS data were multiplied by the ratio of watershed-level grazeable land size to county-level grazeable land size. According to the Dewitz (2023) classification, land cover types suitable for grazing livestock are herbaceous and hay/pasture.

Using the method described above, a total of 23,785 cattle, 217 hogs/pigs, 1,487 sheep/lamb, 2,186 goats, 704 horses, and 215,979 poultry (layers and broilers) were estimated to be living in the watershed (Table 14).

Table 13. County-level livestock populations

Livestock	Milam	Williamson	Total
Cattle	99,601	44,765	144,366
Hogs/Pigs	669	493	1,162
Sheep/Lambs	2,498	4,113	6,611
Goats	3,644	6,056	9,700
Horse	1,634	1,787	3,421
Poultry	2,030,496	9,322	2,039,818

Table 14. Livestock populations in the watershed

Livestock	Milam	Williamson	Total
Cattle	10,458	13,327	23,785
Hogs/Pigs	70	147	217
Sheep/Lambs	262	1,225	1,487
Goats	383	1,803	2,186
Horse	172	532	704
Poultry	213,203	2,775	215,979

On-Site Sewage Facilities

OSSFs are widely used in the Brushy Creek watershed and may contribute to bacteria loadings in water if not properly operated and/or maintained. The number of OSSFs, their locations, ages, types, and functional statuses in the watershed were unknown. Estimations of the number of OSSFs were made by using approximated locations of 911 address points and land parcel data acquired from the Texas Geographic Information Office DataHub (TxGIO 2024), certificated sewer service data (Public Utility Commission of Texas 2017), and aerial imagery.

911 address points located outside of sewer service areas were examined using land parcel data and aerial imagery as the background to determine whether it was located on or close to any structure. This method of locating potential OSSF sites was used given the lack of actual OSSF locations from regional databases. Based on this method, density of OSSFs within the watershed were estimated (Figure 17).

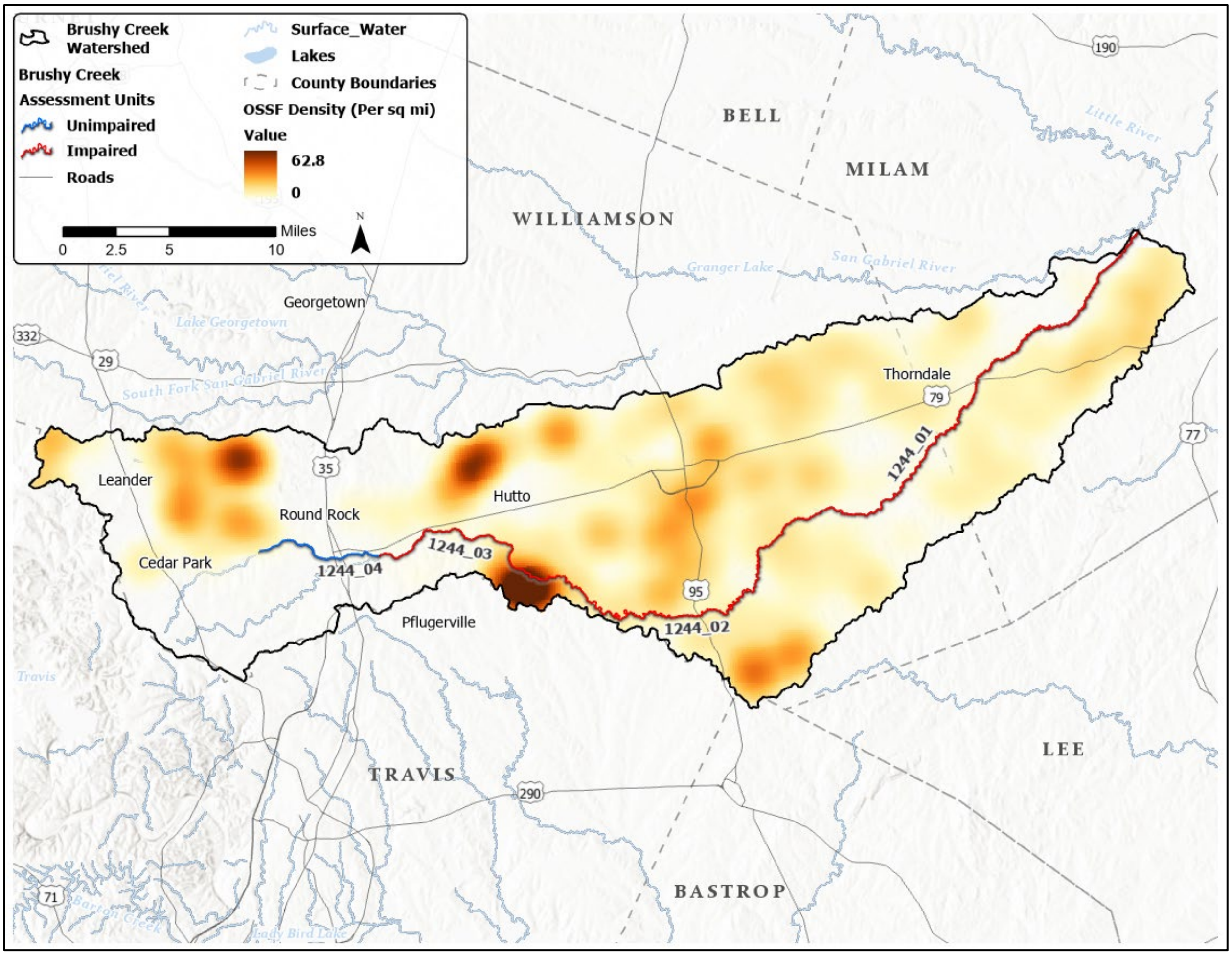

Figure 17. Estimated OSSF density in the watershed

Typical OSSF designs include either (1) anaerobic systems composed of septic tank(s) and an associated drainage or distribution field, or (2) aerobic systems with aerated holding tanks and typically an above ground sprinkler system to distribute the treated effluent. Many factors affect OSSF performance, such as system failure due to age, improper system design for specific site conditions, improper function from lack of maintenance/sludge removal, and illegal discharge of untreated wastewater. Adsorption of field soil properties affects the ability of conventional OSSFs to treat wastewater by percolation. Soil suitability rankings were developed by the USDA NRCS to evaluate the ability of soils to treat wastewater based on soil characteristics such as topography, saturated hydraulic conductivity, depth to the water table, ponding, flooding effects and more (NRCS 2019). Soil suitability ratings are divided into three categories: not limited, somewhat limited, and very limited. Soil suitability dictates the type of OSSFs required to properly treat wastewater. If not properly designed, installed, or maintained, OSSFs in somewhat or very limited soil pose an increased risk of failure. The majority (88.95%) of the soils in the watershed are rated "Very Limited" for OSSF use, followed by smaller portion of the watershed rated “Somewhat Limited” (Figure 18).

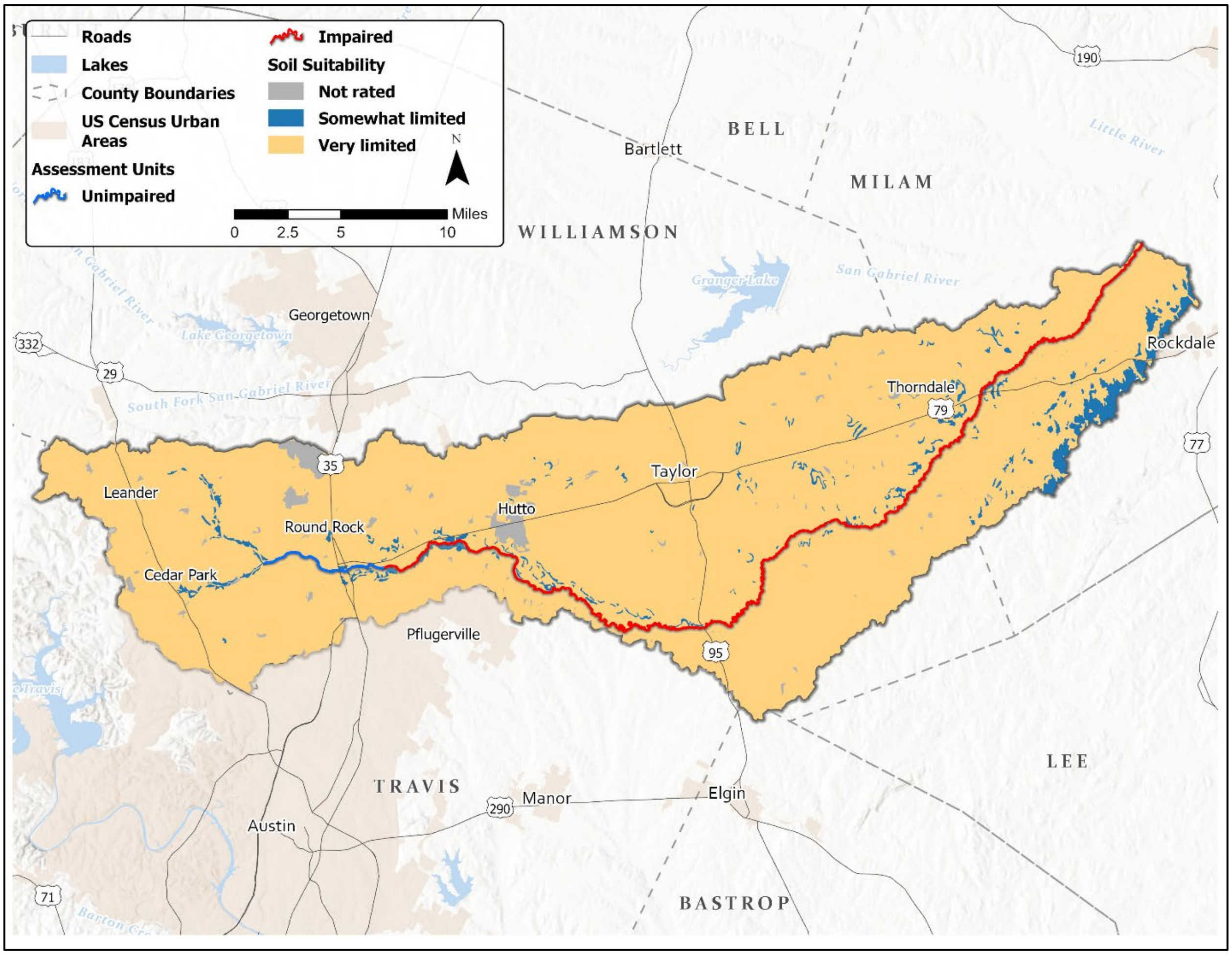

Figure 18. Soil suitability ratings for OSSFs in the watershed

Wildlife and Feral Hogs

Wildlife contributes nutrient and *E. coli* loads to water bodies. Riparian areas generally provide enhanced habitat for wildlife, causing them to frequent these areas and deposit their waste materials directly in and around the water. Depending on the size of the animal and their population density, wildlife can be a significant potential contributor. Common wildlife species in the watershed include white-tailed deer, fox, raccoon, opossum, and many others. However, population density estimates are not available for all of these species. Therefore, in this WPP, population estimations were limited to white-tailed deer.

The Texas Parks and Wildlife Department (TPWD) conducts deer population surveys within Texas at the deer management unit (DMU) level. DMUs are delineated based on similar ecological characteristics within a defined area. The Brushy Creek watershed is situated in DMU 19 South. Between 2005 and 2022, the average estimated deer density within this DMU was around 39 acres of suitable habitat per deer (TPWD 2024). For estimating deer populations, suitable habitat includes the following land cover types defined in Dewitz (2023): forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands. In other words, deer densities were applied to all land cover types except open water, baren land, and developed land. This method estimated that there are 6,430 deer in the watershed (Table 15).

Besides wildlife, feral hogs are also a significant potential contributor of pollutants to water bodies. Feral hogs are a non-native, invasive species that are rapidly expanding throughout Texas and inhabit similar land use types as white-tailed deer. They are especially fond of places where there is dense cover with food and water readily available. Riparian corridors are prime habitat for feral hogs; therefore, they spend much of their time wallowing in or near creeks. This preference for riparian areas does not preclude their use of non-riparian areas during the night. Extensive rooting and wallowing in riparian areas also cause erosion and soil loss.

Statewide feral hog density estimates can range from 32 acres of suitable habitat per hog to 71 acres of suitable habitat per hog (Wagner and Moench 2009; Timmons et al. 2012). Suitable habitat includes the following NLCD land cover types: forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, and woody wetlands. Feral hog density in the Brushy Creek watershed was assumed to be 32 acres of suitable habitat per hog. This method estimated that there are 7,836 feral hogs in the watershed (Table 15).

Table 15. Estimated white-tailed deer and feral hog populations in the watershed

Watershed	White-Tailed Deer Population	Feral Hog Population
Brushy Creek	6,430	7,836

Pets

Dogs can contribute to bacterial and nutrient loads via runoff from lawns, parks, and other areas. This type of loading is easily avoidable if pet owners properly dispose of pet waste. According to the 2020 American Veterinary Medical Association (AVMA) data, on average, a household in the U.S. has 0.657 dogs (AVMA 2022). According to stakeholder suggestion, the population of dogs in the Brushy Creek watershed was estimated as one dog per household. Based on the 2020 U.S. Census Bureau (USCB) census block data (USCB 2020), 175,607 households were estimated to be in the watershed. As a result, 115,374 dogs were estimated to be living in the watershed (Table 16).

Table 16. Estimated dog population in the watershed.

Watershed	Estimated Number of Household	Dog Population
Brushy Creek	175,607	115,374

TPDES-Regulated Wastewater

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

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

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

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

A review of active general permits (TCEQ 2024c) in the Brushy Creek watershed, as of Sep 2024, found 15 WWTFs (Figure 19) and 19 active concrete production permits.

Based on the EPA Enforcement and Compliance History Online (ECHO) database, the violations of the WWTFs in the watershed within the past three years are summarized in Table 17 (EPA 2024a). Shaded rows in Table 16 contain WWTFs that have permitted *E. coli* concentration on their permits (Figure 19). WWTFs that do not have permitted *E. coli* concentration on their permits are not supposed to contribute to *E. coli* loadings to water bodies.

