Characterization of Middle Yegua, Davidson and Deer Creeks Watersheds

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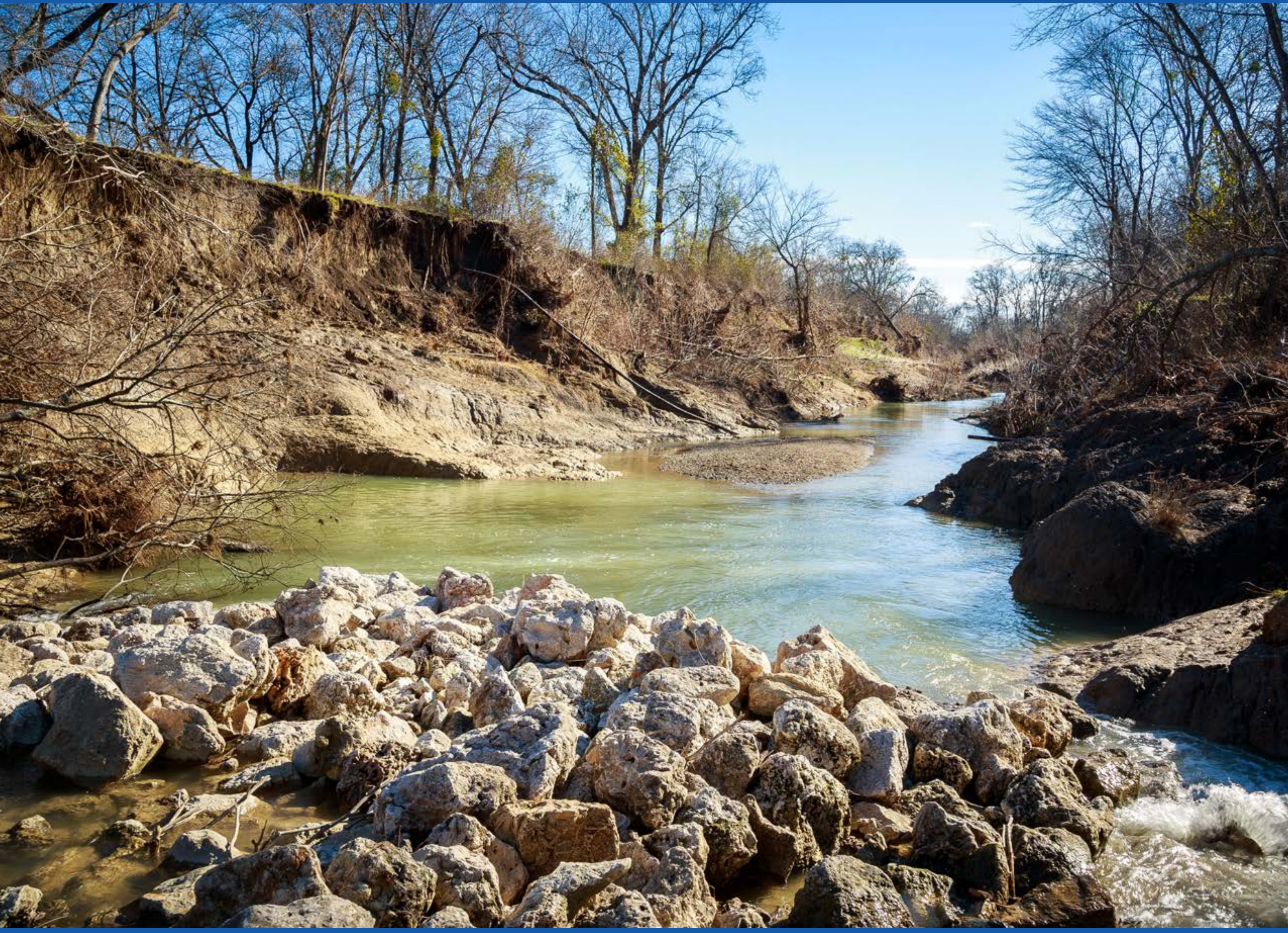

Texas Water Resources Institute
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Stephanie deVilleneuve, Luna Yang, Jacqueline Rambo, Michael Schramm, Allen Berthold
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Cover photo: Deer Creek by Ed Rhodes, Texas Water Resources Institute.

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List of Acronyms

Ac	Acre
ALU	Aquatic-Life Use
AU	Assessment Unit
AVMA	American Veterinary Medical Association
BOD	Biological Oxygen Demand
BRA	Brazos River Authority
cfu	Colony Forming Units
CRP	Clean Rivers Program
CWA	Clean Water Act
DAR	Drainage-Area Ratio Method
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
ECHO	Enforcement and Compliance History Online
ft	Feet
FDC	Flow Duration Curve
gal	Gallon
GIS	Geographic Information System
HSG	Hydrologic Soil Groups
I&I	Inflow and Infiltration
LDC	Load Duration Curve
LULC	Land Use Land Cover
m	Meter
MGD	Million Gallons per Day
mL	Milliliter
MPN	Most Probable Number
MRLC	Multi-resolution Land Characteristics Consortium
MS4	Municipal Separate Storm Sewer Systems
NASS	National Agricultural Statistics Service
NED	National Elevation Database
NLCD	National Land Cover Database
NOAA	National Oceanic Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe
OSSF	On-site Sewage Facilities
RMU	Resource Management Unit
SELECT	Spatially Explicit Load Enrichment Calculation

SSO	Sanitary Sewer Overflow
SSURGO	Soil Survey Geographic Database
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSS	Total Suspended Solids
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USDA	United States Department of Agriculture
USGS	United State Geological Survey
WWTF	Wastewater Treatment Facility
Yr	Year

Executive Summary

Middle Yegua Creek, Davidson Creek and Deer Creek have all been identified as impaired for elevated concentrations of *Escherichia coli* (*E. coli*) in the *2018 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report) (TCEQ 2019b). Davidson Creek was also listed in the 2018 Texas Integrated Report as impaired for depressed dissolved oxygen (TCEQ 2019b). Elevated levels of *E. coli* have been identified in the Middle Yegua Creek watershed since as early as 2010 (TCEQ 2011). For the Davidson Creek watershed, elevated bacteria levels were first identified in 2002 (TCEQ 2002) and depressed dissolved oxygen in 2010 (TCEQ 2011). For the Deer Creek watershed, the bacteria impairment was first identified in 2006 (TCEQ 2008). This characterization addresses the *E. coli* impairments in the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds with supplementary water quality monitoring and a review of the current demographic, climatic, physical and hydrological conditions of the watersheds.

Activities for the project have included 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.

Background Information

Description of the Watersheds and Water bodies

Middle Yegua Creek, Davidson Creek and Deer Creek are all located in the southern portion of the Brazos River Basin in separate watersheds (Figure 1). Each of the watersheds is evaluated separately throughout the report to reflect the individual characteristics and water quality issues of the water bodies.

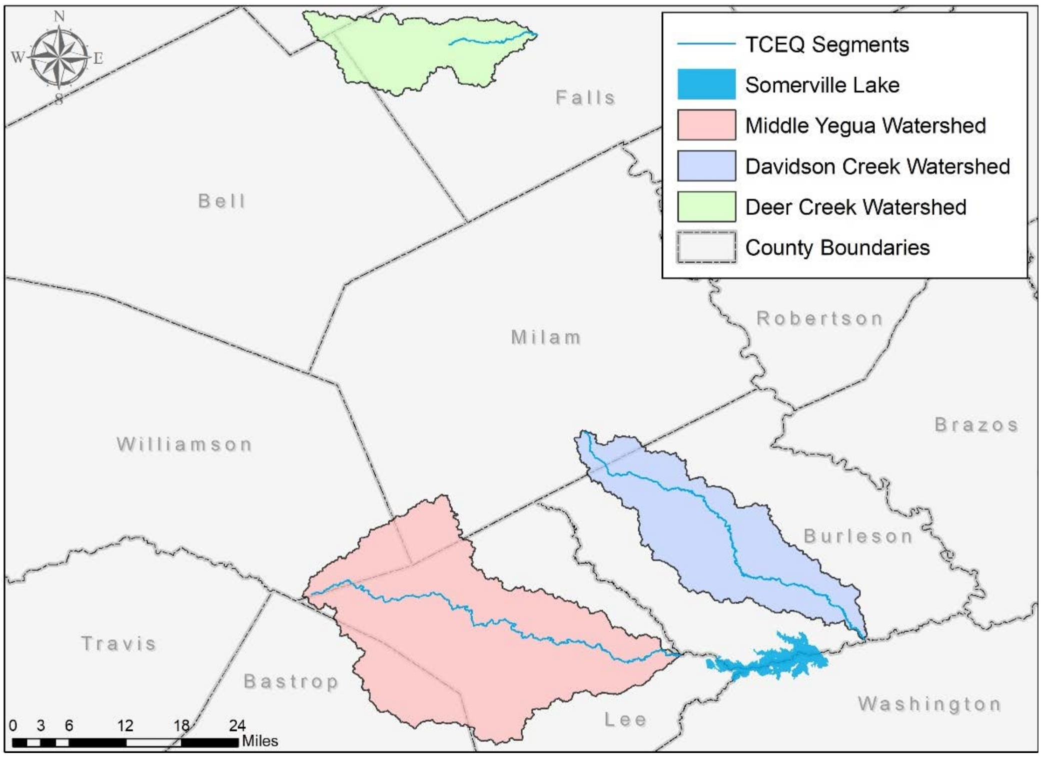

Figure 1. Overview of Characterization Report watersheds.

Middle Yegua Creek (Segment ID 1212A) begins at the confluence with East Yegua and Yegua Creeks in Lee County and flows approximately 62 miles to the Lee County/Williamson County line (Figure 2). Middle Yegua Creek drains an area of approximately 440 square miles in Lee (73%), Bastrop (13%), Williamson (8%) and Milam (6%) counties. The segment is also divided into two assessment units (AU), 1212A_01 and 1212A_02.

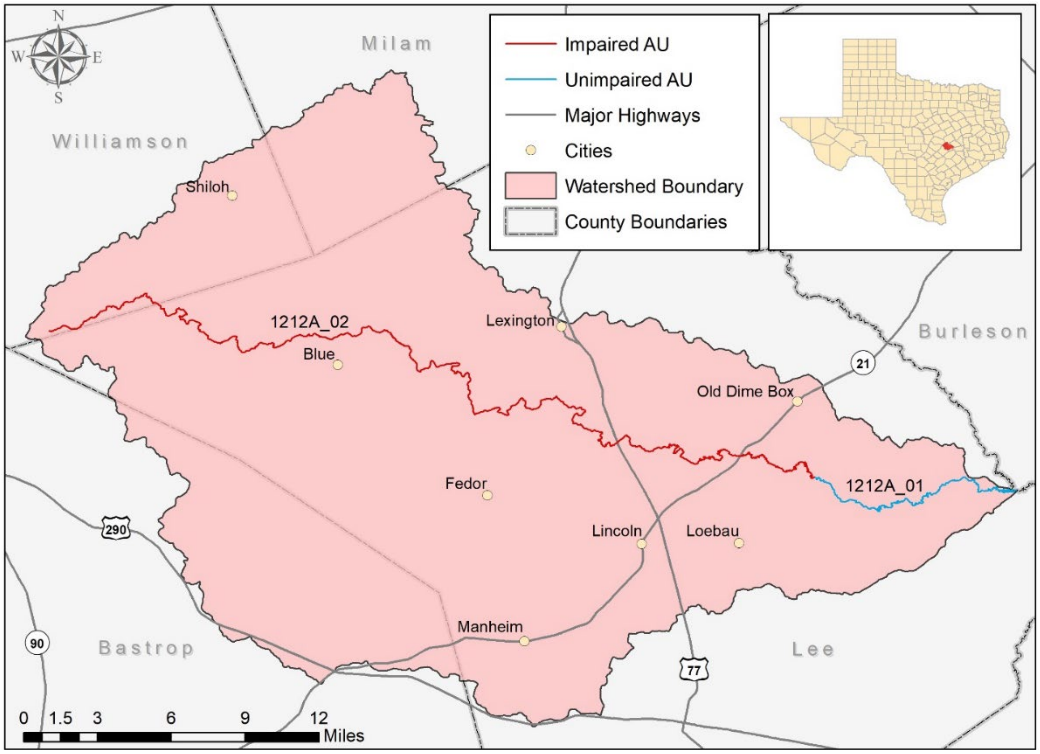

Figure 2. Middle Yegua Creek watershed.

Davidson Creek (Segment ID 1211A) is an intermittent stream with perennial pools that flows approximately 59 miles from the confluence of Yegua Creek to just over 1 mile above CR 322 in Milam County (Figure 3). Davidson Creek drains an area of approximately 218 square miles in Burleson (93%) and Milam (7%) counties. The segment is also divided into two units, 1211A_01 and 1211A_02.

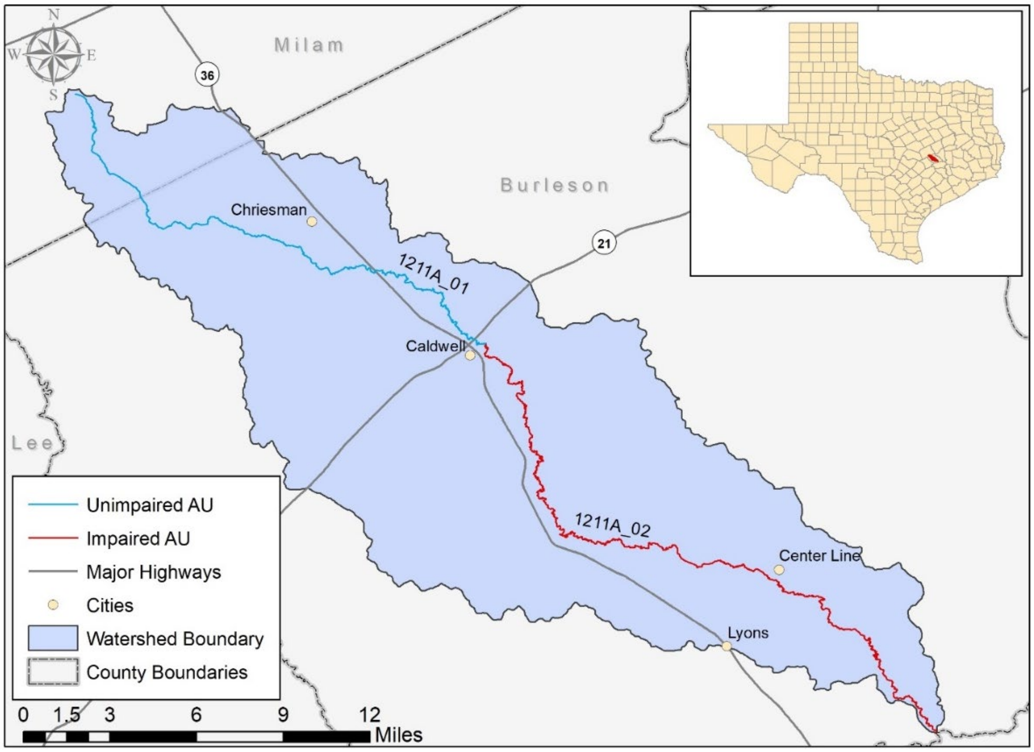

Figure 3. Davidson Creek watershed.

Deer Creek (Segment ID 1242J) is a perennial stream that begins at the confluence of the Brazos River upstream and flows approximately 11 miles to the confluence of Dog Branch northwest of Lott (Figure 4). Deer Creek drains an area of approximately 115 square miles in Falls (87%), McLennan (7%) and Bell (6%) counties. The segment consists of a single AU, 1242J_01.

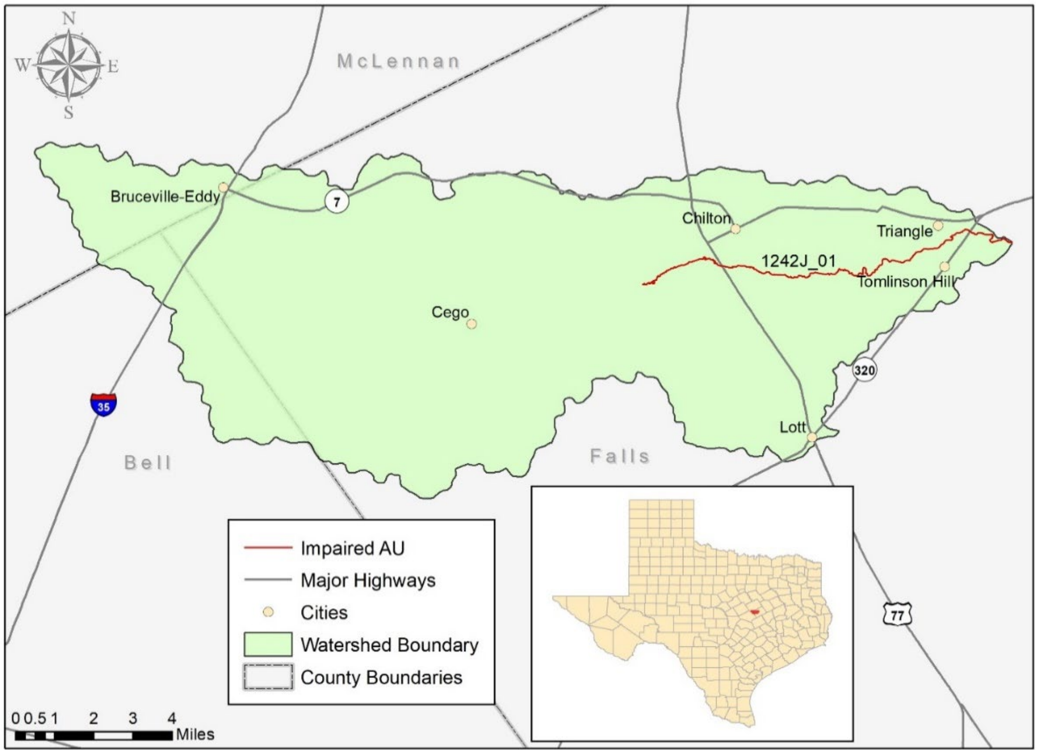

Figure 4. Deer Creek watershed.

Soils and Topography

The soils and topography of a watershed are important components of watershed hydrology. Slope and elevation define where water will flow, while elevation and 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 certain areas.

All three watersheds are predominantly flat and have moderate drainage. The Middle Yegua Creek watershed has a peak elevation of about 232 feet (ft) with the lowest elevation point being approximately 75.5 ft (USGS 2013) (Figure 5). The Davidson Creek watershed has a peak elevation of about 194 ft with the lowest elevation point being approximately 59 ft (USGS 2013) (Figure 6). The Deer Creek watershed has a peak elevation of about 266 ft with the lowest elevation point being approximately 97 ft (USGS 2013) (Figure 7). There is an average of one-degree slope across all the watersheds, with more intense slopes restricted to areas such as cut banks near the creek systems.

