Watershed Characterization of the Angelina River above Sam Rayburn Reservoir Watershed

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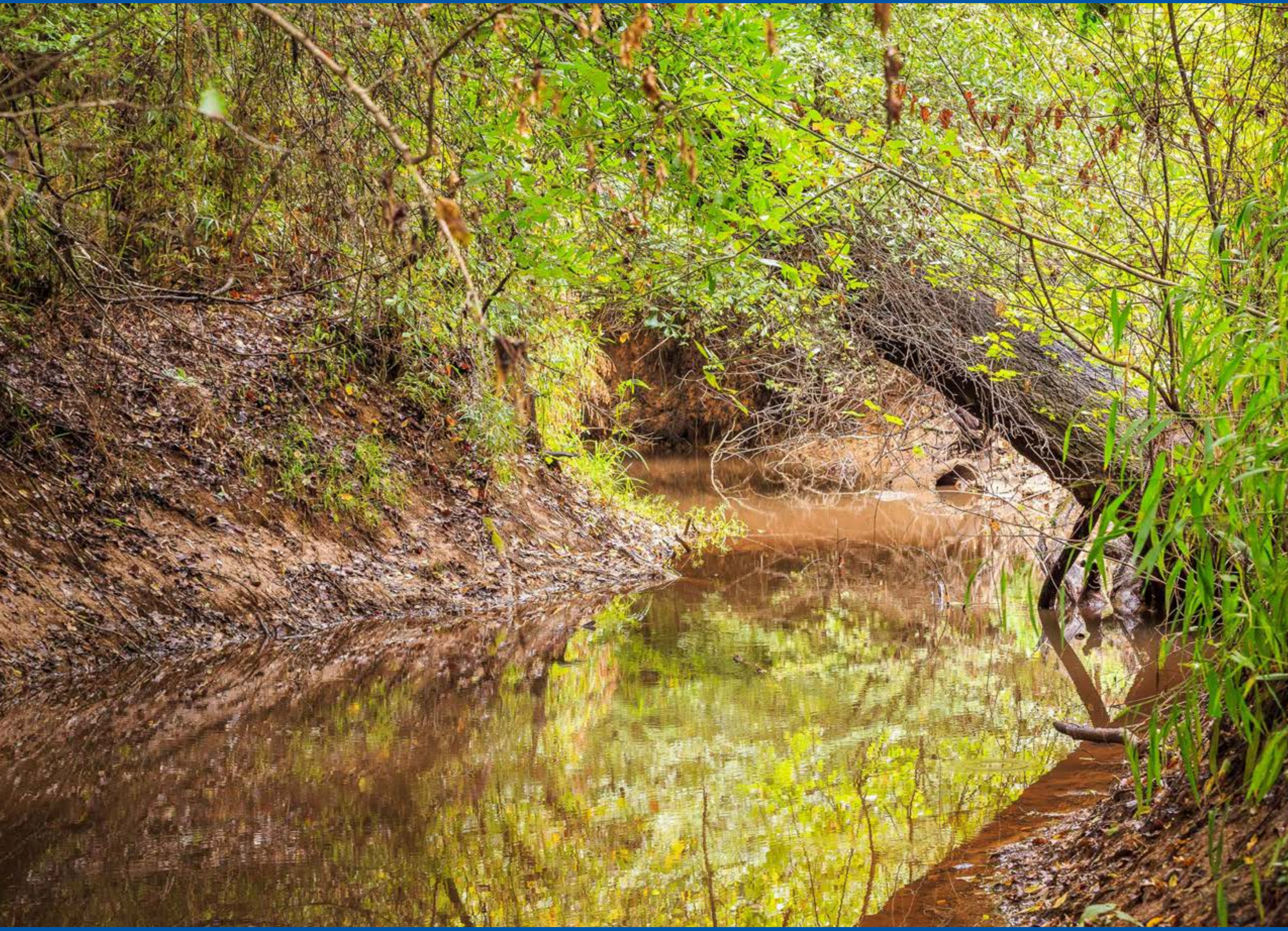

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Segment Numbers: 0611, 611A, 611C, 611D

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List of Acronyms

ANRA	Angelina and Neches River Authority
AU	Assessment Unit
AVMA	American Veterinary Medical Association
BOD	Biological Oxygen Demand
CAFO	Concentrated Animal Feeding Operations
CCN	Convenience and Necessity
cfu	Colony Forming Units
CWA	Clean Water Act
DEM	Digital Elevation Model
DO	Dissolved Oxygen
ECHO	Enforcement and Compliance History Online
EPA	Environmental Protection Agency
FDC	Flow Duration Curve
FIB	Fecal Indicator Bacteria
GIS	Geographic Information System
LDC	Load Duration Curve
MGD	Million Gallons per Day
mL	Milliliter
MPN	Most Probable Number
MSGP	Multi Sector General Permit
MS4	Municipal Separate Storm Sewer Systems
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	On-Site Sewage Facility
PCR	Primary Contact Recreation
PRISM	Parameter Elevation Regressions on Independent Slopes Model
RMU	Resource Management Unit
RUAA	Recreational Use Attainability Analysis
SNC	Significant Non-Compliance
SSO	Sanitary Sewer Overflow
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department

TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

Executive Summary

Angelina River above Sam Rayburn Reservoir and its tributaries, including East Fork Angelina River, Mud Creek, and West Mud Creek, are identified as impaired for elevated concentrations of *Escherichia coli* (*E. coli*) in the *2020 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report; TCEQ 2020). In addition, in the *2018 Texas Integrated Report-Potential Sources of Impairments and Concerns* (TCEQ 2019), Angelina River above Sam Rayburn Reservoir is listed with concerns for total phosphorus and West Mud Creek for ammonia and nitrate. Angelina River above Sam Rayburn Reservoir has been listed as impaired for elevated levels of bacteria since as early as 2000 (TCEQ 2011). East Fork Angelina River was first listed for bacteria impairment in 2002 (TCEQ 2011). For Mud Creek and West Mud Creek, bacteria impairment has been recognized since 2010 (TCEQ 2011). This characterization report assesses the physiographic, climatic, demographic, and hydrologic conditions of the entire area drained by the above-mentioned river and creeks.

Activities for the current project include water quality monitoring, trainings, and meeting with soil and water conservation districts in each watershed to discuss the goals and objectives of addressing the bacteria impairments. Educational programs were delivered to stakeholders to inform them of watershed management and to increase their understanding of what factors contribute to bacteria impairments. Existing data for water quality parameters, flow, livestock, wildlife, stormwater permits, and number of on-site sewage facilities have been analyzed to develop a better understanding of potential causes and sources of bacteria pollution.

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Background Information

Description of the Watershed and Water Bodies

Angelina River is divided by Sam Rayburn Reservoir into two water bodies (segments) with specific identifiers (segment IDs): Angelina River above Sam Rayburn Reservoir (segment 0611) and Angelina River below Sam Rayburn Reservoir (segment 0609). Tributaries of segment 0611 include the East Fork of the Angelina River (segment 0611A), Mud Creek (segment 0611C), and West Mud Creek (segment 0611D).

Segment 0611 is described as a classified freshwater stream that flows 104 miles from the aqueduct crossing 0.6 miles upstream of the confluence of Paper Mill Creek in Angelina/Nacogdoches County to the confluence of Barnhardt Creek and Mill Creek at FM 225 in Rusk County (TCEQ 2020). This segment is composed of four distinct assessment units (AUs), 0611_01, 0611_02, 0611_03, and 0611_04, of which 0611_01 and 0611_04 are listed as impaired for bacteria in water for recreation use (TCEQ 2020). AU 0611_04 has also been listed with concerns for total phosphorous (TCEQ 2018). Segment 0611A flows 30.4 miles from the confluence of the Angelina River at the Rusk/Nacogdoches County line to the upstream perennial portion of the stream west of Mount Enterprise in Rusk County (TCEQ 2020). This segment is composed of two AUs, 0611A_01 and 0611A_02, and both are listed as impaired for bacteria (TCEQ 2020). Segment 0611C flows 45 miles from the confluence of the Angelina River east of Rusk in Cherokee County to the upstream perennial portion of the stream west of Troup in Smith County (TCEQ 2020). This segment is composed of two AUs, 0611C_01 and 0611C_02, and 0611C_01 is listed as impaired for bacteria in water for recreation use (TCEQ 2020). Segment 0611D is 23 miles long, flowing from the confluence of Mud Creek southwest of Troup in Cherokee County to the upstream perennial portion of the stream south of Tyler in Smith County. This segment is composed of two AUs, 0611D_01 and 0611D_02, of which 0611D_01 has been listed as impaired for bacteria in water for recreation use (TCEQ 2020), as well as for elevated concentrations of ammonia and nitrate (TCEQ 2018).

As listed in Table 1, the four analyzed segments together drain an area of approximately 1,030,149 acres, of which 24,201 acres are in Angelina County (2.35%), 209,711 acres in Cherokee County (30.06%), 229,203 acres in Nacogdoches County (22.25%), 290,330 acres in

Rusk County (28.18%), and 176,705 acres in Smith County (17.15%). This drainage area is hereinafter referred to as the Angelina River watershed. Figure 1 depicts an overview of the Angelina River watershed. Table 2 contains information regarding the segments, AUs, and impaired AUs in the watershed.

Table 1. Area of the Angelina River watershed.

County	County area (acres)	Area of watershed within county (acres)	Percent of watershed within each county
Angelina	551,029	24,200.79	2.35
Cherokee	676,996	309,710.83	30.06
Nacogdoches	625,429	229,202.8	22.25
Rusk	598,718	290,329.93	28.18
Smith	605,527	176,705.09	17.15
Watershed Total		1,030,149.44	

Table 2. Descriptions of segments and assessment units (AUs) in the Angelina River watershed.

Segment ID	Name	Description	AUs	Impaired AUs
0611	Angelina River above Sam Rayburn Reservoir	From the aqueduct crossing 1.0 kilometer upstream of the confluence of Paper Mill Creek in Angelina/Nacogdoches County to the confluence of Barnhardt Creek and Mill Creek at FM 225 in Rusk County.	0611_01, 0611_02, 0611_03, 0611_04	0611_01, 0611_04
0611A	East Fork Angelina River	The segment extends from the confluence of the Angelina River at the Rusk/Nacogdoches County line to the upstream perennial portion of the stream west of Mount Enterprise in Rusk County.	0611A_01, 0611A_02	0611A_01, 0611A_02
0611C	Mud Creek	The segment extends from the confluence of the Angelina River east of Rusk in Cherokee County to the upstream perennial portion of the stream west of Troup in Smith County.	0611C_01, 0611C_02	0611C_01
0611D	West Mud Creek	The segment is located from the confluence of Mud Creek southwest of Troup in Cherokee County to the upstream perennial portion of the stream south of Tyler in Smith County.	0611D_01, 0611D_02	0611D_01

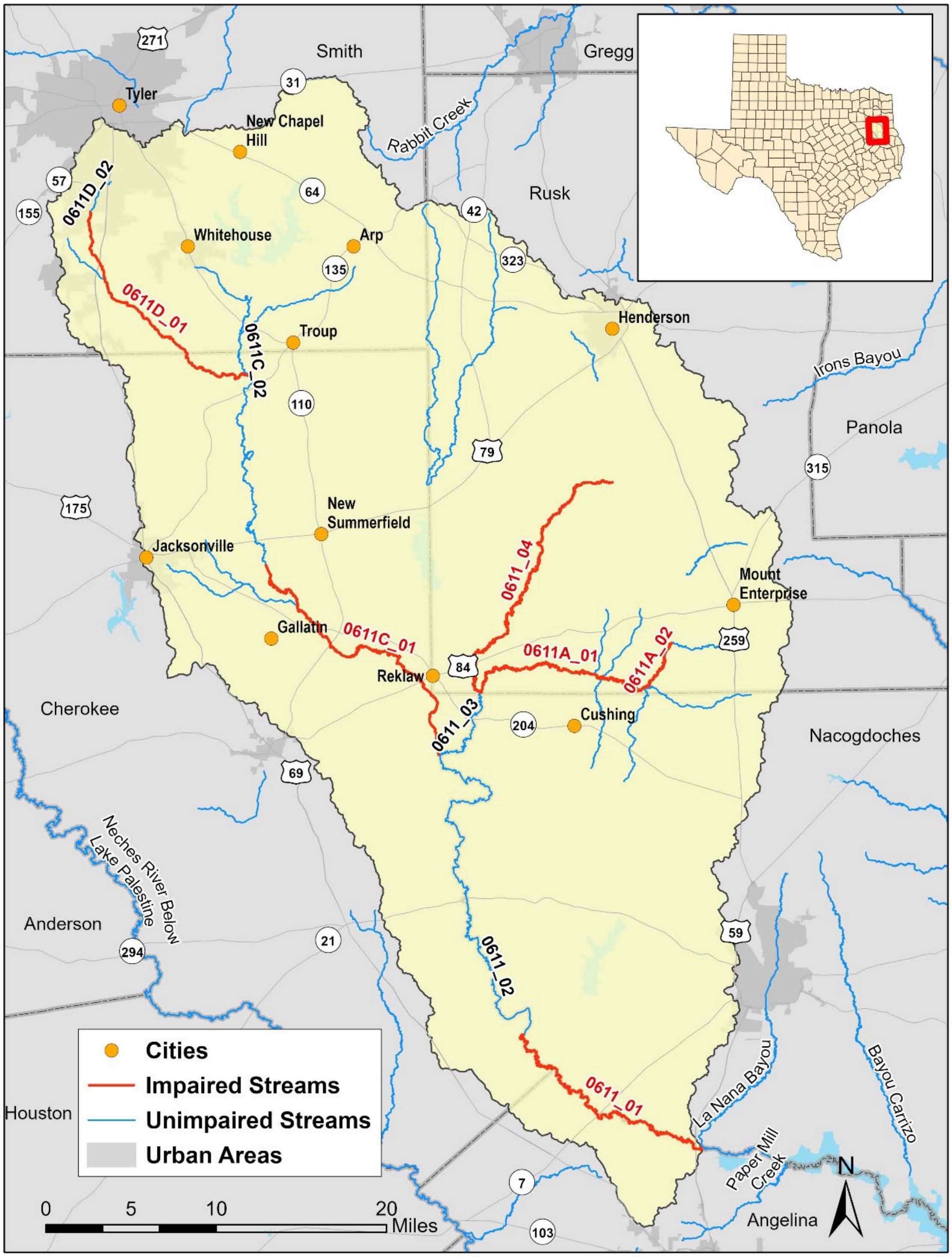

Figure 1. Overview of the Angelina River watershed.

Soils and Topography

The soils and topography of a watershed are important controls on hydrologic response. Slope and elevation determine the direction of the flow, while soil properties influence how much and how fast water will infiltrate into, flow over, or move through the soil into a water body. Soil properties may also limit the types of development and activities that can occur in an area.

Across the Angelina River watershed, the elevation ranges from 164 feet above mean sea level to 771 feet above mean sea level as shown in Figure 2. The digital elevation models (DEMs) were acquired from the U.S. Geological Survey (USGS) National Map dataset (USGS 2019).

Soil data were obtained from the U.S. 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 have 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 have 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 have 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 have a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential,

soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

- Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and the second letter is assigned to undrained areas. Only soils that are in group D in their natural condition are assigned to dual classes.

In general, the soils in the Angelina River watershed have an HSG classification of C (39%) or D (12%; Table 3; Figure 3).

Table 3. Hydrologic soil groups (HSGs) in the Angelina River watershed.

HSG	Acreage	Percentage of total (%)
Null	31,315	3.0
A	100,668	9.8
A/D	639	0.1
B	244,978	23.8
B/D	76,021	7.4
C	402,855	39.1
C/D	45,419	4.4
D	128,251	12.4
Total	1,030,146	

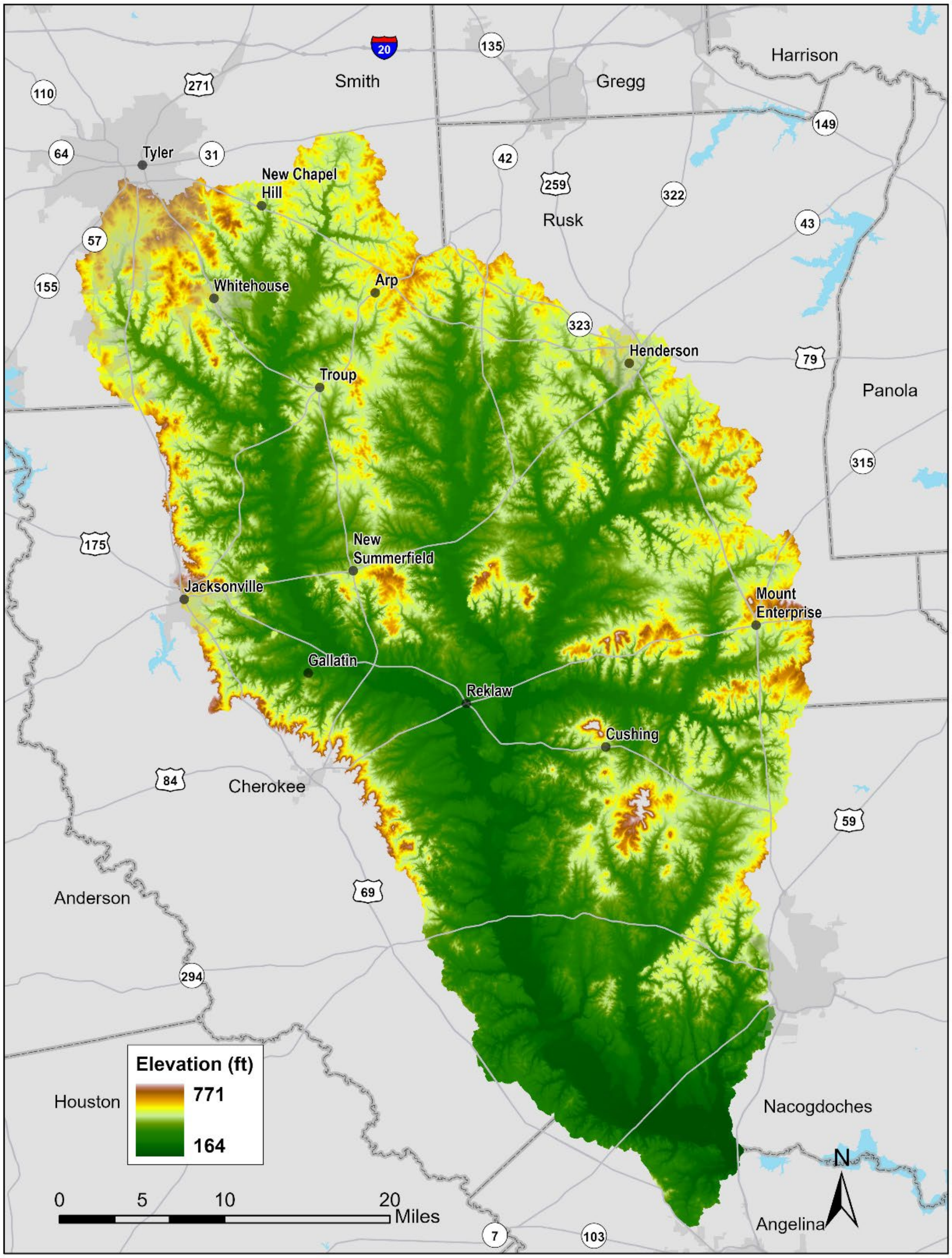

Figure 2. Elevation of the Angelina River watershed.

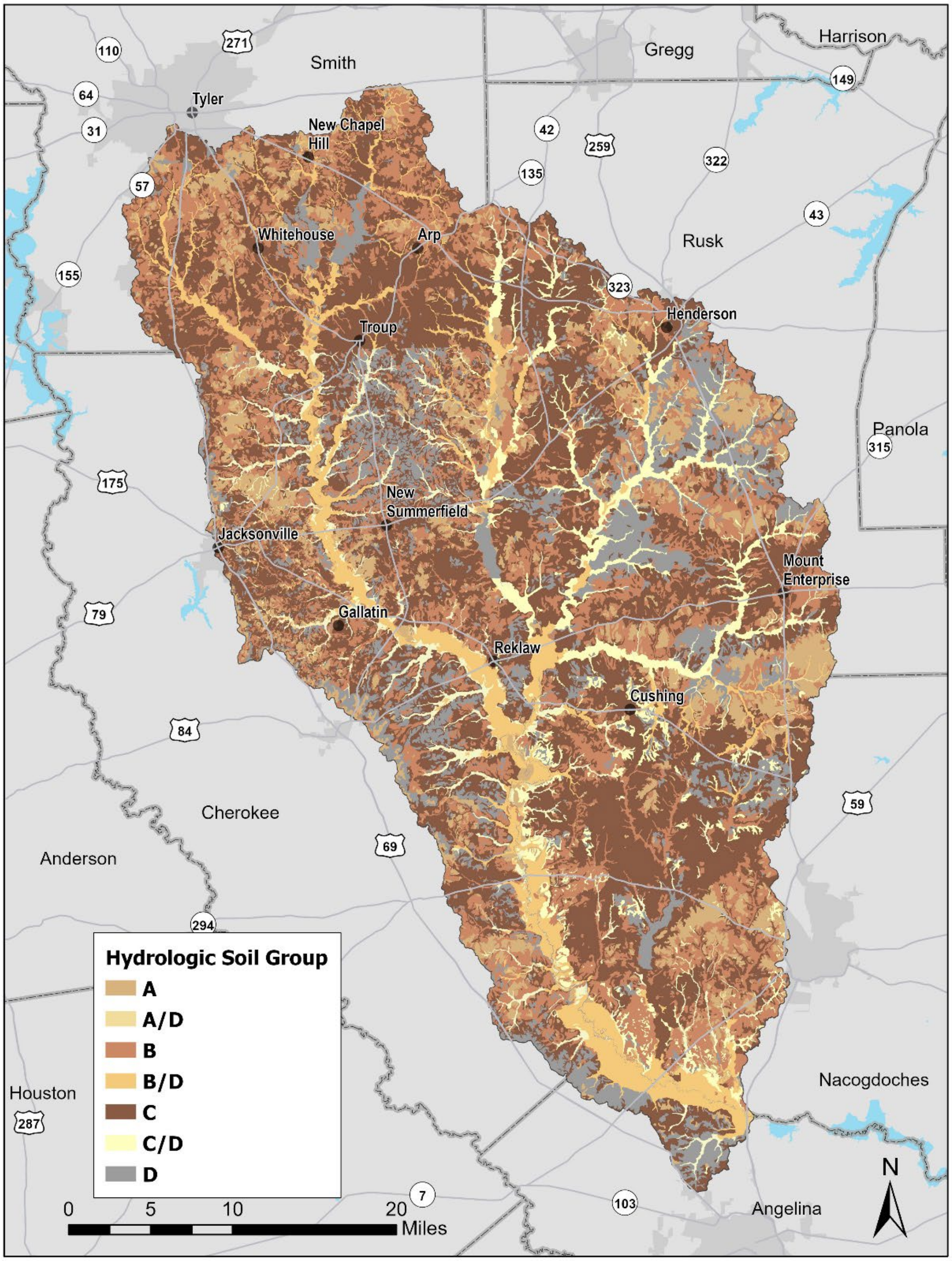

Figure 3. Hydrologic soil groups in the Angelina River watershed.

Ecoregions

Ecoregions are areas with ecosystems that contain similar quality and quantity of natural resources (Griffith et al. 2007). Ecoregions have been delineated into four separate levels, with level I being the most unrefined classification and level IV being the most refined. According to Griffith et al. (2007), the Angelina River watershed is entirely located in one level-III ecoregion, the South Central Plains or Piney Woods region (35). Meanwhile, three distinct level-IV ecoregions are found in the watershed: the Tertiary Uplands (35a), Floodplains and Low Terraces (35b), and Southern Tertiary Uplands (35e). Of them, Tertiary Uplands encompasses the majority of the watershed (Figure 4).

The ecoregion of Tertiary Uplands (35a) contains a diversity of habitats and species. The landscape of this ecoregion contains dissected irregular plains with some low rolling hills and low to moderate gradient streams. The soils are mostly well-drained ultisols and alfisols with sandy and loamy surface textures. Pine density in this region is less than that in the Southern Tertiary Uplands (35e) and Flatwoods (35f) to the south. The natural vegetation has been altered by multiple timber harvest and commercial pin plantation activities. The dominant land cover types in this region are deciduous forest, mixed forest, and pasture.

The ecoregion of Floodplains and Low Terraces (35b) contains nearly level floodplains and associated low terraces, as well as low gradient streams. Soils of the floodplains are clayey and loamy ranging from somewhat poorly drained to very poorly drained. The dominant land cover types in this region are deciduous forest, forested wetlands, and mixed forest.

The ecoregion of Southern Tertiary Uplands (35e) is hillier and more dissected compared to the Flatwoods (35f) to the south. The dominant soils are alfisols and ultisols like the Tertiary Uplands (35a). Historically, the dominant vegetation in this region was the longleaf pine woodlands accompanied by various types of forests. Large parts of the region are public U.S. Forest Service land.