Table 17. WWTF violations in the watershed between 2021 and 2024

Facility Name	TPDES ID	Facility Permitted Flow (MGD)	Permitted *E. coli* Daily Average (cfu/100 mL)	Permitted *E. coli* Single Sample (cfu/100 mL)	# Violations and Reason
Blue Sky Water Reclamation Facility	TX0142646	10.5	-	-	No violation
Brushy Creek WWTP	TX0144771	0.006	-	-	No violation
Civitas At Hutto WWTF	TX0141933	0.075	-	-	No violation
Coupland WSC WWTP	TX0116882	0.025	-	-	-1 flow in conduit
Flora WWTP	TX0141321	0.5	-	-	No violation
Prairie Crossing WWTP	TX0139866	4.5	-	-	No violation
Taylor Tract WWTP	TX0143570	0.3	-	-	No violation
Brushy Creek Regional East WWTP	TX0101940	21.5	126	399	-2 suspended solids -1 ammonia -31 flow in conduit -1 chlorine -2 *E. coli* -1 BOD
Brushy West Regional WWTP	TX0075167	3	126	399	-No violation
City of Cedar Park WWTP	TX0085740	2.5	126	399	-2 total phosphorus -2 chlorine
City of Hutto Central WWTP	TX0025577	0.99	126	399	-4 total phosphorus

City of Leander WWTP	TX0092151	2.25	126	399	-1 DO -1 total phosphorus -1 total suspended solids -1 ammonia -1 BOD
City of Thorndale WWTP	TX0032379	0.16	126	399	-1 BOD -5 suspended solids -1 *E. coli*
Forest Creek WWTP	TX0118265	0.99	126	399	-2 DO -1 flow in conduit -1 ammonia -1 chlorine -1 BOD
Hutto South WWTP	TX0132926	2.5	126	399	-3 *E. coli*
Mustang Creek WWTP	TX0020443	4	126	399	-1 flow in conduit

BOD – biochemical oxygen demand; cfu – colony forming unit; MGD – million gallons per day; mL – milliliter; TPDES – Texas Pollutant Discharge Elimination System; WWTP – wastewater treatment plant; WWTF – wastewater treatment facility; WSC – water supply corporation.

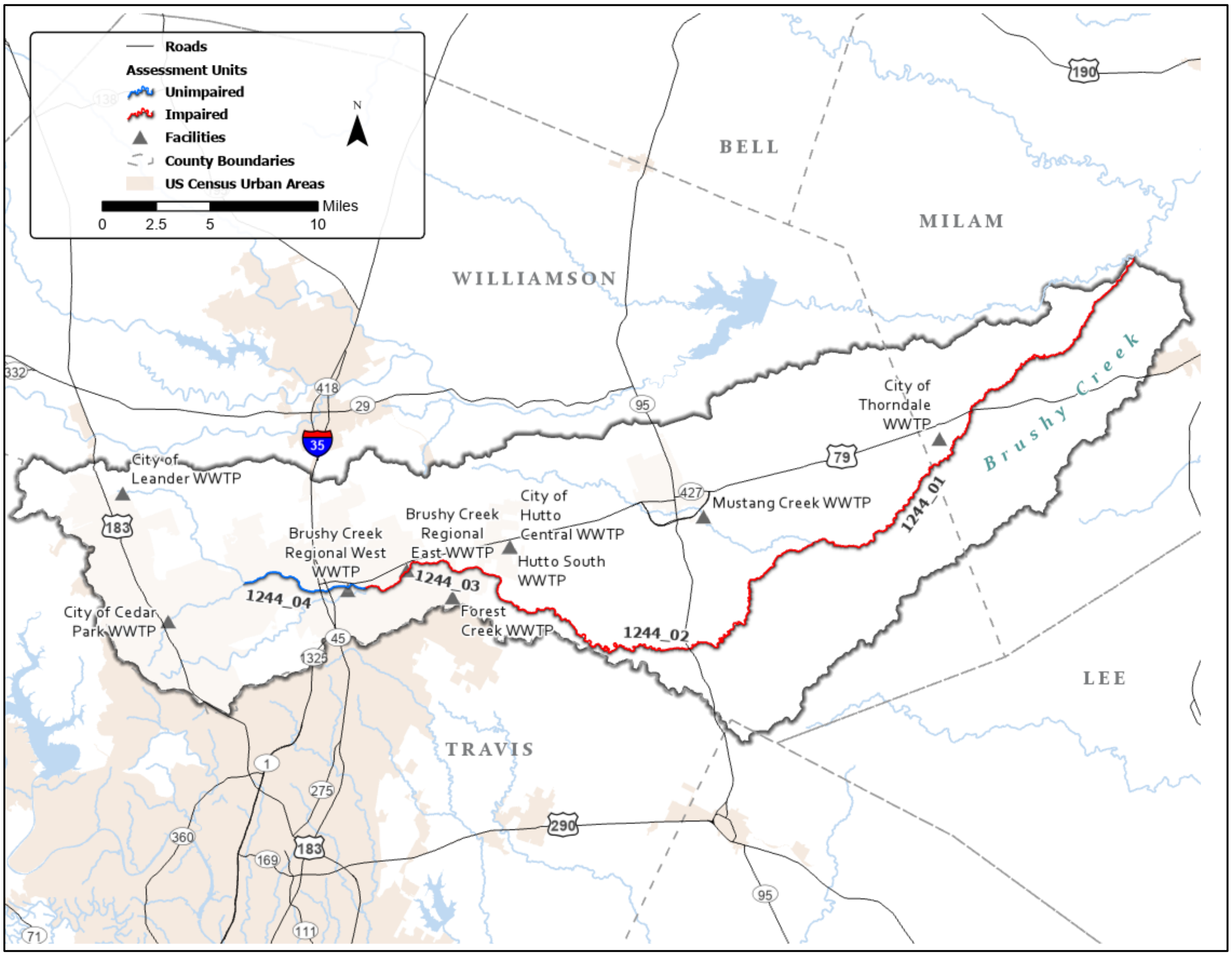

Figure 19. WWTFs in the watershed

TPDES-Regulated Stormwater

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

Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated municipal separate storm sewer system (MS4) entities, stormwater discharges associated with regulated industrial activities, and construction activities.

Stormwater runoff is not subject to regulation.

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

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices (BMPs) to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include all of the following:

- Public education, outreach, and involvement.
- Illicit discharge detection and elimination.
- Construction site stormwater runoff control.
- Post-construction stormwater management in new development and redevelopment.
- Pollution prevention and good housekeeping for municipal operations.
- Industrial stormwater sources (only required for MS4s serving a population of 100,000 people or more in the urban area).
- Authorization for construction activities where the small MS4 is the site operator (optional).

Phase I MS4 individual permits have their own set of MCMs that are like the Phase II MCMs, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program. The Phase I MCMs include all these activities:

- MS4 maintenance activities.
- Post-construction stormwater control measures.
- Detection and elimination of illicit discharges.
- Pollution prevention and good housekeeping for municipal operations.
- Limiting pollutants in industrial and high-risk stormwater runoff.
- Limiting pollutants in stormwater runoff from construction sites.
- Public education, outreach, involvement, and participation.
- Monitoring, evaluating, and reporting.

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

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

As of July 2025, TCEQ Central Registry (TCEQ 2024c) included 16 active Phase II MS4 permits in the Brushy Creek watershed (Table 18).

Table 18. TPDES MS4 permits

Regulated Entity	Authorization Type	TPDES ID	Location
Brushy Creek Municipal Utilities District	MS4 Level 2	TXR040049	Located in the Brushy Creek municipal utility district within the Austin urbanized area in Williamson County
City of Hutto	MS4 Level 2	TXR040105	Area within the City of Hutto limits that is located within the Austin urbanized area
City of Leander	MS4 Level 3	TXR040149	Area within the Leander city limits that is located within the Austin urbanized area
City of Cedar Park	MS4 Level 3	TXR040150	Area within the City of Cedar Park limits located within the Austin urbanized area

Regulated Entity	Authorization Type	TPDES ID	Location
City of Round Rock	MS4 Level 3	TXR040253	Area within the city limits of Round Rock that is part of the Austin urbanized area
North Austin Municipal Utility District NO 1	MS4 Level 2	TXR040266	Area within the north Austin MUD 1 limits that is located within Travis County and the Austin urbanized area
Block House Municipal Utility District	MS4 Level 2	TXR040313	Area within block house MUD that is located within the Austin urbanized area
Ranch at Cypress Creek MUD 1	MS4 Level 2	TXR040365	Area within the ranch at Cypress Creek MUD 1 limits that is located within the Austin urbanized area
Parkside at Mayfield Ranch MUD	MS4 Level 2	TXR040432	Area within the Parkside at Mayfield Ranch MUD that is located within the Austin urbanized area

Regulated Entity	Authorization Type	TPDES ID	Location
Williamson County Water, Sewer, Irrigation and Drainage District 3	MS4 Level 2	TXR040445	Area within the district boundaries approx. 732 acres in SE Williamson County and NE Travis County 2 miles south of Hwy 79 within the Austin urbanized area
Vista Oaks Municipal Utility District of Williamson County	MS4 Level 2	TXR040448	316-acre district at the northeast corner of FM 1431 and CR 175 within the Austin urbanized area
Williamson County Municipal Utility District 11	MS4 Level 2	TXR040482	Area located north of the City of Round Rock that is located within the Austin urbanized area
Williamson County Municipal Utility District 10	MS4 Level 2	TXR040484	Area located north of the City of Round Rock that is located within the Austin urbanized area

Regulated Entity	Authorization Type	TPDES ID	Location
Fern Bluff Municipal Utility District	MS4 Level 1	TXR040625	Area within the City of Round Rock ETJ (Extra-Territorial Jurisdiction) and within the Austin urbanized area
Meadows at Chandler Creek Municipal Utility District	MS4 Level 2	TXR040644	Area within the City of Austin limits that is located within the Austin urbanized area
Williamson County Municipal Utility District 15	MS4 Level 2	TXR040650	Area located within Williamson County limits that is located within the Austin urbanized area

Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. These overflows in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I&I) are typical causes of overflows under conditions of high flow in the WWTF system. Blockages in the line may worsen the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition (EPA 2024b).

According to TCEQ, in the past five years there have been a total of 28 SSOs in the Brushy Creek watershed of varying magnitudes (Table 19; Figure 20; TCEQ 2024d).

Table 19. Summary of reported SSO events between 2019 and 2024

AU	Estimated # Incidents	Total Volume (gallon)	Minimum Volume (gallon)	Maximum Volume (gallon)
1244_01	8	351,000	5,000	200,000
1244_02	0	0	0	0
1244_03	8	255,880	1,000	100,000
1244_04	12	361,980	30	175,000

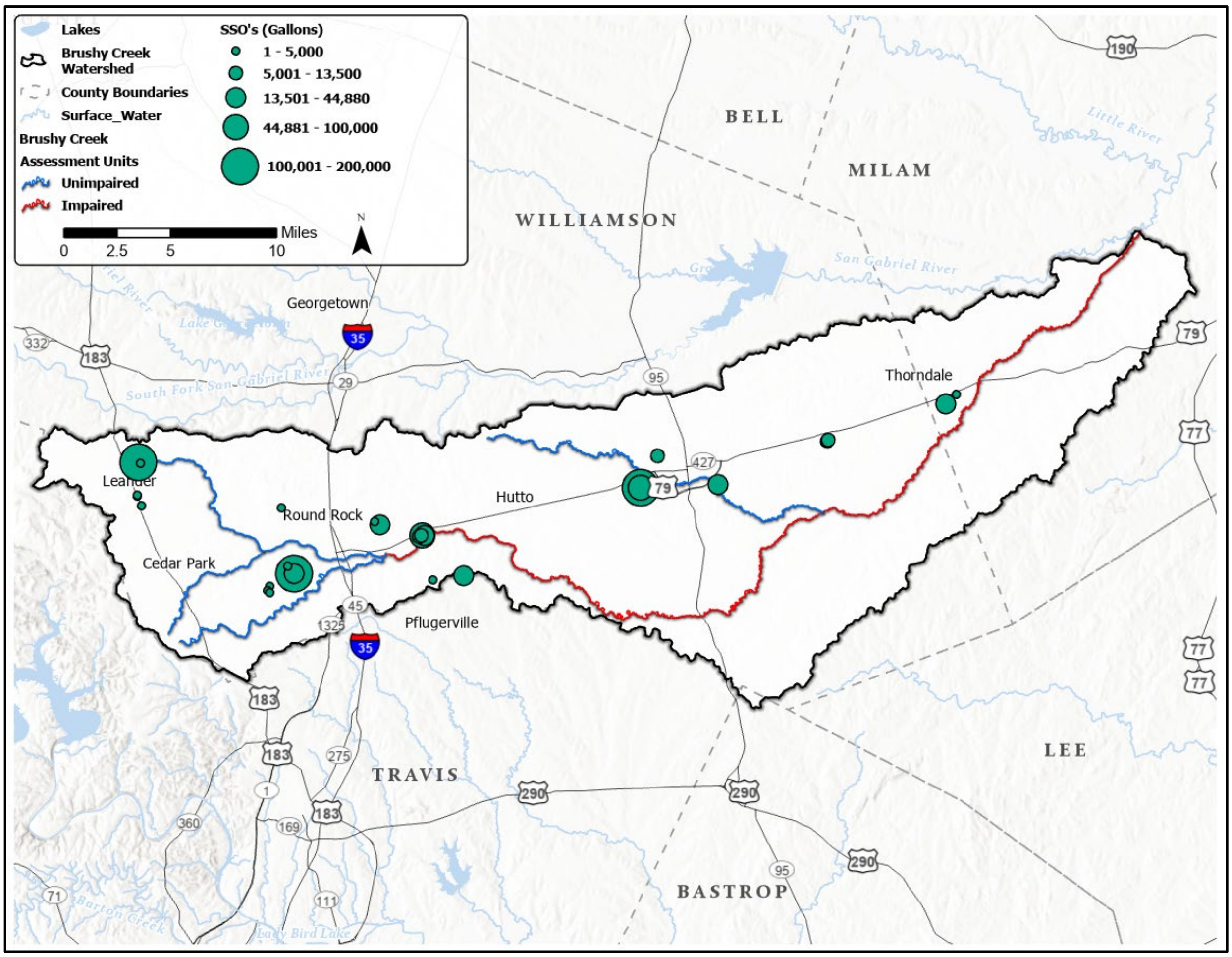

Figure 20. SSO incidents occurred in the watershed between 2019 and 2024

Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term "illicit discharge" is defined in TPDES General Permit TXR040000 for Phase II MS4s as, "Any discharge to a municipal separate storm sewer system that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities."

Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges included in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC 2003) include:

Direct Illicit Discharges:

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

Indirect Illicit Discharges:

- An old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line.

Bacteria Survival and Die-off

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

Illicit and Illegal Dumping

Improper waste disposal can contribute to water quality impairments. Areas that are frequently littered tend to become dumping areas for others as well, which can cause blockages and flooding or more surface areas for bacteria to grow on. Although most items dumped are not necessarily major sources of bacteria and nutrient pollution, items like animal carcasses and household chemical containers can contribute additional bacteria, nutrients, and hazardous waste to the watershed.

Pollutant Source Assessment

Water quality sampling, described in the previous section, has emphasized that the primary water quality issue in the Brushy Creek watershed is elevated fecal indicator bacteria levels in water bodies. As previously mentioned, the current water quality standard established by TCEQ for primary contact recreation use is 126 MPN per 100 mL for *E. coli*. In order to calculate the needed reductions to meet the applicable water quality criteria, the bacteria loading capacity of the Brushy Creek watershed needed to be estimated. Besides, current bacterial loadings for all impaired streams needed to be estimated using data from water quality sampling. Based on this information, load duration curve (LDC) analysis was applied to characterize bacteria concentrations at different flow conditions.

Furthermore, potential load contributions from different possible pollutant sources were estimated using Geographic Information System (GIS) spatial analysis based on the best available data. By doing so, certain subareas within the watershed can be prioritized regarding management measure implementations.

Load Duration Curves

The LDC approach allows for estimation of existing and allowable pollutant loads by utilizing the frequency distribution of streamflow and measured pollutant concentration data (Cleland 2003; EPA 2007). Based on how pollutant loads vary across different streamflow conditions, assumptions can be made regarding pollutant contributors (point source/direct deposition or NPS).

In order to develop an LDC, a flow duration curve (FDC) needs to be developed first. To this end, streamflow data observed at a location (e.g., a SWQM station) were ordered from the highest to the lowest and assigned ranks, i.e., one for the highest flow, two for the second highest flow, and so on. Afterwards, the percentage of time a streamflow value was exceeded can be calculated using its rank divided by the total number of observations plus one. Finally, an FDC is developed by plotting the streamflow data (y-axis) against corresponding exceedance percentages (x-axis).

For Brushy Creek, FDCs were developed for drainage areas above SWQM stations 12054, 22392, 12059, 12060, and 12068. Since USGS stream gages were only available at SWQM station 12068 (USGS gage 08105883 Brushy Creek at IH35), continuous streamflow time series for other SWQM stations had to be estimated using the drainage area-ratio (DAR) method. Details regarding DAR are documented in Appendix A.

After developing FDCs at each monitoring station, flow values in cubic foot per second (cfs) were multiplied by the appropriate criterion for *E. coli* level in water (geometric mean of 126 MPN per 100 mL) and by a conversion factor (2.44658×10^{9}), resulting in maximum daily allowable *E. coli* loads (MPN per day). By plotting the maximum daily allowable loads in the same order as the flow values against the corresponding exceedance percentages, we got an LDC for the geometric mean criterion. After that, each measured load, i.e., measured *E. coli* level multiplied by the instantaneous flow and by a conversion factor (2.44658×10^{9}), was plotted on the LDC at the exceedance percentage associated with the instantaneous flow measurement. Plots of the maximum daily allowable LDCs with measured loads together show the frequency and magnitude at which measured loads exceed the geometric mean criterion for *E. coli.* Measured loads above the LDC indicate non-compliances.

A useful refinement of the LDC approach is to divide the curve into flow regimes to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which non-compliances are occurring.

Selection of the flow-regime intervals was based on general observations of the developed LDCs for geometric mean criterion, which vary from station to station. For monitoring stations 12060, 12059, and 22392, three flow regimes were identified: (1) 0-30 percent (moist condition); (2) 30-80 percent (mid-range flow); and (3) 80-100 percent (low flow). For stations 12068 and 12054, four flow regimes were identified: 1) 0-10 percent (high flow); (2) 10-30 percent (moist condition); (3) 30-80 percent (mid-range flow); and (3) 80-100 percent (low flow).

The geometric mean of the measured *E. coli* loads in each flow regime was also calculated to aid interpretation of the LDCs (Figure 21 – Figure 25)

Load Reduction

The load duration curves (LDCs) developed for the five monitoring stations on Brushy Creek are shown in Figures 21-Figure 25.

From downstream to upstream SWQM station 12054 needed a total reduction of 3.59×10^{14} MPN *E. coli* per year. Station 22392 needed a total reduction of 7.87×10^{14} MPN *E. coli* per year. Station 12059 needed a total reduction of 1.06×10^{15} MPN *E. coli* per year. Station 12060 needed a total reduction of 5.24×10^{14} MPN E. *coli* per year. Station 12068 needed a total reduction of 6.90×10^{13} MPN *E. coli* per year (Table 20 – Table 24). Formulas used for calculating existing load and load reduction needed are documented in Appendix B.

Table 20. Bacteria load reductions required to meet water quality goals at station 12054

AU	Flow Conditions		
1244_01	**Moist**	**Mid – Range**	**Low Flow**
Days per year	109.5	182.5	73
Median flow (cfs)	367	164	109
Existing geomean concentration (MPN/100mL)	491	122	91.4
Allowable daily load (MPN)	1.13E+12	5.06E+11	3.36E+11
Allowable annual load (MPN)	1.24E+14	8.34E+13	3.16E+13
Existing daily load (MPN)	4.41E+12	4.90E+11	2.44E+11
Existing annual load (MPN)	4.83E+14	8.08E+13	2.29E+13
Annual load reduction needed (MPN)	3.59E+14	0.00E+00	0.00E+00
Reduction needed	74.34%	0.00%	0.00%
Total annual load (MPN)	5.86E+14		
Total annual load reduction (MPN)	3.59E+14		
Total percent reduction needed	61%		

MPN – most probable number.

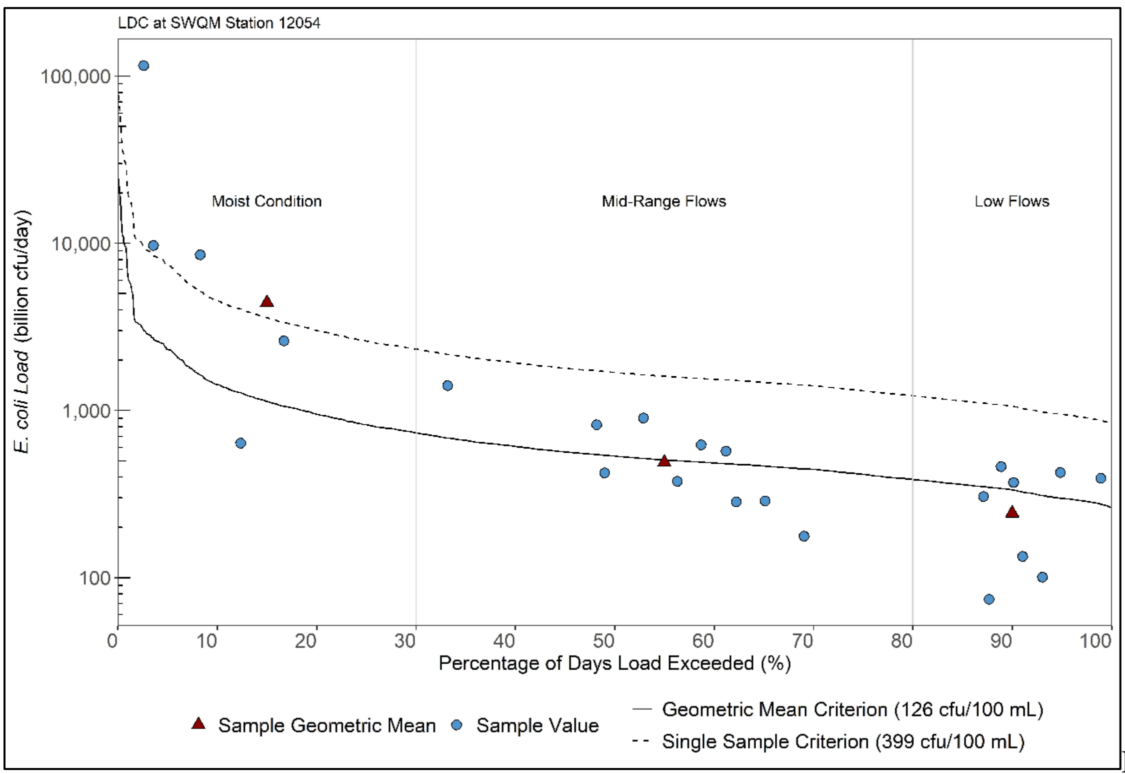

Figure 21. LDC at station 12054

Table 21. **Bacteria load reductions required to meet water quality goals at station 22392**

AU	Flow Conditions		
1244_02	**Moist**	**Mid – Range**	**Low Flow**
Days per year	109.5	182.5	73
Median flow (cfs)	174	76.3	48.7
Existing geomean concentration (MPN/100mL)	1,783	175	40.0
Allowable daily load (MPN)	5.36E+11	2.35E+11	1.50E+11
Allowable annual load (MPN)	5.87E+13	3.88E+13	1.41E+13
Existing daily load (MPN)	7.59E+12	3.27E+11	4.77E+10
Existing annual load (MPN)	8.31E+14	5.39E+13	4.48E+12
Annual load reduction needed (MPN)	7.72E+14	1.51E+13	0.00E+00
Percent reduction needed	92.93%	28.00%	0.00%
Total annual load (MPN)	8.90E+14		
Total annual load reduction (MPN)	7.87E+14		
Total percent reduction needed	89%		

MPN – most probable number

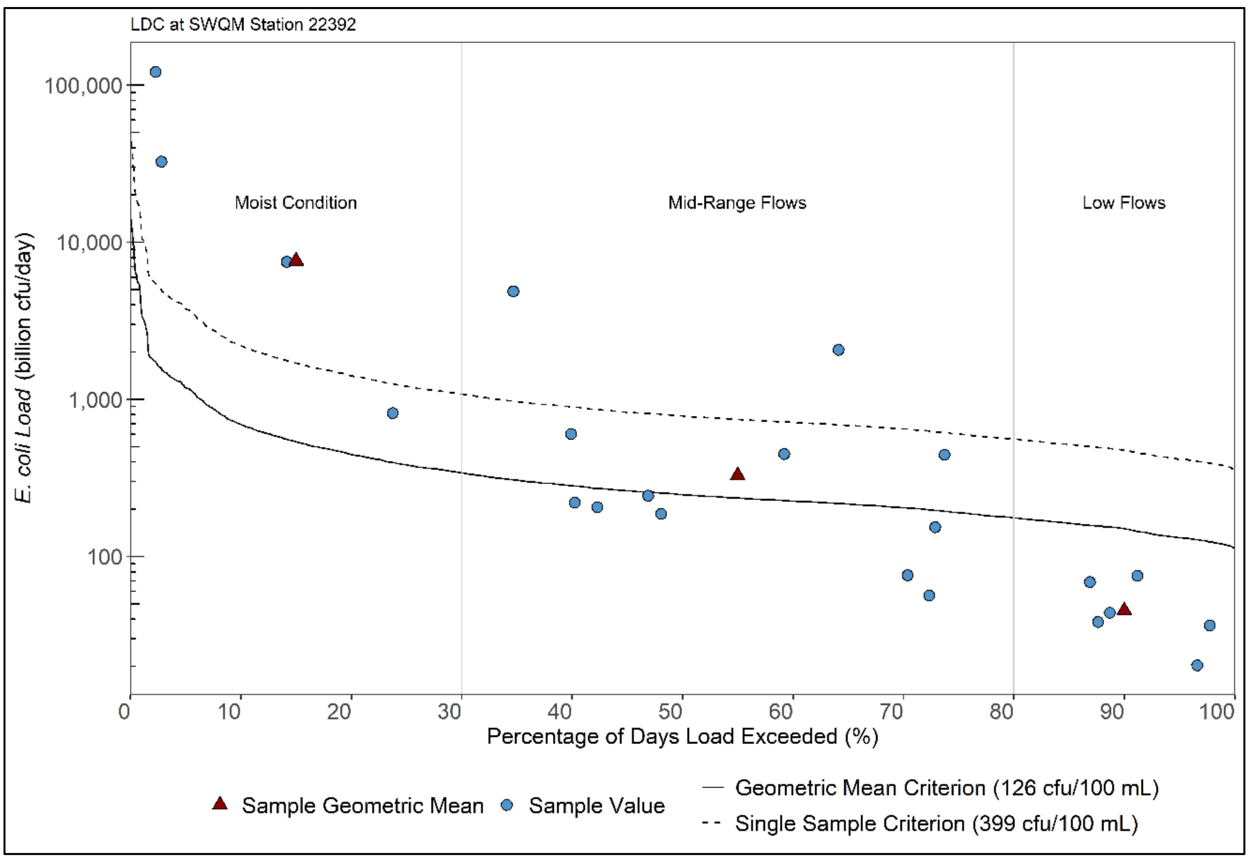

Figure 22. LDC at station 22392

Table 22. **Bacteria load reductions required to meet water quality goals at station 12059**

AU	Flow Conditions			
1244_02	**High Flow**	**Moist**	**Mid – Range**	**Low Flow**
Days per year	36.5	73	182.5	73
Median flow	509	167	63.9	21.7
Existing geomean concentration (MPN/100mL)	2,128	512	260	93.2
Allowable daily load (MPN)	1.57E+12	5.15E+11	1.97E+11	6.69E+10
Allowable annual load (MPN)	5.73E+13	3.76E+13	3.59E+13	4.88E+12
Existing daily load (MPN)	2.65E+13	2.09E+12	4.06E+11	4.95E+10
Existing annual load (MPN)	9.67E+14	1.53E+14	7.42E+13	3.61E+12
Annual load reduction needed (MPN)	9.10E+14	1.15E+14	3.82E+13	0.00E+00
Percent reduction needed	94.08%	75.39%	51.54%	0.00%
Total annual load (MPN)	1.20E+15			
Total annual load reduction (MPN)	1.06E+15			
Total percent reduction needed	89%			

MPN – most probable number.