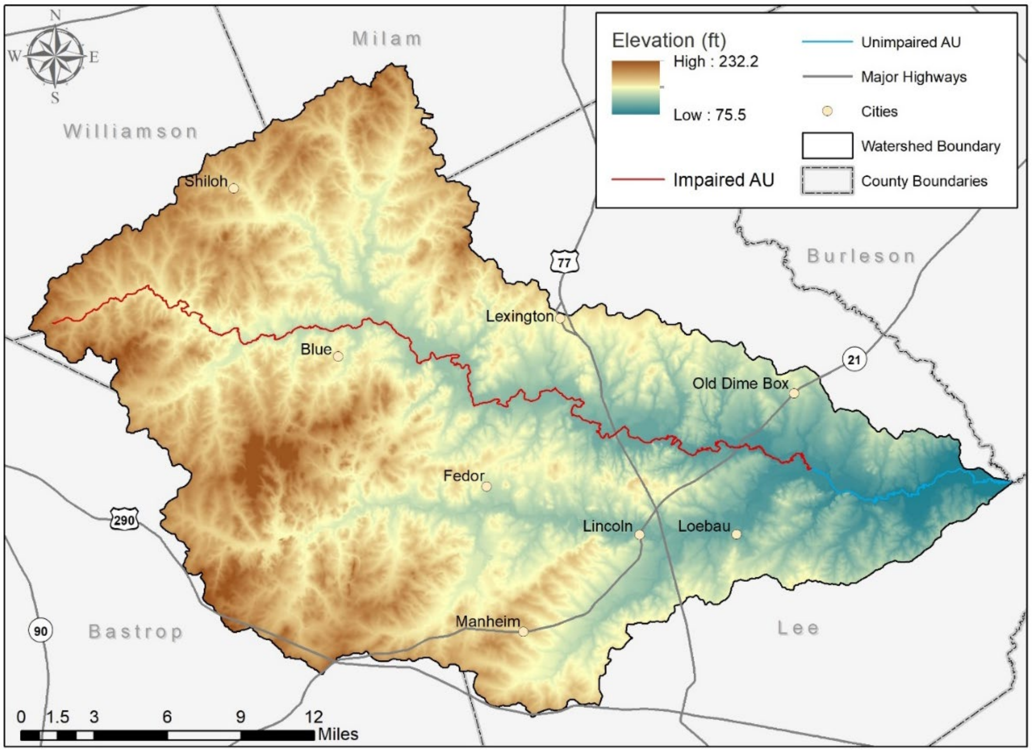

Figure 5. Elevation of the Middle Yegua Creek watershed.

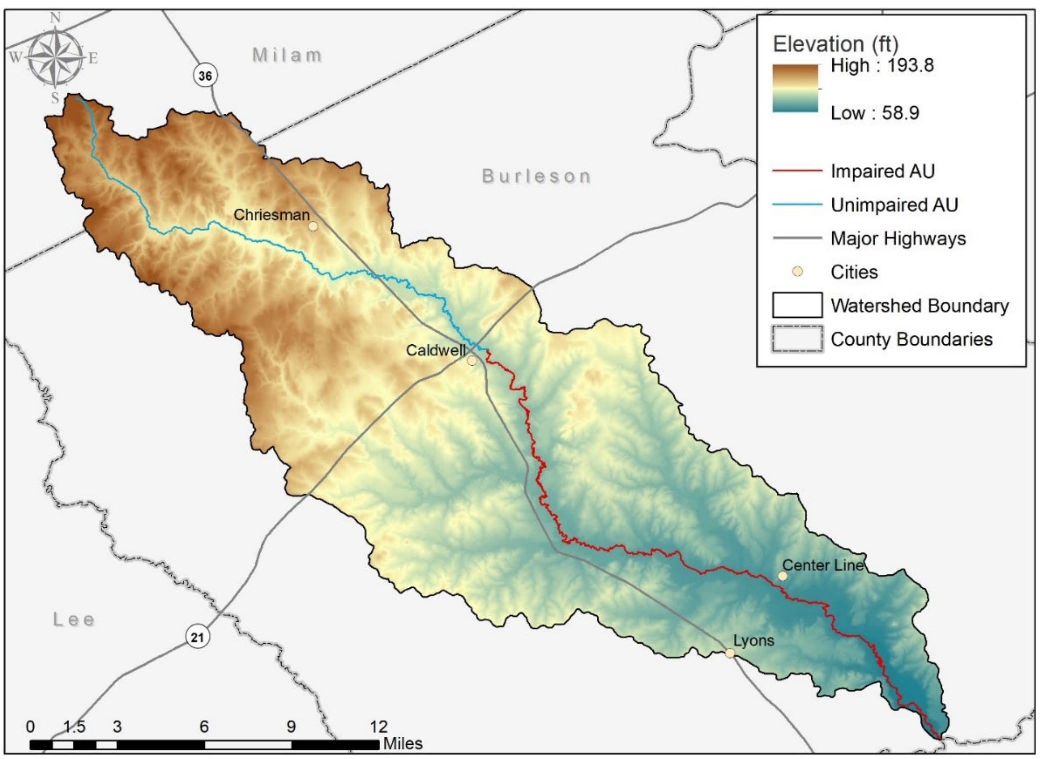

Figure 6. Elevation of the Davidson Creek watershed.

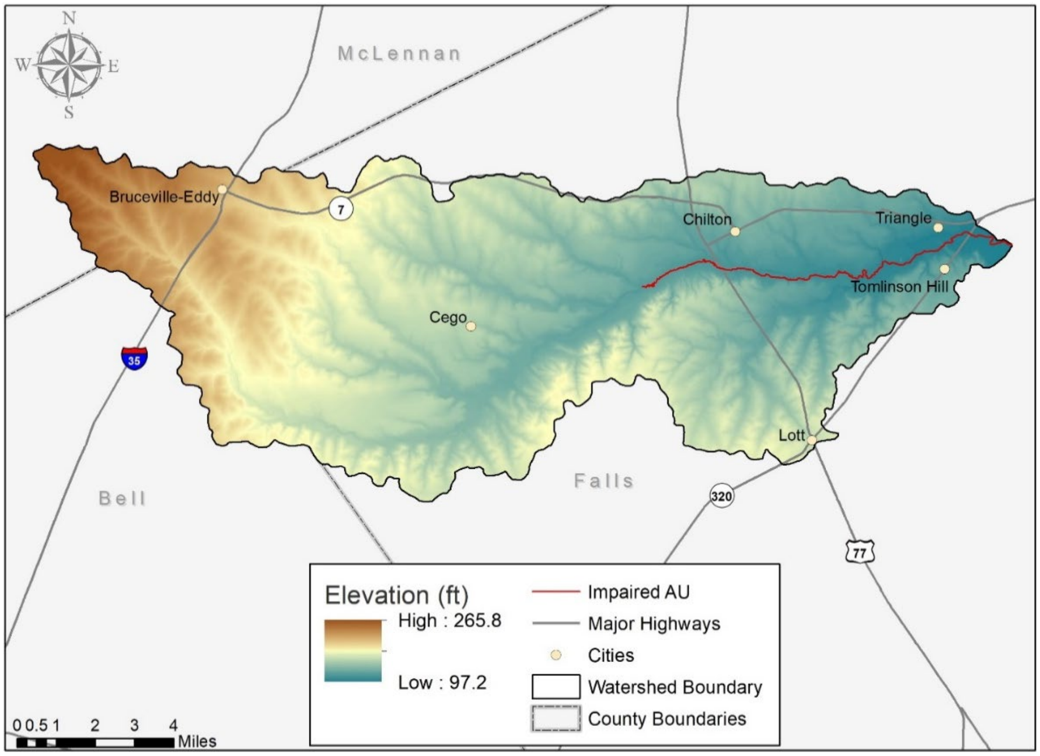

Figure 7. Elevation of the Deer Creek watershed.

Soil data was obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (NRCS 2019). The USDA NRCS SSURGO data assigns different soils to one of seven possible runoff potential classifications or hydrologic soil groups (HSGs). These classifications are based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet and receive precipitation from long-duration storms. The four main groups are A, B, C and D, with three dual classes (A/D, B/D, C/D). The null classification identifies areas where data is incomplete or not available. The USDA NRCS SSURGO database defines the other four classifications below:

Group A – Soils having high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

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

The majority of soils in the Middle Yegua Creek watershed have an HSG of B (37% of the watershed) or D (26%) (Figure 8). The remaining six groups are the least dominant HSGs in the watershed (Table 1) (NRCS 2019).

The majority of soils in the Davidson Creek watershed have an HSG of B (45% of the watershed) or C (21%) (Figure 9). The remaining six groups are the least dominant HSGs in the watershed (Table 2) (NRCS 2019).

The majority of soils in the Deer Creek watershed have an HSG of B (43% of the watershed) or D (24%) (Figure 10). The remaining six groups are the least dominant HSGs in the watershed (Table 3) (NRCS 2019).

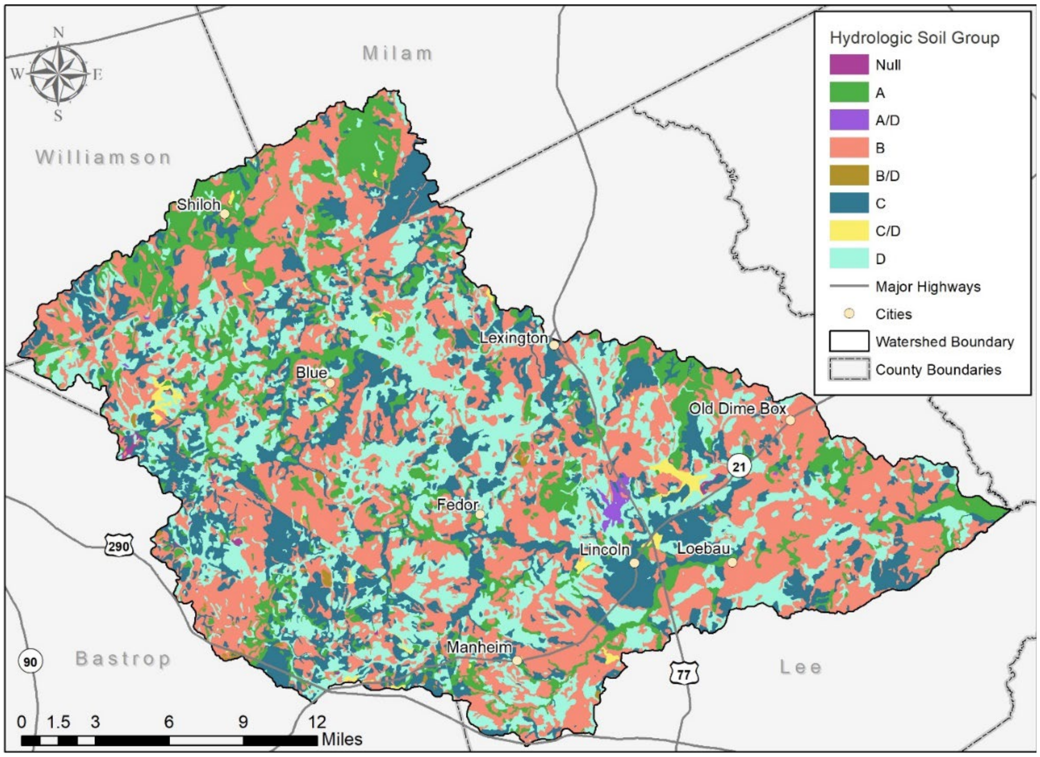

Figure 8. Middle Yegua Creek watershed Hydrologic Soil Groups.

Table 1. Descriptions of the Hydrologic Soil Groups in the Middle Yegua Creek watershed.

Hydrologic Soil Group	Acres	Percent of Total
Null	410	0.1%
A	39,848	14.1%
A/D	781	0.3%
B	104,445	37.1%
B/D	738	0.3%
C	59,172	21.0%
C/D	2,103	0.8%
D	74,300	26.4%
Total	281,798	100%

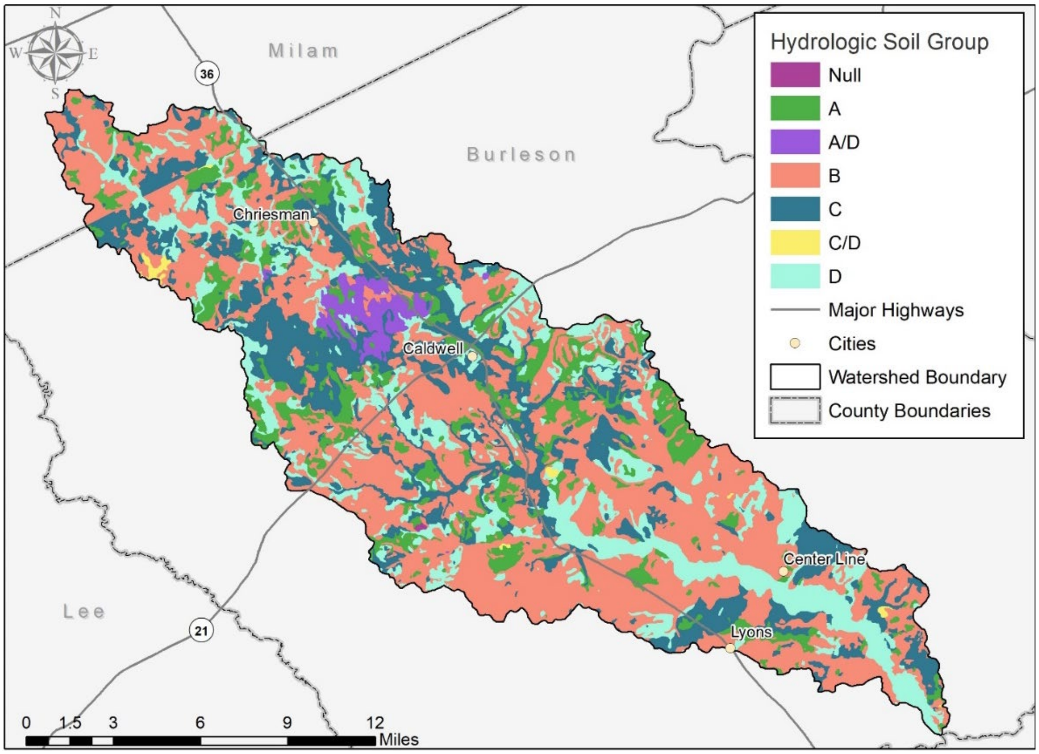

Figure 9. Davidson Creek watershed Hydrologic Soil Groups.

Table 2. Descriptions of the Hydrologic Soil Groups in the Davidson Creek watershed.

Hydrologic Soil Group	Acres	Percent of Total
Null	45	0.03%
A	17,184	12.33%
A/D	2,849	2.04%
B	63,110	45.28%
B/D	0	0.00%
C	29,848	21.42%
C/D	441	0.32%
D	25,890	18.58%
Total	139,367	100%

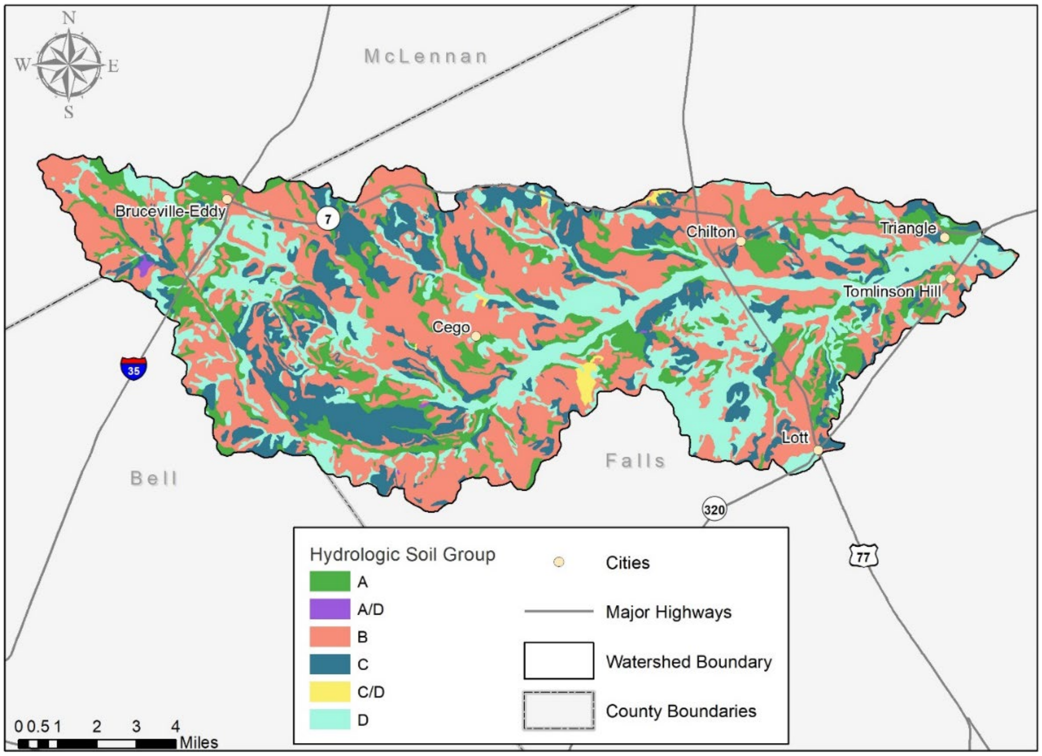

Figure 10. Deer Creek watershed Hydrologic Soil Groups.

Table 3. Descriptions of the Hydrologic Soil Groups in the Deer Creek watershed.

Hydrologic Soil Group	Acres	Percent of Total
Null	0	0.00%
A	11,192	15.23%
A/D	81	0.11%
B	31,407	42.74%
B/D	0	0.00%
C	12,510	17.03%
C/D	337	0.46%
D	17,949	24.43%
Total	73,476	100%

The USDA NRCS provides suitability ratings for septic tank absorption fields based on soil properties, depth to bedrock or groundwater, hydraulic conductivity and other properties that may affect the absorption of on-site sewage facilities (OSSF) effluent, installation and maintenance. 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 that are very unfavorable for OSSF use, with expectation of poor performance and high amounts of maintenance. The majority of the soils in all three watersheds are rated "Very Limited" for OSSF use, followed by smaller areas rated "Somewhat Limited" (Figure 11, Figure 12, Figure 13) (NRCS 2019).

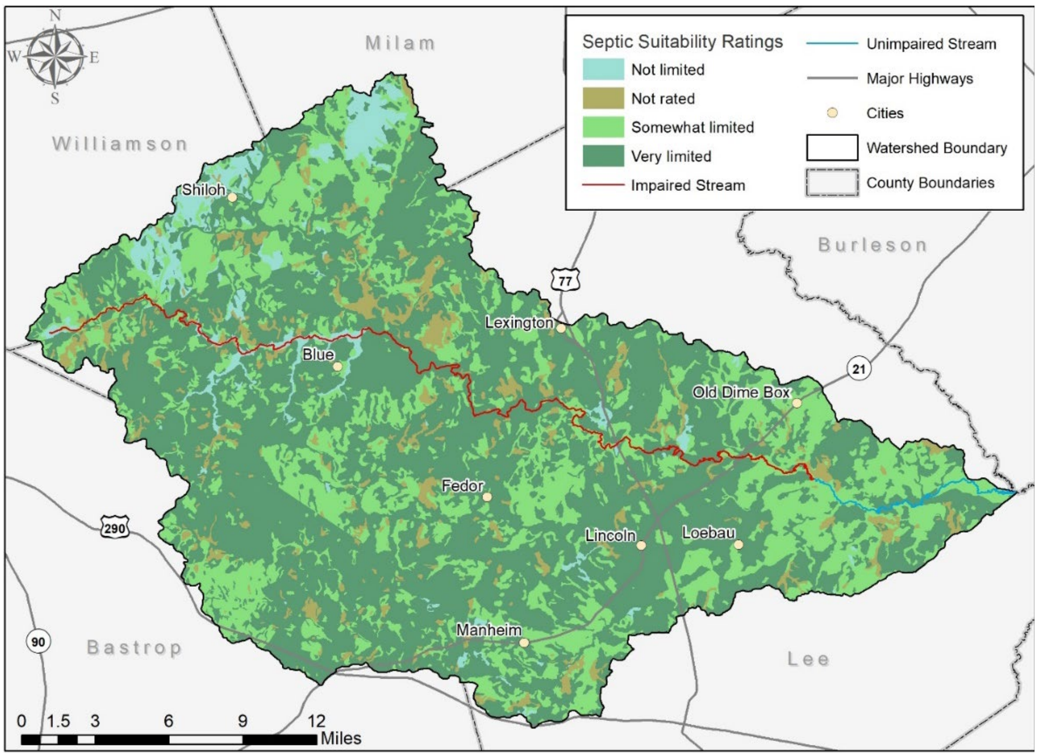

Figure 11. Middle Yegua Creek watershed on-site sewage facility adsorption field ratings.