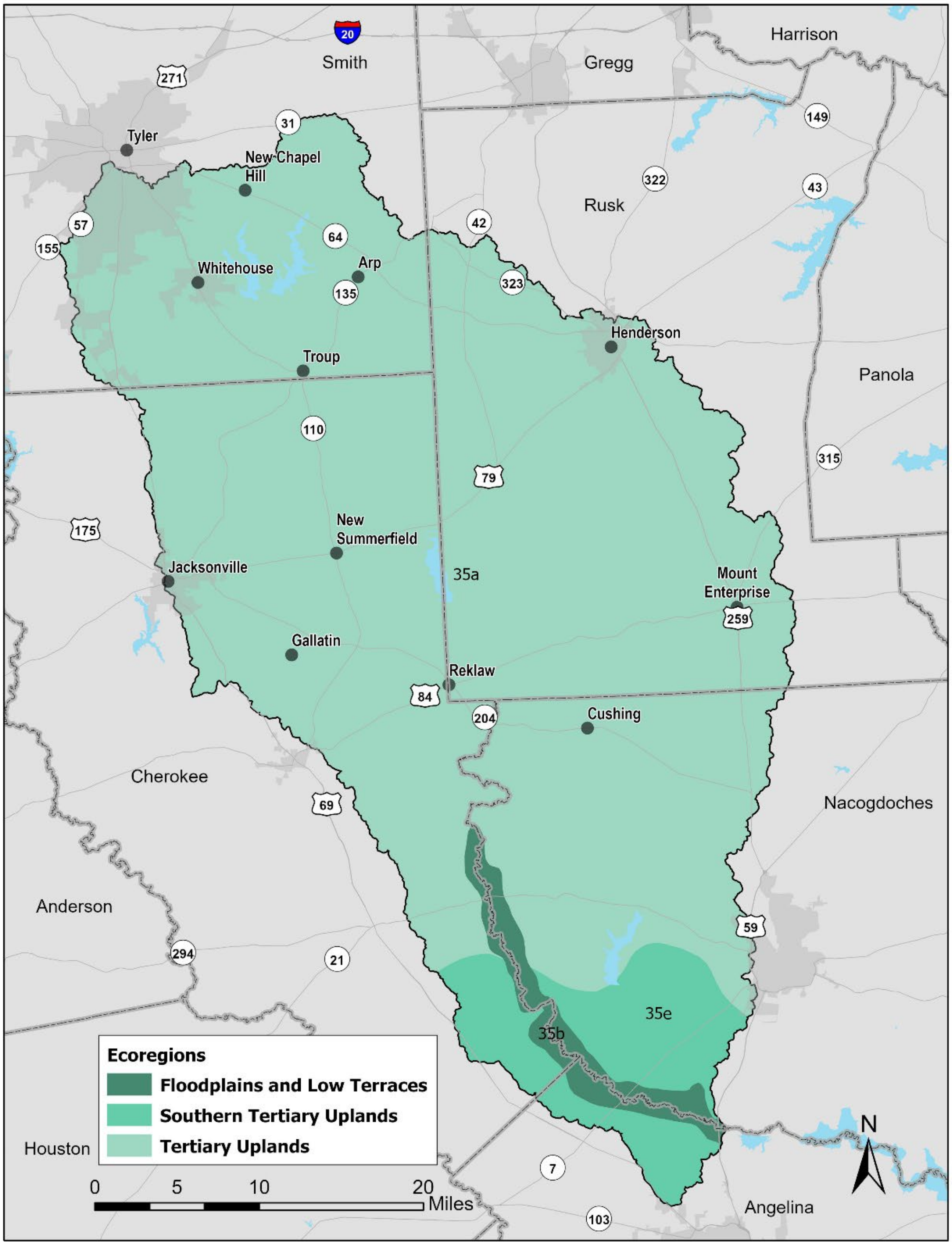

Figure 4. Ecoregions in the Angelina River watershed.

Land Cover

Land cover data were obtained from the 2019 National Land Cover Database (NLCD 2019). Table 4 and Figure 5 describe different types of land cover within the Angelina River watershed. The dominant land covers are pasture/hay (28.01%) and evergreen forest (21.23%). Developed lands (open space, low, medium, or high intensity) constitute approximately 8.63% of the watershed. The largest urbanized area in the watershed is the city of Tyler.

Table 4. National Land Cover Database (NLCD; NLCD 2019) land cover in the Angelina River watershed.

NLCD classification	Acres	Percent of total (%)
Open water	16,573	1.60
Developed, open space	36,669	3.55
Developed, low intensity	32,919	3.18
Developed, medium intensity	14,409	1.39
Developed, high intensity	5,262	0.51
Barren land	1,238	0.12
Deciduous forest	36,573	3.54
Evergreen forest	219,632	21.23
Mixed forest	150,590	14.56
Scrub/shrub	56,724	5.48
Grassland/herbaceous	53,199	5.14
Pasture/hay	289,712	28.01
Cultivated crops	11	0.00
Woody wetlands	113,369	10.96
Emergent herbaceous wetlands	7,448	0.72
Total	1,034,328*	100

*Total acreage for the watershed differs from 1,030,149 acres as listed previously in the report due to calculations that involve raster data in the spatial analysis for land cover.

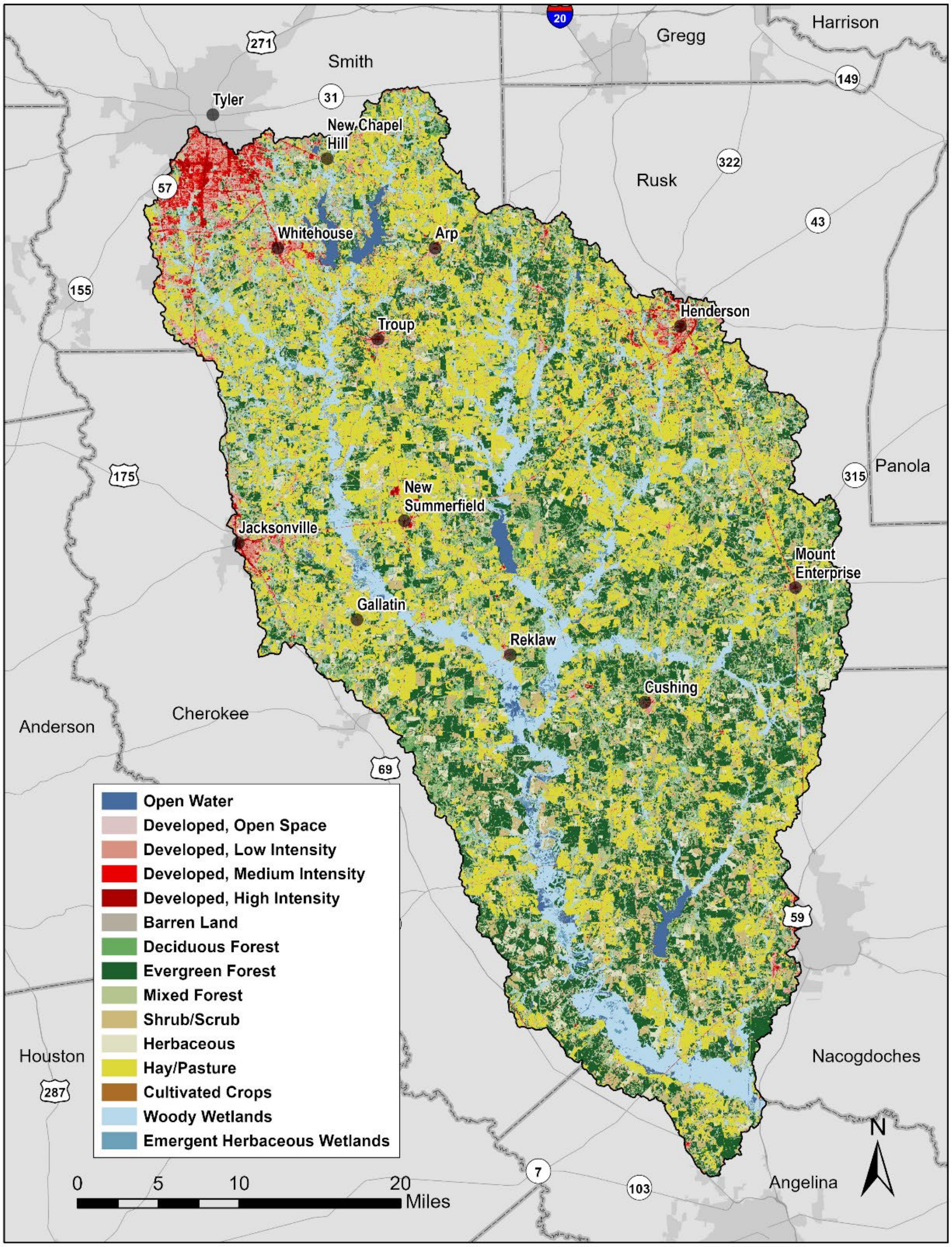

Figure 5. Land use/land cover within the Angelina River above Sam Rayburn Reservoir watershed.

Climate

Precipitation and temperature data between 1981 and 2010 were approximated for the Angelina River watershed using data collected at the weather station USC00417841 in Rusk, Texas (NOAA 2018). During the period of interest, the average daily air temperature was the highest in August (82°F) and the lowest in January (46°F). The average monthly total precipitation ranged between 2.8 and 4.9 inches, with the greatest amount of precipitation in October and the smallest amount in August (Figure 6).

According to the PRISM (Parameter-elevation Regressions on Independent Slopes Model) dataset (PRISM Climate Group 2019), 30-year (1981–2010) average annual precipitation in the Angelina River watershed ranged from 45.7 to 51.2 inches, with a noticeable north-to-south increasing gradient (Figure 7).

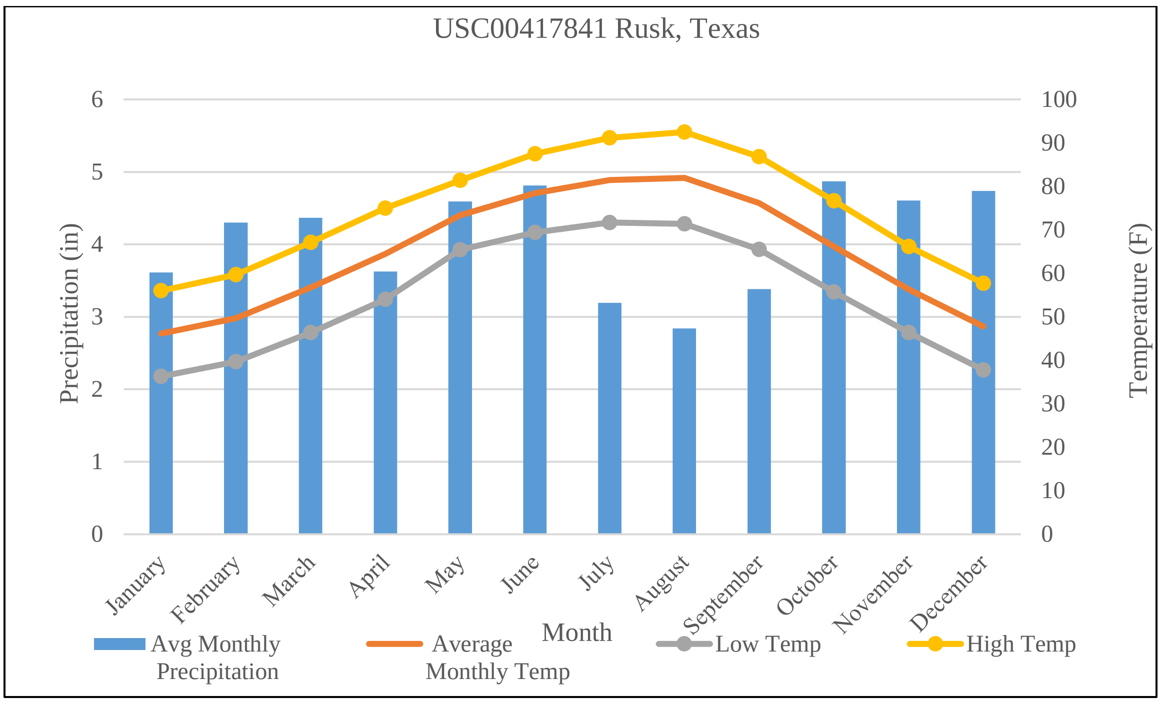

Figure 6. Average monthly precipitation, average, maximum, and minimum air temperature observed in Rusk, Texas between 1981 and 2010.

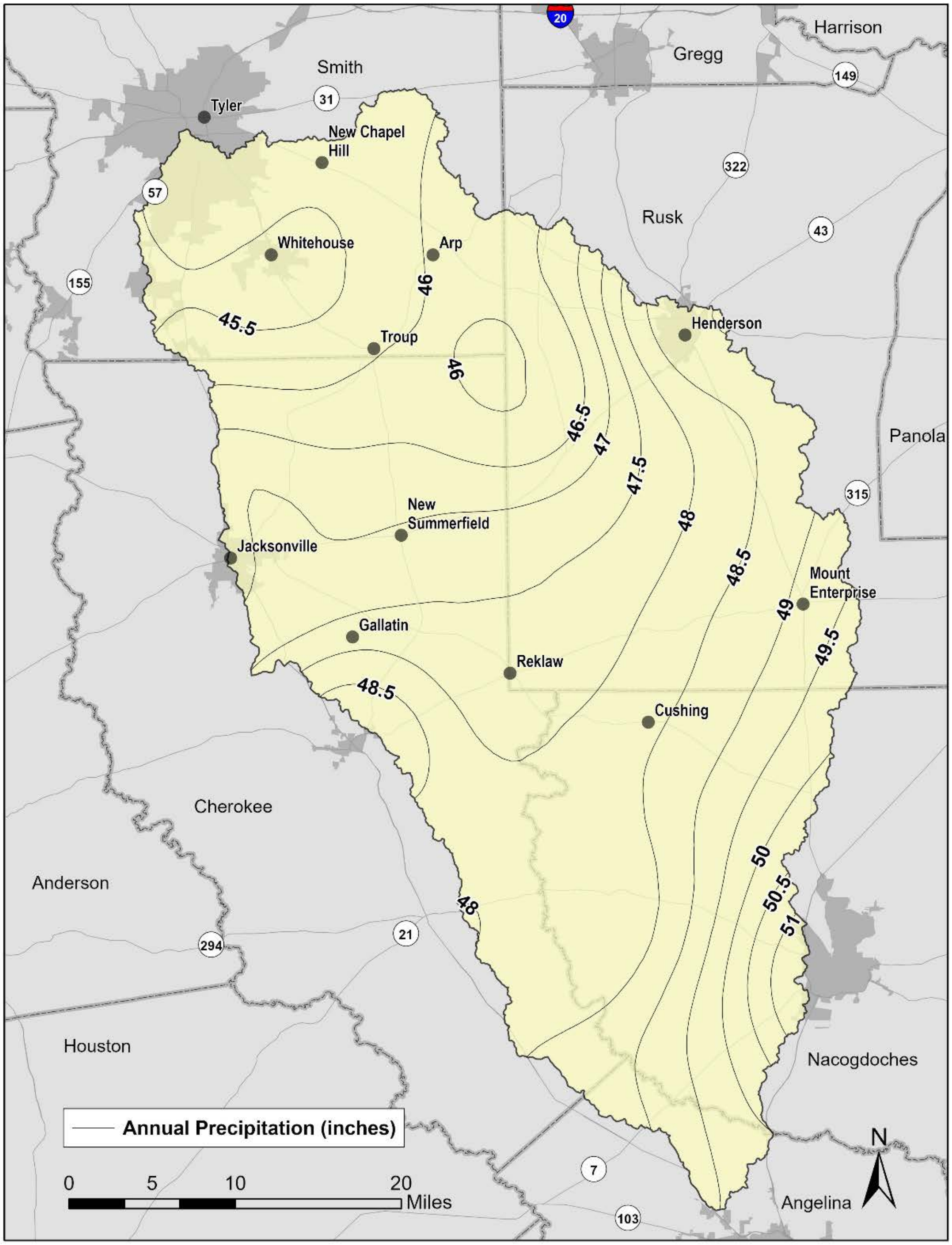

Figure 7. 30-year (1981–2010) average annual precipitation contour for the Angelina River watershed.

Population and Population Projections

Total population across the Angelina River watershed was estimated using the 2010 U.S. Census Bureau census block data (USCB 2010). Given that a census block may not be completely within the watershed, which is particularly the case along the watershed boundary, block-level population density was first estimated using the equation below.

$$Block\ level\ population\ density = census\ block\ population/area\ of\ census\ block$$

Afterwards, block-level population within the watershed was estimated using the equation below.

$$Block\ level\ population\ in\ watershed = block\ level\ population\ density \times area\ of\ block\ in\ watershed$$

Finally, watershed-level population was estimated as the summation of all block-level populations in watershed, which was 157,048. As shown in Figure 9, block-level population density is typically greater near cities and urban areas than in less developed areas.

In order to estimate potential future population in the Angelina River watershed, 2020–2070 population projections by county were acquired from the Texas Water Development Board (TWDB) Regional Water Plan (TWDB 2021; Table 5). Furthermore, block-level population in the watershed was summarized based on county boundaries (Table 6).

Assuming that the decadal population growth rate of an entire county is the growth rate for the portion of the county within the watershed, from 2010 to 2070, the population in the watershed was estimated to increase by 107.6% (Table 7).

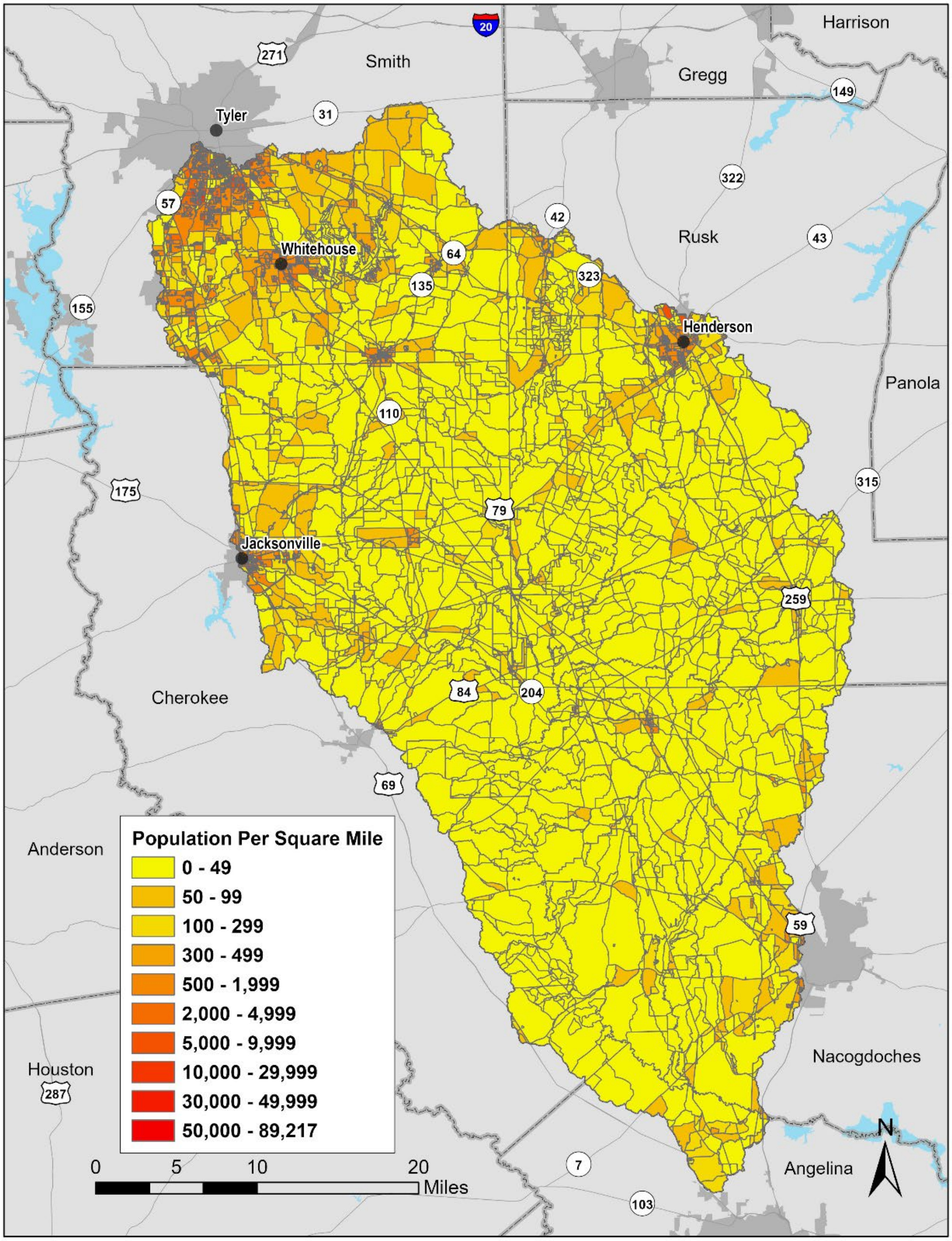

Figure 8. Estimated population density in the Angelina River watershed.

Table 5. Population projections for counties in the Angelina River watershed.

County	2010 U.S. Census county total	Texas Water Development Board projected county population by year						Percent increase (2010–2070)
		2020	2030	2040	2050	2060	2070	
Angelina	80,130	93,316	99,848	105,329	110,332	114,808	118,772	48.2%
Cherokee	46,659	55,634	61,005	66,277	72,560	79,148	86,269	84.9%
Nacogdoches	59,203	72,136	81,040	89,815	99,155	109,035	119,364	101.6%
Rusk	47,372	59,272	66,067	72,669	79,763	87,138	94,780	100.1%
Smith	174,706	233,560	259,400	286,140	315,587	346,896	380,621	117.9%

Table 6. Estimated population in the Angelina River watershed by county.

County	County population in watershed
Angelina	2,464
Cherokee	22,569
Nacogdoches	12,355
Rusk	27,996
Smith	91,664
Watershed Total	157,048

Table 7. Population projection for the Angelina River watershed.

County	2010 population in the watershed	Projected population in the watershed by year						Percent increase (2010–2070)
		2020	2030	2040	2050	2060	2070	
Angelina	2,464	2,869	3,070	3,239	3,393	3,530	3,652	48.2%
Cherokee	22,569	26,910	29,508	32,058	35,097	38,284	41,728	84.9%
Nacogdoches	12,355	15,054	16,912	18,743	20,693	22,754	24,910	101.6%
Rusk	27,996	35,029	39,044	42,946	47,138	51,497	56,013	100.1%
Smith	91,664	122,543	136,101	150,131	165,581	182,008	199,703	117.9%
Watershed	157,048	202,405	224,635	247,117	271,901	298,073	326,006	107.6%

Water Quality

Introduction

Historically, water quality concerns have existed for the Angelina River and Sam Rayburn Reservoir, especially due to the dependence of the reservoir on the inflow from the upper portion of the Angelina River. Concentrations of fecal indicator bacteria (FIB) are evaluated to assess the risk of illness during contact recreation. In freshwater environments, concentrations of *E. coli* bacteria are measured to evaluate the presence of fecal contamination in water bodies from warm-blooded animals and other sources. The presence of FIB may indicate that associated pathogens from the intestinal tracts of warm-blooded animals could be reaching water bodies and can cause illness in people that recreate in them. Indicator bacteria can originate from numerous sources including wildlife, domestic livestock, pets, malfunctioning OSSFs, urban and agricultural runoff, sanitary sewer overflows (SSOs), and direct discharges from wastewater treatment facilities (WWTFs).

On February 7th, 2018, TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ 2018), and on May 19th, 2020, the U.S. Environmental Protection Agency (EPA) approved the categorical levels of recreational use and their associated criteria. Recreational use consists of several categories:

- Primary contact recreation (PCR) 1 covers activities that have a significant risk of ingestion of water (such as swimming) and has a geometric mean criterion for *E. coli* of 126 colony forming units (cfu) per 100 milliliters (mL) and a single sample criterion of 399 cfu per 100 mL.
- PCR 2 includes activities that involve a significant risk of ingestion of water (i.e., swimming, diving, wading and whitewater sports) but occur less frequently than for PCR 1 due to physical characteristics of the water body or limited public access. The geometric mean for the standard is 206 cfu per 100 mL.
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing) and a geometric mean criterion for *E. coli* of 630 cfu per 100 mL.

- Secondary contact recreation 2 is similar to secondary contact recreation 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 cfu per 100 mL.
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for *E. coli* of 2,060 cfu per 100 mL.

The Angelina River above Sam Rayburn Reservoir (segment 0611) is designated as PCR 1, with a corresponding *E. coli* geometric mean criterion of 126 cfu per 100 mL (TCEQ 2018). Segments 0611A, 0611C, and 0611D had recreational use attainability analyses (RUAAs) conducted in 2014 to assess their recreational uses. The East Fork of the Angelina River (segment 0611A) was identified to retain its PCR 1 designation and corresponding *E. coli* geometric mean criteria (Winemiller and Baker 2015). The RUAA for Mud Creek (segment 0611C) advises that the current presumed use of PCR should be revised to secondary contact recreation 1 because the water body was observed to have steep and muddy banks and limited access and therefore decreased possibilities of PCR uses (Winemiller and Baker 2015). The RUAA for West Mud Creek (0611D) recommends that it retains its PCR 1 use and corresponding *E. coli* geometric mean criteria (TSSWCB 2015).