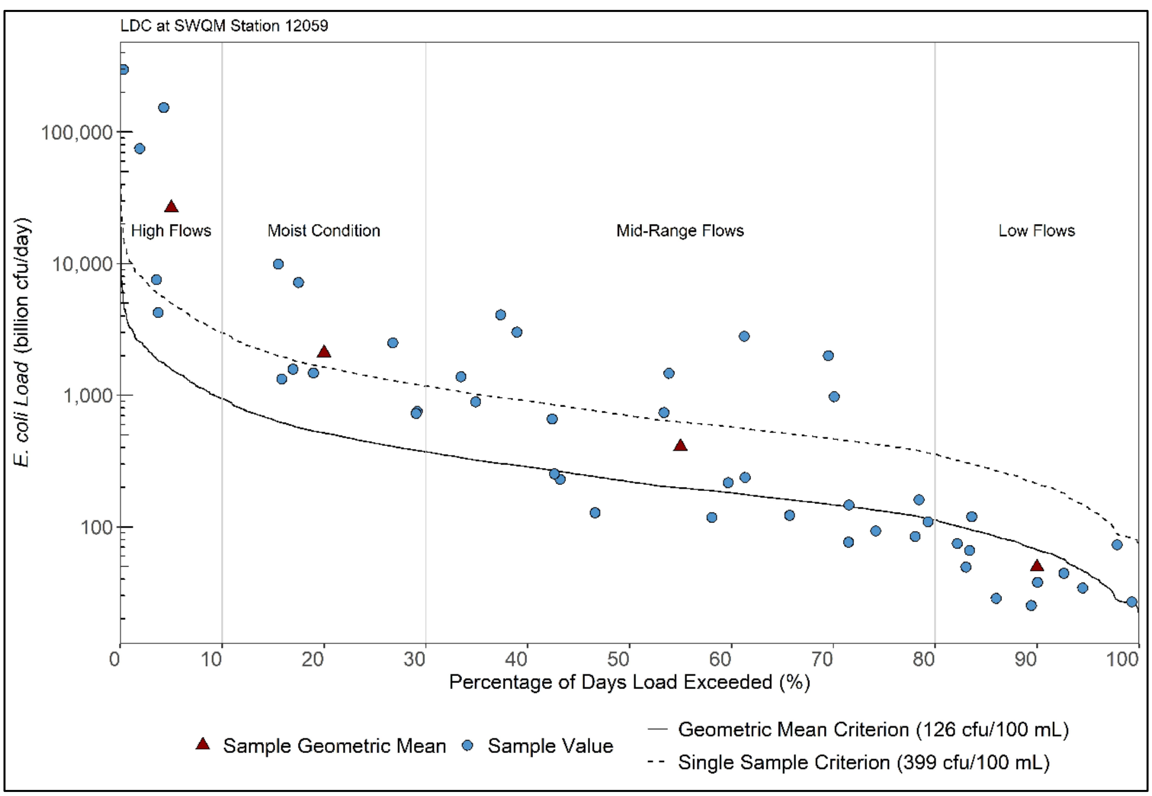

Figure 23. LDC at station 12059

Table 23. Bacteria load reductions required to meet water quality goals at station 12060

AU	Flow Conditions		
1244_03	**Moist**	**Mid-Range**	**Low Flow**
Days per year	109.5	182.5	73
Median flow	238	106	64.2
Existing geomean concentration	675	454	288
Allowable daily load (MPN)	7.34E+11	3.27E+11	1.98E+11
Allowable annual load (MPN)	8.03E+13	5.96E+13	1.44E+13
Existing daily load (MPN)	3.93E+12	1.18E+12	4.52E+11
Existing annual load (MPN)	4.30E+14	2.15E+14	3.30E+13
Annual load reduction needed (MPN)	3.50E+14	1.55E+14	1.86E+13
Percent reduction needed	81.33%	72.25%	56.25%
Total annual load (MPN)	6.78E+14		
Total annual load reduction (MPN)	5.24E+14		
Total percent reduction needed	77.23%		

MPN – most probable number.

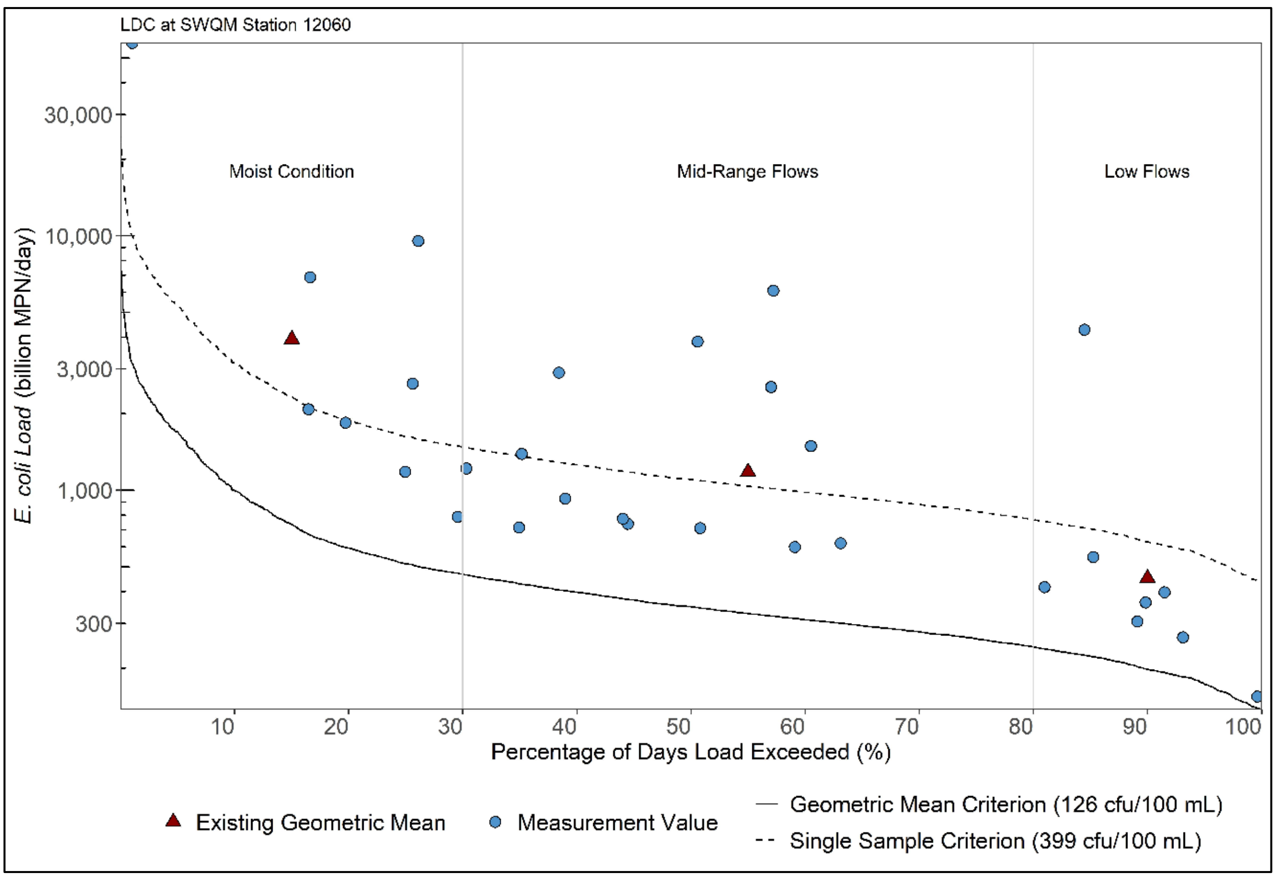

Figure 24. LDC at station 12060

Table 24. Bacteria load reductions required to meet water quality goals at station 12068

AU	Flow Conditions			
1244_04	High Flow	Moist	Mid-Range	Low Flow
Days per year	36.5	73	182.5	73
Median flow	247	69.4	31.3	11.7
Existing geomean concentration	439	103	65.9	74.2
Allowable daily load (MPN)	7.61E+11	2.14E+11	9.65E+10	3.61E+10
Allowable annual load (MPN)	2.78E+13	1.56E+13	1.76E+13	2.63E+12
Existing daily load (MPN)	2.65E+12	1.75E+11	5.05E+10	2.12E+10
Existing annual load (MPN)	9.68E+13	1.28E+13	9.21E+12	1.55E+12
Annual load reduction needed (MPN)	6.90E+13	0.00E+00	0.00E+00	0.00E+00
Percent reduction needed	71.30%	0.00%	0.00%	0.00%
Total annual load (MPN)	1.20E+14			
Total annual load reduction (MPN)	6.90E+13			
Total percent reduction needed	57.36%			

MPN – most probable number.

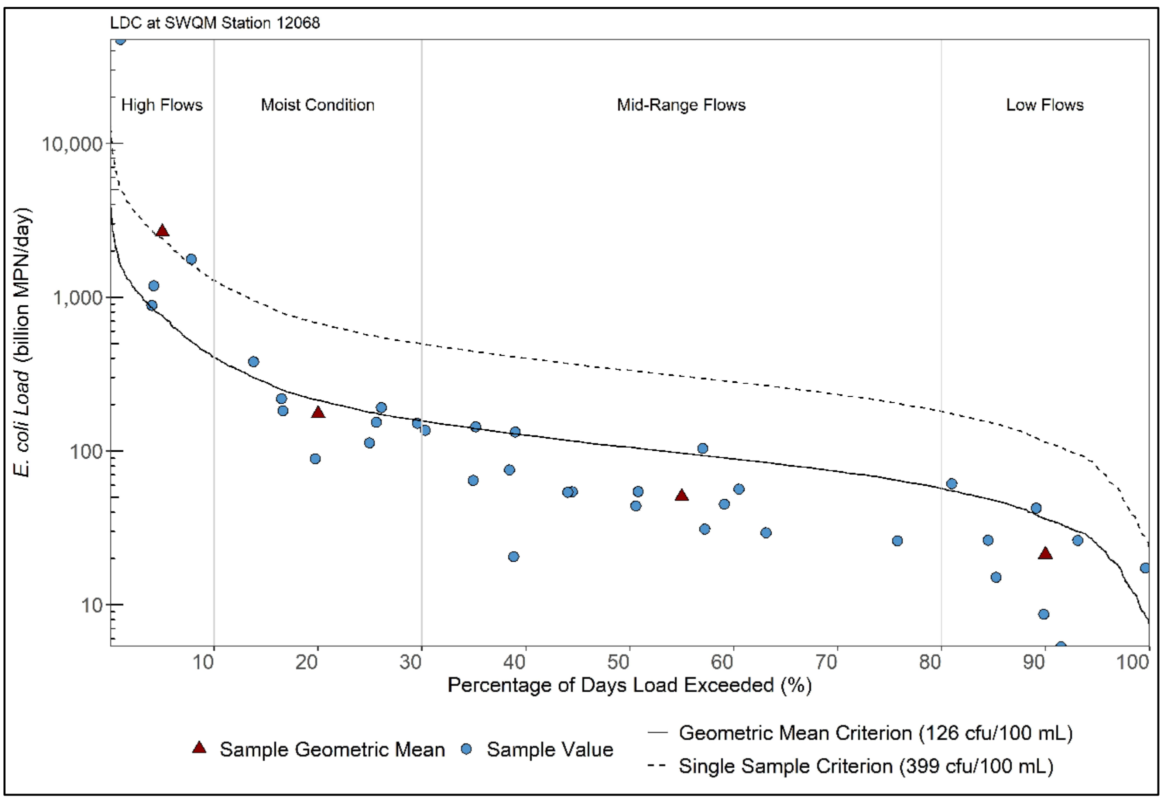

Figure 25. LDC at station 12068

Pollutant Load Estimate by Source

To aid in identifying potential areas of *E. coli* contributions within the watershed, GIS spatial analysis was conducted using the Spatially Explicit Load Enrichment Calculation Tool (SELECT) (Borel et al., 2012). The best available information was used to identify likely non-point sources of bacteria and calculate potential loadings.

Using this analysis approach, the relative potential for *E. coli* loading from each source can be compared and used to prioritize management. The loading estimates for each source are potential loading estimates that do not account for bacteria fate and transport processes that occur between the points where they originate and where they enter the water body. That said, results presented here represent worst case scenarios and do not reflect the *E. coli* loadings expected to enter the water bodies. Potential loadings for identified sources are estimated by subwatershed in the Brushy Creek watershed. Appendix C documents the assumptions and equations used for estimating potential bacteria loadings in the watershed for all identified sources.

Livestock

Livestock, such as cattle, horses, goats, and sheep, can contribute to *E. coli* loads by two pathways, including direct deposition of fecal matter into streams while wading, and runoff from pasture and rangeland that contain elevated levels of *E. coli*. Improving grazing practices and land stewardship can dramatically reduce runoff and bacteria loadings. For example, recent studies in Texas indicate that rotational grazing and grazing livestock in upland pastures during wet seasons results in significant reductions in *E. coli* loadings (Wagner et al. 2012). Furthermore, alternative water sources and shade structures located outside of riparian areas can significantly reduce the amount of time cattle spend in and near streams and consequently reduce fecal deposition (Wagner et al. 2012; Clary et al., 2016).

Based on the best available data, 23,785 cattle, 704 horses, 2,186 goats, and 1,487 sheep were estimated to be evenly distributed across the grazeable land in the Brushy Creek watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatersheds 8 and 10 (Figure 26).