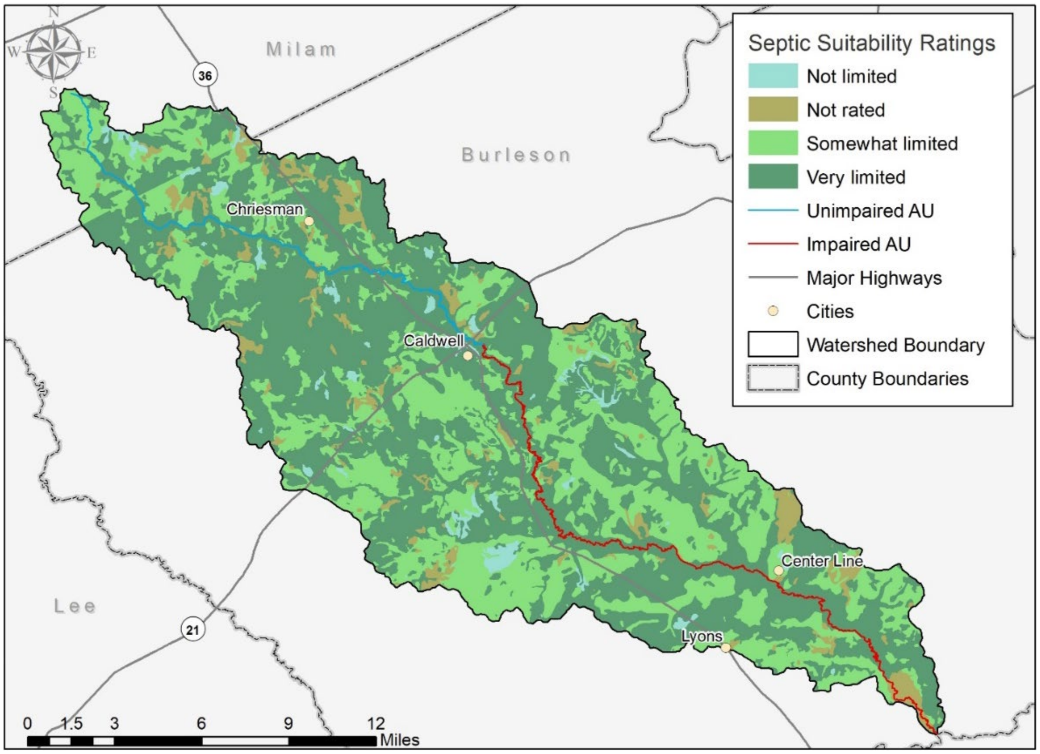

Figure 12. Davidson Creek watershed on-site sewage facility adsorption field ratings.

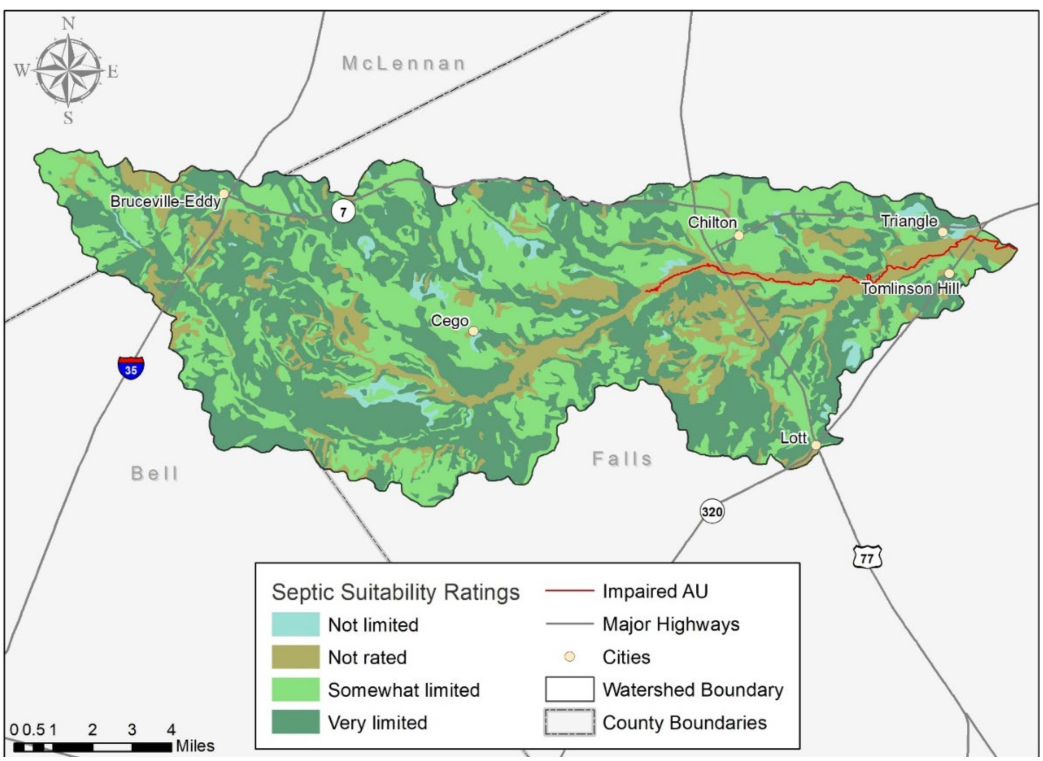

Figure 13. Deer Creek watershed on-site sewage facility adsorption field ratings.

Ecoregions

Ecoregions are land areas with ecosystems that contain similar quality and quantity of natural resources (Griffith et al. 2007). Ecoregions have been delineated into four separate levels; level I is the most unrefined classification while level IV is the most refined. Middle Yegua Creek watershed is located in two ecoregions (level III ecoregions), including the East Central Texas Plains Ecoregion (33) through Bastrop, Lee, Milam and Williamson counties, and a tiny portion in the Texas Blackland Prairies (32) in Williamson County (Figure 14). Davidson Creek is located in one level III ecoregion, the East Central Texas Plains Ecoregion (33) (Figure 15). Deer Creek is also located in one level III ecoregion, the Texas Blackland Prairies Ecoregion (32) (Figure 16). The dominant soil types for these ecoregions are fine-textured clay and acidic, sandy or clay loams, respectively. The watersheds are further subdivided into four level IV ecoregions identified as the Northern Blackland Prairie (32a), Floodplains and Low Terraces (32c), Southern Post Oak Savanna (33b) and San Antonio Prairie (33c).

The landscape in the area of Northern Blackland Prairie (32a) is mainly underlain by Vertisols with dark, fine-textured and calcareous characters. The main land cover are cropland and non-native pasture, with a small portion of deciduous forest and woodlands. Dominant grasses are eastern gamagrass and switchgrass. The Floodplains and Low Terraces (32c) landscape includes broad floodplains. A majority of the bottomland forests have been converted to cropland and pasture.

The Southern Post Oak Savanna (33b) has more woods and forest than the adjacent prairie ecoregions (32). The land cover is a mix of woods, improved pasture and rangeland. The San Antonio Prairies (33c) soils are mostly Alfisols, with some Vertisols and Mollisols. The upland prairies are dominated by little blue stem and yellow Indiangrass. The land cover is comprised of woodland, improved pasture, rangeland and some cropland.

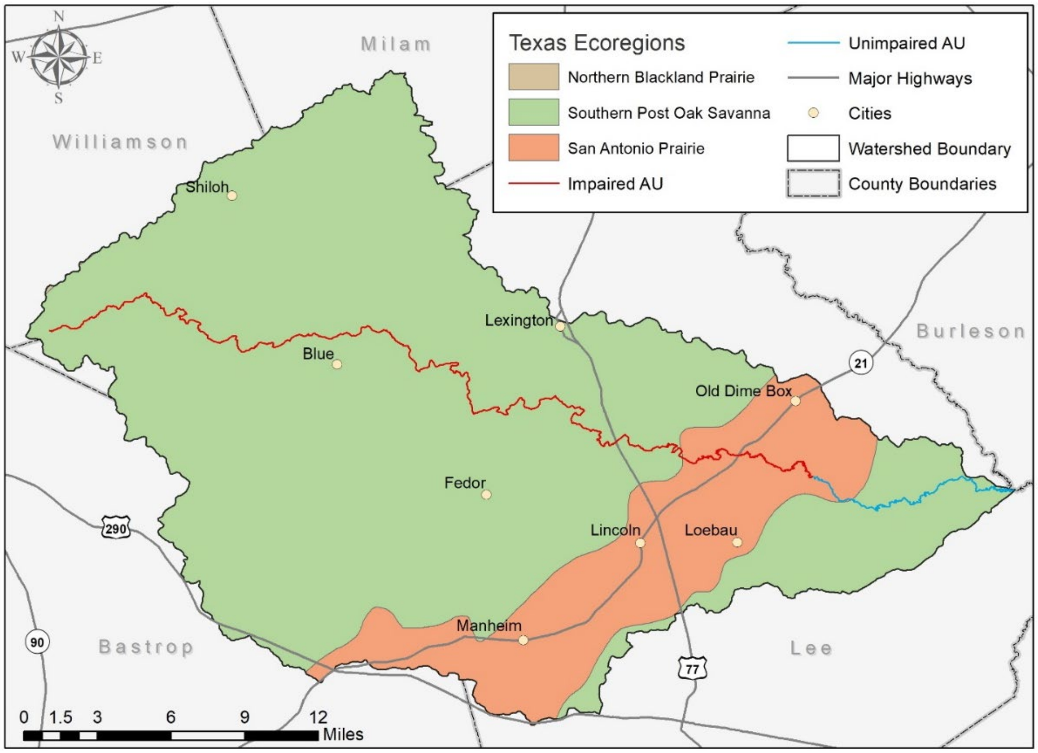

Figure 14. Middle Yegua Creek watershed ecoregions.

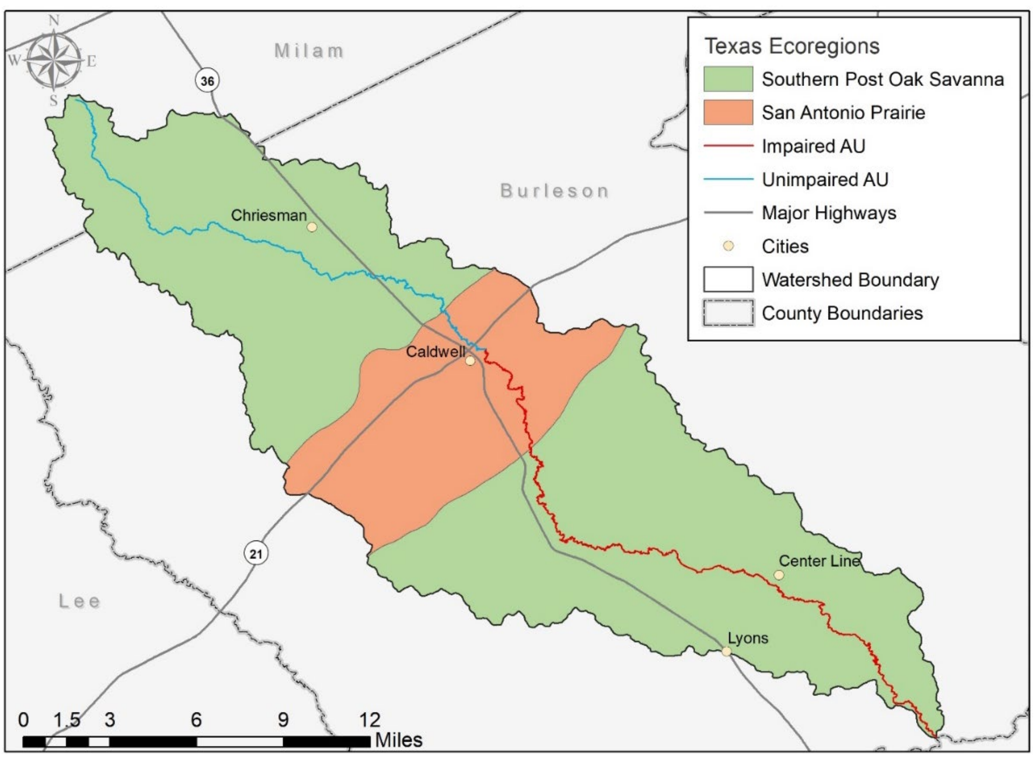

Figure 15. Davidson Creek watershed ecoregions.

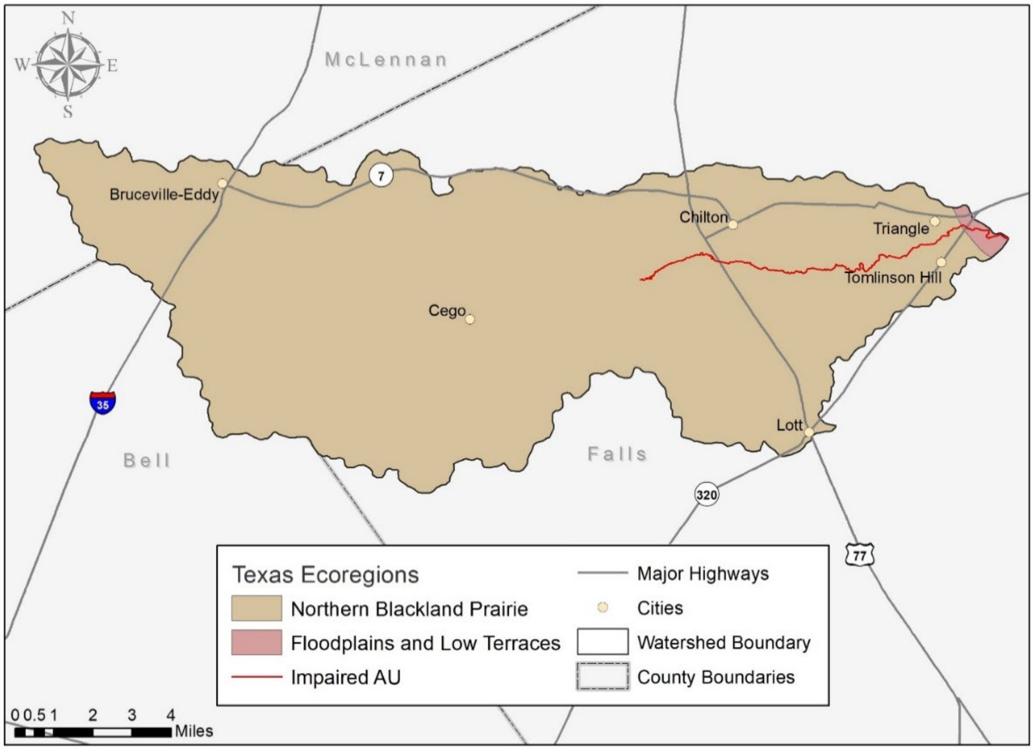

Figure 16. Deer Creek watershed ecoregions.

Land Use and Land Cover

Land use and land cover (LULC) data for each of the watersheds was obtained from the 2016 National Land Cover Database (NLCD) at a 30-meter (m) raster resolution. LULC is categorized into 15 different classifications and the LULC for all the watersheds are described in Figure 17 through Figure 19 and Table 4 through Table 6. The different land covers are not evenly distributed across the watersheds. Quantitatively describing the land use classifications for each watershed is necessary for future planning decisions.

- Open Water: areas of open water that are generally less than 25% vegetation or soil cover.
- Developed, Open Space: areas that have a mixture of constructed materials, but mostly vegetation in the form of lawn grasses exist. Impervious surfaces account for less than 20% of total cover. Such areas typically include large-lot single family housing units, parks, golf courses and vegetation planted in developed settings for recreation, erosion control or aesthetic purposes.

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

The Middle Yegua Creek watershed (Figure 17) encompasses 281,798 acres and is predominantly pasture/hay (55.6%) followed by deciduous forest (14.9%) (Table 4). Urban development comprises approximately 11,103 acres or 4% of the watershed.

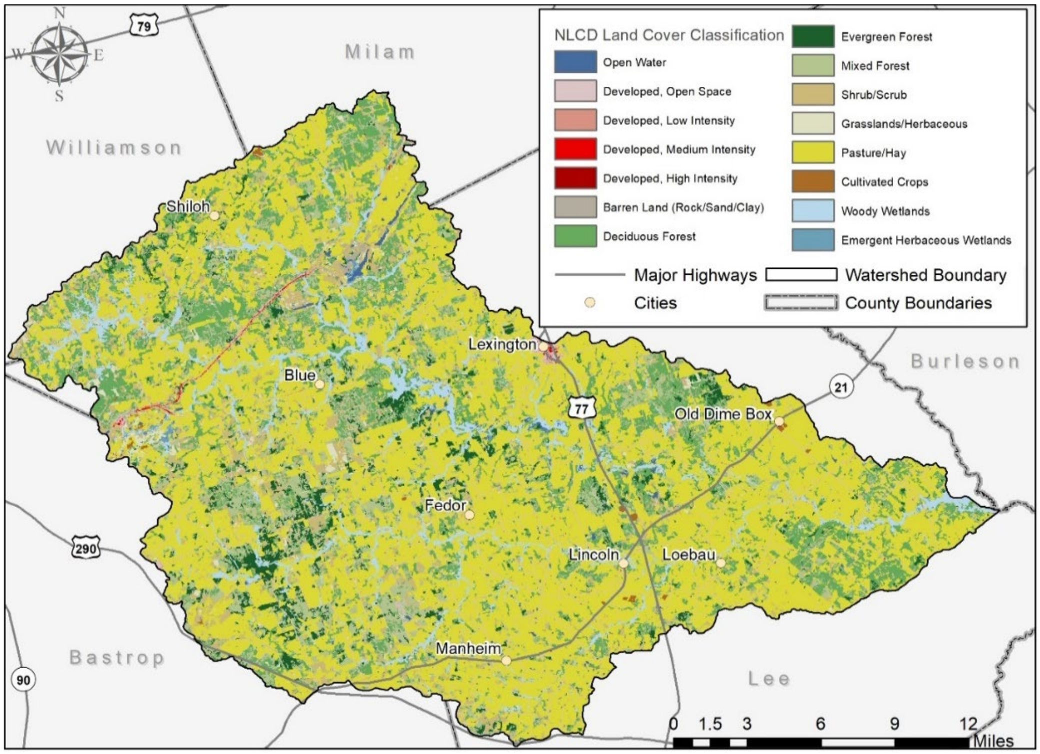

Figure 17. Land use and land cover classifications in the Middle Yegua Creek watershed (NLCD 2016).

Table 4. Land use and land cover classifications for Middle Yegua Creek watershed (NLCD 2016).

NLCD Classification	Acres	Percent of Total
Open Water	1,836	0.7%
Developed, Open Space	9,519	3.4%
Developed, Low Intensity	1,242	0.4%
Developed, Medium Intensity	308	0.1%
Developed, High Intensity	34	0.0%
Barren Land	709	0.3%
Deciduous Forest	41,912	14.9%
Evergreen Forest	9,238	3.3%
Mixed Forest	24,117	8.6%
Shrub/Scrub	17,897	6.4%

NLCD Classification	Acres	Percent of Total
Grassland/Herbaceous	3,814	1.4%
Pasture/Hay	156,655	55.6%
Cultivated Crops	437	0.2%
Woody Wetlands	12,893	4.6%
Emergent Herbaceous Wetlands	1,187	0.4%
Total	281,798	100%

The Davidson Creek watershed (Figure 18) encompasses 139,367 acres and is predominantly pasture/hay (57.4%) followed by deciduous forest (17.8%) (Table 5). Urban development comprises approximately 7,515 acres or 5% of the watershed.