Routine Water Quality Monitoring Data Review

Water quality monitoring is conducted throughout Texas to identify water bodies that are failing to meet their designated water quality standards as well as meet the requirements of sections 303(d) and 305(a) of the CWA. Each segment of the Angelina River watershed has specific water quality standards that it must meet, which can be found in the Texas Surface Water Quality Standards portion of the Texas Administrative code (TAC), Title 30, Chapter 307 (30 TAC § 307) of from the 2020 Texas Integrated Report: Assessment Results for Basin 6-Neches River (TCEQ 2020). TCEQ uses data from the most recent 7-year period and at least 10 data points (20 data points needed to assess bacteria) when assessing the conditions of a water body. Monitoring efforts conducted by the Angelina and Neches River Authority (ANRA), the Texas Water Resources Institute (TWRI), and TCEQ in the Angelina River watershed have occurred at 19 sites at some point in time. Inconsistent data collection occurred at some stations within the watershed, making it difficult to determine the current state of all tributaries and segments for all parameters based upon existing data.

Historical Data

Existing water quality data for the watershed's segments were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on December 15th, 2021. Data used for the following analysis were retrieved for January 1st, 2000–November 30th, 2021, including data that was collected during the project's monitoring efforts. Figure 9 displays the locations of the monitoring stations throughout the watershed.

Analysis of Bacteria Data

Analyzed segments in the Angelina River watershed are required to meet the water quality standards for PCR 1 and maintain *E. coli* levels that are at or below the geometric mean of 126 most probable number (MPN) per 100 mL (MPN/100 mL). All sites, except for station 10630, had a geometric mean for *E. coli* that exceeded the 126 MPN per 100 mL standard (Table 8; Figure 10).

Table 8. Geometric means for historical *E. coli* data in the Angelina River watershed.

Segment ID	Station	Site description	Number of samples	Years	Geometric mean (MPN/100 mL)
0611	10627	Angelina River at US 59	83	2002–2021	165.30
	10630	Angelina River at SH 21	84	2001–2021	90.87
	10633	Angelina River 340m upstream of SH 204	91	2000–2021	165.16
	10635	Angelina River at FM 1798	117	2001–2021	208.82
0611A	13788	East Fork Angelina River at Rusk CR 3218	40	2009–2020	242.06
	10552	East Fork Angelina River at FM 225	68	2001–2020	193.52
0611C	14477	Mud Creek at US 79	106	2000–2021	133.25
	10532	Mud Creek at US 84	141	2000–2021	193.63
0611D	18302	West Mud Creek at US 69	64	2004–2021	239.07

State Highway, SH; Country Road, CR; U.S highway, US; Most Probable Number, MPN.

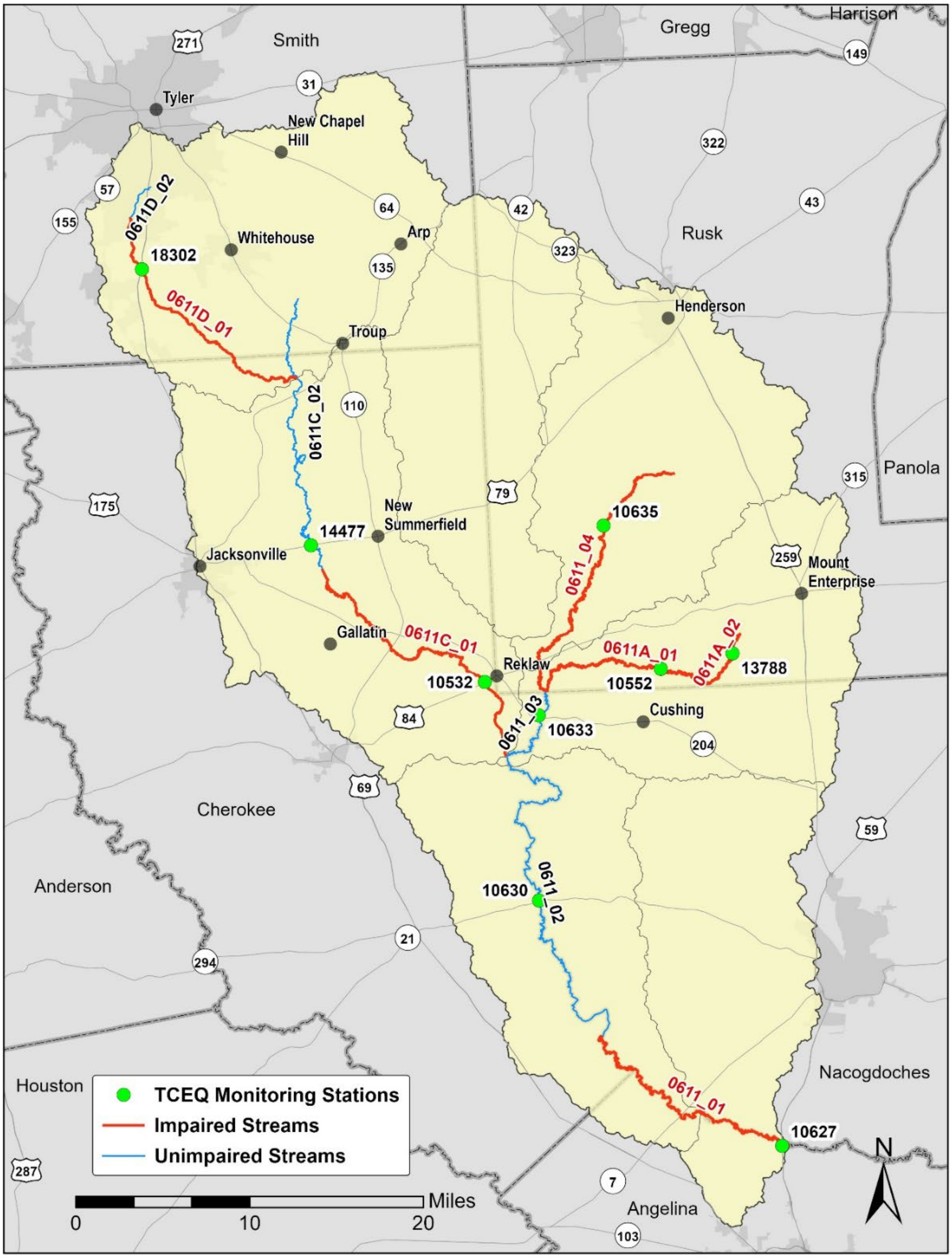

Figure 9. Locations of the Texas Commission on Environmental Quality (TCEQ) monitoring stations in the Angelina River watershed.

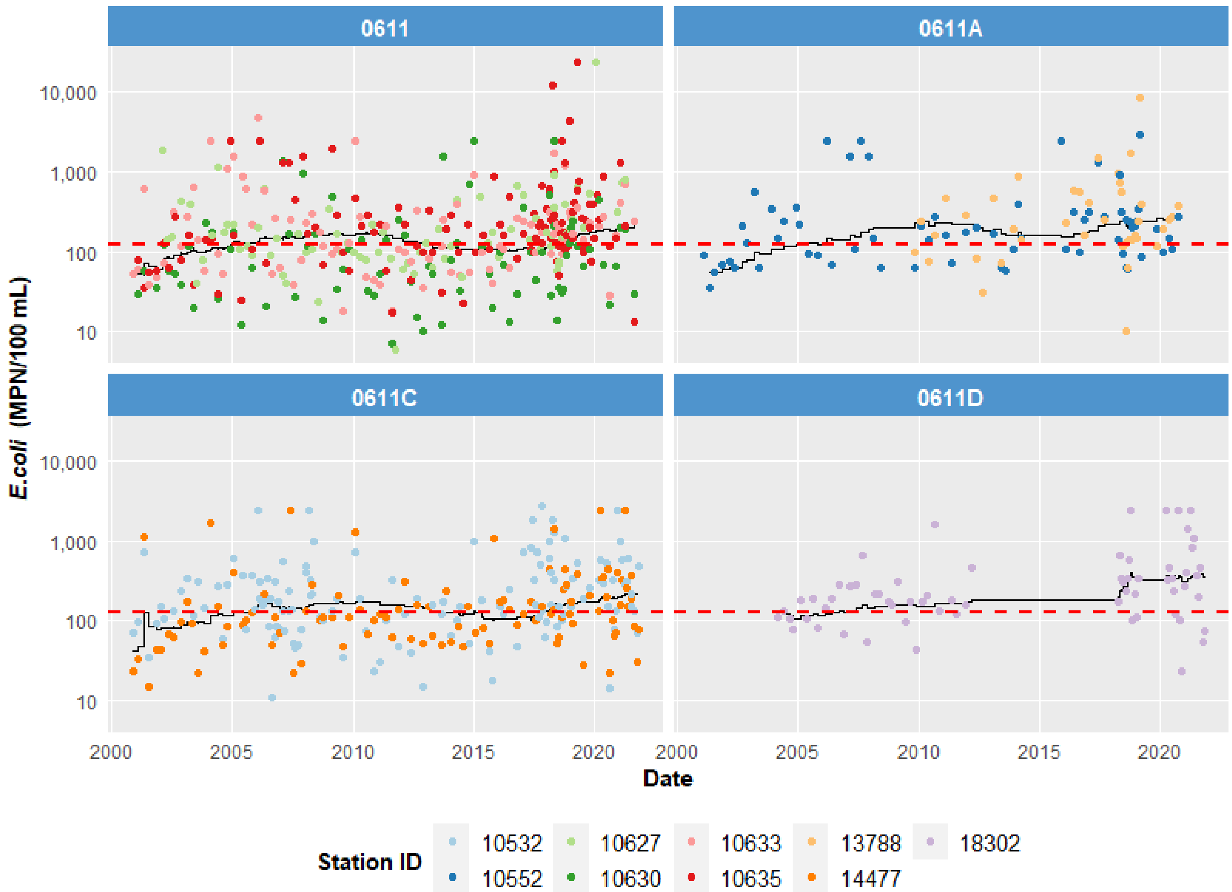

Figure 10. Historical *E. coli* concentrations at monitored segments and stations in the Angelina River watershed from 2000 to 2021. The red dashed line indicates the primary contact recreation 1 standard of 126 most probable number (MPN)/100 milliliters (mL). The black solid line indicates the 7-year rolling geometric mean. The points are measured *E. coli* grab samples.

Dissolved Oxygen

Dissolved oxygen (DO) is used as a metric to determine the suitability of water to support aquatic life and directly measures the concentration of oxygen gas that is incorporated into water. Concentrations can naturally fluctuate in the environment, but anthropogenic activities that contribute excessive organic matter and nutrients may depress these levels. Angelina River above Sam Rayburn Reservoir (segment 0611), East Fork of the Angelina River (segment 0611A), and Mud Creek (segment 0611C) have the same grab screening level criterion of 5 mg/L and a DO grab minimum of 3 milligram per liter (mg/L). West Mud Creek (segment 0611D) has a lower grab screening level criteria of 3 mg/L and a grab minimum of 2 mg/L. All segments have exceeded their grab screening level criteria for most samples gathered between 2000 and 2021 (Figure 11).

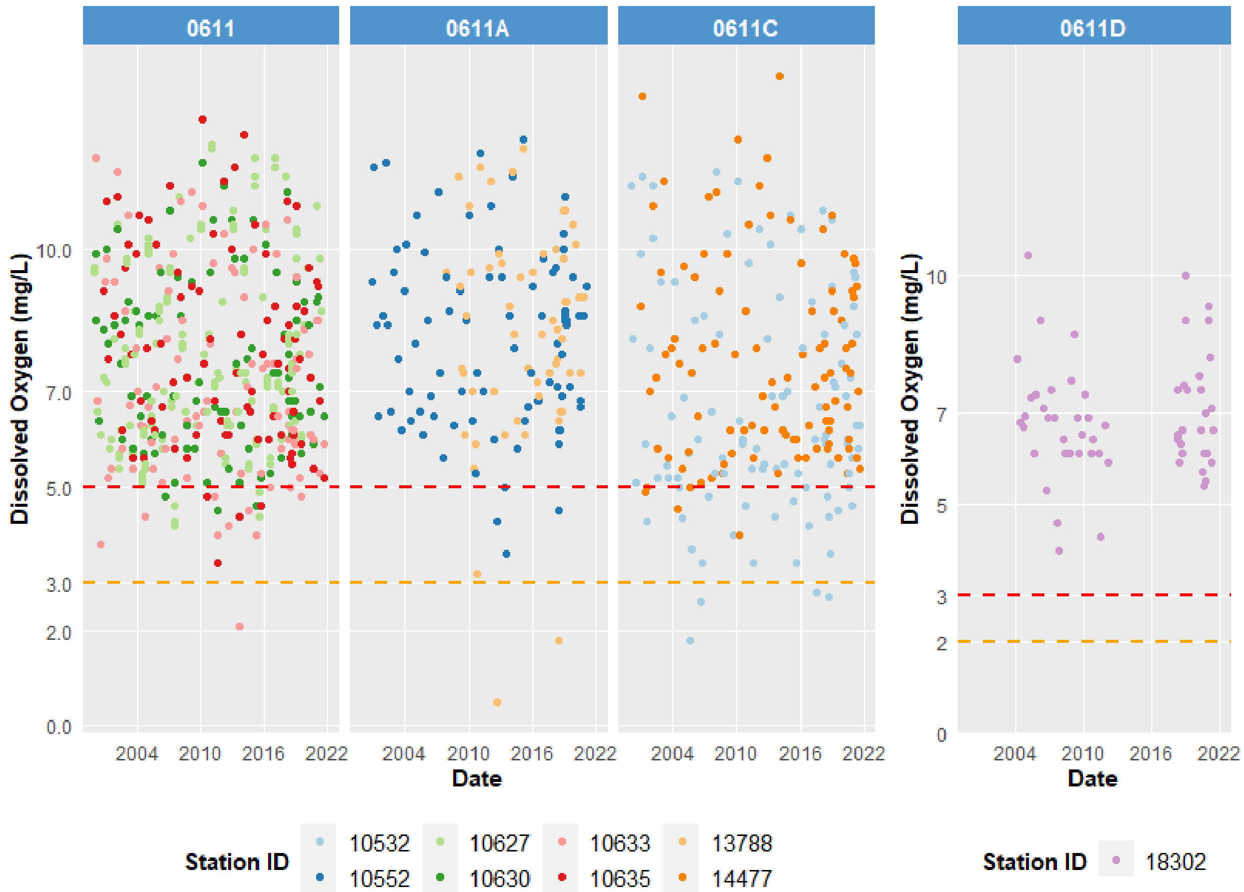

Figure 11. Dissolved oxygen (DO) concentrations at each segment of the Angelina River watershed from 2000 to 2021. The red dashed line represents the DO screening level criterion, and the yellow dashed line represents the grab minimum. The points are measured DO grab samples.

Nutrients

Nutrients such as nitrogen and phosphorus are critical for aquatic plant growth, but excessive amounts in a water body can result in plant and algal blooms, depressing DO levels. Sources of nutrients into the environment include fertilizers transported by surface runoff, effluent from WWTFs, and eroded sediment. Because a numeric criterion is not available for nutrients, a screening level is applied, which is 1.95 mg/L for nitrate, 0.33 mg/L for ammonia, and 0.69 mg/L for total phosphorus. West Mud Creek (segment 0611D) was the only segment identified to have exceeded the nitrate screening level criteria (Figure 12). For ammonia, monitoring station 10633 on Angelina River above Sam Rayburn Reservoir (segment 0611), stations 10532 and 14477 on Mud Creek (segment 0611C), and station 18302 on West Mud Creek (segment 0611D) have exceeded the screening level between 2000 and 2021 (Figure 13). For total phosphorus, stations 10633 and 10635 on segment 0611, stations 10532 and 14477 on segment 0611C, and station 18302 on segment 0611D were identified to have exceeded the screening level criterion between 2000 and 2021 (Figure 14).

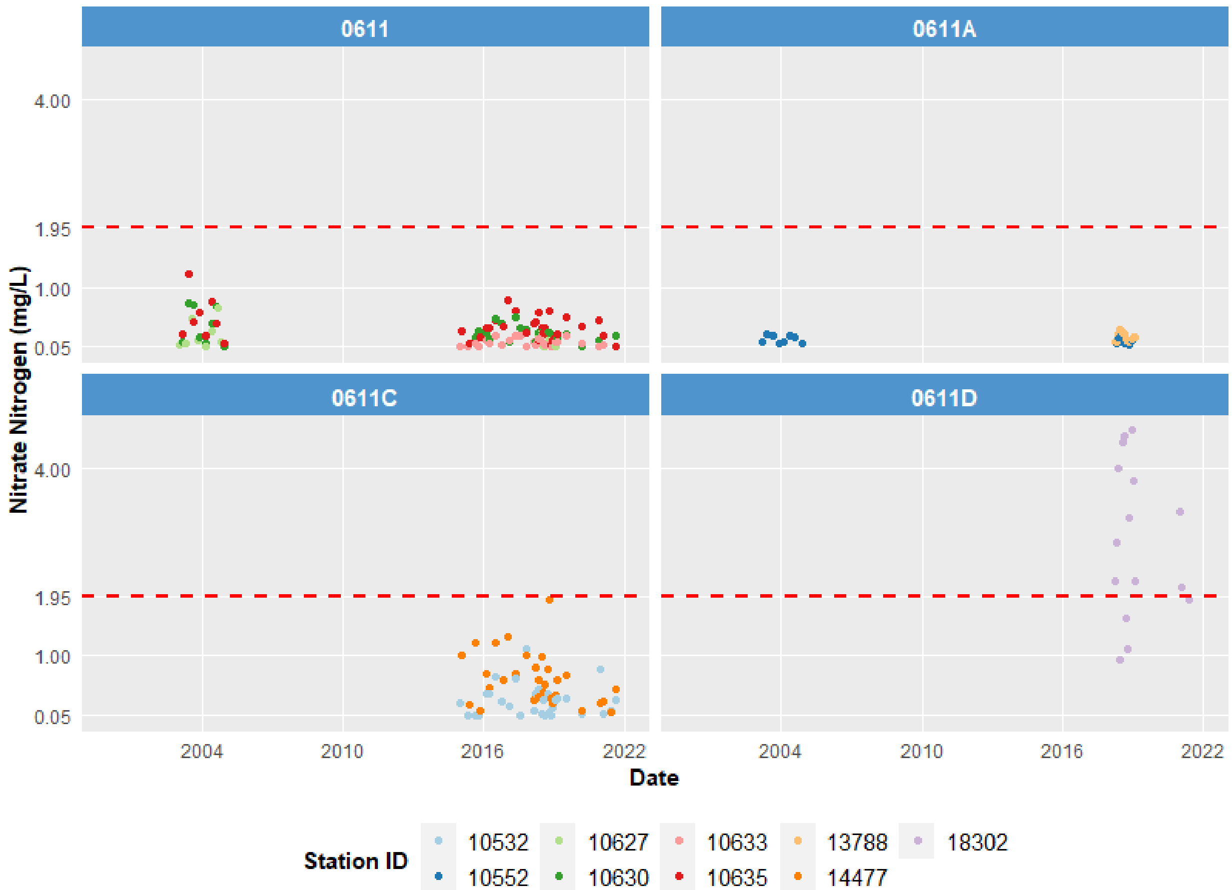

Figure 12. Nitrate nitrogen concentrations measured in the Angelina River watershed from 2000 to 2021. The dotted red line indicates the screening level criteria of 1.95 milligrams per liter (mg/L).

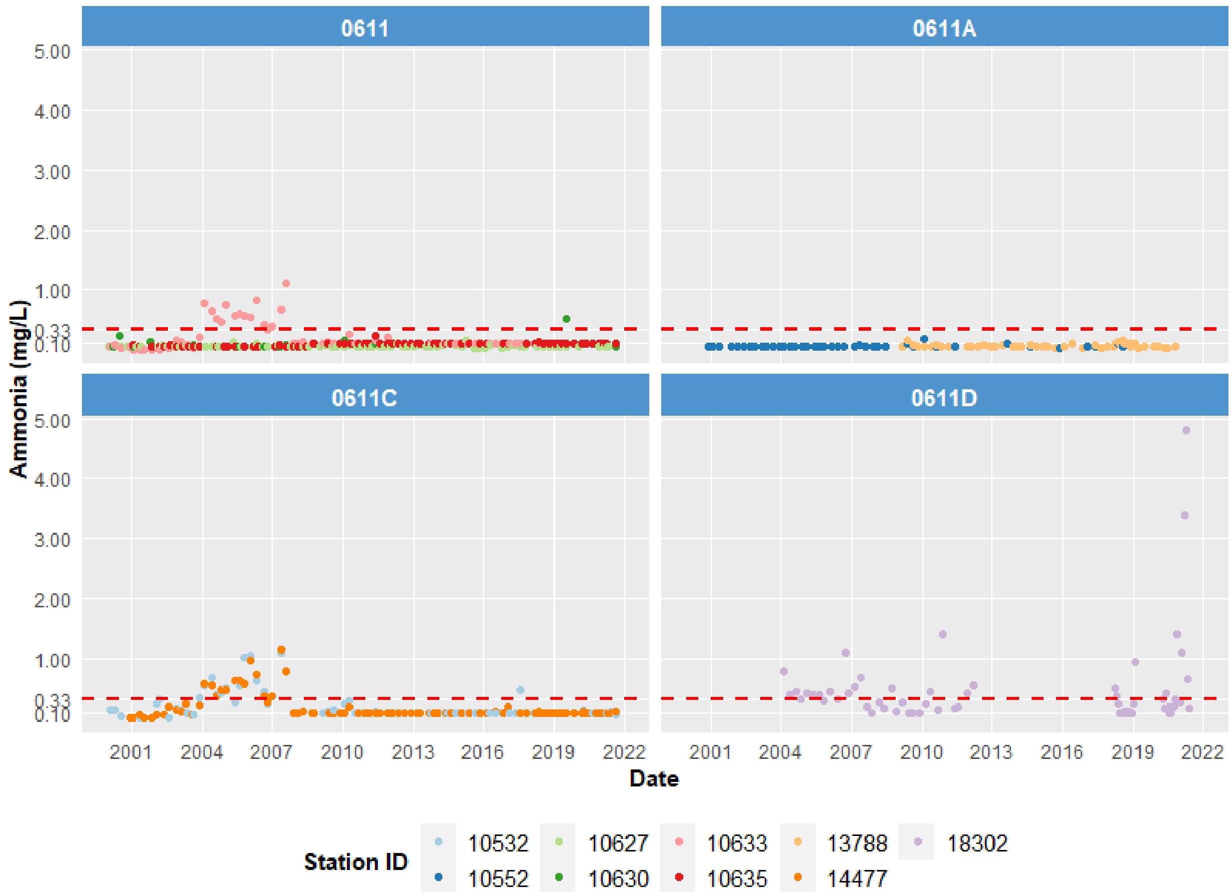

Figure 13. Ammonia concentrations measured at stations in the Angelina River watershed from 2000 to 2021. The red dashed line indicates the screening level criteria of 0.33 milligrams per liter (mg/L).

Figure 14. Total phosphorus concentrations measured at stations in the Angelina River watershed from 2000 to 2021. The screening level criteria for total phosphorus is 0.69 milligrams per liter (mg/L).

Potential Sources of Water Quality Issues

Potential sources of FIB within the watershed are categorized as either originating from point or nonpoint sources. Point sources, which are typically regulated, are permitted as designated by the National Pollutant Discharge Elimination System (NPDES) and the Texas Pollutant Discharge Elimination System (TPDES). Nonpoint sources of pollution (e.g., runoff and direct fecal deposition by wildlife), on the other hand, are not regulated by a permitting system and typically originate from multiple different locations.

Point Source Discharges

Point source pollution is defined as discharge from a regulated end-of-pipe outlet for cooling water, wastewater, or stormwater from municipal or industrial treatment systems (TCEQ and TSSWCB 2013). Within the watershed, permits have been issued by TCEQ for municipal and industrial WWTFs, concrete production facilities, phase II municipal separate storm sewer systems, construction activities, and industrial stormwater discharges. SSOs and illicit/dry weather discharges are considered unintentional discharges from regulated but not permitted systems. Table 9 summarizes information about each facility in the watershed that is permitted to discharge, as reported by TCEQ and the EPA's Enforcement and Compliance History Online (ECHO) tool (EPA 2019b).

Domestic Wastewater Treatment Facility Discharges

In the Angelina River watershed, 14 WWTFs are permitted to discharge treated wastewater effluent. The final permitted discharge limits for WWTFs in the watershed range from 0.0175 to 3 million gallons per day (MGD). Table 9 lists the permit numbers, facility names, receiving waters, permitted flow rates, and recently reported flow rates for each WWTF. Figure 15 provides an overview of the WWTFs within the watershed.

Figure 15. Overview of the wastewater treatment facilities (WWTFs) located within the Angelina River watershed.

Table 9. Permitted point source discharge facilities in the Angelina River watershed.