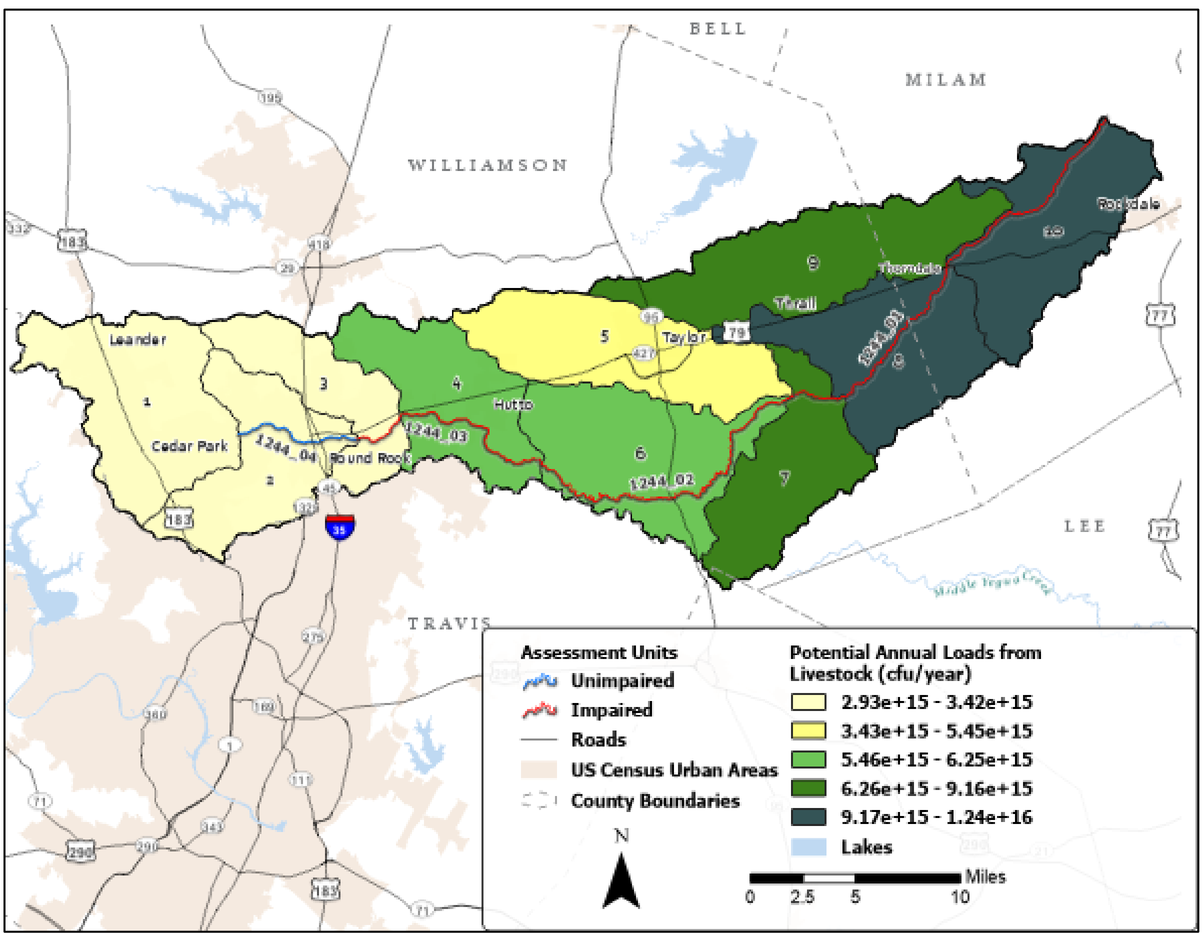

Figure 26. **Potential annual loads from livestock**

Deer

A total of 6,430 deer were estimated to be evenly distributed across the habitable land (i.e., deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands) in the Brushy Creek watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatersheds 6 and 9 (Figure 27).

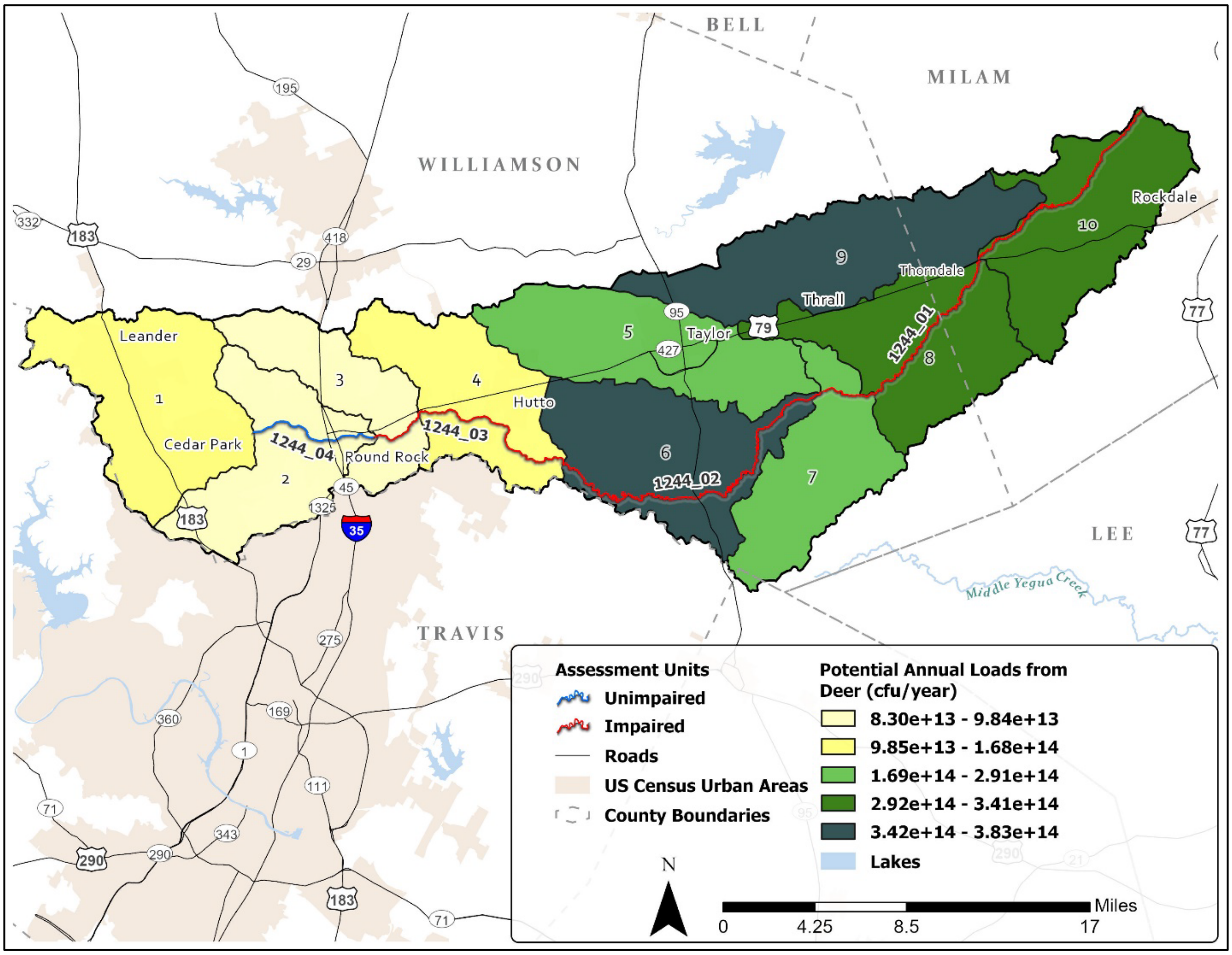

Figure 27. Potential annual loads from deer

Feral Hogs

A total of 7,836 feral hogs were estimated to be evenly distributed across the habitable land in the Brushy Creek watershed. GIS analysis indicated that the highest potential annual loadings may occur in subwatersheds 6 and 9 (Figure 28).

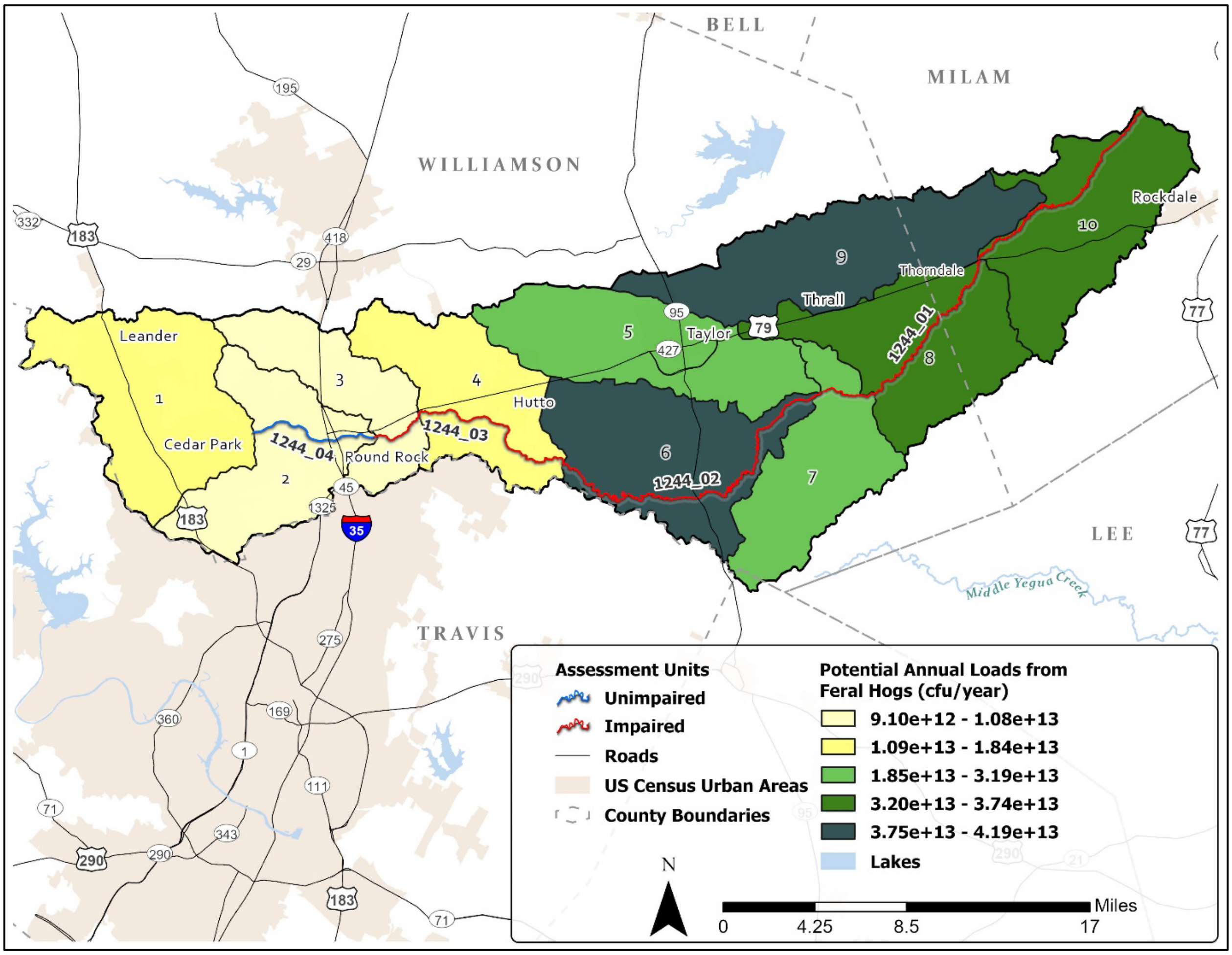

Figure 28. Potential annual loads from feral hogs

Dogs

A total of 115,374 dogs are estimated to live within the watershed. GIS analysis indicated that the highest potential annual loading occurs in populous subwatersheds 1 and 2 (Figure 29).

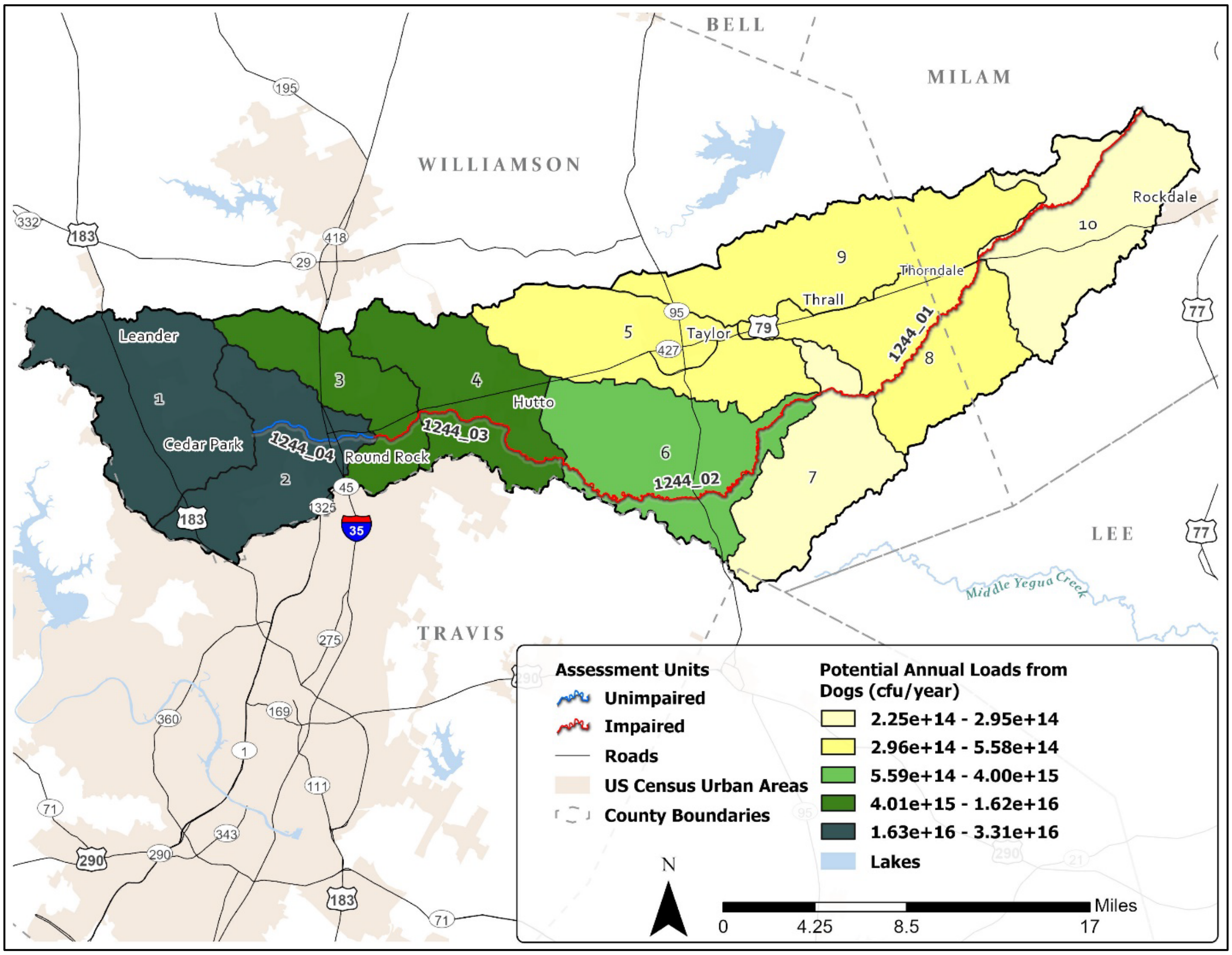

Figure 29. Potential annual loads from dogs

WWTFs

According to the TPDES data, there are nine permitted WWTFs that may contribute *E. coli* loads directly into one of the segments in the Brushy Creek watershed. These wastewater discharges are regulated by TCEQ and each WWTF self-reports their average monthly discharges and *E. coli* concentrations.