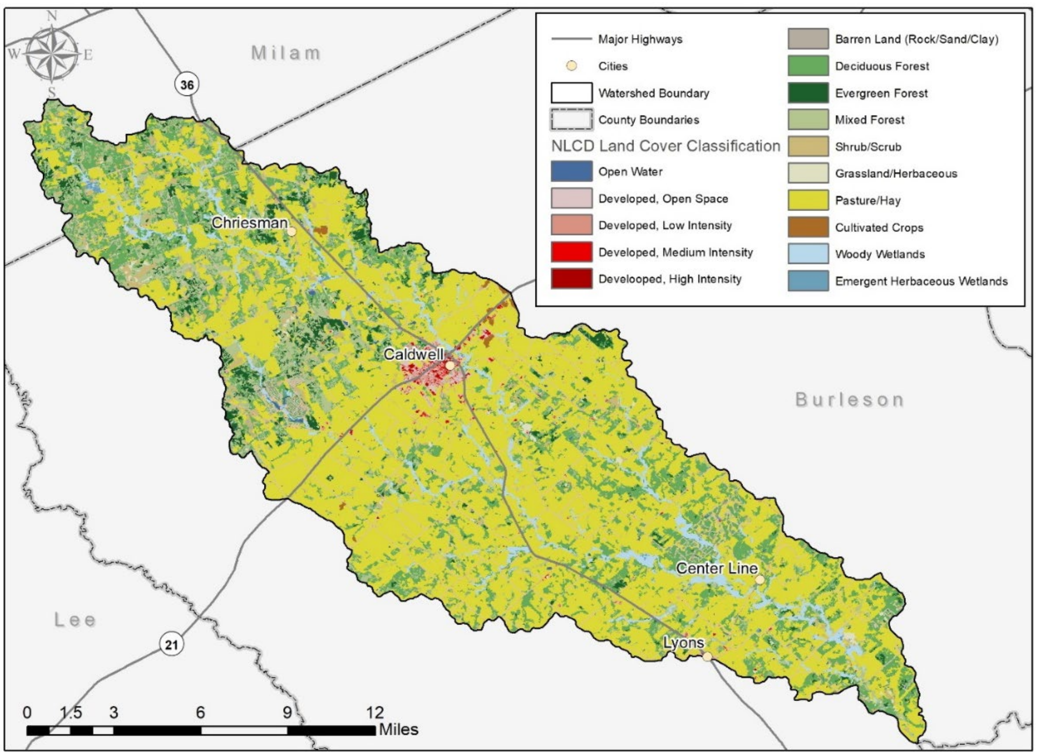

Figure 18. Land use and land cover classifications in the Davidson Creek watershed (NLCD 2016).

Table 5. Land use and land cover classifications for Davidson Creek watershed (NLCD 2016).

NLCD Classification	Acres	Percent of Total
Open Water	521	0.4%
Developed, Open Space	5,478	3.9%
Developed, Low Intensity	1,439	1.0%
Developed, Medium Intensity	465	0.3%
Developed, High Intensity	134	0.1%
Barren Land	379	0.3%
Deciduous Forest	24,762	17.8%
Evergreen Forest	4,169	3.0%
Mixed Forest	11,382	8.2%
Shrub/Scrub	3,304	2.4%
Grassland/Herbaceous	872	0.6%
Pasture/Hay	80,055	57.4%
Cultivated Crops	277	0.2%
Woody Wetlands	5,666	4.1%
Emergent Herbaceous Wetlands	465	0.3%
Total	139,367	100%

The Deer Creek watershed (Figure 19) encompasses 73,476 acres and is predominantly grassland/herbaceous (35.9%) followed closely by cultivated crops (33.6%) (Table 6). Urban development comprises approximately 3,797 acres or 5% of the watershed.

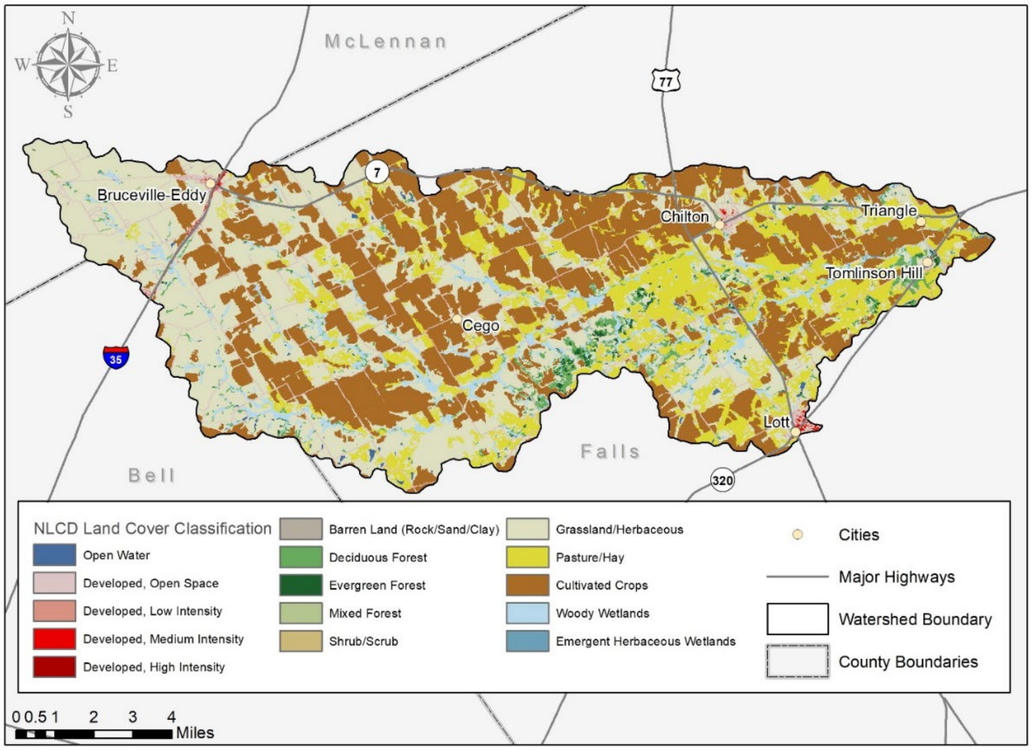

Figure 19. Land use and land cover classifications in the Deer Creek watershed (NLCD 2016).

Table 6. Land use and land cover classifications for Deer Creek watershed (NLCD 2016).

NLCD Classification	Acres	Percent of Total
Open Water	227	0.3%
Developed, Open Space	3,292	4.5%
Developed, Low Intensity	321	0.4%
Developed, Medium Intensity	161	0.2%
Developed, High Intensity	23	0.0%
Barren Land	9	0.0%
Deciduous Forest	1,744	2.4%
Evergreen Forest	356	0.5%
Mixed Forest	157	0.2%
Shrub/Scrub	64	0.1%
Grassland/Herbaceous	26,370	35.9%
Pasture/Hay	12,803	17.4%
Cultivated Crops	24,677	33.6%
Woody Wetlands	3,177	4.3%
Emergent Herbaceous Wetlands	95	0.1%
Total	73,476	100%

Climate

There is one active weather station recording precipitation and temperature data in the Middle Yegua Creek watershed. That weather station is the Lexington, Texas USC00415193 weather station (NOAA 2016), and it was used to determine the approximate precipitation and temperature data for the watershed (Figure 20). Monthly normal air temperature indicates daily mean air temperature was 66.9°F (NOAA 2016). Minimum average daily temperatures reached a low of 37.2°F in January. The maximum average daily temperature reached a peak of 95.3°F in August. Monthly normal precipitation, from the weather station, indicates that the area had a mean annual rainfall from 1981-2010 of 36.6 inches (NOAA 2016). Rainfall normally peaks in October (5.04 inches) with the lowest totals occurring in April (2.05 inches) (NOAA 2016). Average annual precipitation values across the study area from the PRISM Climate Group at Oregon State (2012) indicate average annual rainfall ranges from 34 to 38 inches per year across the watershed, with a clear East to West decreasing gradient (Figure 21).

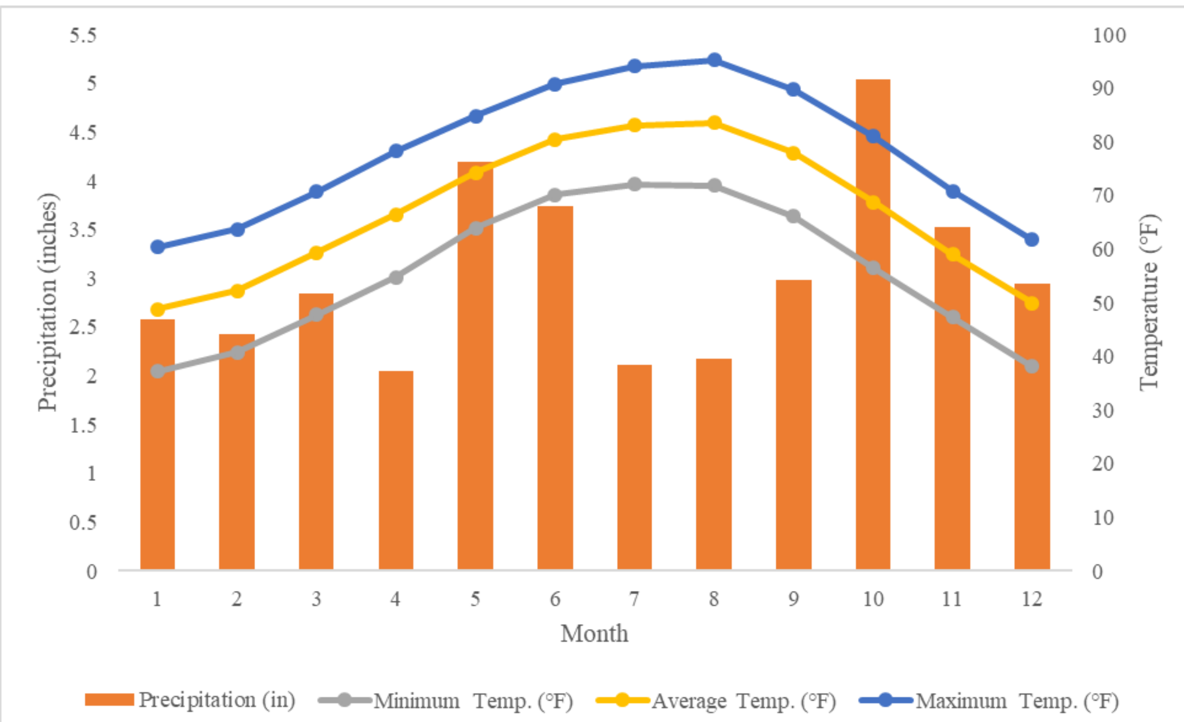

Figure 20. Monthly climate data, including precipitation, normal average, maximum and minimum air temperature, for Lexington, Texas from 1981-2010 (NOAA 2016).

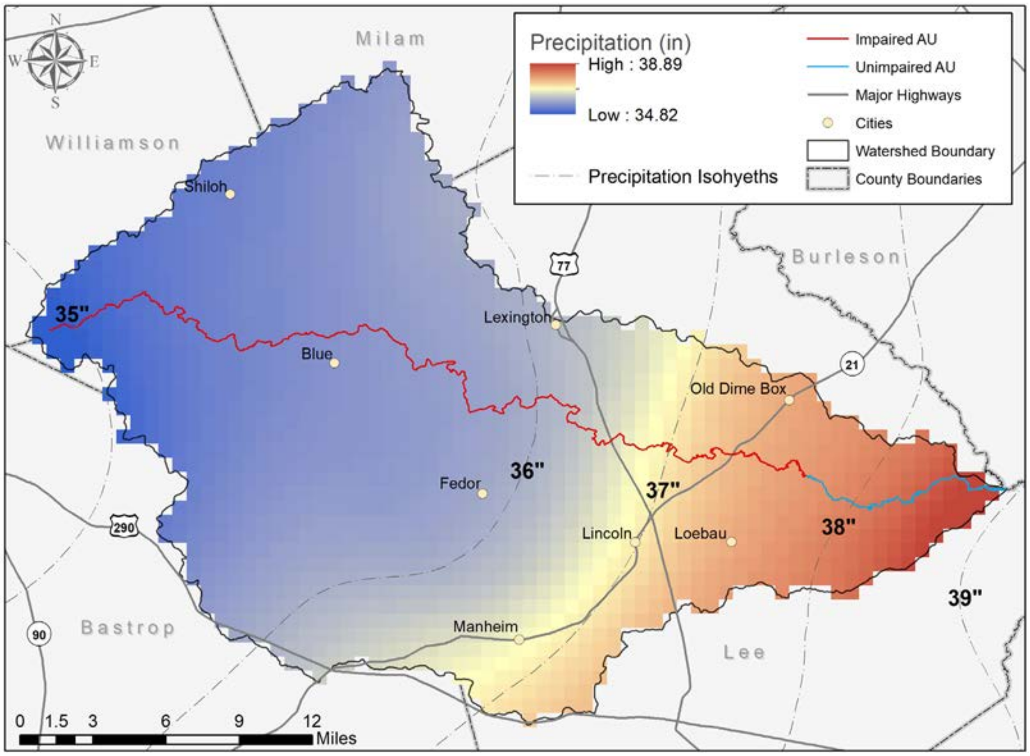

Figure 21. 30-year average precipitation in the Middle Yegua Creek watershed (PRISM 2012).

There are no active weather stations recording precipitation or temperature data within the boundaries of the Davidson Creek or Deer Creek watersheds. Therefore, nearby weather stations were used to determine the approximate precipitation and temperature data for the watersheds.

Therefore, the nearby Somerville Dam, Texas USC00418446 weather station (NOAA 2016) was used to determine the approximate precipitation and temperature data for the watershed (Figure 22). Monthly normal air temperature indicates daily mean air temperature was 67.4°F (NOAA 2016). Minimum average daily temperatures reached a low of 36.8°F in January. The maximum average daily temperature reached a peak of 96.5°F in August. Monthly normal precipitation, from the weather station, indicates that the area had a mean annual rainfall from 1981-2010 of 38.7 inches (NOAA 2016). Rainfall normally peaks in October (4.47 inches) with the lowest totals occurring in July (1.89 inches) (NOAA 2016). Average annual precipitation values across the study area from the PRISM Climate Group at Oregon State (2012) indicate average annual rainfall ranges from 36 to 40 inches per year across the watershed, with a clear East to West decreasing gradient (Figure 23).

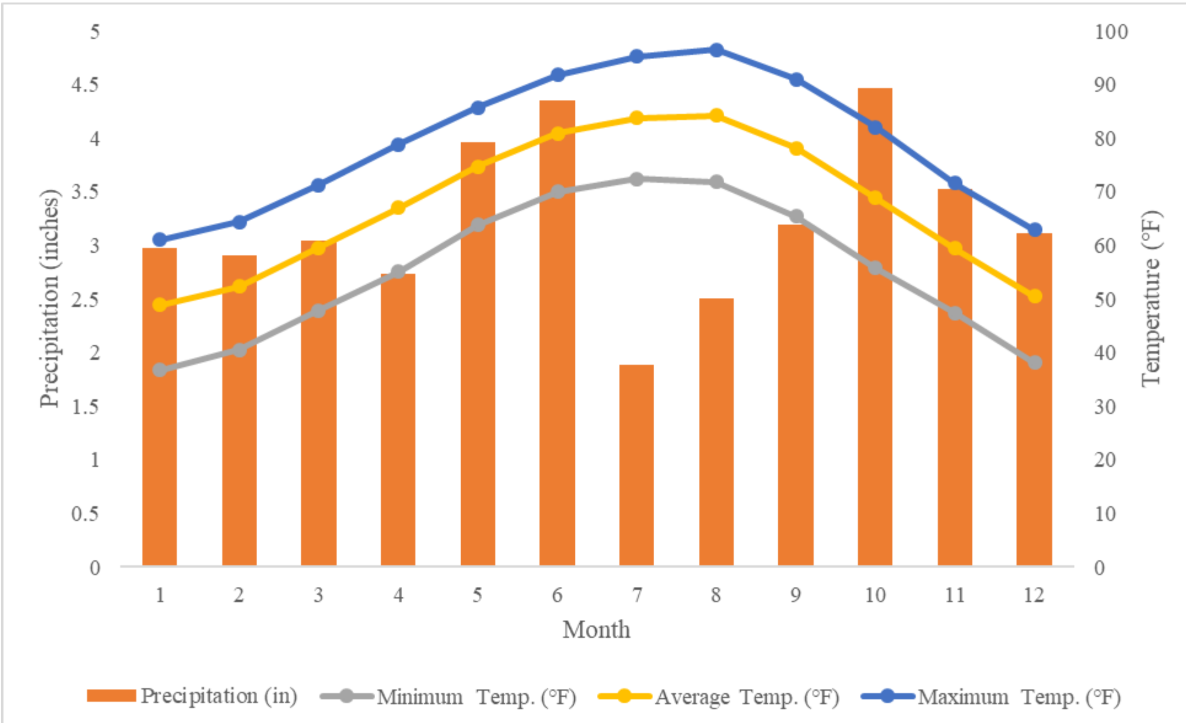

Figure 22. Monthly climate data, including precipitation, normal average, maximum and minimum air temperature, for Somerville Dam, Texas from 1981-2010 (NOAA 2016).

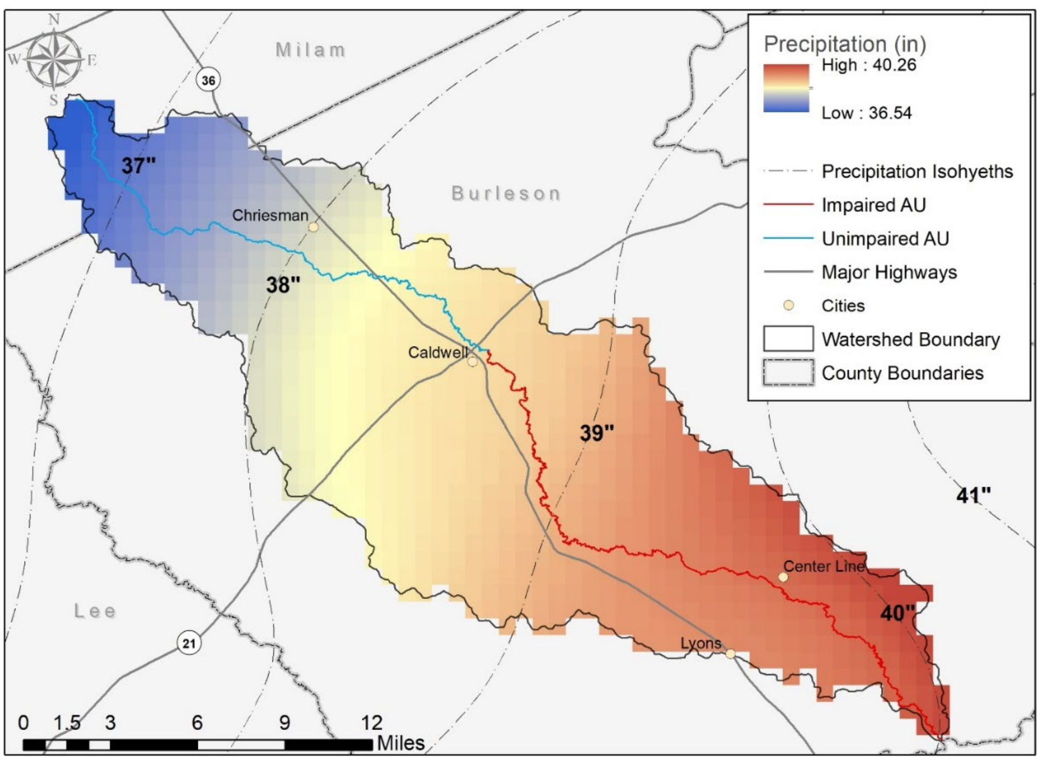

Figure 23. 30-year average precipitation in the Davidson Creek watershed (PRISM 2012).

The weather station chosen to determine the approximate precipitation and temperature data for the Deer Creek watershed was the Marlin, Texas USC00415611 station (NOAA 2016) (Figure 24). Monthly normal air temperature indicates daily mean air temperature was 66.4°F (NOAA 2016). Minimum average daily temperatures reached a low of 35.4°F in January. The maximum average daily temperature reached of peak of 95.6°F in August. Monthly normal precipitation, from the weather station, indicates that the area had a mean annual rainfall from 1981-2010 of 38.5 inches (NOAA 2016). Rainfall normally peaks in May (4.76 inches) with the lowest totals occurring in July (2.07 inches) (NOAA 2016). Average annual precipitation values across the study area from the PRISM Climate Group at Oregon State (2012) indicate average annual rainfall ranges from 35 to 36 inches per year across the watershed (Figure 25).