TPDES permit number	NPDES permit number	Facility name	Receiving waters	Final permitted discharge (MGD)[a]	Recent discharge (MGD)[b]
WQ0010693003	TX0100587	City of Jacksonville (Double Creek) WWTF	To Ragsdale Creek; thence to Keys Creek; thence to Mud Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	2.9	3.078
WQ0013585001	TX0107875	New Summerfield WWTF	To Caney Creek; thence to Bridge Creek; thence to Mud Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.06	0.002
WQ0010437001	TX0053937	City of Cushing WWTF	To an unnamed tributary; thence to Dill Creek; thence to East Form Angelina River; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.081	0.0595
WQ0014283001	TX0122173	City of Mount Enterprise WWTF	To an unnamed tributary; thence to Lockland Branch; thence to Wooten Creek; thence to East Fork Angelina River; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.06	0.0744
WQ0010187001	TX0052779	Southside WWTF (Henderson WWTF)	To Bromley Creek; thence to Shawnee Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin.	3.0	1.571
WQ0014292001	TX0124371	Carlisle ISD WWTF	To an unnamed tributary; thence to a wetland; thence to Johnson Creek; thence to Striker Creek; thence to Lake Striker; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.0175	0.00076
WQ0010511001	TX0054194	City of Arp WWTF	To an unnamed tributary; thence to Kickapoo Creek; thence to Mud Creek; thence to the Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.211	0.331
WQ0013168001	TX0098795	Woodmark WWTF	To an unnamed tributary; thence to Henshaw Creek; thence to West Mud Creek; thence to Mud Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.363	0.496

WQ0011222001	TX0072770	City of Whitehouse (Blackhawk Creek) WWTF	To Blackhawk Creek; thence to Mud Creek; thence to the Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	1.5	0.714
WQ0013000001	TX0101010	Tall Timbers WWTF	To an unnamed tributary; thence to West Mud Creek; thence to Mud Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.312	0.351
WQ0010653002	TX0047988	City of Tyler-Southside WWTF	To West Mud Creek; thence to Mud Creek; thence to the Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	9	6.15
WQ0010304001	TX0033529	City of Troup WWTF	To an unnamed tributary; thence to Caney Creek; thence to Mud Creek; thence to the Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.308	0.430
WQ0012376001	TX0087360	City of New London South WWTF	To an unnamed tributary; thence to Bowles Creek; thence to Alan Lake; thence to Graham Lake; thence to Bowles Creek; thence to Striker Creek; thence to Angelina River above Sam Rayburn Reservoir in segment 0611 of the Neches River Basin	0.1	0.054
WQ0005154000	TX0136093	Clear Water Solutions Plant	To an unnamed tributary of Shawnee Creek; thence to Shawnee Creek; thence to the Angelina River above Sam Rayburn Reservoir segment 0611 of the Neches River Basin	0.03	NA

Texas Pollutant Discharge Elimination System, TPDES; National Pollutant Discharge Elimination System, NPDES; Waste-Water Treatment Facility, WWTF; Waste-Water Treatment Plant, WWTP; Million Gallons per Day, MGD; Independent School District, ISD.

[a]Significant figures represent MGDs as presented in TPDES permits.

[b]All recent discharges were reported on May 31, 2021, except for the city of Cushing WWTF, which was last reported on November 30th, 2020.

TPDES General Permits

TPDES general permits are required for facilities to release processed wastewater. Such permits include construction general permits, concrete production plant general permits, wastewater evaporation pond permits, municipal separate storm sewer system (MS4) permits, and concentrated animal feeding operations (CAFO) permits. Facilities requiring general permits within the watershed include:

- TXG110000 – concrete production facilities; and
- TXG830000 – petroleum contaminant or petroleum substances.

As of December 31, 2021, there are three active general permits within the Angelina River watershed (TCEQ 2020). Two of them are for concrete production facilities and the other one is for petroleum contaminant discharge. While TPDES permits are required for different operations, not all will contribute considerably to FIB contamination in the watershed. Concrete production facilities and operations producing petroleum-contaminated water do not pose a significant risk for bacterial contamination.

Stormwater General Permits

A stormwater general permit is required for any stormwater discharges originating from industrial facilities, construction sites, phase II urban areas, or any other similar activity. These regulated stormwater permits are managed under the TPDES. The three different stormwater general permits include:

- TXR040000 – phase II MS4 general permit for urbanized areas;
- TXR050000 – multi-sector general permit (MSGP) for industrial facilities stormwater discharge; and
- TXR150000 – construction activities that disturb greater than one or more acres and are part of a larger common development plan.

Phase II MS4 permits are issued for municipalities that have a population smaller than 100,000 individuals. The cities of Tyler and Whitehouse both have phase II MS4 permits that fall within the Angelina River watershed. Phase II MS4, construction activities, and MSGP permits only allow stormwater to be released. As of the permit query date, two phase II MS4 general permits, 28 MSGP permits, and 113 construction permits were found to be currently active.

Sanitary Sewer Overflows

Sanitary sewer systems collect and transport wastewater for treatment and can include wastewater from commercial, domestic, and industrial sources (EPA 2019a). SSOs occur when sewer systems release sewage illegally. In dry weather, SSOs primarily occur when there is a blockage in the sewer pipes from grease, tree roots, or other debris. Sewer overflows can also result from severe weather events, sewer defects, power failures, lack of or improper operation and system maintenance, and vandalism (EPA 2019a). SSOs are considered point source pollution and must be addressed immediately by the individual or company holding the NPDES permit. From January 1st, 2016 to May 31st, 2021, there were 66 documented SSO events in the Angelina River watershed releasing an estimated total of 366,111 gallons by five facilities. It is important to note that not all SSO events are recorded, and the actual number of events may be unknown.

Compliance History of Permitted Sources

Data from EPA's ECHO database was reviewed on July 23rd, 2021 to identify non-compliance of *E. coli* permit levels for the WWTFs in the watershed (Table 10; Table 11). Four WWTFs within the watershed from June 1st, 2017 to May 31st, 2021 had exceeded their daily maximum discharge limit for *E. coli* at least once:

- City of Cushing WWTF;
- City of Mount Enterprise WWTF;
- Southside WWTF; and
- City of Arp WWTF.

Significant non-compliance (SNC) violations were reviewed in the ECHO database, which typically result from late or missing reports or discharges that are above the facilities' limitations. Unresolved SNC violations were identified for the following facilities in the watershed:

- New Summerfield WWTF;
- City of Mount Enterprise WWTF;
- Woodmark WWTF; and
- Tall Timbers WWTF.

The Clear Water Solutions, LLC WWTF does not have any *E. coli* limit specified in their TPDES permit, and no *E. coli* levels were reported for this facility.

Table 10. Bacterial monitoring requirements and compliance status for wastewater treatment facilities (WWTFs) in the Angelina River above Sam Rayburn Reservoir watershed.

TPDES permit number	EPA ID	Facility name	Permit monitoring requirement	Minimum self-monitoring requirement	Permit limits		Recent reported values	
					Daily average (cfu/100 mL)	Daily max per sample (cfu/100 mL)	Daily average (cfu/100 mL)	Number of grab samples exceeding daily max
WQ0010693003	TX0100587	Double Creek WWTF (City of Jacksonville)	*E. coli*	1/week	126	399	8.52	0
WQ0013585001	TX0107875	New Summerfield WWTF	*E. coli*	1/quarter	126	399	1	0
WQ0004198000	TX0053937	City of Cushing WWTF	*E. coli*	1/month	126	399	1	1
WQ0014283001	TX0122173	City of Mount Enterprise WWTF	*E. coli*	1/month	126	399	7,360	38
WQ0010187001	TX0052779	Southside WWTF (Henderson WWTF)	*E. coli*	1/week	126	399	1.78	1
WQ0014292001	TX0124371	Carlisle ISD WWTF	*E. coli*	1/quarter	126	399	1	0
WQ0010511001	TX0054194	City of Arp WWTF	*E. coli*	1/month	126	399	387	8
WQ0013168001	TX0098795	Woodmark WWTF	*E. coli*	1/month	126	399	8.5	0
WQ0011222001	TX0072770	Blackhawk Creek WWTF	*E. coli*	1/week	126	399	6.25	0
WQ0013000001	TX0101010	Tall Timbers WWTF	*E. coli*	1/month	126	399	1	0
WQ0010653002	TX0047988	City of Tyler-Southside WWTF	*E. coli*	3/week	126	399	11	0
WQ0010304001	TX0033529	City of Troup WWTP	*E. coli*	1/month	126	399	1	0
WQ0012376001	TX00873600	City of New London South WWTP	*E. coli*	1/month	126	399	1	0

Texas pollutant Discharge Elimination System, TPDES; Waste-Water Treatment Facility, WWTF; Waste-Water Treatment Plant, WWTP; colony forming unit, cfu; Independent School District, ISD; Environmental Protection Agency, EPA.

Table 11. Self-reported exceedances for wastewater treatment facilities (WWTFs) in the Angelina River watershed.

TPDES permit number	EPA ID	Facility	Exceedances
WQ0010693003	TX0100587	City of Jacksonville (Double Creek) WWTF	3 TSS (daily average), 2 nitrogen, ammonia (daily average), 1 flow (2-hour peak), 20 flow (annual average), 1 BOD (daily max)
WQ0013585001	TX0107875	New Summerfield WWTF	1 DO (monthly min) 9 BOD (daily average), 1 pH (max), 1 pH (min), 11 TSS (daily average), 2 flow (daily average), 1 chlorine (monthly min)
WQ0004198000	TX0053937	City of Cushing WWTF	1 *E. coli* (daily average), 1 *E. coli* (single grab)
WQ0014283001	TX0122173	City of Mount Enterprise WWTF	1 DO (monthly min), 2 BOD (daily average), 1 TSS (daily average), 7 flow (daily average), 38 *E. coli* (daily average), 38 *E. coli* (single grab)
WQ0010187001	TX0052779	Southside WWTF (Henderson WWTF)	7 Flow (2-hour peak), 1 *E. coli* (daily average), 1 *E. coli* (daily max), 15 TSS (daily average)
WQ0012376001	TX0087360	City of New London South WWTP	No data available
WQ0005154000	TX0136093	Clear Water Solution Plant	No data available
WQ0014292001	TX0124371	Carlisle ISD WWTF	No data available
WQ0010511001	TX0054194	City of Arp WWTF	2 BOD (daily average), 11 TSS (daily average), 10 flow (daily average), 8 *E. coli* (daily average), 7 *E. coli* (single grab)
WQ0013168001	TX0098795	Woodmark WWTF	1 TSS (daily average), 11 nitrogen, ammonia (daily average), 7 flow (daily average), 1 chlorine (monthly min)
WQ0011222001	TX0072770	City of Whitehouse (Blackhawk Creek) WWTF	1 TSS (daily max)
WQ0013000001	TX0101010	Tall Timbers WWTF	1 DO (monthly min), 7 TSS (daily average), 1 TSS (single grab), 5 nitrogen, ammonia (daily average), 1 nitrogen, ammonia (single grab), 1 chlorine (monthly max)
WQ0010653002	TX0047988	City of Tyler-Southside WWTF	1 DO (monthly min), 1 pH (min), 12 TSS (daily average), 9 TSS (daily max), 4 nitrogen, ammonia (daily average), 4 nitrogen, ammonia (daily max), 4 chlorine (monthly min)
WQ0010304001	TX0033529	City of Troup WWTP	2 TSS (daily average), 1 nitrogen, ammonia (daily average), 11 flow (daily average), 3 chlorine (monthly max)

Texas pollutant Discharge Elimination System, TPDES; Waste-Water Treatment Facility, WWTF; Waste-Water Treatment Plant, WWTP; colony forming unit, cfu; Biochemical Oxygen Demand, BOD; Dissolved Oxygen, DO; Total Suspended Solids (TSS); Independent School District, ISD; Environmental Protection Agency, EPA.

Nonpoint Sources

Nonpoint sources of pollution are defined as any water pollution that does not originate from regulated or point sources (TCEQ and TSSWCB 2013). Nonpoint source pollution from leaking OSSFs, urban and agricultural runoffs, domestic pets, wildlife, and livestock could potentially be unregulated sources of bacteria.

Non-Permitted Agricultural Activities

Agricultural activities can contribute to the *E. coli* load in a watershed. Livestock and wildlife will have a greater chance of contributing *E. coli* to a stream if the pasture has creek access. The county-level estimates of livestock populations, as reported in USDA (2019), were multiplied by the percentage of county-level grazeable land that lies in the Angelina River watershed to estimate the populations of horses, goats, laying hens, sheep, and pigs/hogs in the watershed. Grazeable land for the above livestock is defined as an aggregate of hay/pasture and herbaceous land covers. Table 12 describes the estimated number of livestock for the Angelina River watershed by county.

Table 12. Estimated livestock populations in the Angelina River watershed by county.

County	Percent in watershed	Cattle and calves	Horses	Goats	Sheep and lambs	Hogs and pigs
Angelina	7.0%	1,350	142	112	20	10
Cherokee	52.7%	2,876	1,295	580	169	62
Nacogdoches	39.2%	13,412	454	184	78	19
Rusk	48.5%	19,772	797	551	132	179
Smith	30.1%	13,215	1,778	1,059	378	168
Watershed total		50,624	4,466	2,485	777	439

Water Quality Management Plans

Certain agricultural operations manage their properties under the guidance of the Texas State Soil and Water Conservation Board (TSSWCB) and NRCS through water quality management plans (WQMPs). These site-specific plans are developed and approved by the soil and water conservation districts that work to help meet the goals of the producer. WQMPs commonly include practices and measures that are designed to achieve a level of pollution prevention or abatement to meet state water quality standards when properly installed, maintained, and implemented. Dry poultry production facilities are required to have WQMPs. Poultry facilities are required to have a WQMP in place before operations may begin.

According to TSSWCB, there were 50 poultry facilities in the watershed that house almost seven million birds. These WQMPs prescribe proper handling and utilization of produced litter to ensure adequate water quality protection. On-farm, litter is stored in a litter barn or other impermeable layer before land application (TSSWCB 2019). These WQMPs also include practices such as establishing animal mortality facility, emergency animal mortality management, nutrient management, pest management, and waste utilization, to name a few.

Domestic Pets and Urban Runoff

Domestic pets, specifically dogs, can contribute bacteria when pet waste is not disposed of properly and subsequently reaches nearby water bodies via runoff during rain and storm events. The highest potential loads from domestic pets are anticipated to occur in developed and urbanized areas.

According to the American Veterinary Medical Association (AVMA), there are approximately 0.614 dogs and 0.457 cats per household in the U.S. (AVMA 2018). The number of households in the Angelina River watershed was estimated using USCB (2010) census block house unit data. Using the formula below, populations of dogs and cats in the Angelina River watershed were estimated to be 40,554 and 30,184, respectively (Table 13).

$$Households\ in\ watershed = house\ units\ in\ census\ block / area\ of\ census\ block \times area\ of\ census\ block\ in\ watershed$$

$$Dog\ population = 0.614 \times \#\ of\ households\ in\ watershed$$

$$Cat\ population = 0.457 \times \#\ of\ households\ in\ watershed$$

Table 13. Estimated dog and cat populations in the Angelina River watershed.

Estimated number of households	Estimated dog population	Estimated cat population
66,049	40,554	30,184

Wildlife and Unmanaged Animal Contributions

Fecal indicator bacteria, such as *E. coli*, inhabit the intestines of all warm-blooded animals, including wildlife such as mammals and birds. Wildlife is naturally attracted to the riparian corridors of streams and rivers because they provide access to water, shelters, and food. However, with direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria in water. Fecal bacteria from wildlife are also deposited onto land surfaces and may be washed into nearby water bodies because of rainfall induced overland flow. While several bird and mammal species are likely to contribute bacterial loads in waters, feral hogs and deer are the only species with reasonable density and population estimates for significant bacterial load contribution.

The Texas Parks and Wildlife Department (TPWD) estimated deer population densities by resource management unit (RMU) and ecoregion. The majority of Angelina River watershed lies between RMU 14 and RMU 17, and their average deer densities between 2005 and 2016 were 39.6 acres per deer and 43.49 acres per deer, respectively. An average of these two densities, i.e., 41.545 acres per deer, of habitable land was used to estimate the deer population in the Angelina River watershed. Based on the 925,258 acres of habitable land (deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands), 22,319 deer were estimated to be in the watershed (Table 14).

Feral hog population densities are very challenging to determine and can vary greatly. According to Texas A&M AgriLife Extension (2012), the statewide average density for feral hogs is one hog per 39 acres. By applying this density on the same acreage of habitable land for deer, feral hog population in the Angelina River watershed was approximately 23,776 (Table 14).

Table 14. Estimated deer and feral hog populations in the Angelina River watershed.

Habitat	Acreage	Estimated deer population	Estimated feral hog population
Deciduous forests	36,573	880	938
Evergreen forest	219,632	5,287	5,632
Mixed forest	150,590	3,625	3,861
Scrub/shrub	56,724	1,365	1,454
Grassland/herbaceous	53,199	1,281	1,364
Pasture/hay	289,712	6,973	7,429
Cultivated crops	11	0	0
Woody wetlands	113,369	2,729	2,907
Emergent herbaceous wetlands	7,448	179	191
Watershed total	927,258	22,319	23,776

Failing On-Site Sewage Facilities

On-site sewage facilities (OSSFs), commonly known as septic systems, can be a potential contributor of *E. coli* in water bodies. Several pathways of the liquid waste in OSSFs provide opportunities for bacteria to enter the ground and surface waters if the systems are not properly operating. On the other hand, properly designed and operated OSSFs are expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel et al. 1996). Several factors influence the likelihood of pollutants from an OSSF entering a water body, including the functional status of the system, location of the system, soils of the system, density of systems in selected areas, and the age of the system.

Comprehensive data describing the locations of OSSFs in the Angelina River above Sam Rayburn Reservoir are unavailable; therefore, the number of OSSFs in the watershed were estimated using secondary sources. One method that has been applied in other watersheds makes use of census block-level house unit data, 911 address points, convenience and necessity (CCN) sewer area, city boundary, and recent aerial imagery of the watershed (see details in Gregory et al. 2013). Following this method, a total of 29,161 OSSFs were estimated to be in the watershed, but the estimate has not been verified by on-site inspections. Table 15 displays the estimated number of OSSFs by county.

Table 15. Estimated number of on-site sewage facilities (OSSFs) in the watershed by county.

County	Number of OSSFs
Angelina	848
Cherokee	5,488
Nacogdoches	4,737
Rusk	7,084
Smith	11,004
Watershed total	29,161

The density of OSSFs within an area has the potential to influence the local water quality. A high OSSF density may exceed the capacity of the soil to absorb and mitigate the pollutants from the system. When the soil becomes saturated, effluent will pond on the surface or percolate into shallow groundwater sources. Ponded effluent on the surface can runoff during rain events and adversely impact local water quality. The greatest density of OSSFs in the watershed is found near Whitehouse and New Chapel Hill, with a density ranging from 155 to 385 OSSFs per square mile. The density is significantly lower (0–12 systems per square mile) throughout most of the watershed, as depicted in Figure 16.

The proximity of OSSFs to a water body is an important factor when determining the potential water quality impacts of these systems. The closer a single system or cluster of systems are to a water body, the less distance any improperly managed effluent must travel to reach a stream, therefore increasing the risk of pollution. Within the Angelina River watershed, 15 OSSFs are estimated to be within 100 yards of an impaired segment and nine OSSFs are estimated to be within 50 yards of an impaired segment.

NRCS provides ratings of the soil suitability to handle leachate from the septic system based on soil properties, depth to bedrock or groundwater, hydraulic conductivity, and other properties that may affect the absorption of effluents from OSSFs. A “not limited” rating indicates soils with features favorable to OSSF use. “Somewhat limited” indicates soils that are moderately favorable with limitations that can be overcome by design, planning, and installation. “Very limited” indicates soils being very unfavorable for OSSF use with expectation of poor performance and high amounts of maintenance (NRCS 2019). 85.44% of land area in the Angelina River watershed is rated “very limited” for OSSF use, followed by a smaller percentage of area (13.20%) rated “somewhat limited” (Table 16; Figure 17).

Table 16. Soil suitability in the Angelina River watershed.

County	Soil suitability (acres)		
	Not rated	Somewhat limited	Very limited
Watershed total	13,974.60	135,983.12	880,188.73
Percentage of total	1.36	13.20	85.44

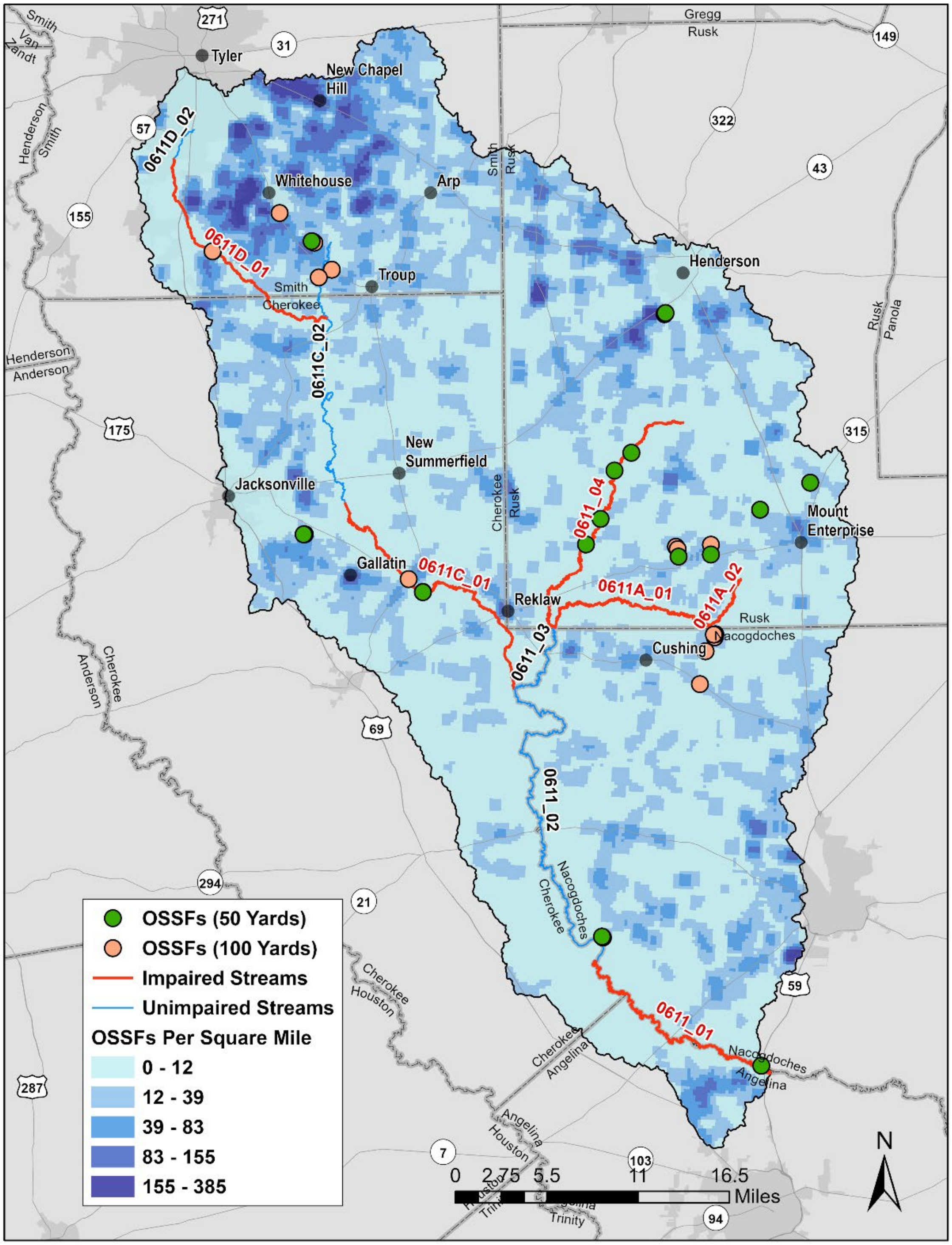

Figure 16. Estimated locations and densities of on-site sewage facilities (OSSFs) in the Angelina River watershed.