Although the permitted discharge volumes and bacteria concentrations are below permitted values, potential loading was calculated using the maximum permitted discharges and *E. coli* concentrations to assess the maximum potential load. The highest potential loading may occur in subwatershed 3 (Figure 30).

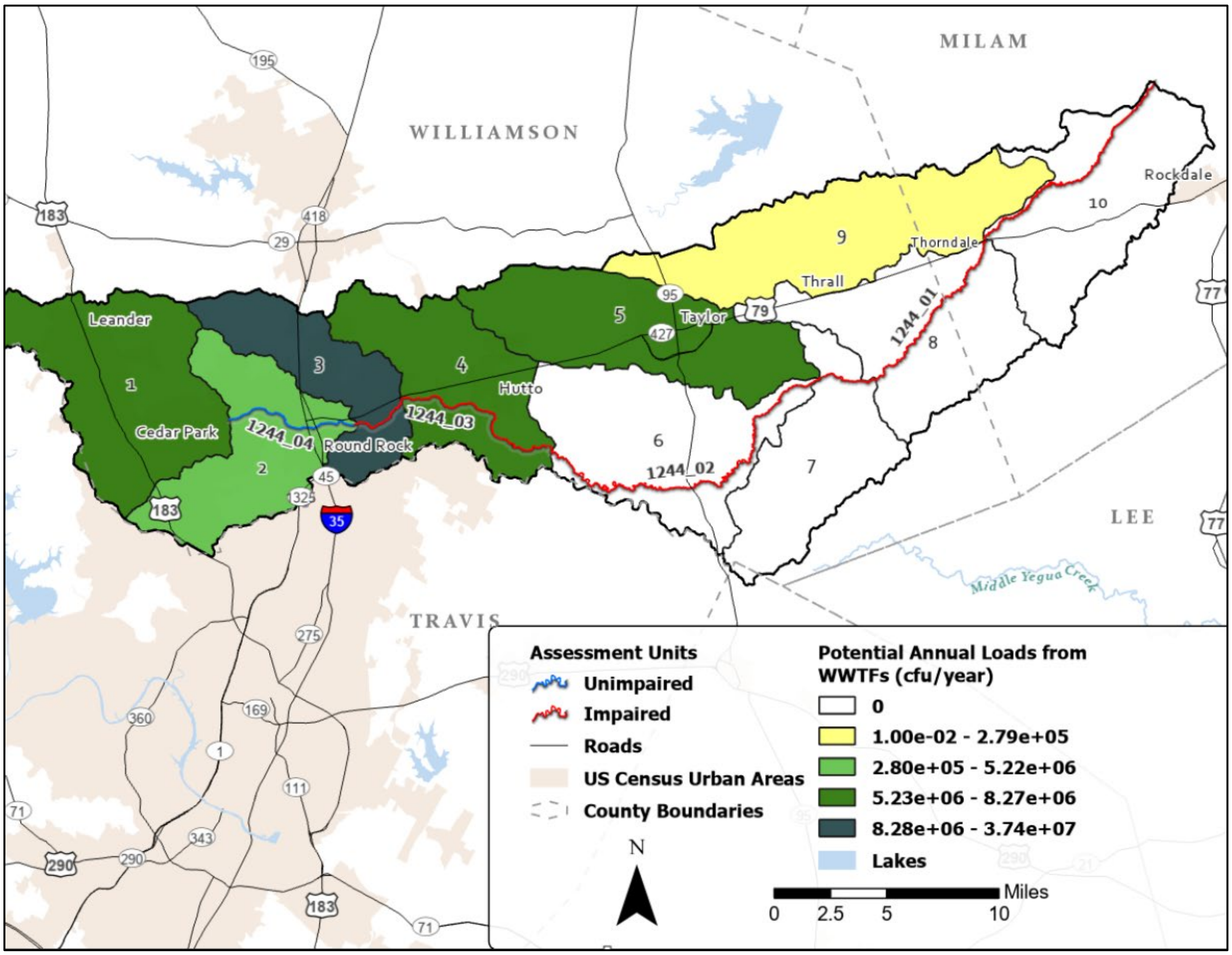

Figure 30. **Potential annual loads from WWTFs**

OSSFs

A total of 5,359 OSSFs were estimated to be located within the Brushy Creek watershed, of which 12% are assumed to fail in any given year (Reed, Stowe, and Yanke, 2001). GIS analysis indicated that the highest potential annual loading may occur in subwatershed 4 (Figure 31).

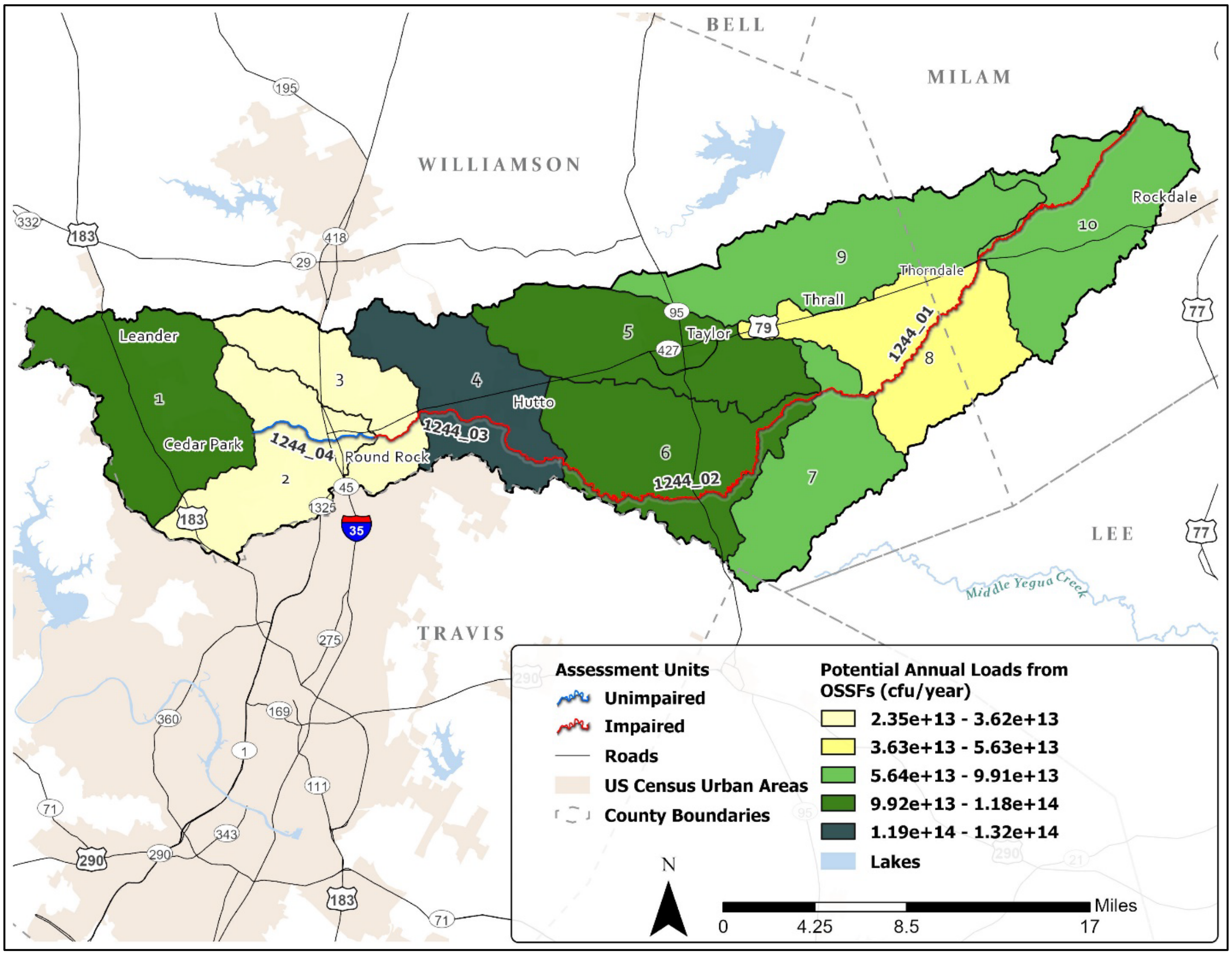

Figure 31. Potential annual loads from OSSFs

Load Reduction and Sources Summary

The LDC analysis provided in the first half of this section indicates the flow conditions under which *E. coli* loadings enter a water body and the amount of reduction needed to meet the primary contact recreation standard.

Segment 1244_01 (Brushy Creek) above SWQM station 12054 exceeded the capacity of the water body under moist flow conditions and a reduction of 3.59×10^{14} MPN per year is needed.

Segment 1244_02 above SWQM station 22392 exceeded the capacity of the water body under moist and mid-range flow conditions. A total reduction of 7.87×10^{14} MPN per year is needed. This segment above station 12059 exceeded the capacity of the water body under all flow conditions except for low-flow conditions. A total reduction of 1.06×10^{15} MPN per year is needed.

Segment 1244_03 above SWQM station 12060 exceeded the capacity of the water body under all flow conditions. A total reduction of 5.24×10^{14} MPN per year is needed.

Segment 1244_04 above SWQM above station 12068 only exceeded the capacity of the water body under high-flow condition. A total reduction of 6.90×10^{13} MPN per year is needed

Given the relatively good compliances of permitted dischargers in the watershed, bacteria loading exceedances during dry and low flow conditions are likely attributable to direct deposition from livestock and wildlife in addition to discharges from OSSFs in riparian areas.

Bacteria in runoff are likely to contribute to exceedances during higher flow conditions. Sources of bacteria-laden runoff might include runoff from rangeland, pastureland, and drainage fields of faulty OSSFs. Besides, I&I (inflow and infiltration) during heavy rainfall events and resulting SSOs or unauthorized discharges may also contribute to elevated loads during high flow conditions.

Among all the pollutant sources analyzed, livestock appeared to be the most significant potential contributor of *E. coli* loading (Table 25). Identifying where grazeable (i.e., herbaceous and hay/pasture) lands are the most concentrated in the watershed helps to highlight important areas to address and implement potential improvements in grazeable land runoff.

Total potential loadings are most likely underestimated because many other wildlife sources of fecal bacteria are not included in the analysis.

Spatial analysis also suggests relatively high potential for loadings from dogs in subwatersheds that encompass cities, and it will be important to address pet waste and stormwater runoff from impervious surfaces in these areas.

Table 25. **Summary of potential source loads from smallest to largest contributors.**

WWTFs	6.60×10^{7}	3
Horses	5.90×10^{13}	8, 10
Feral Hogs	2.73×10^{14}	6, 9
Goats	2.17×10^{15}	8, 10
Deer	2.48×10^{15}	6, 9
OSSFs	7.98×10^{15}	4
Sheep	1.98×10^{16}	8, 10
Cattle	4.68×10^{16}	8, 10
Dogs	1.01×10^{17}	1, 2
Total	**1.81×10^{17}**	**1, 2**

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Appendix A: Estimating Streamflow

For LDC analysis, continuous streamflow records are required to construct FDCs. For Brushy Creek, long-term continuous streamflow observations are available only at USGS gages 08105883 (Brushy Creek at IH35) and 08105888 (Brushy Creek near Kennedy Fort Blvd). Additionally, there is another gage, 08106050 (Brushy Creek near Taylor), that measures continuous daily stage data (i.e., relative distance between the water surface and a reference point) and streamflow data only during high flow/flooding events (Figure A-1). Gage 08105883 is located at SWQM station 12068 (AU 1244_04) and can be directly used to construct the FDC for this location. However, the other SWQM stations lack long-term streamflow records necessary for LDC analysis.