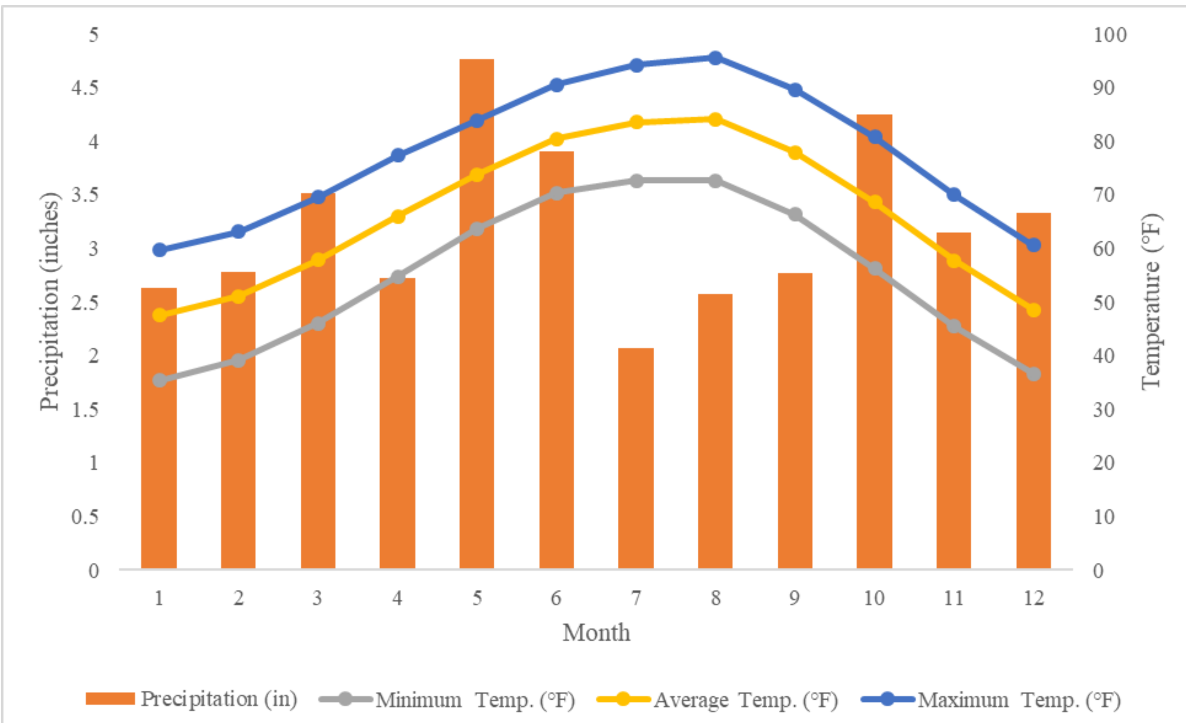

Figure 24. Monthly climate data, including precipitation, normal average, maximum and minimum air temperature, for Marlin, Texas from 1981-2010 (NOAA 2016).

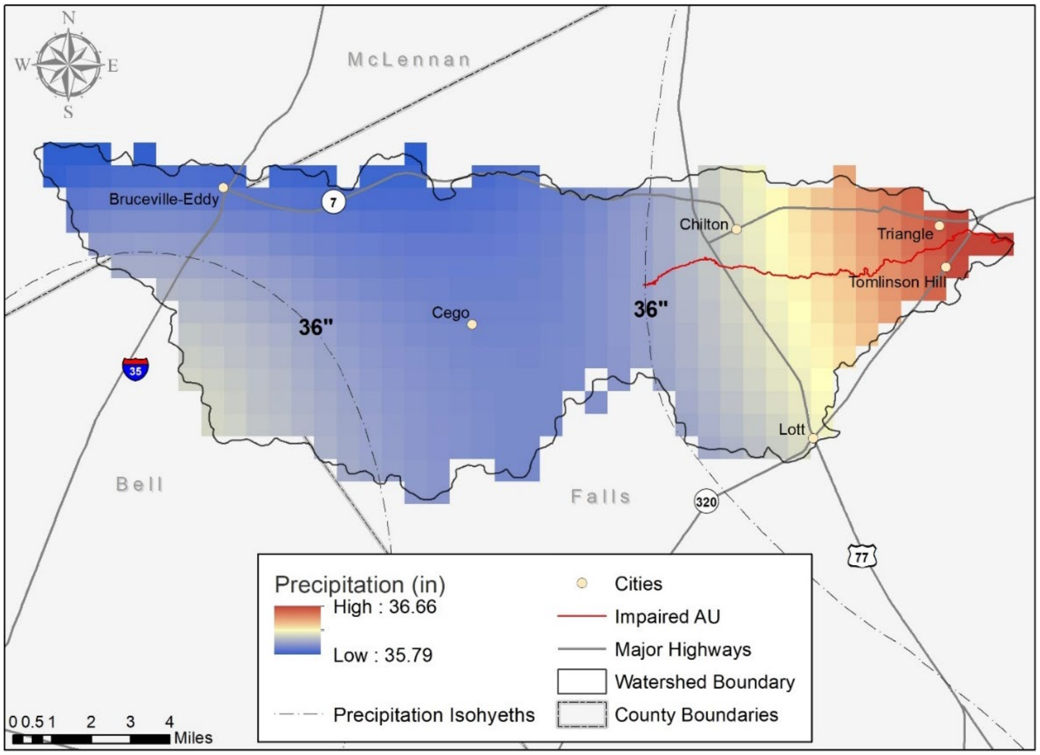

Figure 25. 30-year average precipitation in the Deer Creek watershed (PRISM 2012).

Demographics

Population estimates for all three watersheds were developed using 2010 US Census block data (USCB 2010). Because US Census block boundaries are not the same as the watersheds boundaries, their populations were estimated by multiplying the census block populations to the percent of each block within the watersheds (Figure 26, Figure 27, Figure 28). The following are the approximate populations of each watershed:

- Middle Yegua Creek watershed: 8,137
- Davidson Creek watershed: 8,666
- Deer Creek watershed: 4,116

Texas Water Development Board (TWDB) Regional Water Plan Population and Water Demand Projections (TWDB 2016) were used to estimate population projections for counties within the watersheds (Table 7, Table 8, Table 9). From 2020-2070 the population of the Middle Yegua Creek watershed is estimated to increase by 92.9%, the Davidson Creek watershed by 33.9%, and the Deer Creek watershed by 64.1%. Note that the 2010 population totals in Tables 7-9 are based on county-level population data and differ slightly from the US Census block-based population estimates outlined above.

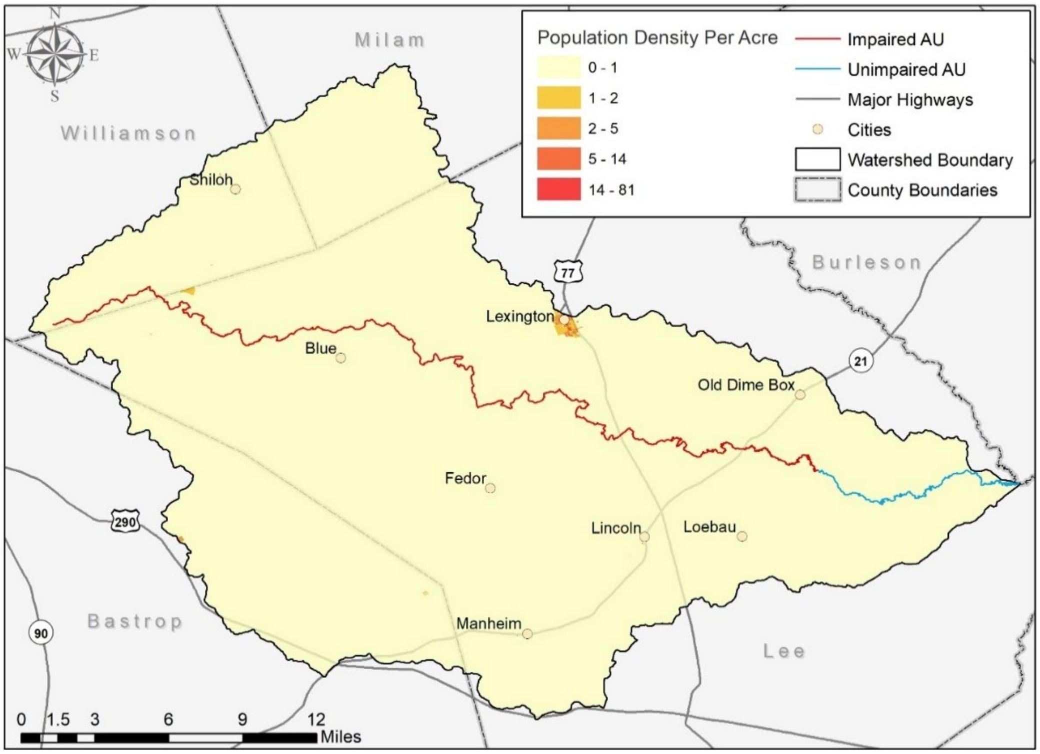

Figure 26. Middle Yegua Creek watershed 2010 population by census block.

Table 7. Population projections by county for the Middle Yegua Creek watershed (TWDB 2016).

County	2010 U.S. Census	Projected Population in the Watershed by Year						Percent Increase (2010-2070)
		2020	2030	2040	2050	2060	2070	
Bastrop	493	837	1,181	1,524	1,868	2,212	2,555	418.1
Lee	8,463	9,081	9,699	10,316	10,934	11,552	12,170	43.8
Milam	686	722	758	795	831	867	904	31.8
Williamson	1,458	2,179	2,899	3,620	4,341	5,061	5,782	296.5
Total	11,100	12,819	14,537	16,256	17,974	19,693	21,411	92.9

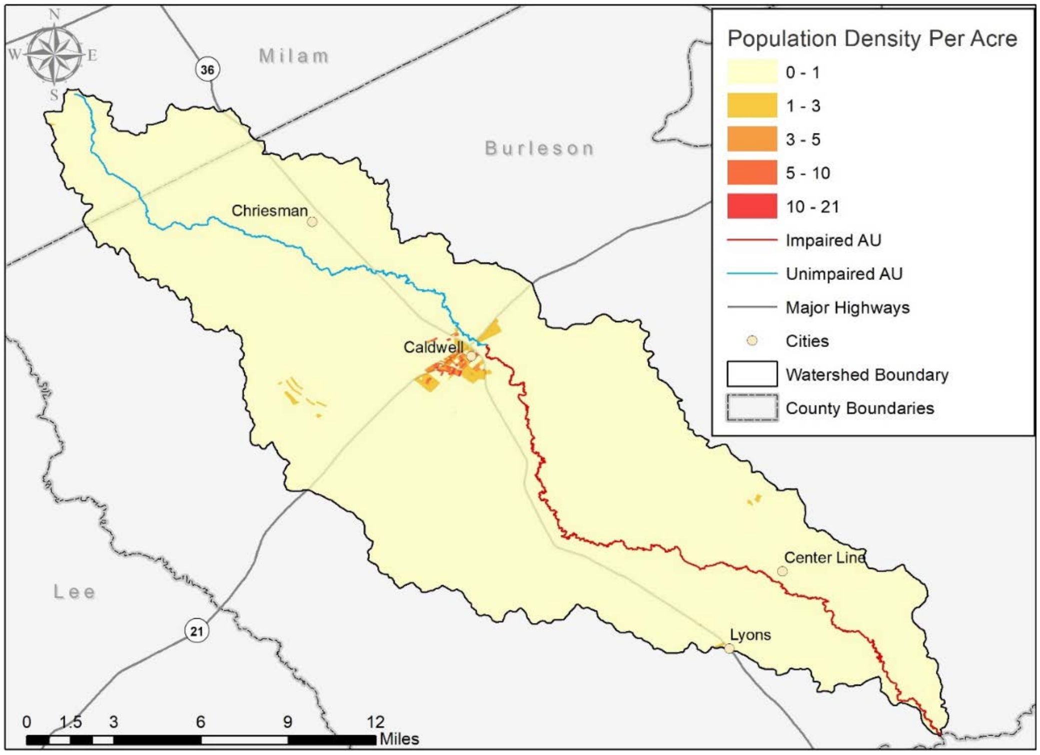

Figure 27. Davidson Creek watershed 2010 population by census block.

Table 8. Population projections by county for the Davidson Creek watershed (TWDB 2016).

County	2010 U.S. Census	Projected Population in the Watershed by Year						Percent Increase (2010-2070)
		2020	2030	2040	2050	2060	2070	
Burleson	5,129	5,419	5,710	6,000	6,291	6,582	6,872	34.0
Milam	349	368	386	405	423	442	460	31.8
Total	5,478	5,787	6,096	6,405	6,714	7,023	7,332	33.9

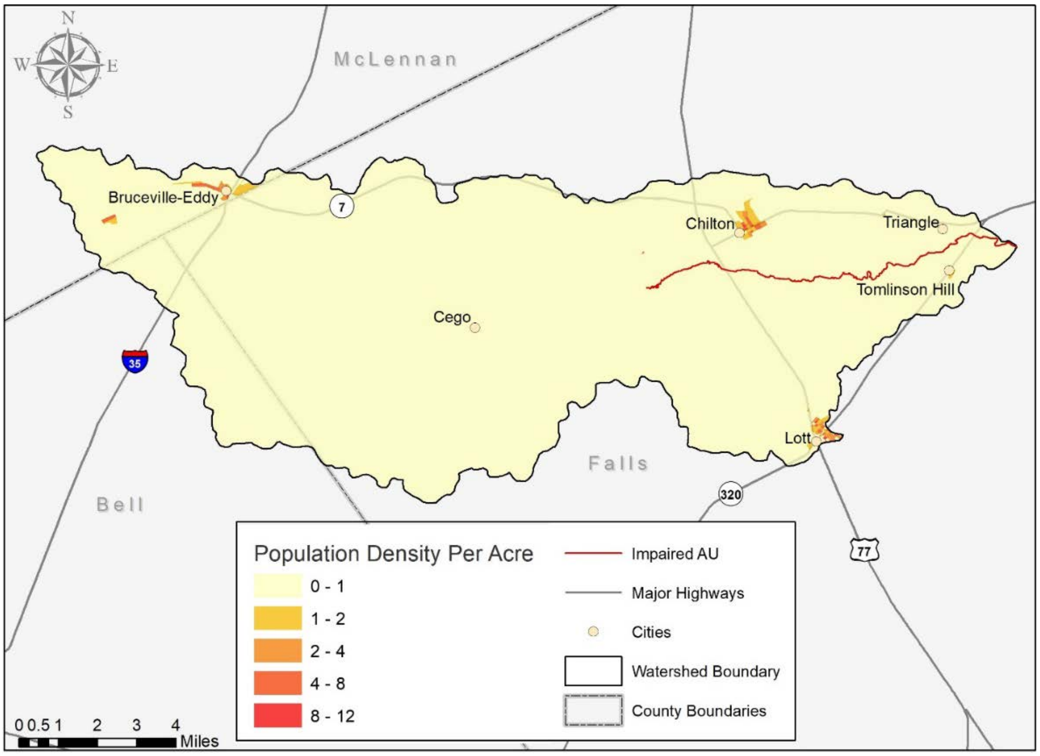

Figure 28. Deer Creek watershed 2010 population by census block.

Table 9. Population projections by county for the Deer Creek watershed (TWDB 2016).

County	2010 U.S. Census	Projected Population in the Watershed by Year						Percent Increase (2010-2070)
		2020	2030	2040	2050	2060	2070	
Bell	2,364	2,844	3,324	3,804	4,284	4,763	5,243	121.8
Falls	2,335	2,411	2,488	2,564	2,640	2,716	2,793	19.6
McLennan	1,783	1,919	2,056	2,192	2,329	2,465	2,601	45.9
Total	6,482	7,175	7,867	8,560	9,252	9,945	10,637	64.1

Water Quality

Introduction

Under the Federal Clean Water Act (CWA) section 303(d) and 305(b), the State of Texas is required to identify water bodies that are unable to meet water quality standards for their designated uses. The Texas Commission on Environmental Quality (TCEQ) assigns unique "segment" identifiers to each water body. Locations within a segment are broken up into hydrologically distinct AUs. The AUs are evaluated every two years to determine if they meet designated water quality standards, and those that are not meeting requirements are listed on the 303(d) List in the Texas Integrated Report (TCEQ 2019b):
https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/18txir/2018_303d.pdf

TCEQ defines the designated uses for all water bodies, which in turn establishes the water quality criteria to which a water body must adhere. Currently, all water bodies in the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds must meet "primary contact recreation" uses and support aquatic life use. The water quality for recreation use is evaluated by measuring concentrations of fecal indicator bacteria in 100 milliliters (mL) of water. Aquatic life use is a measure of a water body's ability to support a healthy aquatic ecosystem. Aquatic life use is evaluated based on the dissolved oxygen (DO) concentration, toxic substance concentrations, ambient water and sediment toxicity, and indices of habitat, benthic macroinvertebrates and fish communities. General use water quality requirements also include measures of temperature, pH, chloride, sulfate and total dissolved solids. Currently, water bodies are also screened for levels of concern for nutrients and chlorophyll-a.

According to the *2018 Texas Integrated Report* and *303(d) List* (TCEQ 2019b), there is one impaired AU due to elevated levels of bacteria in each watershed: AU 1212A_02 in Middle Yegua Creek, AU 1211A_02 in Davidson Creek and AU 1242J_01 in Deer Creek (Figure 29, Figure 30, Figure 31). Davidson Creek is impaired for low DO concentrations along with the elevated levels of bacteria. There are also concerns for depressed dissolved oxygen and habitat in Middle Yegua Creek as well as concerns for the macrobenthic community in Deer Creek.

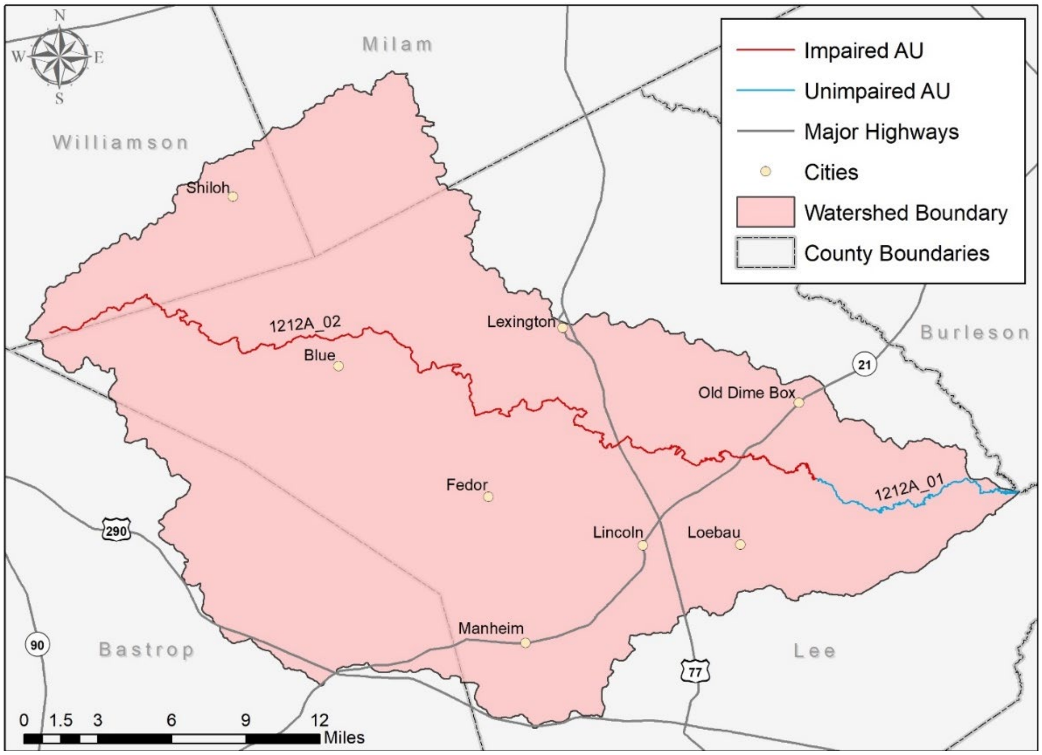

Figure 29. Texas Commission on Environmental Quality assessment units and watershed impairments for Middle Yegua Creek watershed.