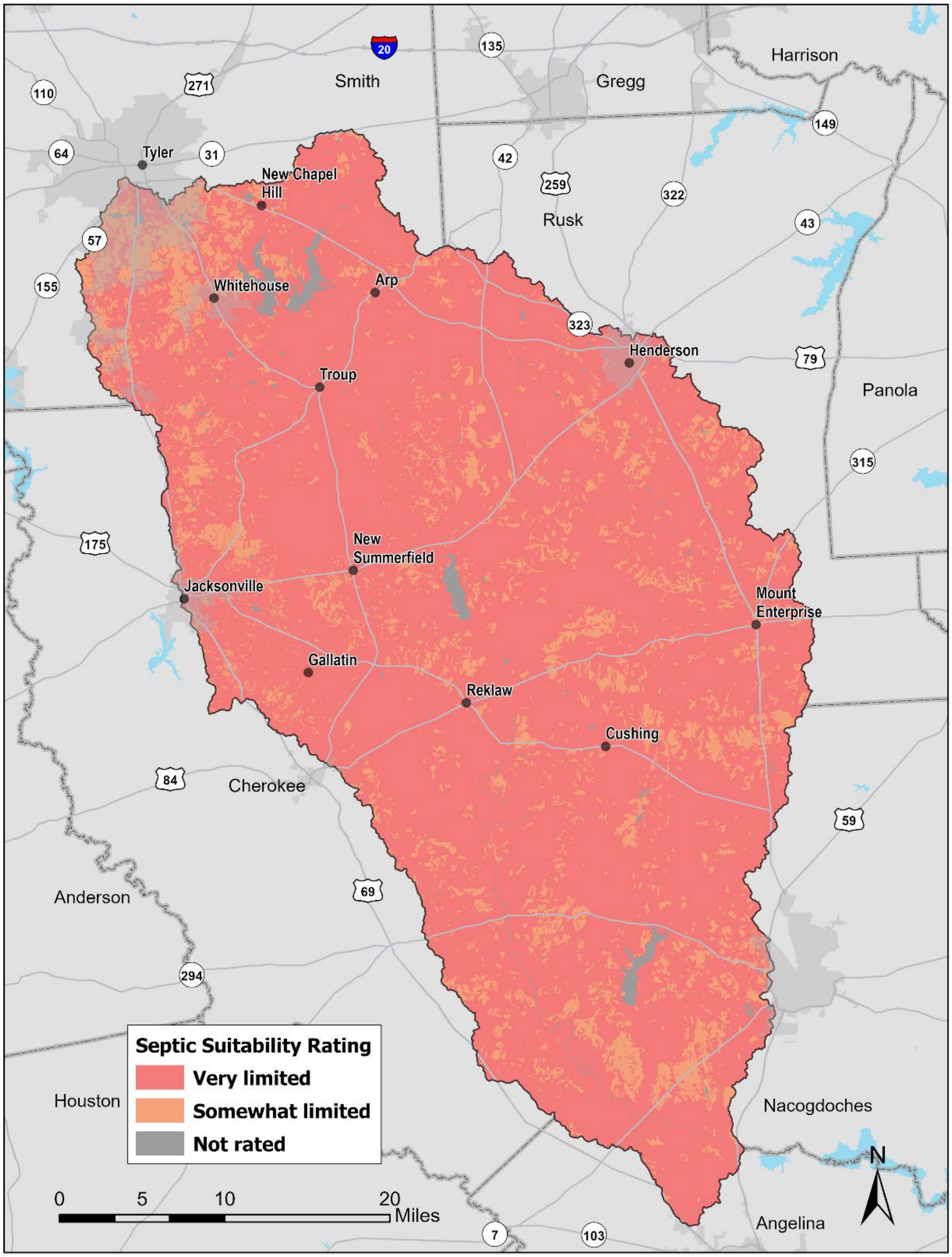

Figure 17. On-site sewage facility adsorption field ratings in the Angelina River watershed.

Pollutant Source Assessment

Introduction

Water quality sampling, described in the previous section, has emphasized that the primary water quality issue in the Angelina River watershed is elevated FIB levels in water bodies. As previously mentioned, the current water quality standard established by TCEQ for PCR 1 is 126 MPN/100 mL for *E. coli*. To calculate the reductions needed to meet PCR 1 water quality criteria, the bacterial loading capacity of the Angelina River watershed needed to be estimated. The current bacterial load for all impaired streams was also calculated using data from water quality sampling and the load duration curve (LDC) method. By measuring the difference between the load capacity of the stream and the current bacterial load, this section estimates the reductions needed to meet water quality standards.

Furthermore, this section estimates the relative load contributions from different potential fecal bacteria sources. By estimating the relative potential contribution made by different fecal bacteria sources across the watershed, areas can be prioritized regarding when and where future potential management measures should occur. Geographic information system (GIS) spatial analysis based on the best available data was conducted to assess the spatial distribution of *E. coli* loadings in the watershed.

Source and Load Determination

Load Duration Curves

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland 2003). In addition to estimating stream loads, the LDC method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment.

In order to develop an LDC, a flow duration curve (FDC) needs to be developed first. To this end, streamflow data (e.g., instantaneous flows) measured at a location (e.g., 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 percent of time a streamflow value was exceeded can be calculated using its rank divided by the total number of flow observations plus one. Finally, an FDC is developed by plotting flow data (y-axis) against corresponding exceedance percentages (x-axis).

Further, at each monitoring station, flow values in cubic feet per second (cfs) were multiplied by the appropriate criterion for *E. coli* level in water (geometric mean of 126 MPN per 100 mL for PCR 1) and by a conversion factor (2.44658×10^9), resulting in maximum daily allowable loads with a unit of MPN/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-compliance.

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 10532 and 10663 on segment 0611 (Angelina River above Sam Rayburn Reservoir), three flow regimes were identified: (1) 0%–30% (high flow); (2) 30%–75% (normal flow); and (3) 75%–100% (no flow). For station 13788 on segment 0611A (East Fork Angelina River), three flow regimes were identified: (1) 0%–30% (high flow); (2) 30%–65% (mid-range condition); and (3) 65%–100% (low flow). For the rest of the stations, i.e., 10627, 10630, and 10635 on segment 0611, 10552 and 14477 on segment 0611C (Mud Creek), and 18302 on segment 0611D (West Mud Creek), five flow regimes were defined based on Cleland (2003): (1) 0%–10% (high flows); (2) 10%–40% (moist conditions); (3) 40%–60% (mid-range); (4) 60%–90% (dry conditions); and (5) 90%–100% (low flows).

The geometric mean of the measured *E. coli* loads in each flow regime was also calculated to aid interpretation of the LDCs (Figure 18–Figure 26).

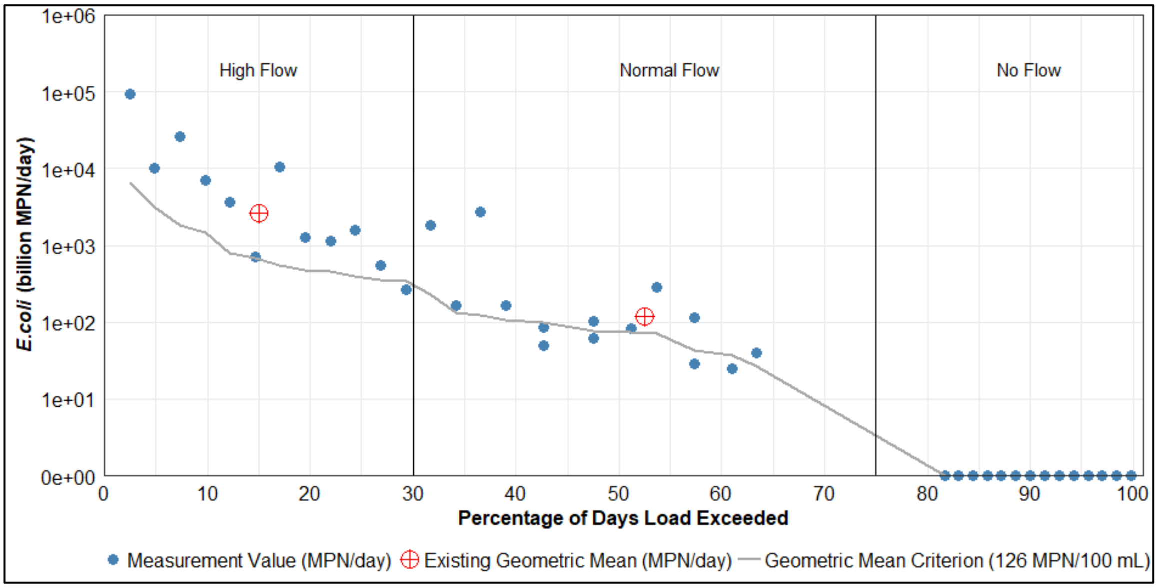

Figure 18. Load duration curve for station 10532 (n=40). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

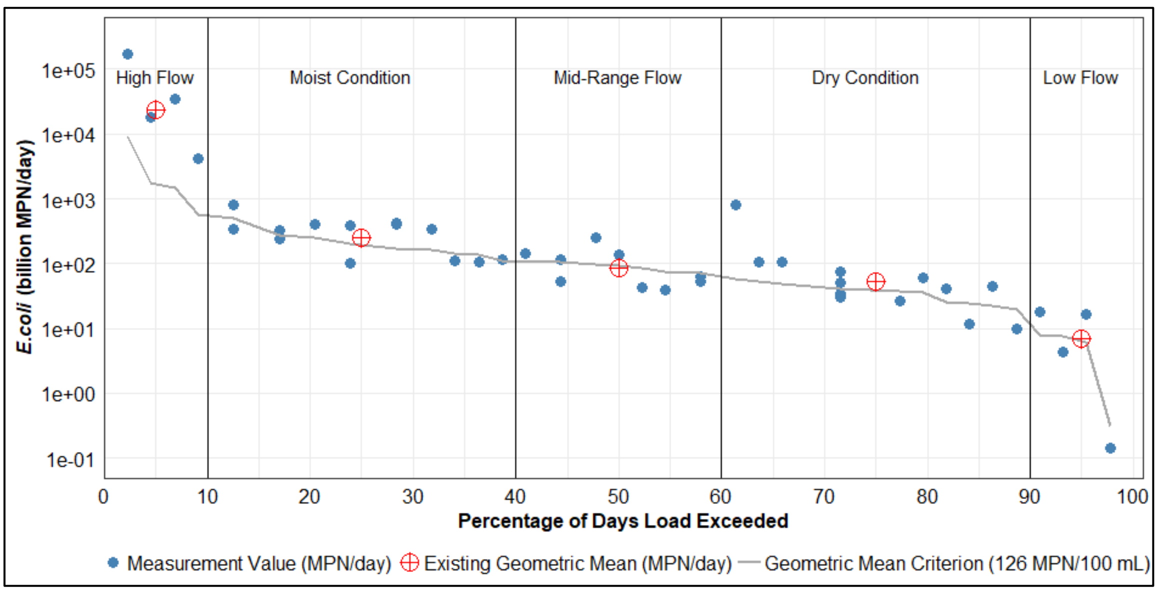

Figure 19. Load duration curve for station 10552 (n=43). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

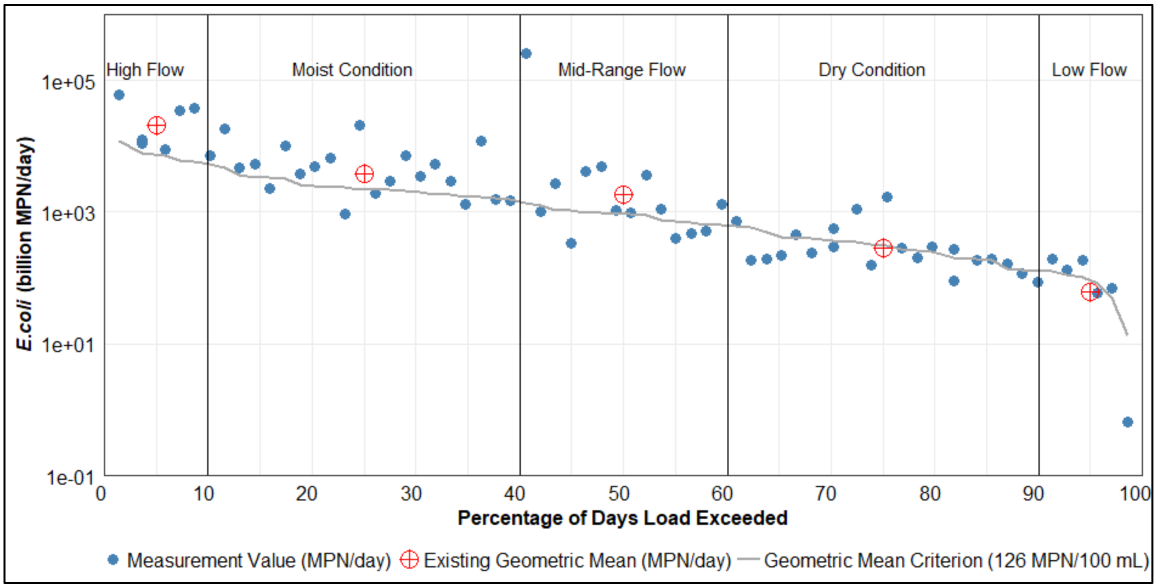

Figure 20. Load duration curve for station 10627 (n=68). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

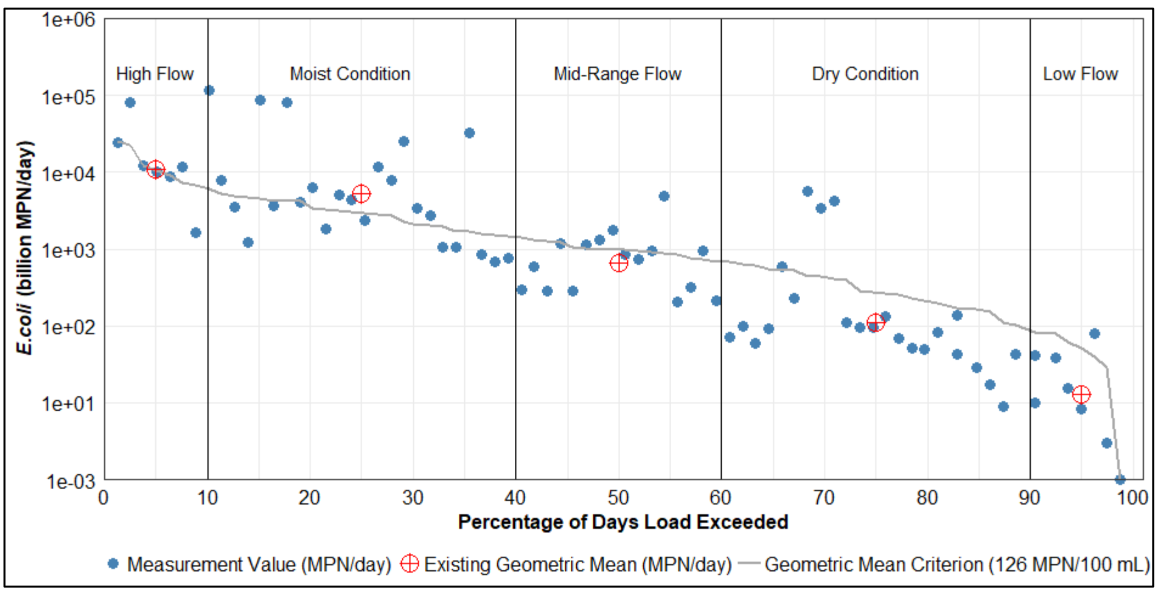

Figure 21. Load duration curve for station 10630 (n=78). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

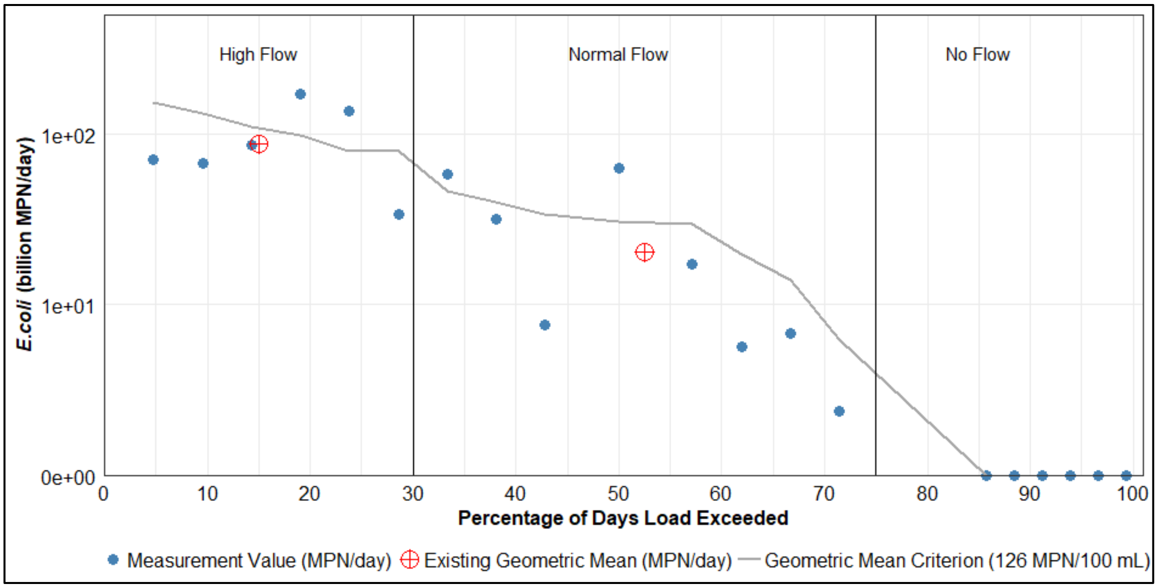

Figure 22. Load duration curve for station 10633 (n=20). The solid grey line indicates the allowable load at geometric metric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

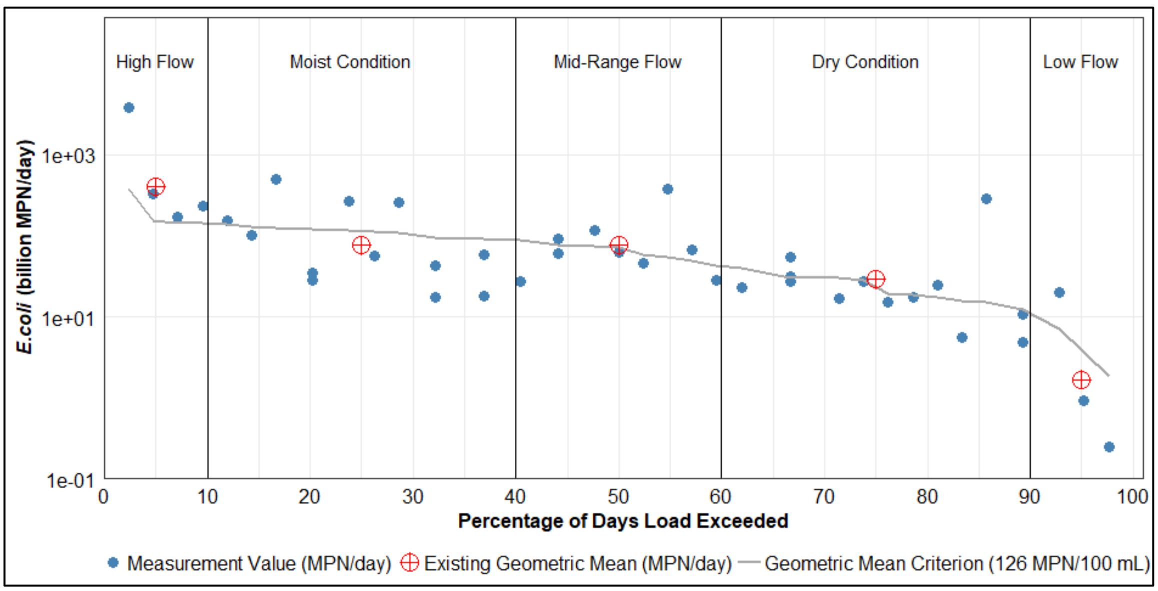

Figure 23. Load duration curve for station 10635 (n=41). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

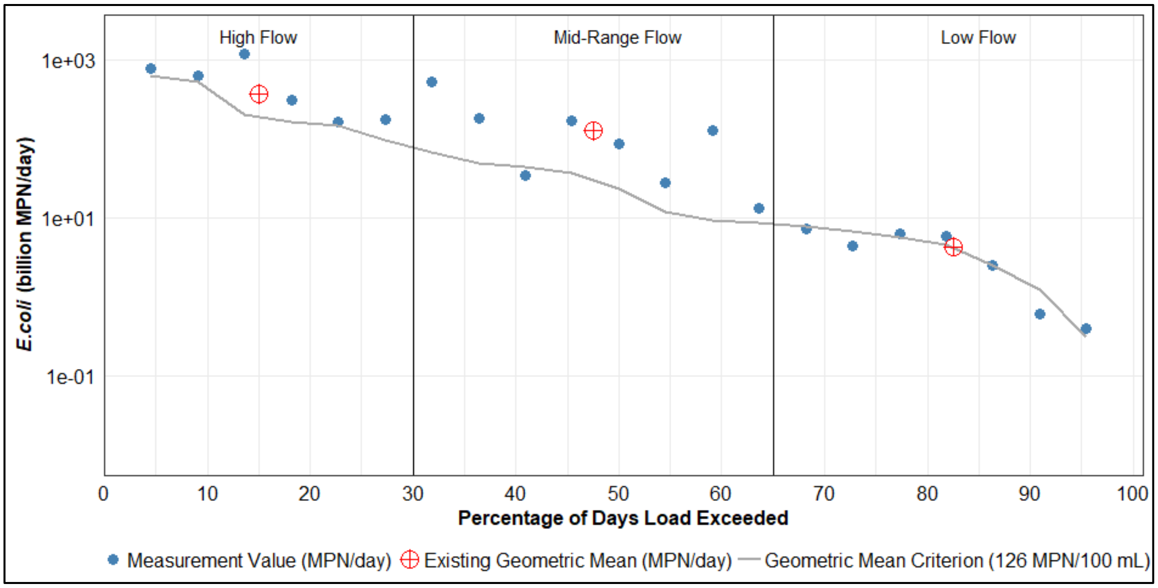

Figure 24. Load duration curve for station 13788 (n=21). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

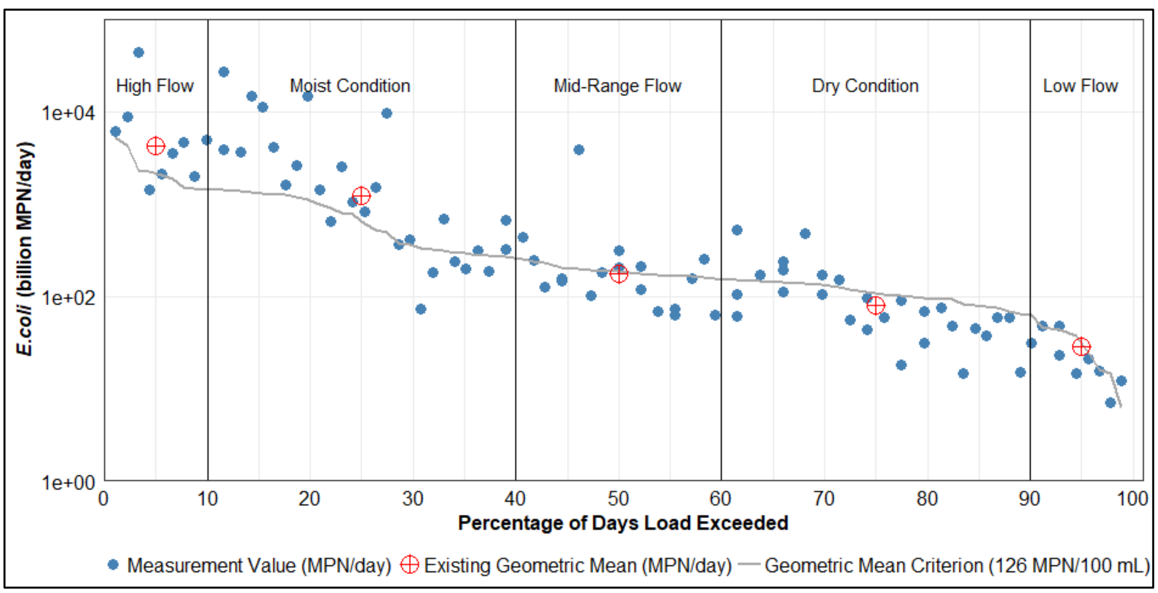

Figure 25. Load duration curve for station 14477 (n=90). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

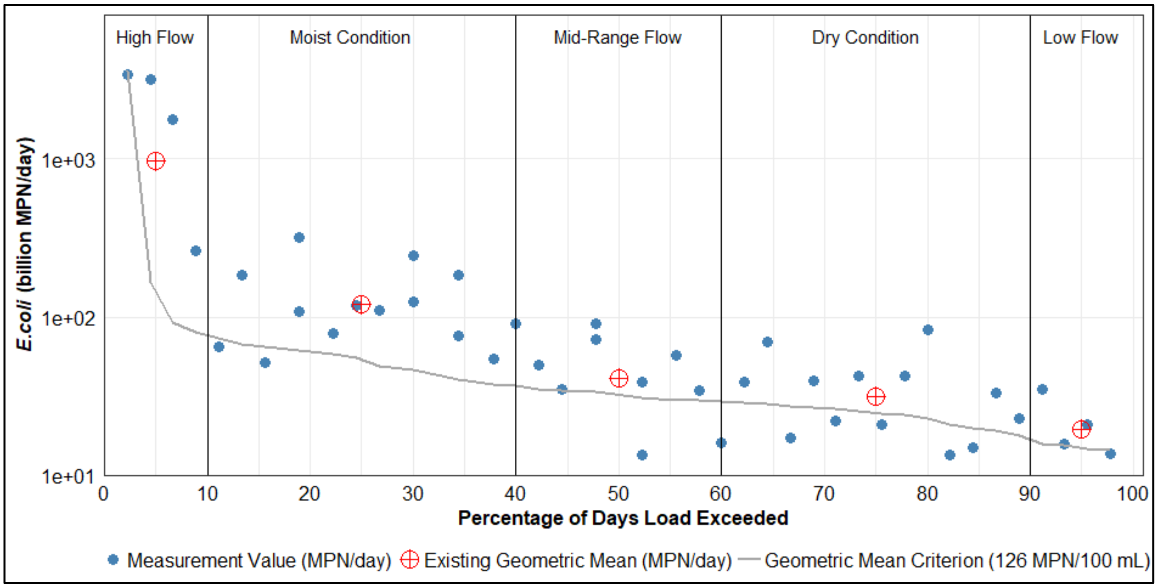

Figure 26. Load duration curve for station 18302 (n=44). The solid grey line indicates the allowable load at geometric mean criterion (126 most probable number [MPN]/100 milliliters [mL]), and the red crossed circles indicate the existing geomean load in each flow regime (MPN/day).