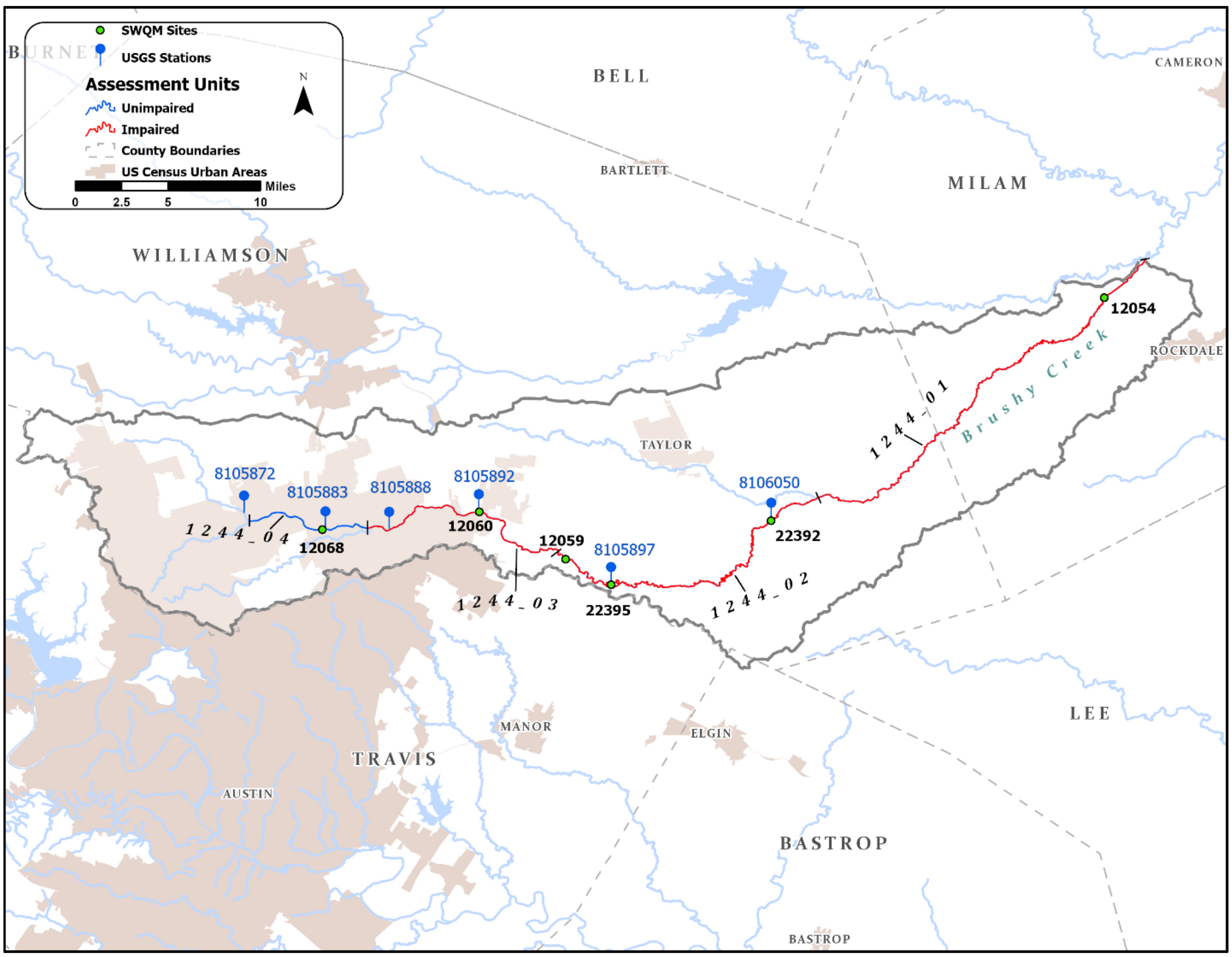

Figure A-1. Locations of SWQM stations and USGS gages in the watershed

To approximate long-term streamflow records at SWQM station 12060, Asquith et al. (2006)'s DAR method was applied to transfer streamflow data from USGS gage 08105883 (reference gage) using Equation A-1. Similarly, for SWQM station 12059, DAR was applied to transfer streamflow data from USGS gage 08105888 (reference gage) using Equation A-1. Table A-1 provides the drainage area information used in Equation A-1.

Traditionally, a value of ϕ = 1 is used in DAR. However, empirical analysis of Texas streamflows suggests that ϕ = 1 introduces substantial bias in estimates at very low- and very high-streamflow conditions (Asquith et al., 2006). Based on these findings, a range of values for ϕ was applied across different percentiles (ϕ ranges between 0.7 and 0.935) (Asquith et al., 2006).

It is important to note that DAR-estimated streamflow records require further adjustments if additional discharge or diversions exist between the reference gages and the target location. For SWQM stations 12060 and 12059, discharges from WWTFs (Table A-2) were added to the DAR-estimated streamflow records over the entire study period, which spans October 1, 2014 – September 30, 2024. This nine-year period was selected based on the availability of streamflow data at the reference gages, and FDC developed using this data were considered representative of the general FDC characteristics of the area.

Equation A-1

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

where:

Y = *streamflow for the ungaged location,*

X = *streamflow for the gaged location,*

A_y = *drainage area for the ungaged location,*

A_x = *drainage area for the gaged location, and*

ϕ = *exponent based on streamflow percentile*

Table A-1. Drainage area ratios used at each SWQM station

Target Location (drainage area mi.^{2})	Reference Gage (drainage area mi.^{2})	Drainage Area Ratio
SWQM Station 12068 (70.50)	USGS 08105883 (70.5)	1.00
SWQM Station 12060 (164.23)	USGS 08105883 (70.5)	2.33
SWQM Station 12059 (187.61)	USGS 08105888 (113)	1.66

SWQM – Surface Water Quality Monitoring; USGS – U.S. Geological Survey.

Table A-2. Extra discharges used to adjust DAR-estimated streamflow at SWQM stations 12060 and 12059

Target Location	Facility Name (TPDES ID)	Additional Discharge
SWQM Station 12060	- Brushy Creek Regional East WWTP (TX0101940) - Brushy Creek Regional West WWTP (TX0075167) - Forest Creek WWTP (TX0118265)	(21.5 + 0.99 + 3) MGD = 34.79 cfs
SWQM Station 12059	- City of Hutto Central WWTP (TX0025577) - City of Hutto South WWTP (TX0132926)	(2.5+0.99) MGD = 5.40 cfs

TPDES – Texas Pollutant Discharge Elimination System; SWQM – Surface Water Quality Monitoring; WWTP – Wastewater Treatment Plant; MGD – Million Gallons per Day; cfs – cubic feet per second.

For SWQM station 22392, two flow estimation methods were applied and compared. First, DAR was applied using USGS gage 08105888 as the reference gage. The drainage area ratio used in Equation A-1 was 164.23 mi.^{2}/70.5 mi.^{2} = 2.33. Second, streamflow data were estimated based on a rating curve developed for this location. A rating curve is a graphical representation that shows the relationship between the stage in depth and streamflow in volume.

Previously, Yang et al. (2024) developed a rating curve at SWQM station 22392 using data collected by a noncontact radar flowmeter between January 24, 2024, and January 29, 2024 (Equation A-2).

Equation A-2

$$H = 0.4348 \times Q^{0.4687}$$

where Q is streamflow in cubic feet per second and H is water depth in feet.

Since USGS gage 08106050 measures "gage height", which is the distance between water surface and a reference point, instead of water depth (H), gage height records needed to be converted to H first and then used in Equation A-2. In Yang et al. (2024), the conversion relationship was quantified using Equation A-3.

Equation A-3

$$H = -3.7161 + 0.8333 \times Gage\ Height$$

Using the rating curve and DAR methods, two continuous streamflow time series were estimated for SWQM station 22392 (Figure A-2; Figure A-3).

It was clear that DAR notably underestimated flows across all flow regimes compared to the rating curve method. Given that the hydrograph produced by the rating curve appeared to be more realistic, particularly in lower flows, than that produced by the DAR method, for SWQM station 22392, rating curve-estimated flows were used for LDC analysis.

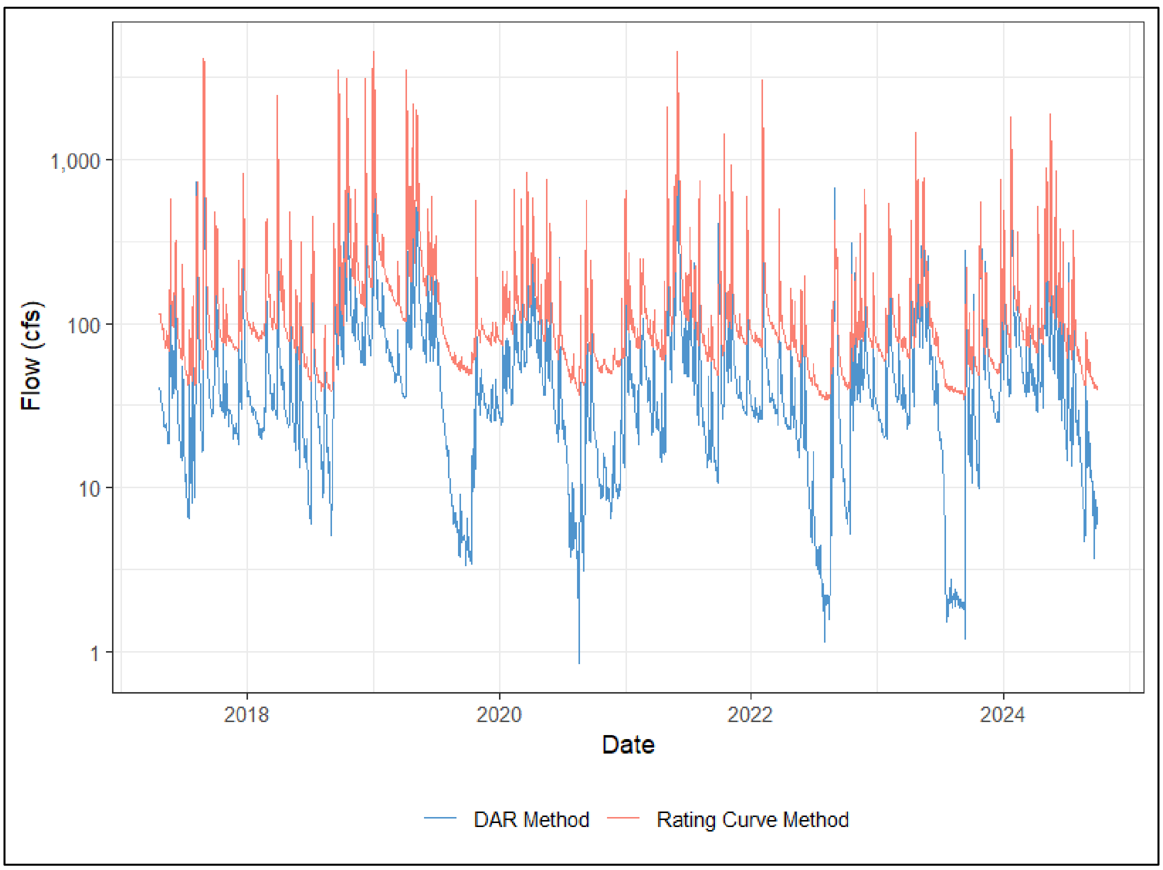

Figure A-2. Method comparison in hydrographs at SWQM station 22392

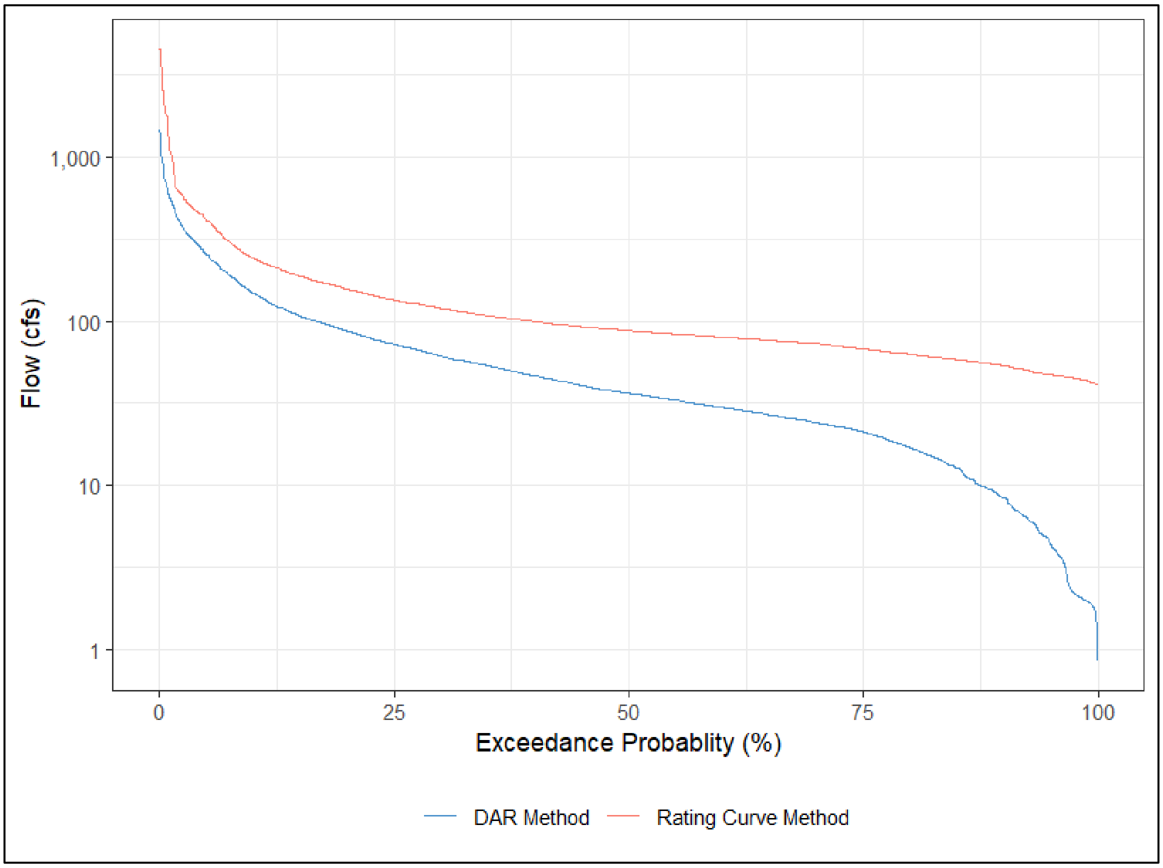

Figure A-3. Method comparison in FDCs at SWQM station 22392

For SWQM station 12054, streamflow time series extrapolated independently from two reference locations were compared. First, USGS gage 08106350 at Little River near Rockdale was used as the reference gage in DAR, and the drainage area ratio was 517.62 mi.^{2}/6,959 mi.^{2} = 0.074. Second, SWQM station 22392 was used as the reference gage, and, based on the drainage area ratio of 517.62/241.49 = 2.14, rating curve-estimated streamflow data were extrapolated (Figure A-4; Figure A-5). It was clear that DAR-estimated flows using USGS gage 08106350 as the reference gage were significantly smaller than that estimated using SWQM station 22392 as the reference gage. Discharges from two WWTFs were used to further adjust the DAR results (Table A-3).