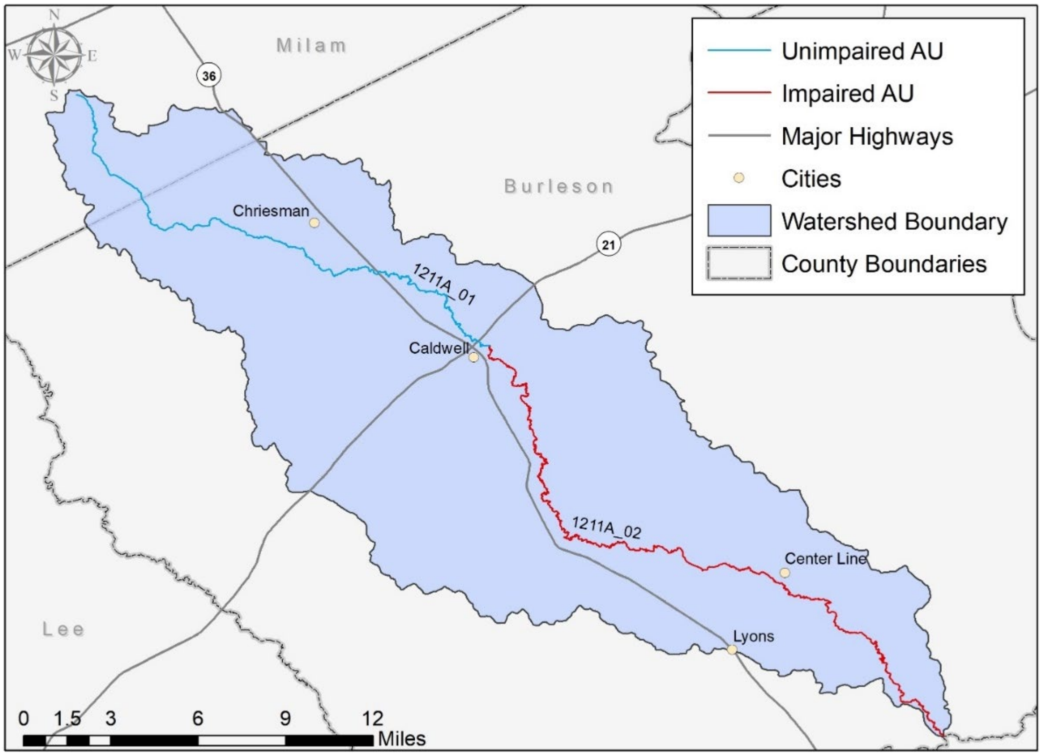

Figure 30. Texas Commission on Environmental Quality assessment units and watershed impairments for Davidson Creek watershed.

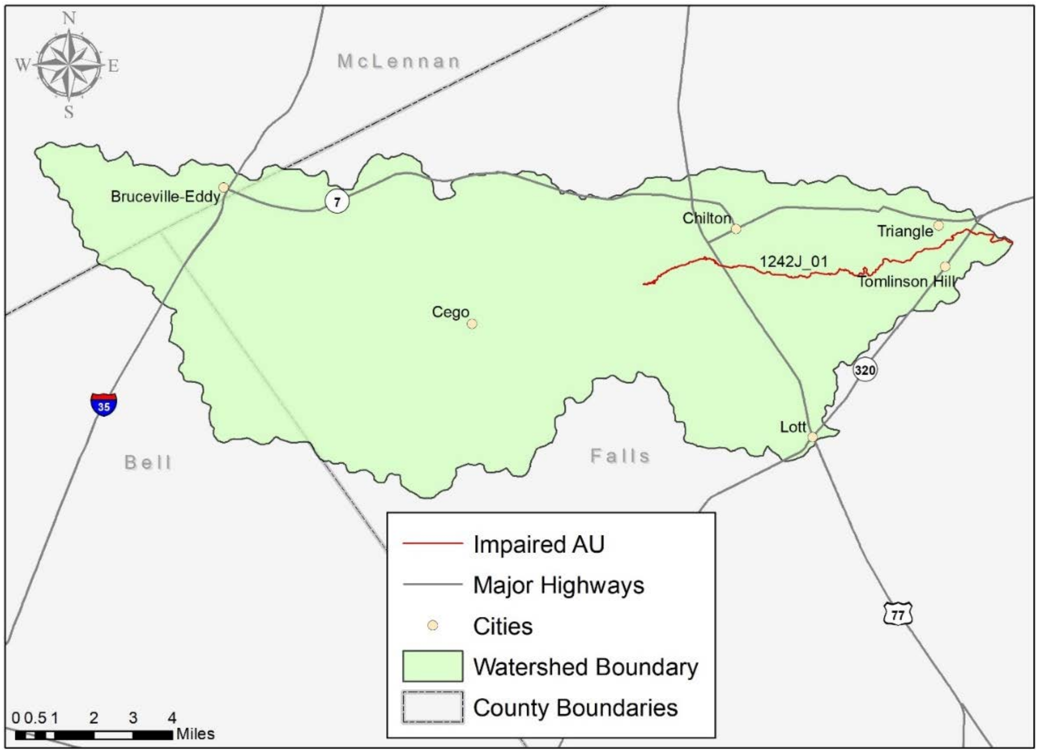

Figure 31. Texas Commission on Environmental Quality assessment unit and watershed impairment for Deer Creek watershed.

Water quality is monitored at designated sampling sites throughout the watershed. The TCEQ Surface Water Quality Monitoring Program (SWQM) coordinates the collection of water quality samples at specified water quality monitoring sites in the watersheds and the state (Figure 32, Figure 33, Figure 34). Through the TCEQ Clean Rivers Program (CRP), the Brazos River Authority (BRA) conducts quarterly monitoring of field parameters (clarity, temperature, DO, specific conductance, pH, salinity and flow), conventional parameters (total suspended solids, sulfate, chloride, ammonia, total hardness, nitrate-nitrogen, total phosphorous, alkalinity, total organic carbon, turbidity and chlorophyll-a), and bacteria. Sites currently being monitored by BRA are detailed in Table 10. The sites monitored by the Texas Water Resources Institute (TWRI) are detailed in Table 11. At these sites, TWRI conducted monthly monitoring of field parameters (clarity, temperature, DO, specific, conductance, pH and flow) and bacteria over a period of 15 months.

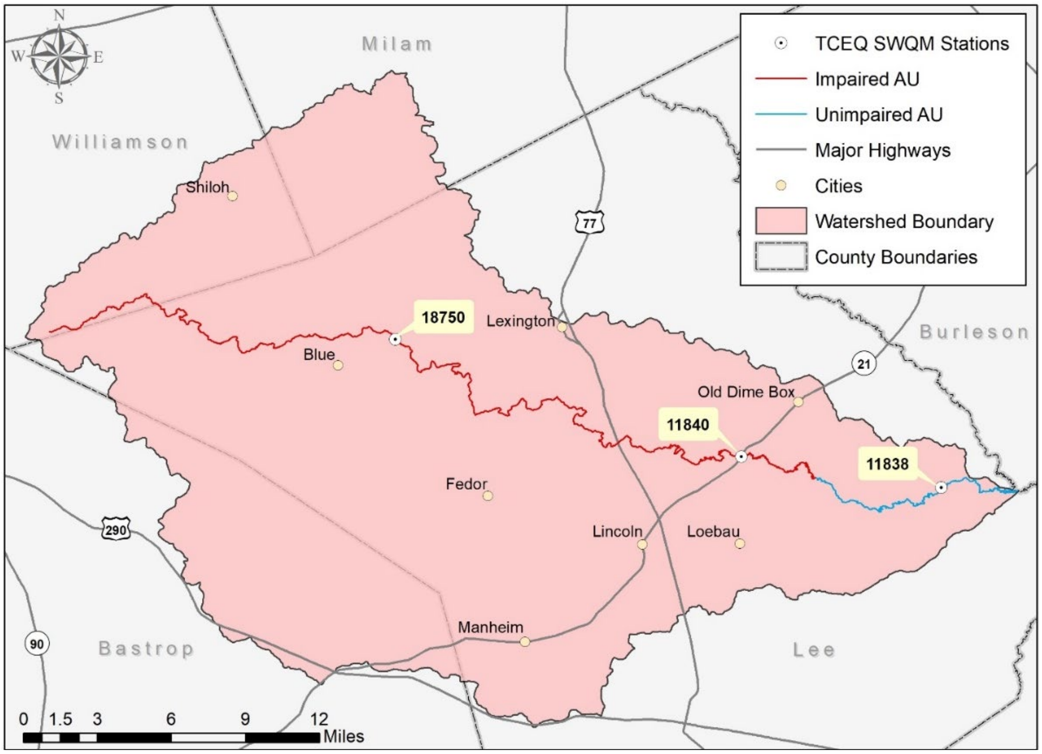

Figure 32. Surface Water Quality Monitoring Program (SWQM) stations in the Middle Yegua Creek watershed.

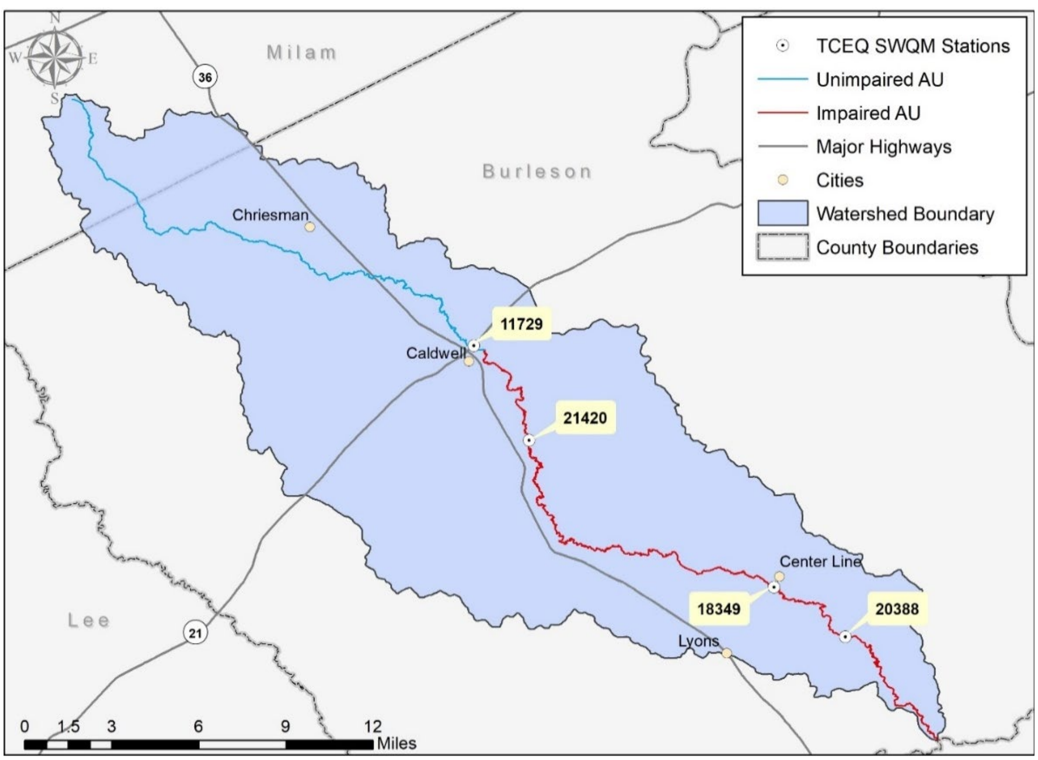

Figure 33. Surface Water Quality Monitoring Program (SWQM) stations in the Davidson Creek watershed.

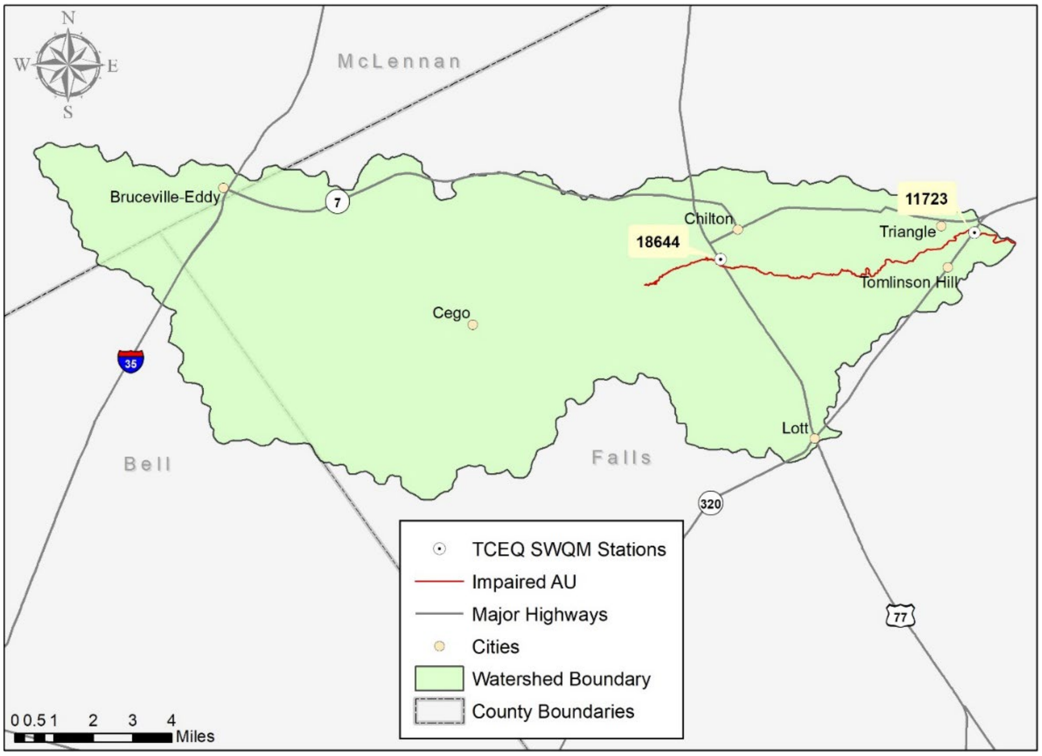

Figure 34. Surface Water Quality Monitoring Program (SWQM) stations in the Deer Creek watershed.

Table 10. Sites currently monitored by Brazos River Authority.

Station			Number of Annual Samples Collected				
ID	AU	Description	24 hr DO	Conventional	Field	Flow	Bacteria
11840	1212A_02	Middle Yegua Creek at SH 21 4.4 miles NE of Lincoln	4	4	4	4	4
20388	1211A_02	Davidson Creek 100 meters upstream of Burleson CR 423 NE of Somerville	4	4	4	4	4
11723	1242J_01	Deer Creek immediately downstream of SH 320 W of Marlin		4	4		4

assessment unit, AU; hour, hr; dissolved oxygen, DO

Table 11. Sites currently monitored by Texas Water Resources Institute.

Station			Number of Samples Collected Between December 2018 – February 2020		
ID	AU	Description	Field	Flow	Bacteria
18750	1212A_02	Middle Yegua Creek immediately upstream of FM 696	15	15	15
11840	1212A_02	Middle Yegua Creek at SH 21 4.4 miles NE of Lincoln	15	15	15
11838	1212A_01	Middle Yegua Creek immediately upstream of FM 141 4 miles SE of Dime Box	15	14*	15
18349	1211A_02	Davidson Creek downstream of FM 60 near Lyons Texas	15	15	15
21420	1211A_02	Davidson Creek at CR 122 in Burleson County	15	15	15
11729	1211A_02	Davidson Creek immediately downstream of SH 21 0.5 miles NE of Caldwell	15	15	15
18644	1242J_01	Deer Creek downstream of US 77 S of Chilton	15		15
11723	1242J_01	Deer Creek immediately downstream of SH 320 W of Marlin	15		15

*Flow measurement could not be collected for this station in April 2019 due to unsafe conditions.
assessment unit, AU

Bacteria

As mentioned above, concentrations of fecal indicator bacteria 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 fecal indicator bacteria 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).

Under the primary contact recreation standards, the geometric mean criterion for bacteria is 126 most probable number (MPN) of *E. coli* per 100mL. Currently, all water bodies in the Middle

Yegua Creek, Davidson Creek and Deer Creek watersheds are evaluated under this standard. As previously mentioned, three AUs [1212A_02 (Middle Yegua Creek), 1211A_02 (Davidson Creek), and 1242J_01 (Deer Creek)] are listed as impaired due to elevated indicator bacteria Table 12.

Table 12. Geometric means for historical *E. coli* data.

AU	Description	Current Standard	*E. coli* Geometric Mean (MPN/100mL)	Supporting/Not Supporting
1212A_02	Middle Yegua Creek – From the confluence with West Yegua Creek upstream to headwaters of water body in Williamson County	126 MPN/100 mL *E. coli*	749.13[1]	Not Supporting
1211A_02	Davidson Creek – Portion of Davidson Creek from confluence with unnamed tributary upstream to headwaters in Milam County	126 MPN/100 mL *E. coli*	2,212.19[2]	Not Supporting
1242J_01	Deer Creek – Perennial stream from the confluence of the Brazos River upstream to the confluence of Dog Branch northwest of Lott	126 MPN/100 mL *E. coli*	459.59[1]	Not Supporting

[1] *2016 Texas Integrated Report* Assessment Results (TCEQ 2019a)
[2] *2014 Texas Integrated Report* Assessment Results (TCEQ 2015a)
assessment unit, AU; most probable number, MPN

Currently, *E. coli* concentrations are measured at eight stations throughout the watersheds by TWRI and one station by the SWQM Water Quality Monitoring Team: one station in Middle Yegua Creek AU 1212A_01, two stations in Middle Yegua Creek AU 1212A_02, four stations in Davidson Creek AU 1211A_02 and two stations in Deer Creek AU 1242J_01. There are also sites on Middle Yegua Creek AU 1212A_02 (SWQM station 18751) and Deer Creek AU 1242J_01 (SWQM station 16407) that are no longer active but *E. coli* samples were collected at historically. *E. coli* measurements for each impaired AU, including historical stations, are shown in Figure 35 through Figure 37.

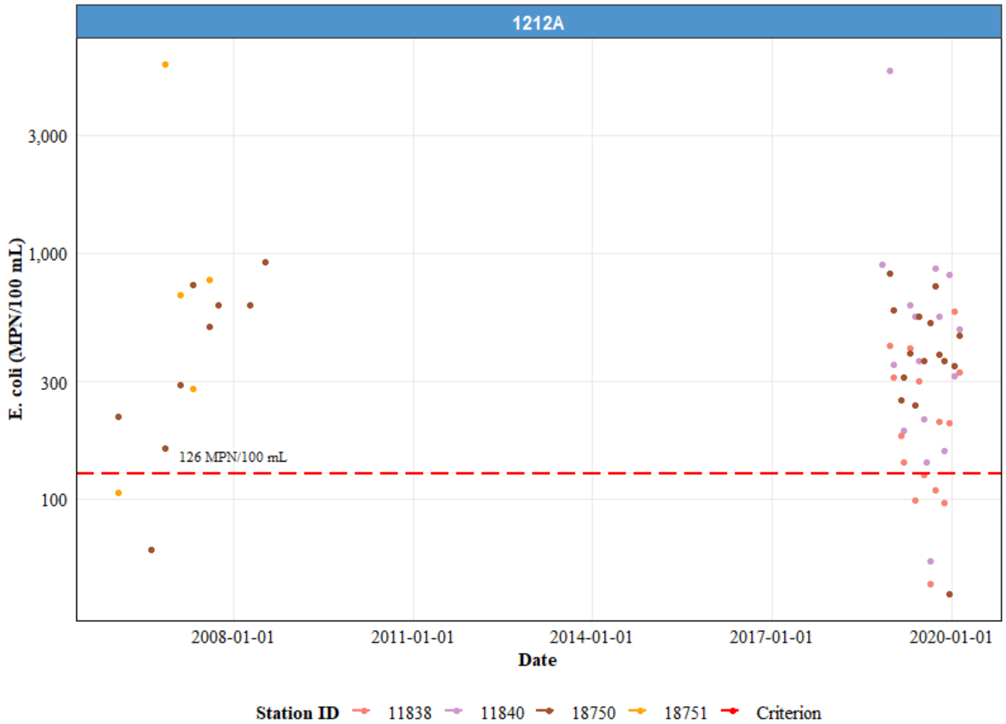

Figure 35. Historical *E. coli* concentrations for the Middle Yegua Creek watershed.