Load Reduction

Based on the LDCs developed for the nine monitoring stations in the Angelina River watershed, station 10633 was the only one that did not need a total load reduction for bacteria. Station 10532 needed a total reduction of 1.21×10^{14} MPN/year, station 10552 needed a total reduction of 7.75×10^{14} MPN/year, station 10627 needed a total reduction of 7.30×10^{14} MPN/year, station 10630 needed a total reduction of 2.58×10^{14} MPN/year, station 10635 needed a total reduction of 9.41×10^{12} MPN/year, station 13788 needed a total reduction of 2.91×10^{13} MPN/year, station 14477 needed a total reduction of 2.51×10^{14} MPN/year, and station 18302 needed a total reduction of 4.78×10^{13} MPN/year (Table 17–Table 25). Formulas used for calculating existing load and load reduction needed are documented in Appendix A.

Table 17. Bacterial load reductions required to meet water quality goals at station 10532.

	Flow conditions		
	High flow	Normal flow	No flow
Days per year	109.5	127.75	127.75
Median flow	222	23	0
Existing geomean concentration	329	127	0
Allowable daily load (billion MPN)	684.36	70.90	0.00
Allowable annual load (billion MPN)	74,937.42	11,645.33	0.00
Existing daily load (billion MPN)	1,786.90	71.50	0.00
Existing annual load (billion MPN)	195,665.55	11,743.88	0.00
Annual load reduction needed (billion MPN)	120,728.13	98.55	0.00
Reduction needed	61.70%	0.84%	0.00%
Total annual load (billion MPN)	207,409.43		
Total annual load reduction (billion MPN)	120,826.68		
Total percent reduction	58.26%		

Most Probable Number, MPN.

Table 18. Bacterial load reductions required to meet water quality goals at station 10552.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low flow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	547	65	30	12	2
Existing geomean concentration	1,699	155	117	177	141
Allowable daily load (billion MPN)	1,686.23	200.37	92.48	36.99	6.17
Allowable annual load (billion MPN)	61,547.40	21,940.52	6,751.04	4,050.41	225.21
Existing daily load (billion MPN)	22,737.40	246.50	85.90	52.00	6.90
Existing annual load (billion MPN)	829,915.10	26,991.75	6,270.70	5,694.00	251.85
Annual load reduction needed (billion MPN)	768,367.71	5,051.24	0.00	1,643.60	26.65
Percent reduction needed	92.58%	18.71%	0.00%	28.87%	10.58%
Total annual load (billion MPN)	869,123.40				
Total annual load reduction (billion MPN)	775,089.18				
Total percent reduction	89.18%				

Most Probable Number, MPN.

Table 19. Bacterial load reductions required to meet water quality goals at station 10627.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low flow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	2,320	720	307	100	27
Existing geomean concentration	361	218	245	117	92
Allowable daily load (billion MPN)	7,151.84	2,219.54	946.39	308.27	83.23
Allowable annual load (billion MPN)	261,042.16	243,039.63	69,086.47	33,755.57	3,037.90
Existing daily load (billion MPN)	20,490.60	3,840.20	1,840.20	286.20	60.80
Existing annual load (billion MPN)	747,906.90	420,501.90	134,334.60	31,338.90	2,219.20
Annual load reduction needed (billion MPN)	486,864.74	177,462.27	65,248.13	0.00	0.00
Percent reduction needed	65.10%	42.20%	48.57%	0.00%	0.00%
Total annual load (billion MPN)	1,336,301.50				
Total annual load reduction (billion MPN)	729,575.14				
Total percent reduction	54.60%				

Most Probable Number, MPN.

Table 20. Bacterial load reductions required to meet water quality goals at station 10630.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low flow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	3,440	968	318	88	17
Existing geomean concentration	129	222	86	52	31
Allowable daily load (billion MPN)	10,604.46	2,984.04	980.30	271.28	52.41
Allowable annual load (billion MPN)	387,062.79	326,752.38	71,561.90	29,705.16	1,912.97
Existing daily load (billion MPN)	10,856.90	5,257.60	669.10	112.00	12.90
Existing annual load (billion MPN)	396,276.85	575,707.20	48,844.30	12,264.00	470.85
Annual load reduction needed (billion MPN)	9,214.06	248,954.82	0.00	0.00	0.00
Percent reduction needed	2.33%	43.24%	0.00%	0.00%	0.00%
Total annual load (billion MPN)	1,033,563.20				
Total annual load reduction (billion MPN)	258,168.88				
Total percent reduction	24.98%				

Most Probable Number, MPN.

Table 21. Bacterial load reductions required to meet water quality goals at station 10633.

	Flow conditions		
	High flow	Normal	No flow
Days per year	109.5	164.25	91.25
Median flow	36	10	0
Existing geomean concentration	99	96	76
Allowable daily load (billion MPN)	110.98	30.83	0.00
Allowable annual load (billion MPN)	12,152.31	5,063.83	0.00
Existing daily load (billion MPN)	87.20	23.50	0.00
Existing annual load (billion MPN)	9,548.40	3,859.88	0.00
Annual load reduction needed (billion MPN)	0.00	0.00	0.00
Percent reduction needed	0.00%	0.00%	0.00%
Total annual load (billion MPN)	13,408.28		
Total annual load reduction (billion MPN)	0.00		
Total percent reduction	0.00%		

Most Probable Number, MPN.

Table 22. Bacterial load reductions required to meet water quality goals at station 10635.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low flow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	50	38	23	9	1
Existing geomean concentration	325	82	136	128	57
Allowable daily load (billion MPN)	155.37	117.14	70.90	28.67	3.70
Allowable annual load (billion MPN)	5,671.01	12,826.83	5,175.70	3,139.37	135.05
Existing daily load (billion MPN)	400.70	76.20	76.50	29.10	1.70
Existing annual load (billion MPN)	14,625.55	8,343.90	5,584.50	3,186.45	62.05
Annual load reduction needed (billion MPN)	8,954.55	0.00	408.80	47.09	0.00
Percent reduction needed	61.23%	0.00%	7.32%	1.48%	0.00%
Total annual load (billion MPN)	31,802.45				
Total annual load reduction (billion MPN)	9,410.43				
Total percent reduction	29.59%				

Most Probable Number, MPN.

Table 23. Bacterial load reductions required to meet water quality goals at station 13788.

	Flow conditions		
	High flow	Mid-range	Low flow
Days per year	109.5	127.75	127.75
Median flow	66	12	2
Existing geomean concentration	227	427	116
Allowable daily load (billion MPN)	203.46	36.99	4.62
Allowable annual load (billion MPN)	22,278.87	4,725.47	590.21
Existing daily load (billion MPN)	366.50	125.40	4.30
Existing annual load (billion MPN)	40,131.75	16,019.85	549.33
Annual load reduction needed (billion MPN)	17,852.88	11,294.38	0.00
Percent reduction needed	44.49%	75.50%	0.00%
Total annual load (billion MPN)	56,700.93		
Total annual load reduction (billion MPN)	29,147.26		
Total percent reduction	51.41%		

Most Probable Number, MPN.

Table 24. Bacterial load reductions required to meet water quality goals at station 14477.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low Ffow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	659	198	60	36	12
Existing geomean concentration	267	255	118	89	97
Allowable daily load (billion MPN)	2,031.49	610.37	184.96	110.98	36.99
Allowable annual load (billion MPN)	74,149.39	66,835.52	13,502.08	12,152.31	1,350.14
Existing daily load (billion MPN)	4,304.80	1,235.30	173.20	78.40	28.50
Existing annual load (billion MPN)	157,125.20	135,265.35	12,643.60	8,584.80	1,040.25
Annual load reduction needed (billion MPN)	82,975.82	68,429.84	0.00	0.00	0.00
Percent reduction needed	52.81%	50.59%	0.00%	0.00%	0.00%
Total annual load (billion MPN)	314,659.20				
Total annual load reduction (billion MPN)	151,405.65				
Total percent reduction	48.12%				

Most Probable Number, MPN.

Table 25. Bacterial load reductions required to meet water quality goals at station 18302.

	Flow conditions				
	High flow	Moist	Mid-range	Dry	Low flow
Days per year	36.5	109.5	73	109.5	36.5
Median flow	54	18	11	8	4.8
Existing geomean concentration	730	273	153	161	167
Allowable daily load (billion MPN)	166.47	55.49	33.91	24.66	14.80
Allowable annual load (billion MPN)	6,076.16	998.82	373.01	197.28	71.04
Existing daily load (billion MPN)	964.40	120.20	41.20	31.50	19.60
Existing annual load (billion MPN)	35,200.60	13,161.90	3,007.60	3,449.25	715.40
Annual load reduction needed (billion MPN)	29,124.45	12,163.08	2,634.59	3,251.97	644.36
Percent reduction needed	82.74%	92.41%	87.60%	94.28%	90.07%
Total annual load (billion MPN)	55,534.75				
Total annual load reduction (billion MPN)	47,818.45				
Total percent reduction	86.11%				

Most Probable Number, MPN.

Pollutant Source Load Estimates

GIS Analysis

To aid in identifying potential areas of *E. coli* contributions within the watershed, GIS spatial analysis was conducted using the method used by the Spatially Explicit Load Enrichment Calculation Tool (SELECT; Borel et al. 2012). The best available information was used to identify likely nonpoint 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 Angelina River watershed (Figure 27). Appendix A documents the assumptions and equations used for estimating potential bacterial loadings in the watershed for all identified sources.

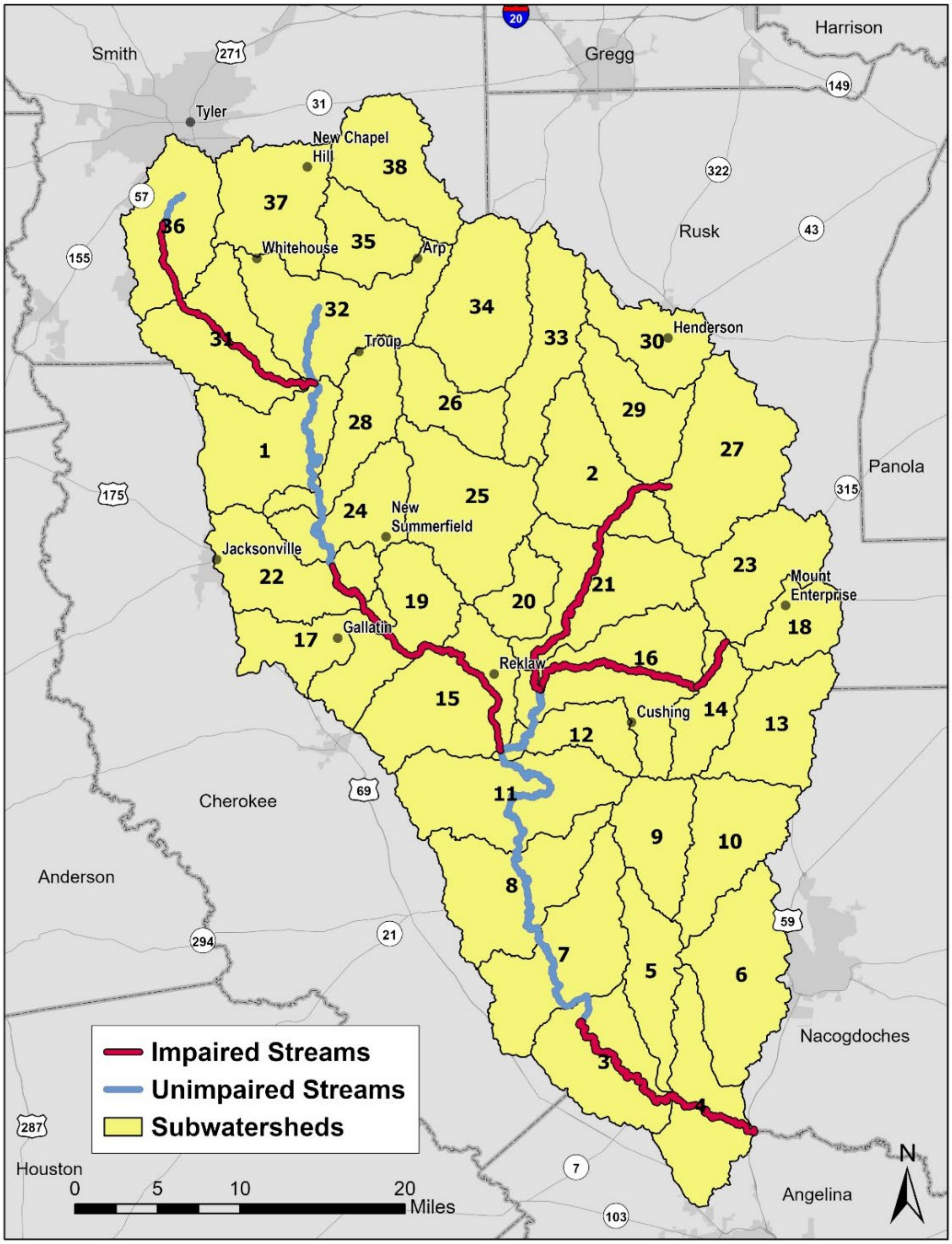

Figure 27. Subwatersheds in the Angelina River above Sam Rayburn Reservoir watershed.

Livestock

Cattle

Cattle can contribute to *E. coli* loading by two pathways: 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 bacterial 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* levels (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. 2013; Clary et al. 2016).

Based on available data, 48,027 cattle were estimated to be evenly distributed across the grazeable land in the Angelina River watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatershed 32 (Figure 28). Total potential annual load due to cattle at the watershed level is 9.95×10^{16} cfu per year.

Goats

A total of 2,485 goats were estimated to be evenly distributed across the grazeable land in the Angelina River watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatershed 32 (Figure 29), and the estimated potential annual loading due to goats at the watershed level is 2.47×10^{15} cfu per year.

Horses

A total of 4,466 horses were estimated to be evenly distributed across the grazeable land in the Angelina River watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatershed 32 (Figure 30). The estimated total potential annual load due to horses at the watershed level is 3.74×10^{14} cfu per year.

Sheep

A total of 777 horses were estimated to be evenly distributed across the grazeable land in the Angelina River watershed. GIS analysis indicated the highest potential annual loading may occur in subwatershed 32 (Figure 31). The estimated total potential annual load due to horses at the watershed level is 1.06×10^{16} cfu per year.

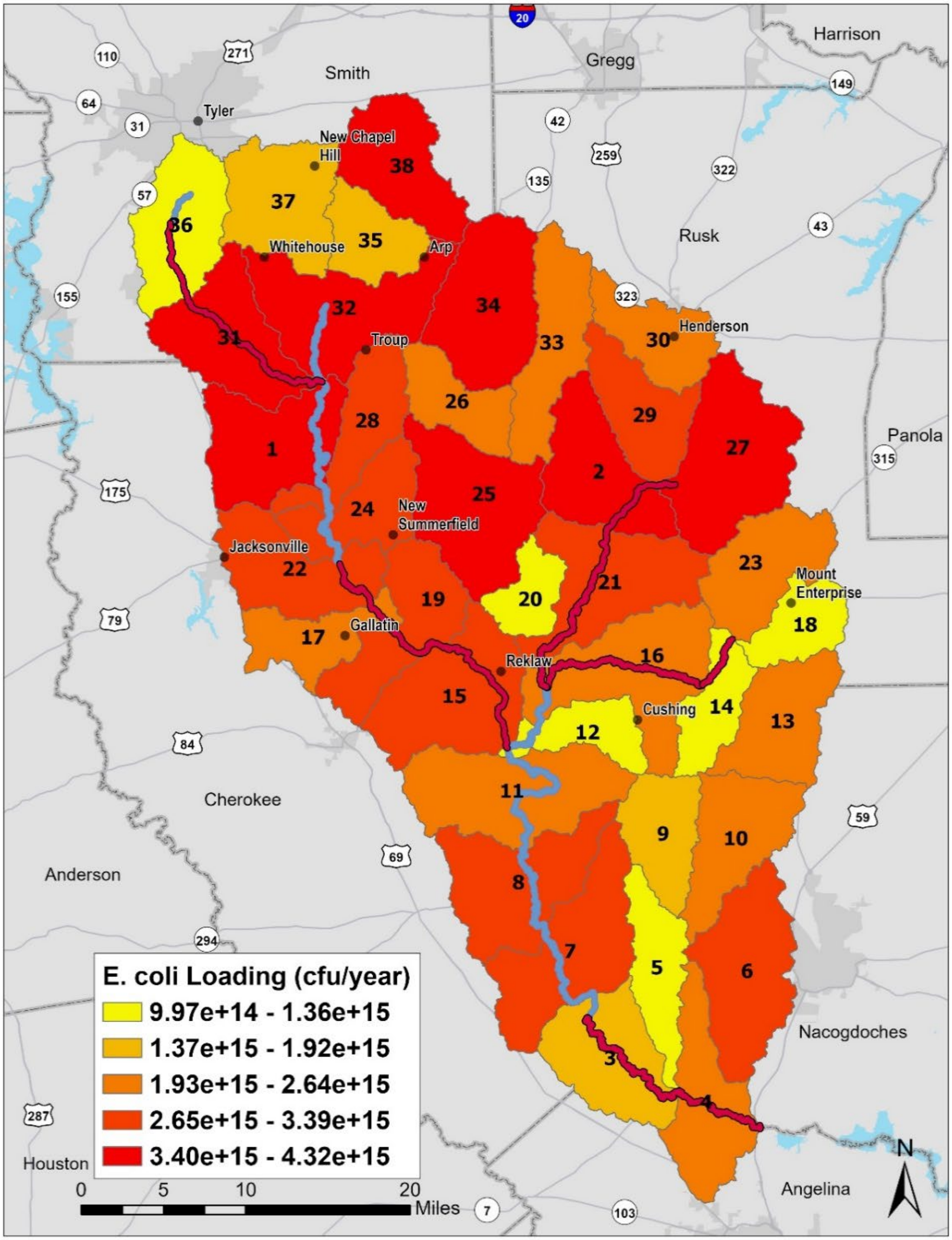

Figure 28. *E. coli* loadings from cattle in the Angelina River watershed.

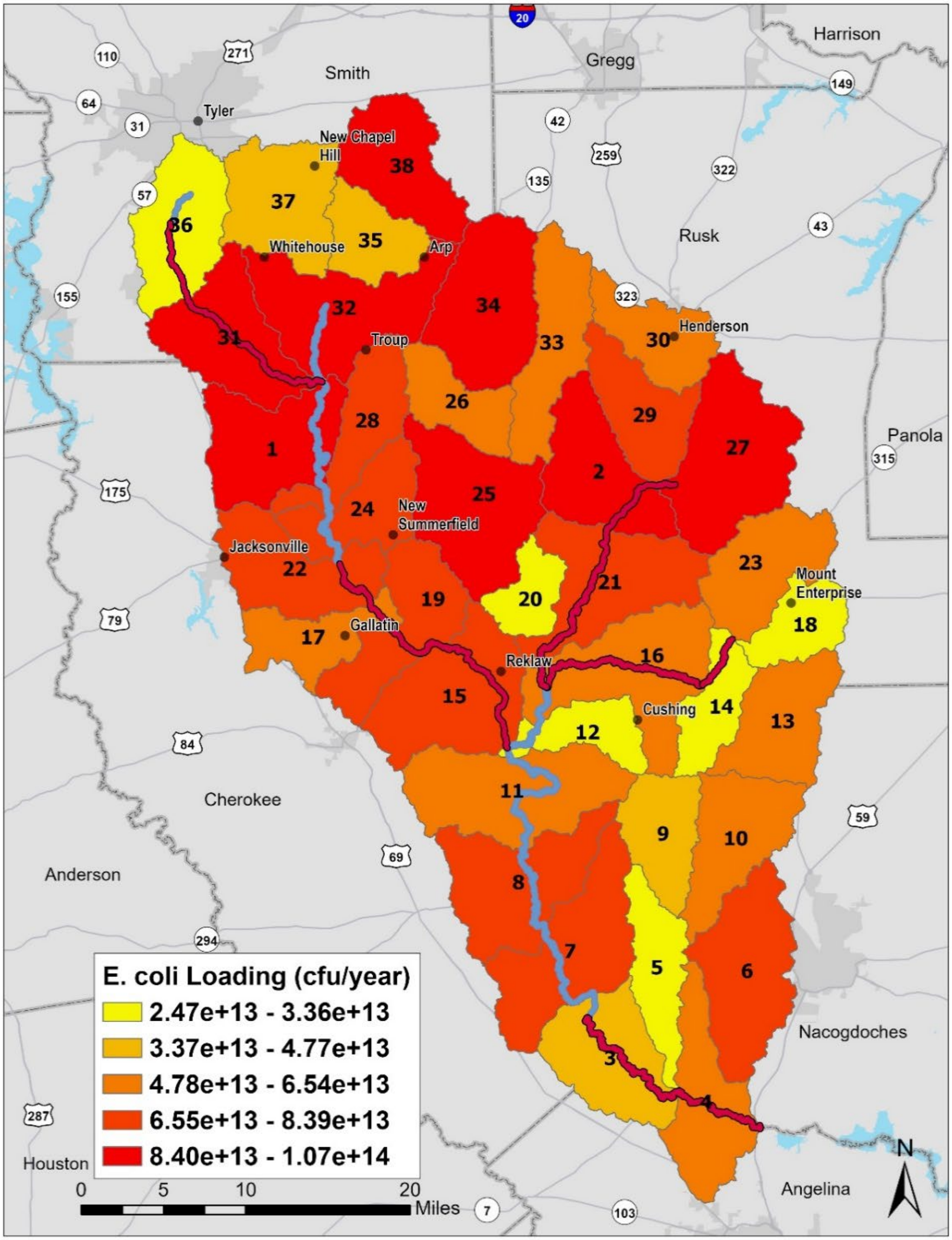

Figure 29. *E. coli* loadings from goats in the Angelina River watershed.

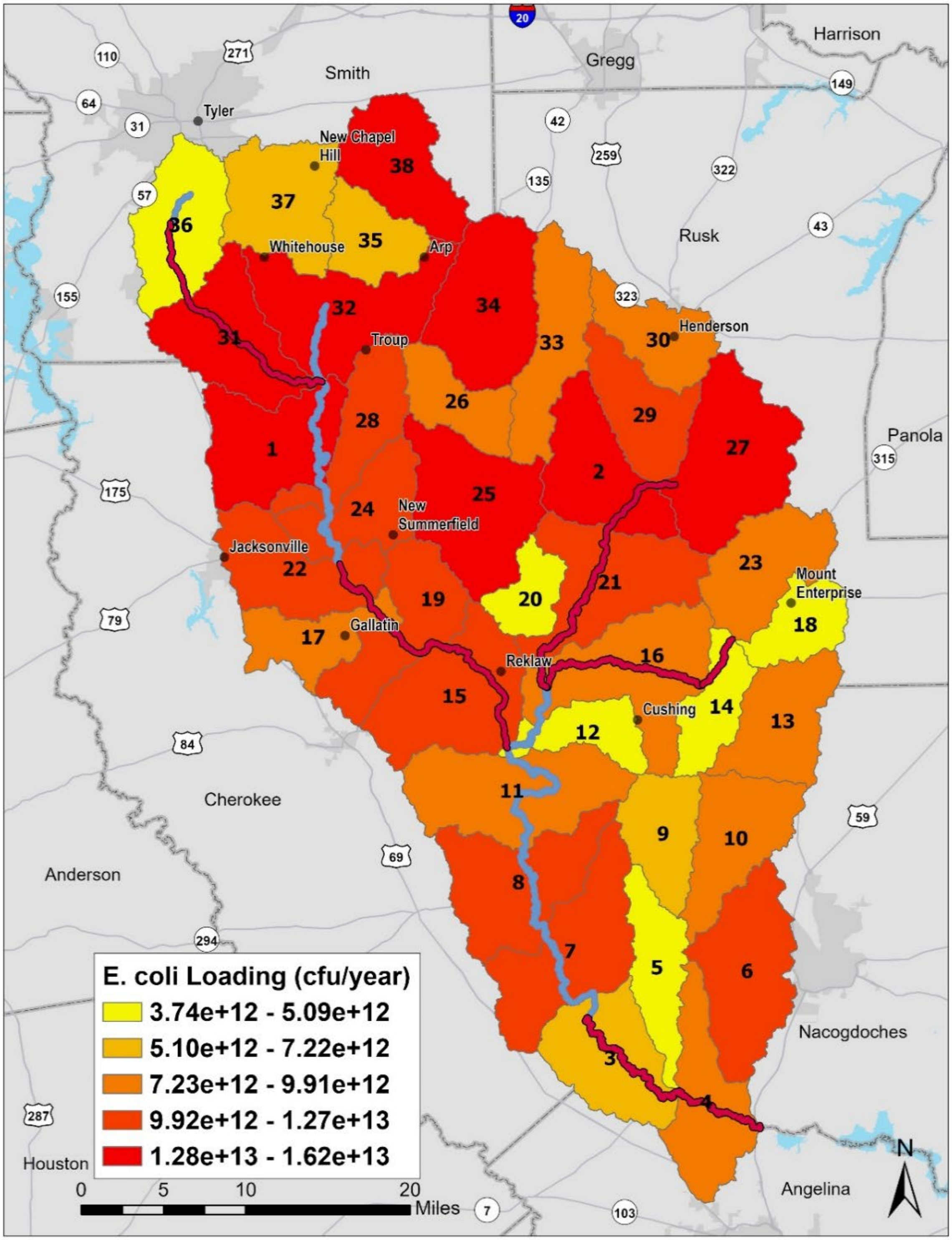

Figure 30. *E. coli* loadings from horses in the Angelina River watershed.