Table A-3. Extra discharges used to adjust DAR-estimated streamflow at SWQM station 12054

Target Location	Facility Name (TPDES ID)	Additional Discharge
SWQM Station 12054	- Mustang Creek WWTP (TX0020443) - City of Thorndale WWTP (TX0032379)	(4+0.16) MGD = 6.44 cfs

TPDES – Texas Pollutant Discharge Elimination System; SWQM – Surface Water Quality Monitoring; WWTP – Wastewater Treatment Plant; MGD – Million Gallons per Day; cfs – cubic feet per second.

Given that SWQM station 12054 was located distantly downstream of 22392, its flow magnitude should be greater than that of SWQM station 22392, DAR-estimated flow magnitude using USGS gage 08106350, however, resulted in flow magnitude that was too small to be realistic. That said, for this location, streamflow extrapolated from SWQM station 22392 was used in LDC analysis.

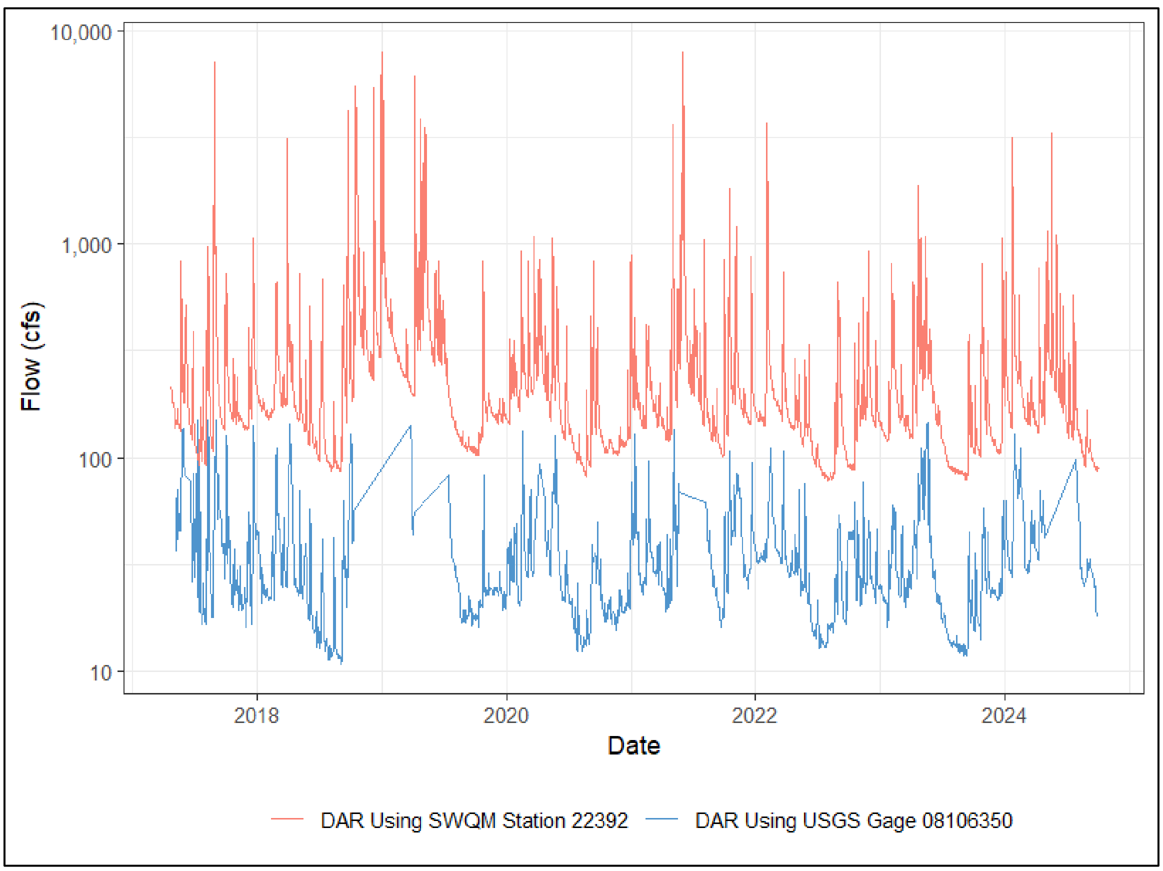

Figure A-4. Method comparison in hydrographs at SWQM station 12054

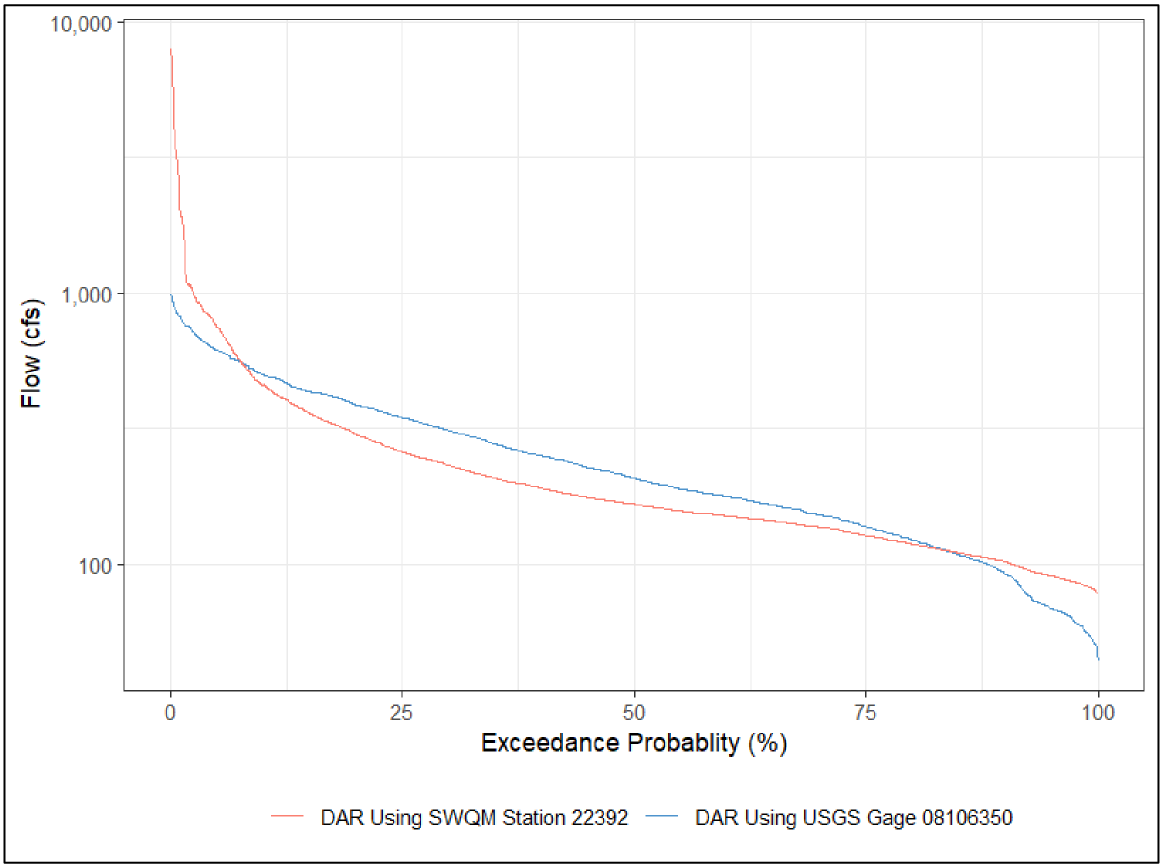

Figure A-5. Method comparison in FDCs at SWQM station 12054

Appendix A Reference

Yang, L., Gregory, L., and Lundeen, E. 2024. Brushy creek watershed monitoring and historical streamflow estimation final report and data summary report. Texas Water Resources Institute. TR-554. College Station, Texas. https://twri.tamu.edu/publications/technical-reports/2024-technical-reports/tr-554/.

Appendix B: Annual Bacteria Load Reductions

LDCs and measured *E. coli* loading are summarized by flow conditions. The generalized loading capacity for each of the flow conditions was computed by using the median daily loading capacity within that flow condition. Flow conditions were defined differently for the analyzed SWQM stations in the Brushy Creek watershed based on the availability of water quality data. The required daily load reduction was calculated as the difference between the median loading capacity and the geometric mean of measured *E. coli* loading within each flow condition. To estimate the needed annual bacteria load reductions, the required daily load was multiplied by the number of days per year in each flow condition. Table B-1 includes the calculations used to determine annual reductions in each flow condition. The sum of load reductions within each flow condition is the estimated annual load reductions required in the watersheds.

Table B-1. Example of bacteria load reduction calculations by flow condition

	Flow Condition				
	High Flow	**Moist**	**Mid-Range**	**Dry**	**Low Flow**
Percentage of Year	**10%**	**30%**	**20%**	**30%**	**10%**
Days per Year	Percentage of Year × 365				
Median Flow (cfs)	Median observed or median estimated flow in each flow condition				
Existing Geomean Concentration (MPN/100 mL)	Geometric mean of observed *E. coli* samples in each flow condition				
Allowable Daily Load (MPN)	Median Flow × 126 MPN/100 mL × 28316 mL/cubic foot × 86,400 seconds/day				
Allowable Annual Load (MPN)	Allowable Daily Load × Days per year				
Existing Daily Load (MPN)	Median Flow × Existing Geomean Concentration × 28,316.8 mL/cubic foot × 86,400 seconds/day				
Existing Annual Load (MPN)	Existing Daily Load × Days per year				
Annual Load Reduction Needed (MPN)	Existing Annual Load – Allowable Annual Load				
Percent Reduction Needed	(Existing Annual Load – Allowable Annual Load)/Existing Annual Load × 100%				
Total Annual Load (MPN)	Sum of Existing Annual Loads				
Total Annual Load Reduction (MPN)	Sum of Annual Load Reductions Needed				
Total Percent Reduction	Total Annual Load Reduction/Total Annual Load × 100%				

cfs – cubic feet per second; MPN – most probable number; mL – milliliter.

Appendix B Reference

Asquith, W. H., Roussel, M. C., and Vrabel, J. 2006. Statewide analysis of the drainage-area ratio method for 34 streamflow percentile ranges in Texas. 2328-0328. US Geological Survey.

Appendix C: Potential Bacteria Loading Calculations

GIS analysis was used to estimate spatial distribution of potential bacteria loadings from various sources across the watershed at subwatershed scale. This analysis distributed bacteria loadings across the watersheds based primarily on land cover and population/household distributions.

Potential Bacterial Loadings from Livestock

Watershed livestock population estimates were estimated based on the 2022 Census of Agriculture county-level statistics (NASS 2024). The county-level data were refined to reflect acres of grazeable land (herbaceous and hay/pasture) within the Angelina River watershed as identified in the NLCD (2021). Based on Wagner and Moench (2009) and the estimated number of livestock (Table C-1), we calculated the potential annual loadings from cattle, horses, goats, and sheep using the equation below:

Equation C-1

Potential annual loadings = *number of livestock in the watershed*
× *livestock to animal unit conversion factor (Wagner and Moench 2009)*
× *fecal coliform produced per animal unit per day (Wagner and Moench 2009)*
× *fecal coliform to E. coli conversion rate (Wagner and Moench 2009)*
× *365 days*

In the Brushy Creek watershed, there are an estimated 23,785 cattle contributing to 4.68×10^{16} *E. coli* per year, 705 horses contributing to 5.90×10^{13} *E. coli* per year, 10,876 goats contributing to 2.17×10^{15} cfu *E. coli* per year, and 1,487 sheep contributing to 1.98×10^{16} cfu *E. coli* per year.

For each subwatershed, the number of livestock was estimated using the acreage of the grazeable land in the subwatershed multiplied by the livestock density estimated for the entire Brushy Creek watershed. The livestock density was determined as the ratio of the total estimated number of livestock in the Brushy Creek watershed to the total acreage of the grazeable land in the Brushy Creek watershed (Table C-1). Conversions factors used in Equation C-1 are listed in Table C-2.

Table C-1. Estimated livestock density in the Brushy Creek watershed

Livestock	Estimated Population	Grazeable Land (acres)	Estimated Livestock Density
Cattle	23,785	106,770	0.22277
Horses	705	106,770	0.00659
Goats	10,876	106,770	0.02047
Sheep	1,487	106,770	0.01393

Table C-2. Conversion factors used in the equation

Livestock	Animal Unit Conversion	Fecal coliform (cfu/AU/Day)
Cattle	1	8.55×10^{9}
Horse	1.25	2.91×10^{8}
Goats	0.17	2.54×10^{10}
Sheep	0.2	2.90×10^{11}
Deer	0.112	1.50×10^{10}
Feral Hogs	0.125	1.21×10^{9}

cfu – colony forming unit; AU – animal unit

Potential Bacteria Loadings from Other Animals

Loadings from deer and feral hogs were also estimated using Equation 1.

In the Brushy Creek watershed, there is an estimated 6,430 deer contributing to 2.48×10^{15} cfu *E. coli* per year and 7,836 feral hogs contributing to 2.73×10^{14} cfu *E. coli* per year.

For each subwatershed, the number of livestock was estimated using the acreage of the habitable land in the subwatershed multiplied by the regional-level animal density estimated by TPWD (2024) and Timmons et al. (2012) (Table C-3). Conversions factors used in Equation C-1 are listed in Table C-4.

Table C-3. Deer and feral hog densities in the Brushy Creek watershed

Animal	Density (acres/animal)	Habitable Land (acres)	Estimated Population
Deer	39	250,758	6,430
Feral Hogs	32	250,758	7,836

Table C-4. Conversion factors used in the equation

Livestock	Animal Unit Conversion	Fecal coliform (cfu/AU/Day)
Deer	0.112	1.50×10^{10}
Feral Hogs	0.125	1.21×10^{9}

cfu – colony forming unit; AU – animal unit

Appendix C Reference

National Agricultural Statistic Service. NASS. 2024. U.S. Department of Agriculture 2022 Census of Agriculture United States Summary and State Data. https://www.nass.usda.gov/Publications/AgCensus/2022/index.php#full_report

National Land Cover Database. NLCD. 2021. Multi-Resolution Land Characteristics Consortium (MRLC). USGS. https://www.mrlc.gov/data/nlcd-2021-land-cover-conus

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Texas Parks and Wildlife Department. TPWD. 2024. Statewide white-tailed deer density data request through email. J. Salmeron.