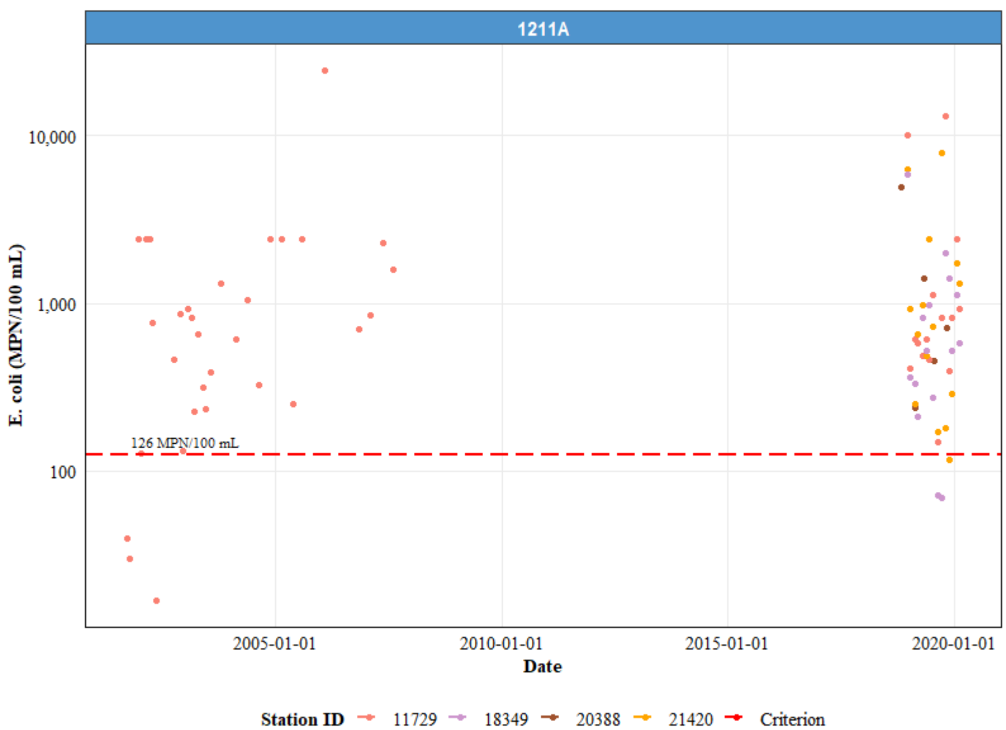

Figure 36. Historical *E. coli* concentrations for the Davidson Creek watershed.

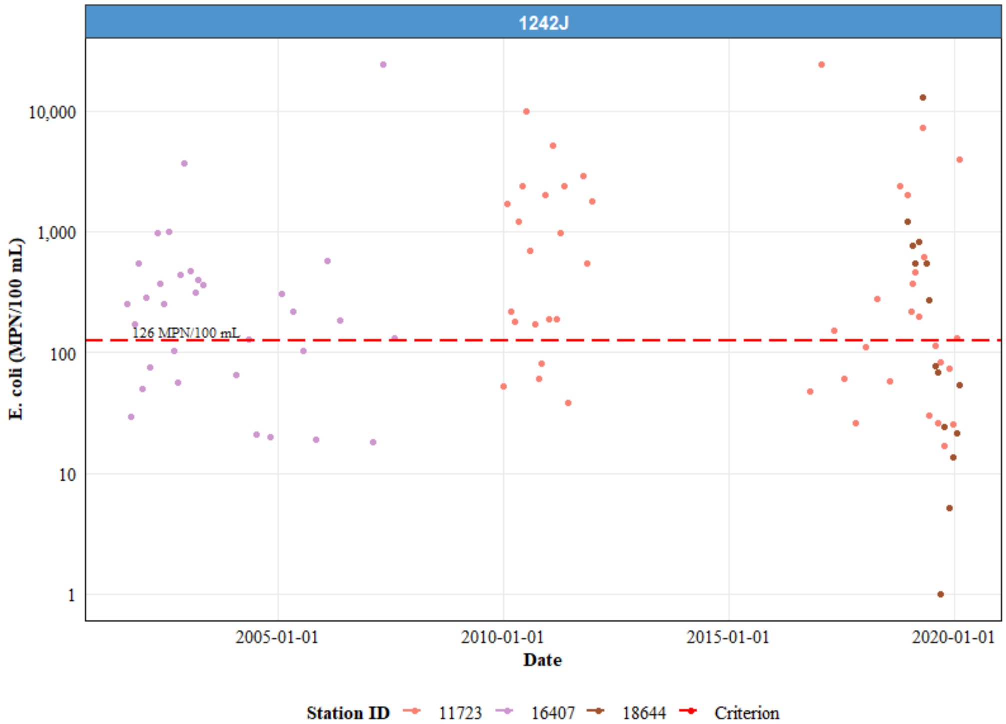

Figure 37. Historical *E. coli* concentrations for the Deer Creek watershed.

Dissolved Oxygen

DO is essential for aquatic organisms to survive and refers to the concentration of oxygen gas incorporated into water. DO concentrations naturally fluctuate in the environment, but anthropogenic activities can contribute excessive organic matter and nutrients, consequently depressing DO concentrations. Every water body assessed by the Texas State Water Quality Standards is assigned an aquatic life-use (ALU) category of either minimal, limited, intermediate, high or exceptional. To ensure that water bodies protect these ALU categories, DO criteria are implemented. Classified water bodies are required to meet an average DO criterion measured over 24 hours and a minimum DO criterion (TCEQ 2015b). Unclassified streams are assigned an ALU based upon the flow-type for the specific segment, which are 30 categorized as perennial, intermittent with perennial pools and intermittent without perennial pools. Specific DO criteria are associated with each unclassified stream type, unless a site specific ALU has been assigned to the unclassified water body. The 24-hour average DO criteria are measured over 24 hours and sampling events occur at various times throughout the year to represent unbiased and seasonally representative data. When 24-hour average DO is not available, grab DO measurements are utilized and include a minimum criterion and screening level criterion (TCEQ 2015b). Limited 24-hour average DO data is available for Davidson Creek AU 1211A_02, with sampling events occurring between 2003 and 2019 (Figures 38-40). All segments in the watersheds are assumed to support a subcategory of aquatic life use. The ALU categories and DO screening levels are listed for each water body in Table 13, and grab samples dissolved oxygen concentrations are plotted in Figures 41-43. Middle Yegua

Creek AU 1212A_02 has a concern for depressed DO while Davidson Creek AU 1211A_02 is listed to not support the DO standards and criteria.

Table 13. Aquatic life-use (ALU) and dissolve oxygen (DO) criteria for the Middle Yegua, Davidson and Deer Creeks watersheds.

Segment	Water Body	ALU Category	DO Screening Level Criteria (mg/L)	DO Grab Minimum (mg/L)	24 hr DO Average (mg/L)	24 hr DO Minimum (mg/L)
1212A	Middle Yegua Creek	High	5 (CS)[1]	3	-	-
1211A	Davidson Creek	Intermediate	4	3	4 (NS)[2]	3 (NS)[2]
1242J	Deer Creek	High	5	3	-	-

[1] CS: Concern for Screening Level;
[2] NS: Not Supporting
milligrams, mg; liter, L; hour, hr

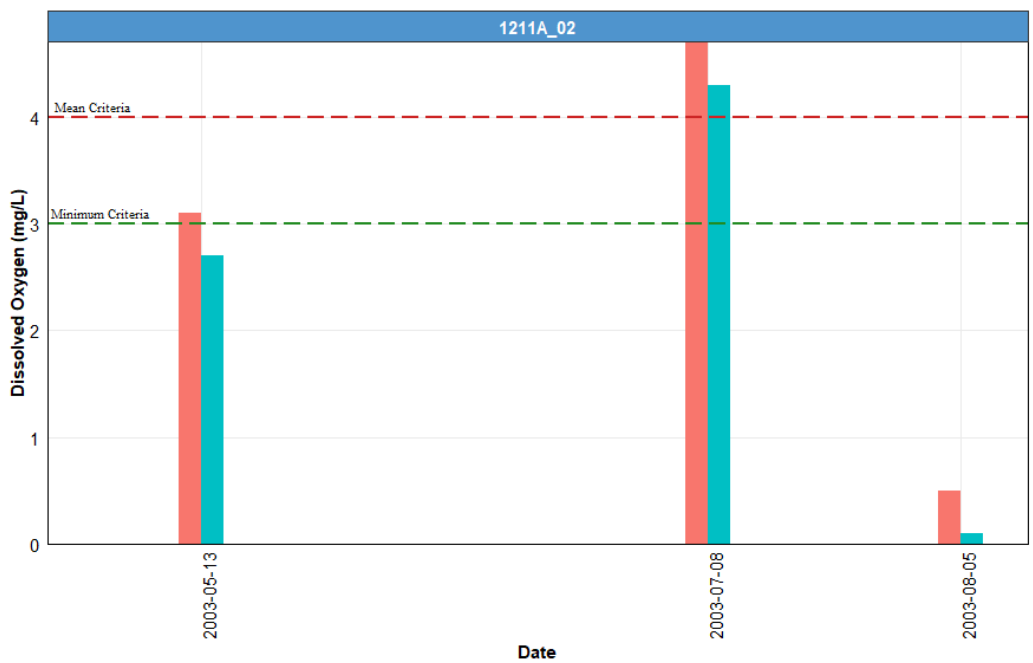

Figure 38. Historical 24-hour dissolved oxygen concentrations for the Davidson Creek watershed station 20388. The orange bar indicates average 24-hour dissolved concentrations and the blue bar indicates minimum 24-hour dissolved oxygen concentrations.

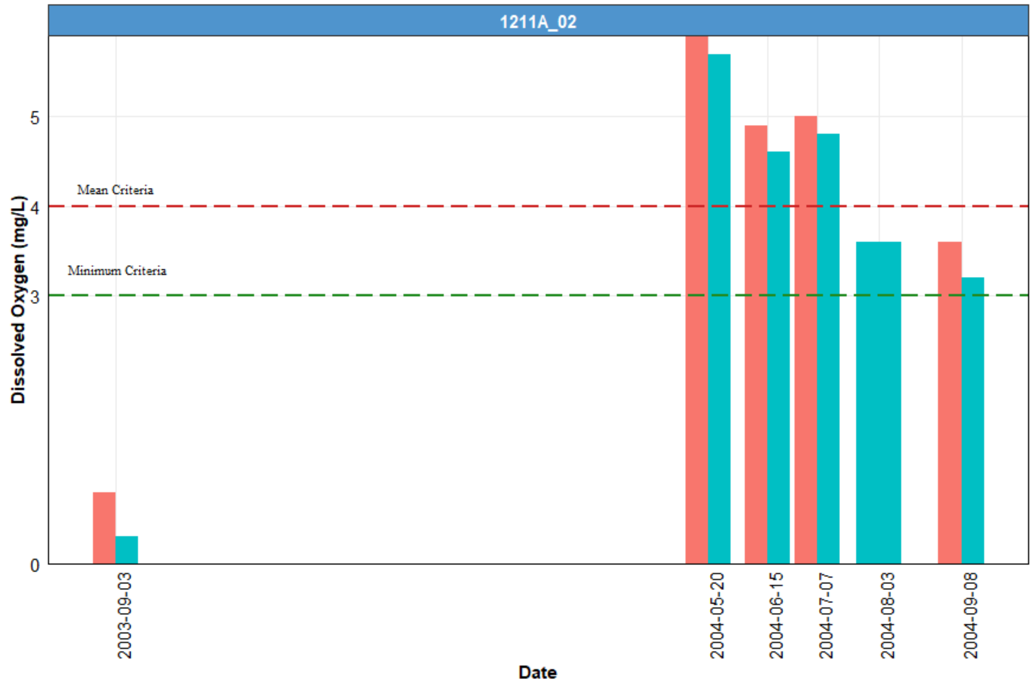

Figure 39. Historical 24-hour dissolved oxygen concentrations for the Davidson Creek watershed station 11729 between 2003 and 2004. The orange bar indicates average 24-hour dissolved concentrations and the blue bar indicates minimum 24-hour dissolved oxygen concentrations.

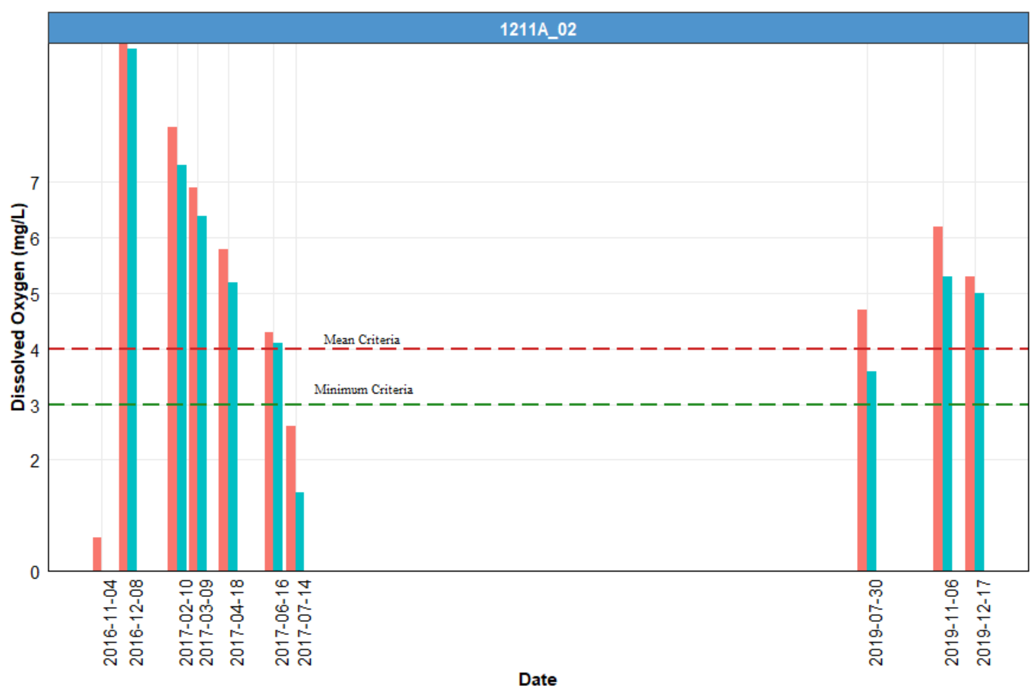

Figure 40. Historical 24-hour dissolved oxygen concentrations for the Davidson Creek watershed station 11729 between 2016 and 2019. The orange bar indicates average 24-hour dissolved concentrations and the blue bar indicates minimum 24-hour dissolved oxygen concentrations.

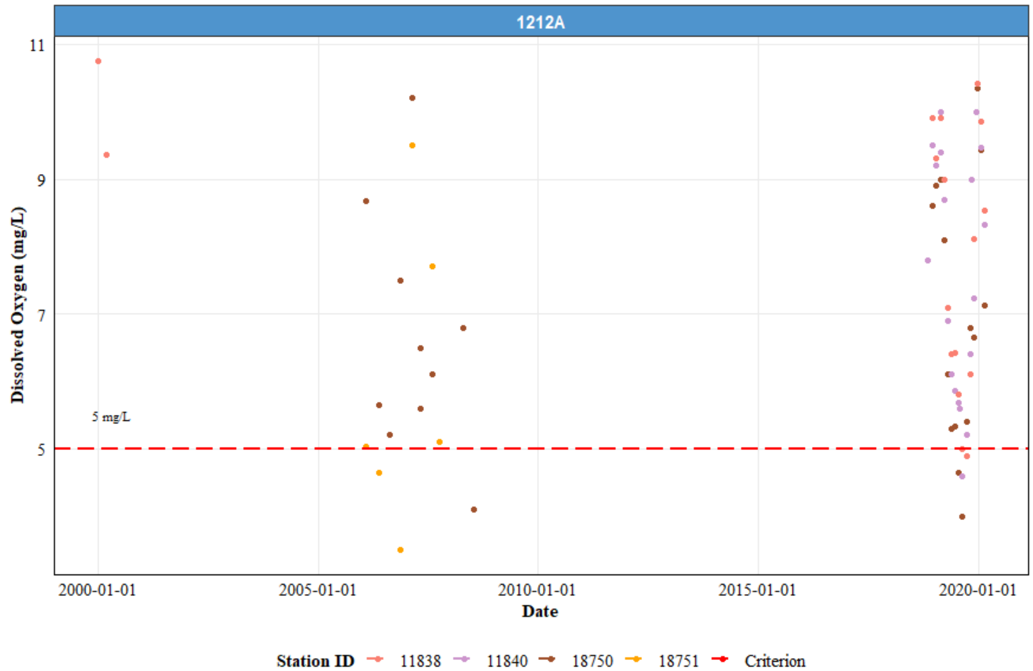

Figure 41. Historical grab sample dissolved oxygen concentrations for the Middle Yegua Creek watershed.

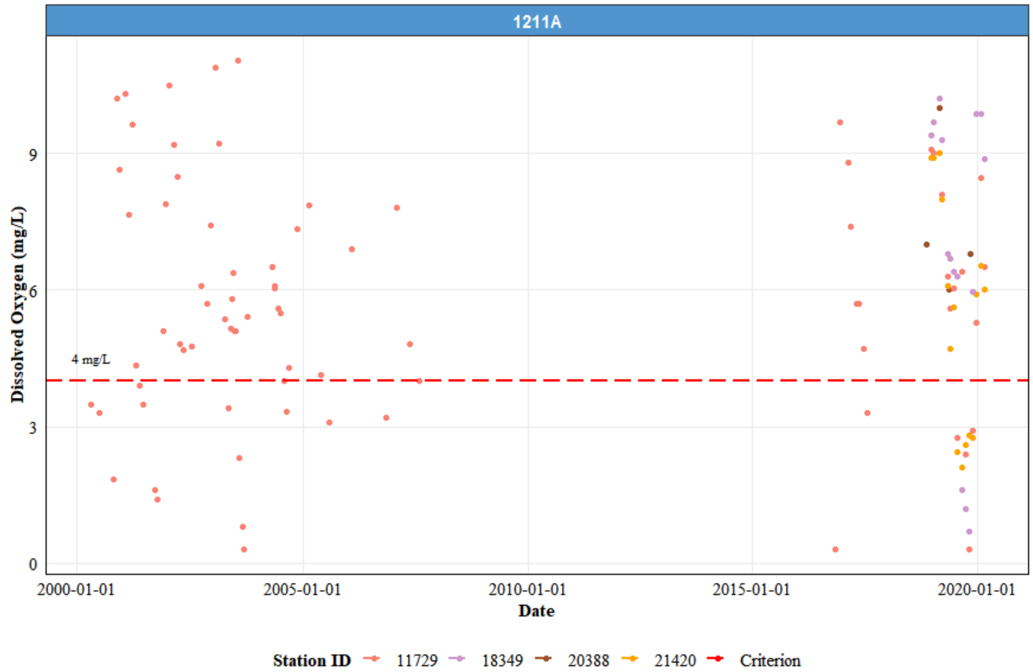

Figure 42. Historical grab sample dissolved oxygen concentrations for the Davidson Creek watershed.