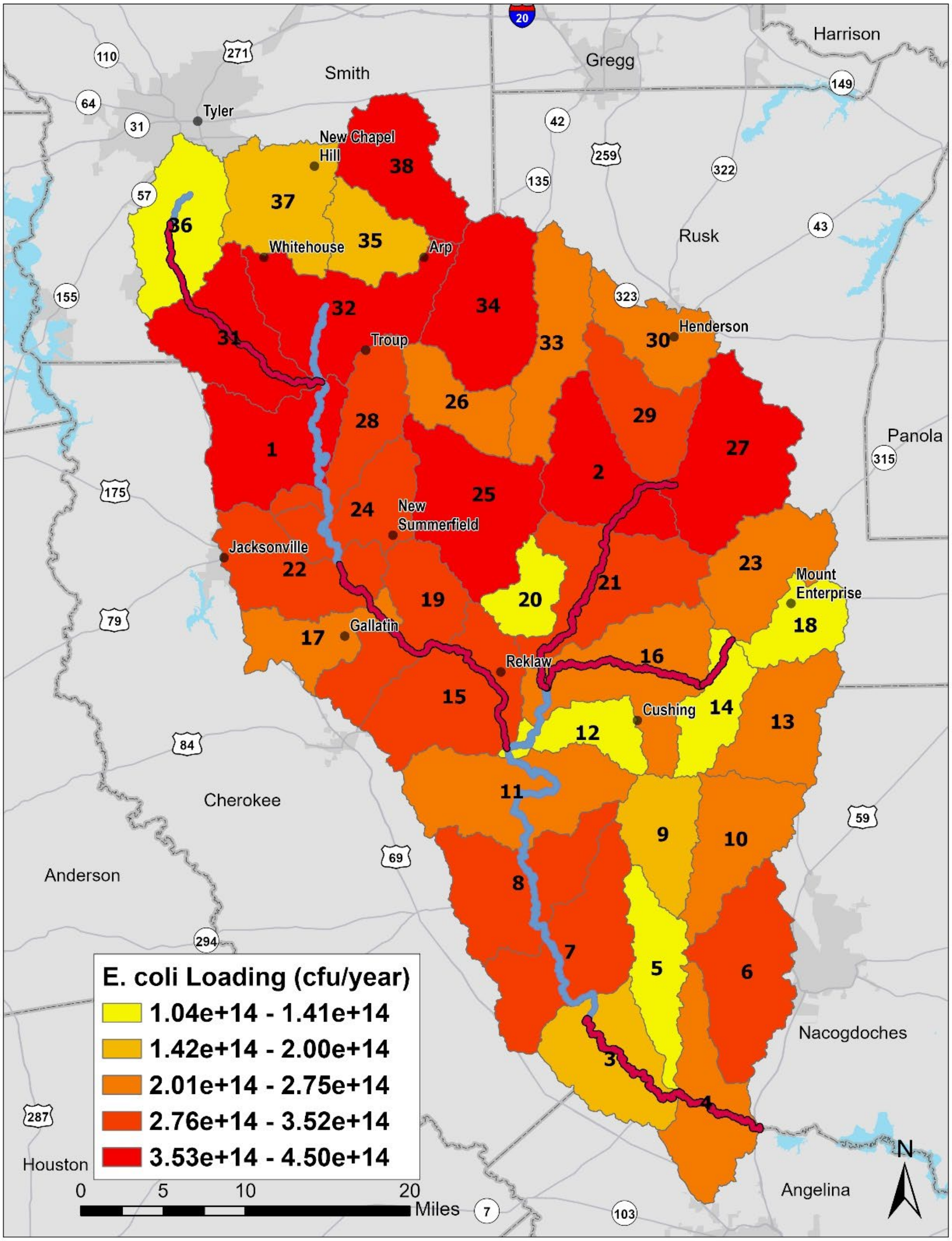

Figure 31. *E. coli* loadings from sheep in the Angelina River watershed.

Wildlife

Deer

A total of 22,319 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 Angelina River watershed. GIS analysis indicated that the highest potential annual loading may occur in subwatershed 11 (Figure 32). The estimated total potential annual loading due to deer at the watershed level is 8.62×10^{15} cfu per year.

Feral Hogs

A total of 23,776 feral hogs were estimated to be evenly distributed across the habitable land in the Angelina River watershed. GIS analysis indicated that the highest potential annual loadings may occur in subwatershed 11 (Figure 33). The estimated total potential annual loading due to feral hogs at the watershed level is 8.27×10^{14} cfu per year.

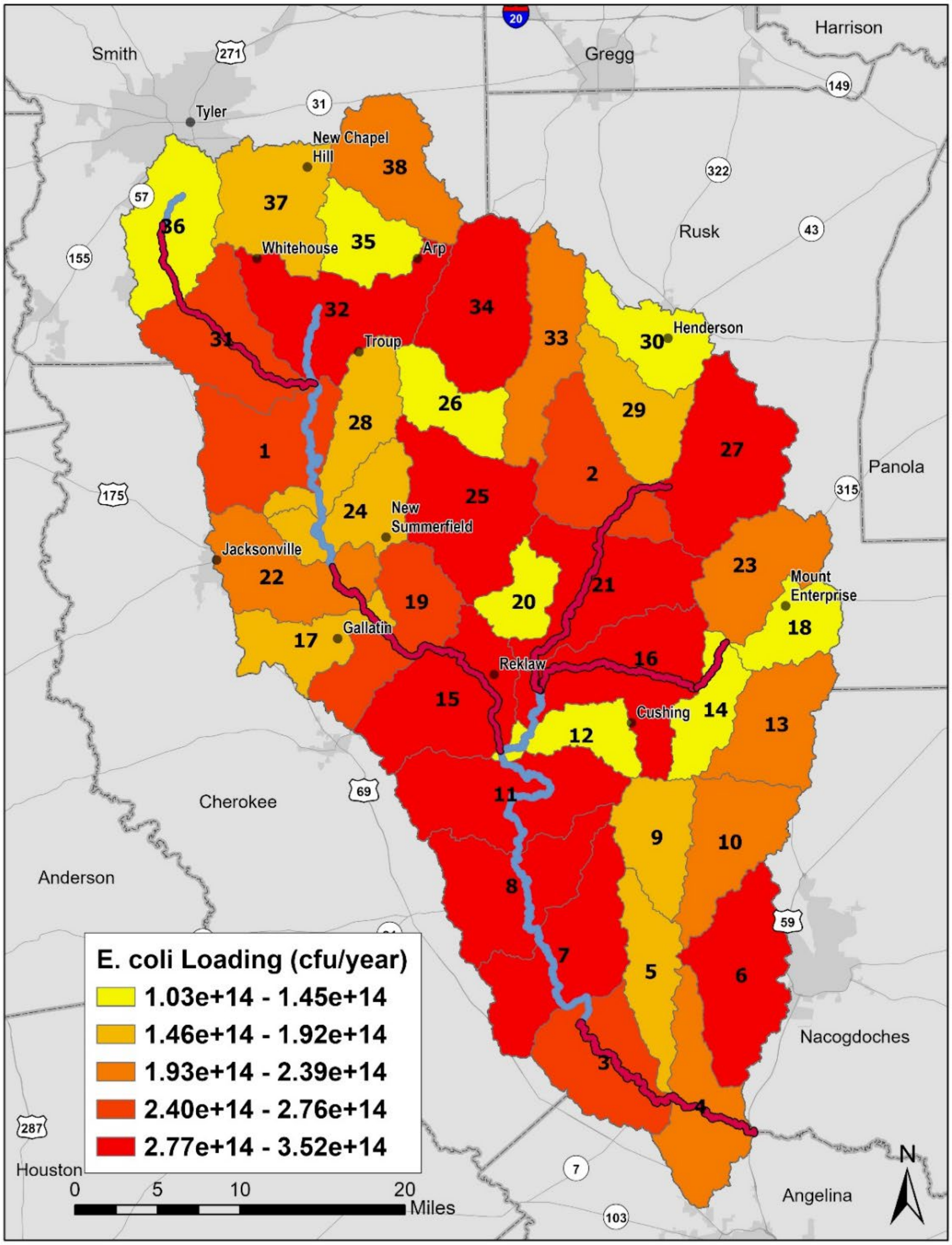

Figure 32. *E. coli* loadings from deer in the Angelina River watershed.

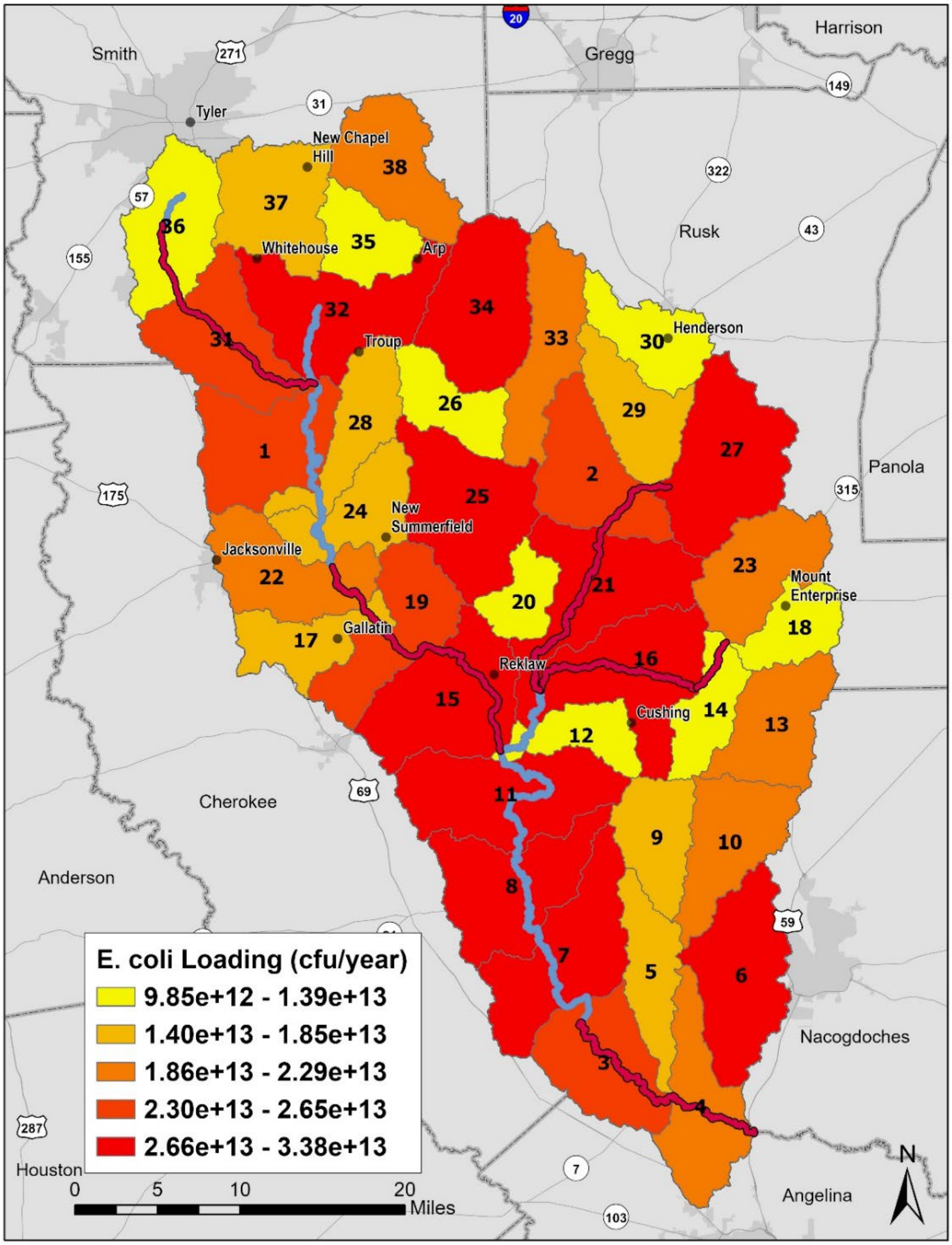

Figure 33. *E. coli* loadings from feral hogs in the Angelina River watershed.

OSSFs

A total of 29,161 OSSFs were estimated to be located within the Angelina River watershed, of which 19% (about 5,541) 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 37 (Figure 34). The estimated total potential annual loading due to OSSFs at the watershed level is 7.98×10^{15} cfu per year.

Domestic Pets: Dogs

A total of 40,554 dogs are estimated to live within the watershed. GIS analysis indicated that the highest potential annual loading occurs in subwatershed 36 (Figure 35). The estimated total potential annual loading due to dogs at the watershed level is 4.66×10^{16} cfu per year.

WWTFs

According to TCEQ and NPDES data, there are six permitted WWTFs that discharge directly into one of the segments in the Angelina River 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 concentrations to assess the maximum potential load. The total potential bacterial load based on maximum permitted discharges across the Angelina River watershed is 5.36×10^{12} cfu per year (Figure 36), and the highest potential loading may occur in subwatershed 36.

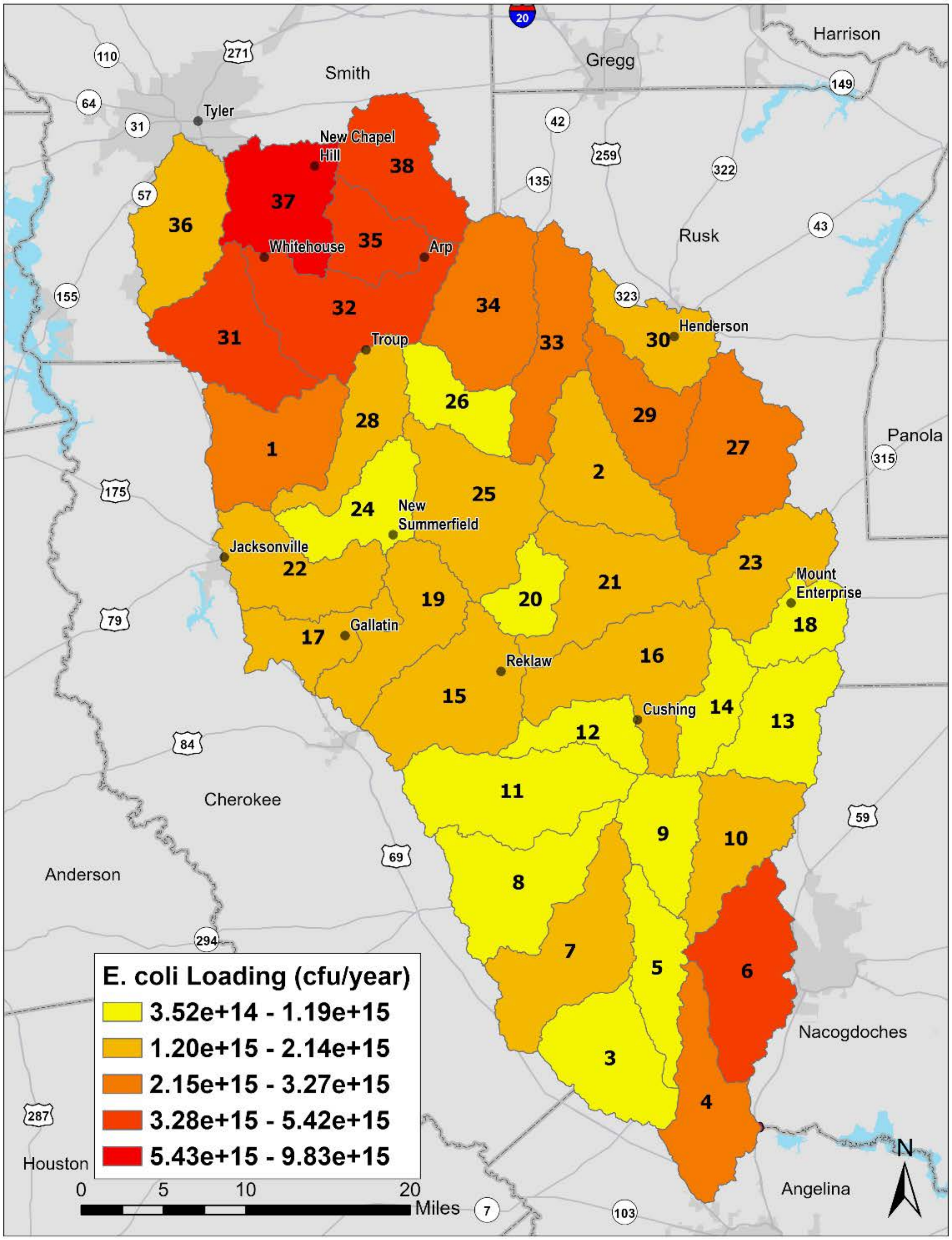

Figure 34. *E. coli* loadings from on-site sewage facilities (OSSFs) in the Angelina River watershed.

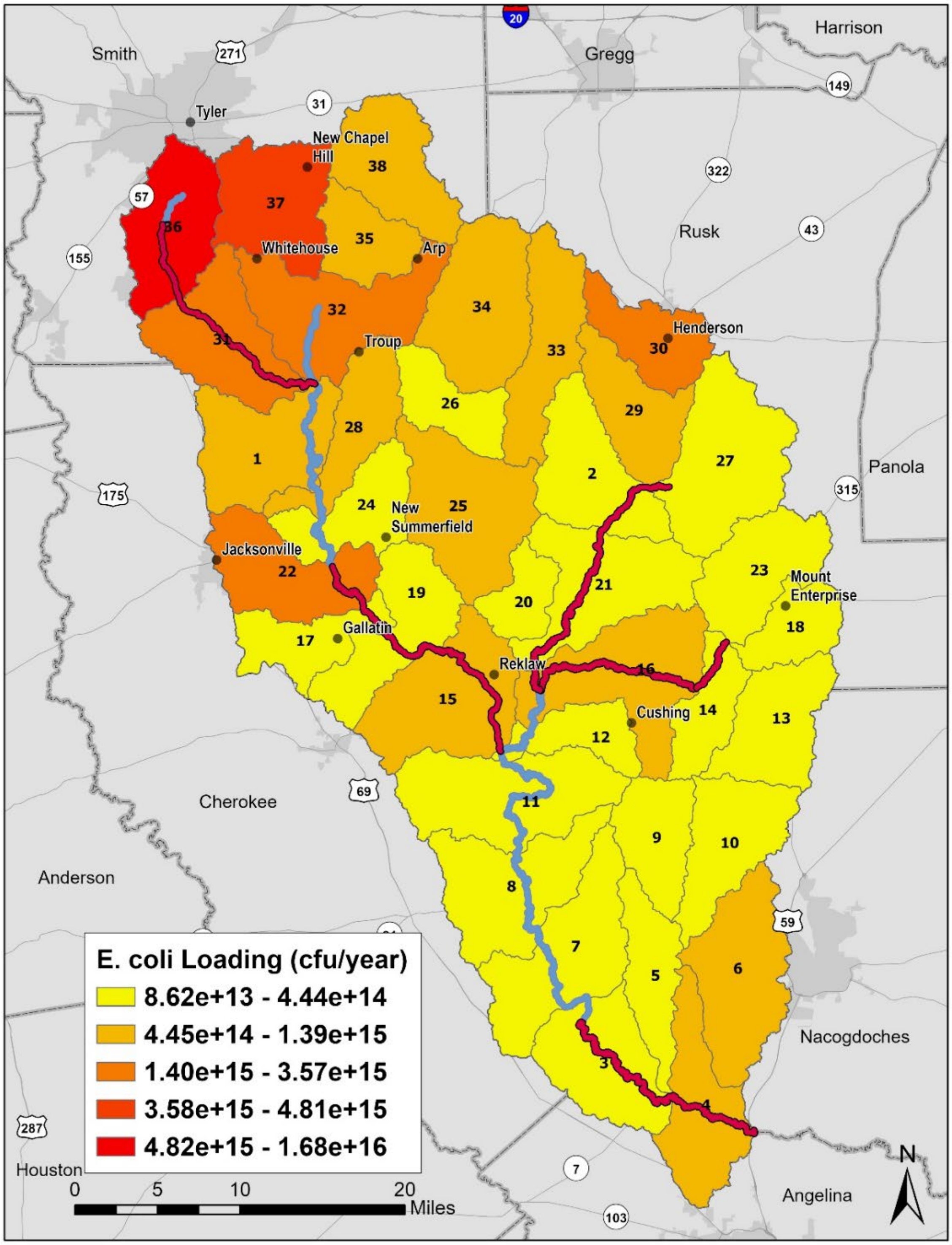

Figure 35. *E. coli* loadings from dogs in the Angelina River watershed.

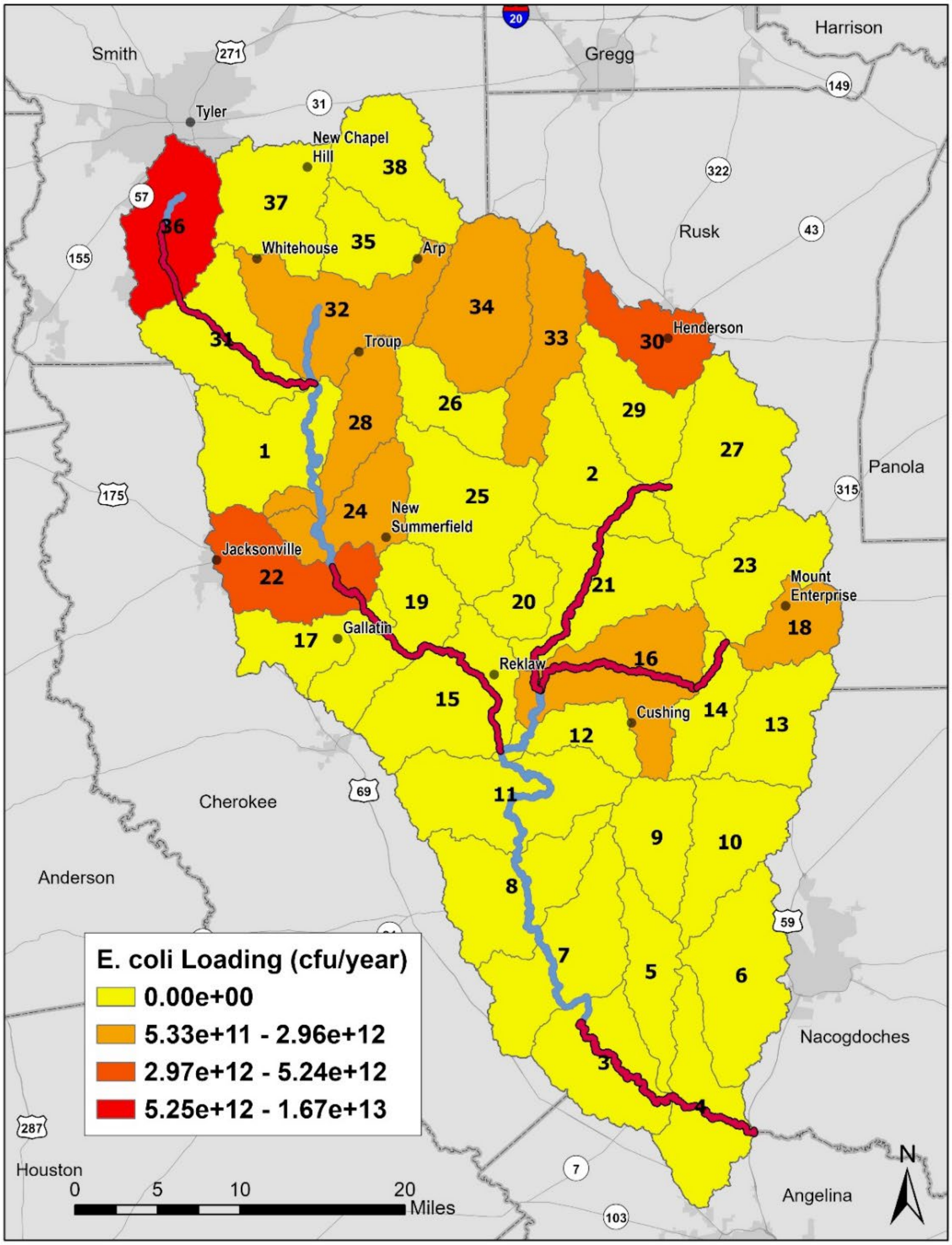

Figure 36. *E. coli* loadings from wastewater treatment facilities (WWTFs) in the Angelina River watershed.

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 PCR I standard.

Segment 0611 (Angelina River above Sam Rayburn Reservoir) above SWQM station 10635 exceeded the capacity of the water body under all flow conditions except for under the moist condition, and a reduction of 9.41×10^{12} cfu per year is needed. On the other hand, segment 0611 above SWQM station 10633 met the PCR 1 geometric mean criterion for *E. coli*, and no reduction is needed. Segment 0611 above SWQM station 10630 exceeded the capacity of the water body under high and moist flow conditions, and a total reduction of 2.58×10^{14} cfu per year is needed. Segment 0611 above SWQM station 10627 exceeded the capacity of the water body under high, moist, and mid-range flow conditions, and a total reduction of 7.30×10^{15} cfu per year is needed.

Segment 0611A (East Fork Angelina River) above SWQM station 13788 exceeded the capacity of the water body under high and mid-range flow conditions, and a total reduction of 1.91×10^{13} cfu per year is needed. Segment 0611A above SWQM station 10552 exceeded the capacity of the water body under high and moist flow conditions, and a total reduction of 7.75×10^{14} cfu per year is needed.

Segment 0611C (Mud Creek) above SWQM station 14477 exceeded the capacity of the water body under high and moist flow conditions, and a total reduction of 1.51×10^{14} cfu per year is needed. Segment 0611C above SWQM station 10532 exceeded the capacity of the water body under high and mid-range flow conditions, and a total reduction of 1.21×10^{14} cfu per year is needed.

Segment 0611D (West Mud Creek) above SWQM station 18302 exceeded the capacity of the water body under all flow conditions, and a total reduction of 4.78×10^{13} cfu per year is needed to meet the PCR 1 standard.

Given the relatively good compliances of permitted dischargers in the watershed, bacterial 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. 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 analyzed pollutant sources, livestock appeared to be the most significant potential contributor of *E. coli* loading (Table 26). Conversely, WWTFs appeared to have the least potential of contributing to *E. coli* loading. Total potential loadings are most likely underestimated because many other wildlife sources of fecal bacteria are not included in the analysis.

Identifying where grazeable lands (i.e., herbaceous and hay/pasture) are the most concentrated in the watershed helps to highlight important areas to address and implement potential improvements in grazeable land runoff.

GIS 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 26. Summary of potential source loads in the Angelina River watershed.

Source	Potential loadings (colony forming units/year)	Highest priority subwatershed(s)
Cattle	9.95×10^{16}	32
Horses	3.74×10^{14}	32
Goats	2.47×10^{15}	32
Sheep	1.04×10^{16}	32
Deer	8.62×10^{15}	11
Feral hogs	8.27×10^{14}	11
OSSFs	7.98×10^{15}	37
Dogs	4.66×10^{16}	36
WWTFs	3.10×10^{13}	36
Total	7.77×10^{16}	

on-site sewage facility, OSSF

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Appendix A: Annual Bacterial 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 Angelina River watershed based on the availability of the instantaneous flow 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 bacterial load reductions, the required daily load was multiplied by the number of days per year in each flow condition. Table A-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 A-1. Bacterial load reduction calculations by flow condition.

<table>
<tr><th></th><th colspan="5">Flow Condition</th></tr>
<tr><td>SWQM station 10532, 10633</td><td colspan="2">High flow</td><td colspan="2">Normal flow</td><td>No flow</td></tr>
<tr><td>Percent of year</td><td colspan="2">30%</td><td colspan="2">45%</td><td>25%</td></tr>
<tr><td>SWQM stations 13788</td><td colspan="2">High flow</td><td colspan="2">Mid-range</td><td>Dry</td></tr>
<tr><td>Percent of year</td><td colspan="2">30%</td><td colspan="2">35%</td><td>35%</td></tr>
<tr><td>SWQM stations 10552, 10627,10630, 10635, 14477, 18302</td><td>High flow</td><td>Moist</td><td>Mid-range</td><td>Dry</td><td>Low flow</td></tr>
<tr><td>Percent of year</td><td>10%</td><td>30%</td><td>20%</td><td>30%</td><td>10%</td></tr>
<tr><td>Days per year</td><td colspan="5">Percent of Year × 365</td></tr>
<tr><td>Median flow (cubic feet per second)</td><td colspan="5">Median observed or median estimated flow in each flow category</td></tr>
<tr><td>Existing geomean concentration (MPN/100 mL)</td><td colspan="5">Geometric mean of observed E. coli samples in each flow category</td></tr>
<tr><td>Allowable daily load (billion MPN)</td><td colspan="5">Median flow × 126 MPN/100 mL × 283.2 100 mL/cubic foot × 86,400 seconds/day</td></tr>
<tr><td>Allowable annual load (billion MPN)</td><td colspan="5">Allowable daily load × days per year</td></tr>
<tr><td>Existing daily load (billion MPN)</td><td colspan="5">Median flow × existing geomean concentration × 283.2 100 mL/cubic foot × 86,400 seconds/day</td></tr>
<tr><td>Existing annual load (billion MPN)</td><td colspan="5">Existing daily load × days per year</td></tr>
<tr><td>Annual load reduction needed (billion MPN)</td><td colspan="5">Existing annual load – allowable annual load</td></tr>
<tr><td>Percent reduction needed</td><td colspan="5">(Existing annual load – allowable annual load)/existing annual load × 100</td></tr>
<tr><td>Total annual load (billion MPN)</td><td colspan="5">Sum of existing annual loads</td></tr>
<tr><td>Total annual load reduction (billion MPN)</td><td colspan="5">Sum of annual load reductions needed</td></tr>
<tr><td>Total percent reduction</td><td colspan="5">Total annual load reduction/total annual load × 100</td></tr>
</table>

Surface Water Quality Monitoring, SWQM, Most Probable Number, MPN.

Appendix B: Potential Bacterial Loading Calculations

The GIS analysis methodology was used to estimate potential bacterial loads in the overall watershed, as well as within the subwatersheds. This geospatial approach also serves as a method to understand relative contributions and spatial distribution across the watersheds without relying on data-intensive (and expensive) modeling approaches.

This analysis distributes inputs across the watersheds based on land use and land cover attributes. The bacterial loadings are calculated from published bacteria data. The loadings are then spatially distributed across the watersheds based on appropriate land cover.

Potential Bacterial Loadings from Livestock

Watershed livestock population estimates were estimated based on the 2017 Census of Agriculture (USDA 2019) county-level statistics. 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 2019 NLCD. Based on Wagner and Moench (2009) and the estimated number of livestock (Table B-1), we calculated the potential annual loadings from cattle, horses, goats, and sheep using the equation below:

$$\begin{aligned} \textit{Potential annual loadings} = \; & \textit{number of livestock in the watershed} \\ \times \; & \textit{livestock to animal unit conversion factor} \\ \times \; & \textit{fecal coliform produced per animal unit per day} \\ \times \; & \textit{fecal coliform to E. coli conversion rate} \\ \times \; & \textit{365 days} \end{aligned}$$

Table B-1. Potential *E. coli* loading calculations for livestock.

Source	Estimated population	Livestock to animal unit conversion factor	Fecal coliform produced per animal unit per day (cfu/day)	Fecal coliform to *E. coli* conversion rate	Potential annual loading (cfu/year)
Cattle	50,624	1.00	8.55×10^{9}	0.63	9.95×10^{16}
Horses	4,466	1.25	2.91×10^{8}	0.63	3.74×10^{14}
Goats	2,485	0.17	2.54×10^{10}	0.63	2.47×10^{15}
Sheep	777	0.20	2.90×10^{11}	0.63	1.04×10^{16}

colony forming unit, cfu.

In the Angelina River watershed, there is an estimated 50,624 cattle contributing 9.95×10^{16} *E. coli* per year, 4,466 horses contributing 3.74×10^{14} *E. coli* per year, 2,485 goats contributing 2.47×10^{15} *E. coli* per year, and 777 sheep contributing 1.04×10^{16} *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 Angelina River watershed. The livestock density was determined as the ratio of the total estimated number of livestock in the Angelina River watershed to the total acreage of the grazeable land in the Angelina River watershed (Table B-2). The estimated number of livestock and corresponding *E. coli* loading in each subwatershed are listed in Table B-3.

Table B-2. Estimated livestock density in the Angelina River watershed.

Livestock	Estimated population	Grazeable land (acres)	Estimated livestock density
Cattle	50,624	342,911	0.147631
Horses	4,466	342,911	0.013025
Goats	2,485	342,911	0.007247
Sheep	777	342,911	0.002266

Table B-3. Estimated number of livestock and corresponding *E. coli* loading in subwatersheds.

Subwatershed	Number of cattle	*E. coli* loading from cattle (cfu/year)	Number of horses	*E. coli* loading from horses (cfu/year)	Number of goats	*E. coli* loading from goats (cfu/year)	Number of sheep	*E. coli* loading from sheep (cfu/year)
1	1,936	3.81×10^{15}	171	1.43×10^{13}	95	9.43×10^{13}	30	3.96×10^{14}
2	2,110	4.15×10^{15}	186	1.56×10^{13}	104	1.03×10^{14}	32	4.32×10^{14}
3	830	1.63×10^{15}	73	6.13×10^{12}	41	4.05×10^{13}	13	1.70×10^{14}
4	1,172	2.30×10^{15}	103	8.65×10^{12}	58	5.71×10^{13}	18	2.40×10^{14}
5	689	1.36×10^{15}	61	5.09×10^{12}	34	3.36×10^{13}	11	1.41×10^{14}
6	1,462	2.88×10^{15}	129	1.08×10^{13}	72	7.13×10^{13}	22	2.99×10^{14}
7	1,594	3.13×10^{15}	141	1.18×10^{13}	78	7.77×10^{13}	24	3.26×10^{14}
8	1,542	3.03×10^{15}	136	1.14×10^{13}	76	7.52×10^{13}	24	3.16×10^{14}

9	734	1.44×10^{15}	65	5.42×10^{12}	36	3.58×10^{13}	11	1.50×10^{14}
10	1,276	2.51×10^{15}	113	9.42×10^{12}	63	6.22×10^{13}	20	2.61×10^{14}
11	1,123	2.21×10^{15}	99	8.29×10^{12}	55	5.47×10^{13}	17	2.30×10^{14}
12	515	1.01×10^{15}	45	3.80×10^{12}	25	2.51×10^{13}	8	1.05×10^{14}
13	1,086	2.13×10^{15}	96	8.01×10^{12}	53	5.29×10^{13}	17	2.22×10^{14}
14	507	9.97×10^{14}	45	3.74×10^{12}	25	2.47×10^{13}	8	1.04×10^{14}
15	1,668	3.28×10^{15}	147	1.23×10^{13}	82	8.13×10^{13}	26	3.41×10^{14}
16	1,158	2.28×10^{15}	102	8.55×10^{12}	57	5.65×10^{13}	18	2.37×10^{14}
17	1,208	2.38×10^{15}	107	8.92×10^{12}	59	5.89×10^{13}	19	2.47×10^{14}
18	594	1.17×10^{15}	52	4.38×10^{12}	29	2.89×10^{13}	9	1.22×10^{14}
19	1,657	3.26×10^{15}	146	1.22×10^{13}	81	8.08×10^{13}	25	3.39×10^{14}
20	512	1.01×10^{15}	45	3.78×10^{12}	25	2.50×10^{13}	8	1.05×10^{14}
21	1,722	3.39×10^{15}	152	1.27×10^{13}	85	8.39×10^{13}	26	3.52×10^{14}
22	1,496	2.94×10^{15}	132	1.10×10^{13}	73	7.29×10^{13}	23	3.06×10^{14}
23	1,263	2.48×10^{15}	111	9.32×10^{12}	62	6.16×10^{13}	19	2.59×10^{14}
24	1,684	3.31×10^{15}	149	1.24×10^{13}	83	8.21×10^{13}	26	3.45×10^{14}
25	1,865	3.67×10^{15}	165	1.38×10^{13}	92	9.09×10^{13}	29	3.82×10^{14}
26	1,191	2.34×10^{15}	105	8.79×10^{12}	58	5.81×10^{13}	18	2.44×10^{14}
27	2,170	4.27×10^{15}	191	1.60×10^{13}	107	1.06×10^{14}	33	4.44×10^{14}
28	1,483	2.92×10^{15}	131	1.09×10^{13}	73	7.23×10^{13}	23	3.04×10^{14}
29	1,441	2.83×10^{15}	127	1.06×10^{13}	71	7.02×10^{13}	22	2.95×10^{14}
30	1,093	2.15×10^{15}	96	8.06×10^{12}	54	5.33×10^{13}	17	2.24×10^{14}
31	1,822	3.58×10^{15}	161	1.34×10^{13}	89	8.88×10^{13}	28	3.73×10^{14}
32	2,199	4.32×10^{15}	194	1.62×10^{13}	108	1.07×10^{14}	34	4.50×10^{14}
33	1,342	2.64×10^{15}	118	9.91×10^{12}	66	6.54×10^{13}	21	2.75×10^{14}
34	2,116	4.16×10^{15}	187	1.56×10^{13}	104	1.03×10^{14}	32	4.33×10^{14}
35	890	1.75×10^{15}	79	6.57×10^{12}	44	4.34×10^{13}	14	1.82×10^{14}
36	585	1.15×10^{15}	52	4.31×10^{12}	29	2.85×10^{13}	9	1.20×10^{14}
37	978	1.92×10^{15}	86	7.22×10^{12}	48	4.77×10^{13}	15	2.00×10^{14}
38	1,910	3.75×10^{15}	168	1.41×10^{13}	94	9.31×10^{13}	29	3.91×10^{14}

colony forming unit, cfu.

Potential Bacterial Loadings from Feral Hogs and Wildlife

Feral hog and deer populations were estimated based on an assumed population density of 39 acres per hog and 41.56 deer per 1,000 acres of suitable habitat (Wagner and Moench 2009). The acreage of the habitable land is an aggregate of deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent herbaceous wetlands classified in NLCD (2019). Based on the estimated number of feral hogs and deer in the Angelina River watershed, we calculated the potential annual loadings from feral hogs and deer using the equation below:

Potential annual loading = *number of feral hogs or deer in watershed*
× *feral hogs or deer to animal unit conversion factor*
× *fecal coliform produced per animal unit per day*
× *fecal coliform to E. coli conversion rate*
× *365 days*

Table B-4. Assumptions used in potential daily load calculations for feral hogs and deer.

	Estimated population	Population to animal unit conversion factor	Fecal coliform produced per animal unit per day (cfu/day)	Fecal coliform to *E. coli* conversion rate	Potential annual loading (cfu/year)
Feral hog	23,776	0.125	1.21×10^{9}	0.63	8.27×10^{14}
Deer	22,319	0.112	1.50×10^{10}	0.63	8.62×10^{15}

colony forming unit, cfu.

In the Angelina River watershed, there are an estimated 23,776 feral hogs contributing 8.27×10^{14} *E. coli* per year and an estimated 22,319 while-tailed deer contributing to 8.62×10^{15} *E. coli* per year (Table B-4). For each subwatershed in the Angelina River watershed, the populations of feral hogs and deer were estimated using the acres of habitable land in the subwatershed and the population densities (Table B-5).

Table B-5. Estimated number of feral hogs and deer and corresponding *E. coli* loadings in subwatersheds.

Subwatershed	Number of feral hogs	*E. coli* loading from feral hogs (cfu/year)	Number of deer	*E. coli* loading from deer (cfu/year)
1	762	2.65×10^{13}	715	2.76×10^{14}
2	702	2.44×10^{13}	659	2.54×10^{14}
3	717	2.49×10^{13}	673	2.60×10^{14}
4	660	2.29×10^{13}	619	2.39×10^{14}
5	418	1.45×10^{13}	393	1.52×10^{14}
6	807	2.81×10^{13}	758	2.93×10^{14}
7	891	3.10×10^{13}	836	3.23×10^{14}

8	840	2.92×10^{13}	789	3.05×10^{14}
9	476	1.66×10^{13}	447	1.73×10^{14}
10	645	2.24×10^{13}	606	2.34×10^{14}
11	971	3.38×10^{13}	912	3.52×10^{14}
12	337	1.17×10^{13}	316	1.22×10^{14}
13	619	2.15×10^{13}	581	2.25×10^{14}
14	379	1.32×10^{13}	356	1.37×10^{14}
15	913	3.18×10^{13}	857	3.31×10^{14}
16	953	3.32×10^{13}	895	3.46×10^{14}
17	414	1.44×10^{13}	389	1.50×10^{14}
18	345	1.20×10^{13}	324	1.25×10^{14}
19	689	2.40×10^{13}	646	2.50×10^{14}
20	283	9.85×10^{12}	266	1.03×10^{14}
21	849	2.95×10^{13}	797	3.08×10^{14}
22	599	2.08×10^{13}	562	2.17×10^{14}
23	632	2.20×10^{13}	593	2.29×10^{14}
24	494	1.72×10^{13}	464	1.79×10^{14}
25	886	3.08×10^{13}	832	3.21×10^{14}
26	401	1.39×10^{13}	376	1.45×10^{14}
27	948	3.30×10^{13}	890	3.44×10^{14}
28	503	1.75×10^{13}	472	1.82×10^{14}
29	531	1.85×10^{13}	498	1.92×10^{14}
30	351	1.22×10^{13}	330	1.27×10^{14}
31	695	2.42×10^{13}	653	2.52×10^{14}
32	832	2.89×10^{13}	781	3.02×10^{14}
33	634	2.20×10^{13}	595	2.30×10^{14}
34	836	2.91×10^{13}	785	3.03×10^{14}
35	320	1.11×10^{13}	301	1.16×10^{14}
36	310	1.08×10^{13}	291	1.12×10^{14}
37	496	1.73×10^{13}	466	1.80×10^{14}
38	636	2.21×10^{13}	597	2.31×10^{14}

colony forming unit, cfu.

Potential Bacterial Loadings from Dogs

The dog populations in the watersheds were estimated using AVMA (2018) statistics for the average number of dogs per household (i.e., 0.614) and an estimate of number of households in the watershed (i.e., 66,049) derived from USCB (2010).

Potential load = *number of dogs in the watershed*
× *fecal coliform produced per dog per day (Borel et al. 2015)*
× *fecal coliform to E. coli conversion rate*
× *365 days*

Table B-6. Potential *E. coli* loadings from dogs.

Estimated population	Fecal coliform produced per dog per day (cfu/day)	Fecal coliform to *E. coli* conversion rate	*E. coli* loading (cfu/year)
40,554	5.0×10^{9}	0.63	4.66×10^{16}

colony forming unit, cfu.

In the Angelina River watershed, there are an estimated 40,554 dogs contributing 4.66×10^{16} *E. coli* per year (Table B-6). For each subwatershed in the Angelina River watershed, the population of dogs was estimated using the estimated number of house units in the subwatershed multiplied by 0.614. The number of house units in a subwatershed is calculated using the house density per census block multiplied by the area of the census block in the subwatershed. The estimated number of dogs and the *E. coli* loading in each subwatershed are listed in Table B-7.

Table B-7. Estimated number of dogs and corresponding *E. coli* loading in subwatersheds.

Subwatershed	Number of dogs	*E. coli* loading from dogs (colony forming units/year)
1	529	6.08×10^{14}
2	324	3.73×10^{14}
3	109	1.25×10^{14}
4	581	6.68×10^{14}
5	232	2.67×10^{14}
6	1,207	1.39×10^{15}
7	269	3.09×10^{14}
8	172	1.98×10^{14}
9	142	1.63×10^{14}

10	376	4.32×10^{14}
11	173	1.99×10^{14}
12	223	2.56×10^{14}
13	219	2.52×10^{14}
14	75	8.62×10^{13}
15	445	5.12×10^{14}
16	447	5.14×10^{14}
17	386	4.44×10^{14}
18	261	3.00×10^{14}
19	314	3.61×10^{14}
20	81	9.31×10^{13}
21	167	1.92×10^{14}
22	2,758	3.17×10^{15}
23	282	3.24×10^{14}
24	356	4.09×10^{14}
25	422	4.85×10^{14}
26	130	1.49×10^{14}
27	345	3.97×10^{14}
28	580	6.67×10^{14}
29	449	5.16×10^{14}
30	3,109	3.57×10^{15}
31	1,713	1.97×10^{15}
32	2,292	2.64×10^{15}
33	504	5.79×10^{14}
34	663	7.62×10^{14}
35	811	9.32×10^{14}
36	**14,655**	$\mathbf{1.68 \times 10^{16}}$
37	4,181	4.81×10^{15}
38	677	7.78×10^{14}

Potential Bacterial Loadings from OSSFs

OSSF locations in the watersheds were estimated with visually validated 911 address data. Nearly all the OSSFs occur on soils with an expected failure rate of 19% (Reed, Stowe, and Yanke 2001). We calculated the potential annul *E. coli* loading from OSSFs in the Angelina River watershed (Table B-8) using the following equation:

Potential load = *number of OSSFs in the watershed*
× *failure rate*
× *average number of people per household*
× *sewage discharge rate*
× *mL to gallon*
× *fecal coliform concentration in sewage*
× *fecal coliform to E. coli conversion rate*
× *365 days*

Table B-8. Potential *E. coli* loading calculation for on-site sewage facilities (OSSFs).

Source	Estimated number in the watershed	Failure rate	Average number of people per household	Sewage discharge rate (gallon/person/day)	mL to gallon	Fecal coliform concentration in sewage (cfu/100 mL)	Fecal coliform to *E. coli* conversion rate	*E. coli* loading (cfu/year)
OSSFs	29,161	19%	2.38	70	3758.2	1.0×10^{6}	0.63	7.98×10^{15}

colony forming unit, cfu.

In the Angelina River watershed, there are an estimated 29,161 OSSFs and an estimated 5,541 failing OSSFs contributing 7.98×10^{15} *E. coli* per year. For the subwatersheds in the Angelina River watershed, the estimated number of failing OSSFs and the annual *E. coli* loading are listed in Table B-9.

Table B-9. Estimated number of dogs and corresponding *E. coli* loading in subwatersheds.

Subwatershed	Number of failing OSSFs	*E. coli* loading from failing OSSFs (cfu/year)
1	173	2.50×10^{14}
2	136	1.96×10^{14}
3	23	3.36×10^{13}
4	208	2.99×10^{14}
5	76	1.09×10^{14}
6	277	3.99×10^{14}
7	97	1.39×10^{14}
8	59	8.51×10^{13}
9	47	6.81×10^{13}

10	108	1.55×10^{14}
11	60	8.62×10^{13}
12	55	7.96×10^{13}
13	79	1.14×10^{14}
14	29	4.16×10^{13}
15	135	1.95×10^{14}
16	103	1.49×10^{14}
17	123	1.77×10^{14}
18	61	8.78×10^{13}
19	94	1.35×10^{14}
20	29	4.10×10^{13}
21	86	1.24×10^{14}
22	110	1.58×10^{14}
23	91	1.31×10^{14}
24	59	8.43×10^{13}
25	133	1.91×10^{14}
26	42	5.99×10^{13}
27	156	2.25×10^{14}
28	105	1.52×10^{14}
29	175	2.52×10^{14}
30	142	2.05×10^{14}
31	360	5.18×10^{14}
32	346	4.98×10^{14}
33	185	2.67×10^{14}
34	217	3.12×10^{14}
35	317	4.56×10^{14}
36	103	1.49×10^{14}
37	653	9.40×10^{14}
38	279	4.02×10^{14}

colony forming unit, cfu; On-Site Sewage Facility, OSSF.

Potential Bacterial Loadings from WWTFs

Currently, 10 permitted WWTFs operate in the Angelina River watershed. All are permitted to discharge wastewater effluent from treated household sewage and are required to monitor bacteria levels in their discharge. The bacterial loads were estimated at a worst-case scenario of full permitted discharge at 126 cfu per 100 mL *E. coli*. The potential annual bacterial load from WWTFs is calculated using the following equation:

$$\begin{aligned} \textit{Potential load} = \quad & \textit{maximum permitted discharge} \\ \times \quad & \textit{bacteria concentration in sewage} \\ \times \quad & \textit{mL to gallon} \\ \times \quad & \textit{gallon to MGD} \\ \times \quad & \textit{365 days} \end{aligned}$$

Table B-10. Potential *E. coli* loading from wastewater treatment facilities (WWTFs).

Source	Total permitted discharge (MGD)	Bacterial concentration (cfu/100 mL)	mL to gallon	Gallon to MGD	*E. coli* loading (cfu/year)
WWTFs	17.9425	126	3758.2	1×10^{6}	3.10×10^{13}

colony forming unit, cfu; Million Gallons per Day, MGD.

In the Angelina River watershed, there is an estimated 17.9425 MGD permitted discharge from WWTFs contributing 3.10×10^{13} *E. coli* per year. For the subwatersheds in the Angelina River watershed, the permitted discharge from WWTFs and the *E. coli* loading were calculated based on the location of the WWTFs (Table B-11).

Table B-11. Permitted discharge from wastewater treatment facilities (WWTFs) and corresponding *E. coli* loading in subwatersheds.

Subwatershed	Permitted discharge (MGD)	*E. coli* loading from WWTFs (cfu/year)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0

12	0	0
13	0	0
14	0	0
15	0	0
16	0.081	1.40×10^{11}
17	0	0
18	0.06	1.04×10^{11}
19	0	0
20	0	0
21	0	0
22	2.9	5.01×10^{12}
23	0	0
24	0.06	1.04×10^{11}
25	0	0
26	0	0
27	0	0
28	0.308	5.32×10^{11}
29	0	0
30	3.03	5.24×10^{12}
31	0	0
32	1.711	2.96×10^{12}
33	0.0175	3.02×10^{10}
34	0.1	1.73×10^{11}
35	0	0
36	9.675	1.67×10^{13}
37	0	0
38	0	0

colony forming unit, cfu; Million Gallons per Day, MGD; Waste-Water Treatment Facility, WWTF.

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