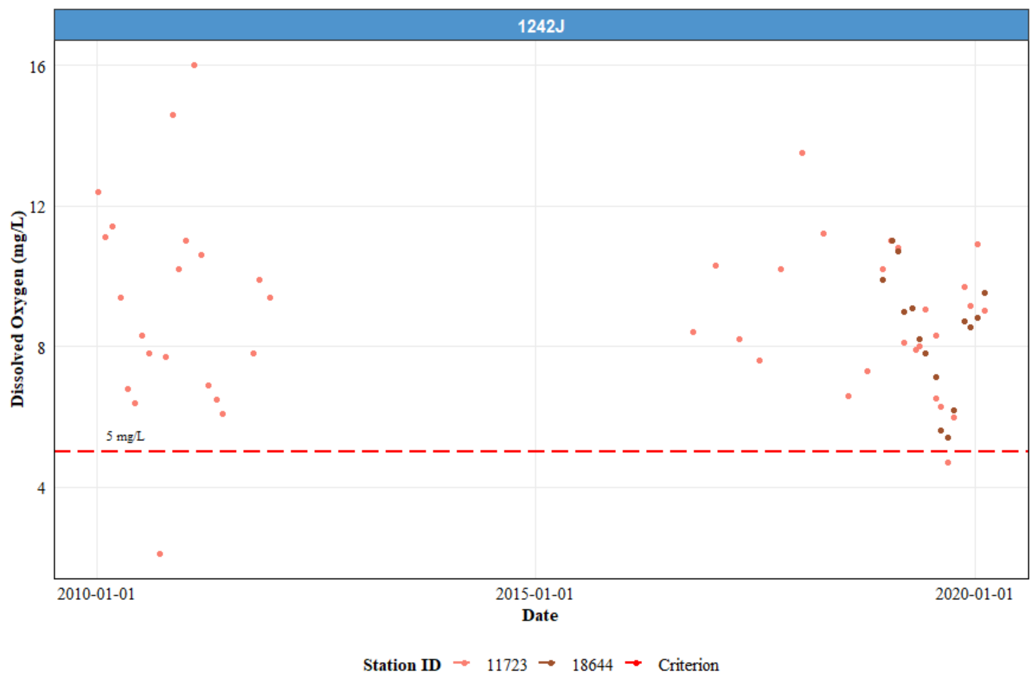

Figure 43. Historical grab sample dissolved oxygen concentrations for the Deer Creek watershed.

Flow

Generally, streamflow (the amount of water flowing in a river/creek at a given time) is dynamic and always changing in response to both natural (e.g. precipitation events) and anthropogenic (e.g. changes in land cover) factors. From a water quality perspective, streamflow is important because it influences the ability of a water body to assimilate pollutants.

There are two United States Geological Survey (USGS) streamflow gages in the watersheds. USGS streamflow gage 08109700 is located at SWQM Station 11840 in Middle Yegua Creek. Instantaneous streamflow information is available at this station dating back to August 1962. A second streamflow gage (08110100) is located at SWQM Station 18349 in the lower portion of the Davidson Creek watershed. This gage has instantaneous streamflow records dating back to October 1962. Instantaneous streamflow data for each gage was used to calculate the monthly aggregated streamflow from January 2009 through December 2019 (Figure 44, Figure 45).

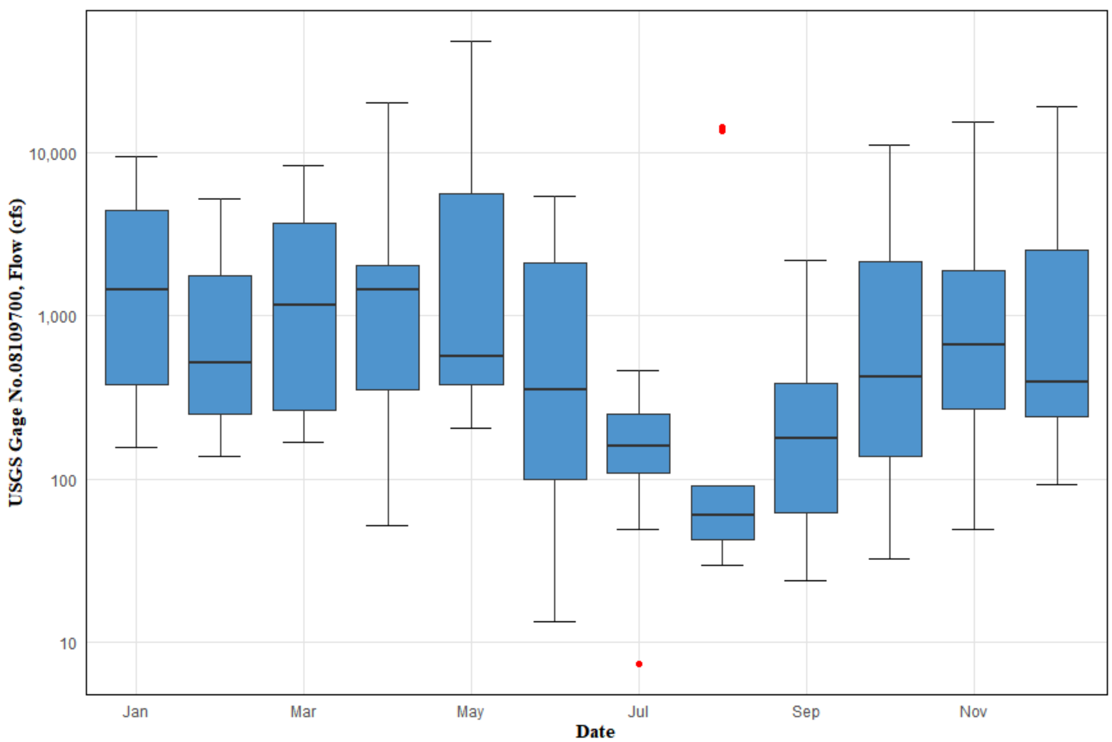

Figure 44. Aggregated monthly streamflow for Middle Yegua Creek from January 2009 through December 2019. colony forming units, cfu

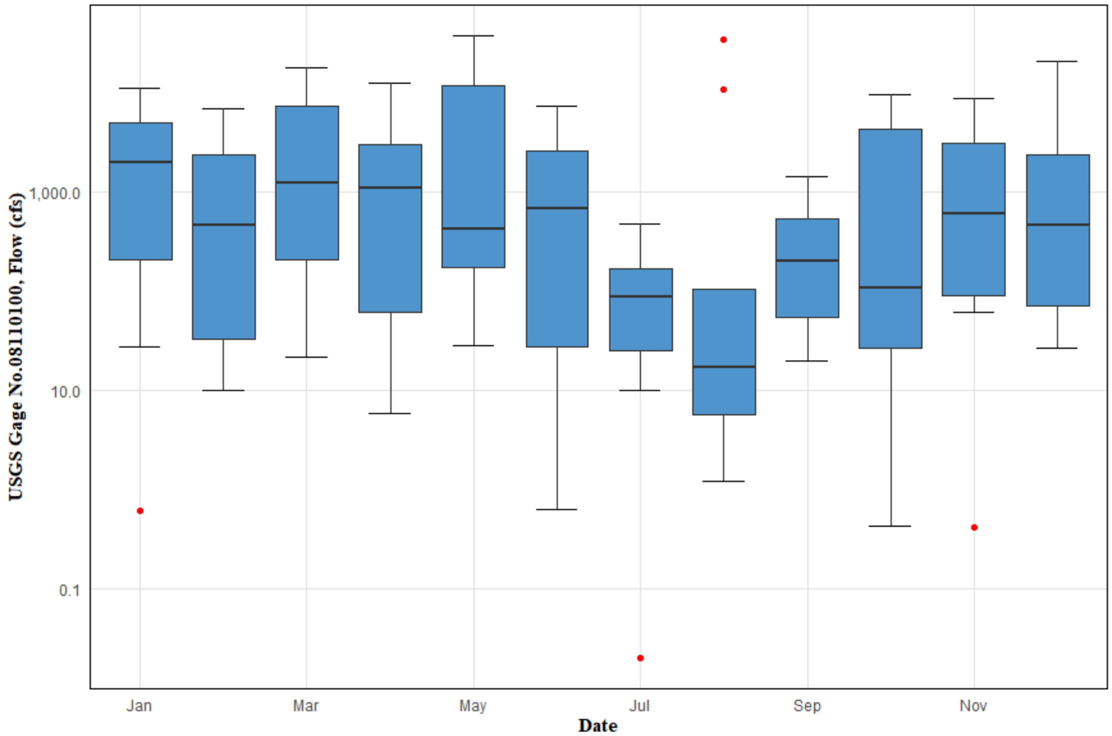

Figure 45. Aggregated monthly streamflow for Davidson Creek from January 2009 through December 2019. colony forming units, cfu

Hydrologic data in the form of daily streamflow records were unavailable in the Deer Creek watershed. However, streamflow records are available in a nearby watershed (Middle Bosque River) with similar characteristics (Figure 46). There is one USGS streamflow gage in the Middle Bosque River watershed (08095300) that has instantaneous streamflow records dating back to October 2007. This gage was used to develop mean daily streamflow for Deer Creek AU 1242J_01 from January 2009 through December 2019 using the Drainage-Area Ratio Method (DAR) described in the Pollutant Source Assessment section of the document (Figure 47).

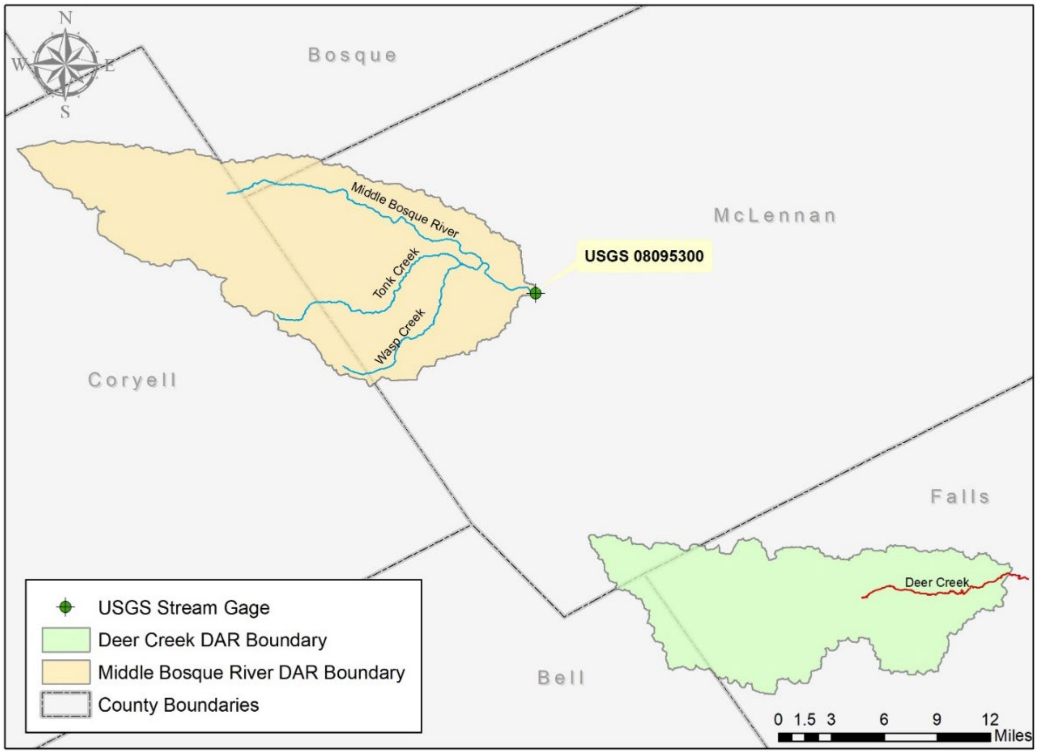

Figure 46. USGS streamflow gage and watershed used in streamflow development for Deer Creek. Drainage-Area Ratio Method, DAR

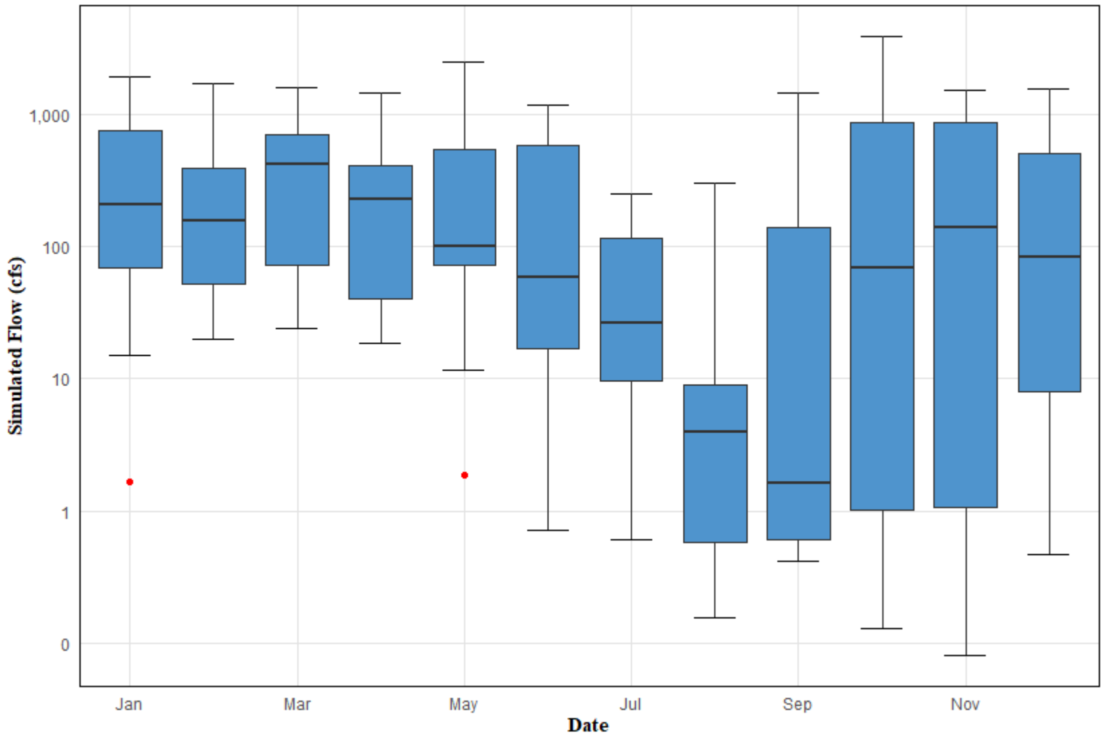

Figure 47. Aggregated monthly streamflow for Deer Creek from January 2009 through December 2019. colony forming unit, cfu

Potential Sources of Water Quality Issues

Domestic Livestock

Domestic livestock farms, particularly cattle, are common throughout the rural watersheds. Runoff from rain events can transport fecal matter and bacteria from pastures and rangeland into nearby creeks and streams. Livestock with direct access to streams can also wade and defecate directly into water bodies resulting in direct contributions of bacteria to the water. Streamside riparian buffers, fencing and grazing practices that reduce the time livestock spend near streams can reduce livestock impacts on water quality.

Because watershed-level livestock numbers are not available, populations were estimated using the USDA National Agricultural Statistics Services (NASS) and USGS NLCD datasets. Specifically, the horse, goat, sheep, poultry and pig/hog populations for each county was obtained using the USDA NASS 2017 dataset. The county-level data were multiplied by a ratio based on the acres of grazeable land, identified with USGS NLCD data, divided by the total number of acres in the county. Then, the proportion of grazeable acres in the watersheds within each county was used to estimate the number of livestock from each county that occur in the watersheds (Table 14). Grazeable land for cattle is defined as aggregate of pasture/hay, shrub/scrub, forest and herbaceous LULC classifications. A stocking rate of 10 acre (ac)/animal unit was used for the forest, shrub/scrub, and herbaceous land uses to determine the number of cattle in each watershed. A stocking rate of 3 ac/animal unit was used for the hay/pastureland use.

Table 14. Estimated grazing livestock populations in the watersheds.

Segment	Water Body	Cattle	Horses	Goats/Sheep	Pigs/Hogs	Poultry
1212A	Middle Yegua Creek	54,389	1,149	2,072	663	30,336
1211A	Davidson Creek	27,103	456	709	251	46,804
1242J	Deer Creek	6,911	247	683	37	623

Wildlife and Feral Hogs

Bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. Wildlife are naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. While several bird and mammal species are likely to contribute bacteria loads in area waterways, feral hogs and white-tailed deer are the only species with reasonable density and population estimates for significant bacteria load contribution.

A common estimate frequently used in the State of Texas is a density of one hog per 33.3 acres (Wagner and Moench 2009). Appropriate LULC classes for feral hogs in the watersheds include forest, wetland, shrub/scrub, herbaceous, pasture/hay and cultivated crops. White-tailed deer estimates for the watersheds are not available; therefore, estimates from the Texas Parks and Wildlife (TPWD) resource management unit (RMU) 19 for Middle Yegua Creek and Davidson Creek watersheds and RMU CTP for Deer Creek were utilized. The estimated deer population for RMU 19 from 2005-2015 is 41.7 acres per deer and the estimated deer population for RMU CTP from 2005-2015 is approximately 26.7 acres per deer. The estimates for feral hogs and white-tailed deer for each watershed are in Table 15.

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

Segment	Water Body	Feral Hogs	Deer
1212A	Middle Yegua Creek	8,053	6,767
1211A	Davidson Creek	3,932	3,348
1242J	Deer Creek	2,085	2,753

Domestic Pets

Fecal matter from pets can contribute to bacteria loads in the watersheds when not picked up and disposed of properly. In rural areas, such as the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds, pets often spend most their time roaming around outdoors, making proper waste disposal impractical. The American Veterinary Medical Association (AVMA) estimates there are approximately 0.614 dogs and 0.457 cats/home across the United States (AVMA 2018). The estimated number of domestic pets in the watersheds can be calculated by multiplying these ratios with the number of households in each watershed (Table 16).

Table 16. Estimated dog and cat populations in the watersheds.

Segment	Water Body	Estimated Number of Households	Estimated Number of Dogs	Estimated Number of Cats
1212A	Middle Yegua Creek	3,675	2,256	1,679
1211A	Davidson Creek	3,965	2,435	1,812
1242J	Deer Creek	1,633	1,003	746

On-Site Sewage Facilities

Given the rural nature of the watersheds, many homes are not connected to centralized sewage treatment facilities and therefore use OSSFs. Typical OSSF designs include either (1) anaerobic systems composed of septic tank(s) and an associated drainage or distribution field, or (2) aerobic systems with aerated holding tanks and typically an above ground sprinkler system to distribute the effluent. Failing or undersized OSSFs will contribute direct bacteria loads as the effluent from the systems move through or over the ground into adjacent water bodies.

Based on visually validated county 911 data and areas of existing wastewater service, estimations of the number of OSSFs that may occur in each watershed were determined (Table 17). Given the extensive occurrence of “Very Limited” soils for OSSF use (Figure 11, Figure 12, Figure 13), the vast majority of these systems occur in areas with expected failure rates of at least 15% (Reed, Stowe and Yanke 2001). Figure 48 through Figure 50 depict expected distributions of all OSSFs in the watersheds but does not identify failing OSSFs.

Although most well-maintained OSSFs are likely to function properly, failing OSSFs can leak or discharge untreated waste onto distribution fields. Runoff generated during storm events can transport this waste overland and into nearby water bodies. Untreated OSSF effluent can contribute to levels of indicator bacteria, dissolved oxygen, nutrients and other water quality parameters.

Table 17. Number of estimated on-site sewage facilities (OSSFs) in the watersheds.

Segment	Water Body	Estimated OSSFs
1212A	Middle Yegua Creek	3,953
1211A	Davidson Creek	2,408
1242J	Deer Creek	1,685

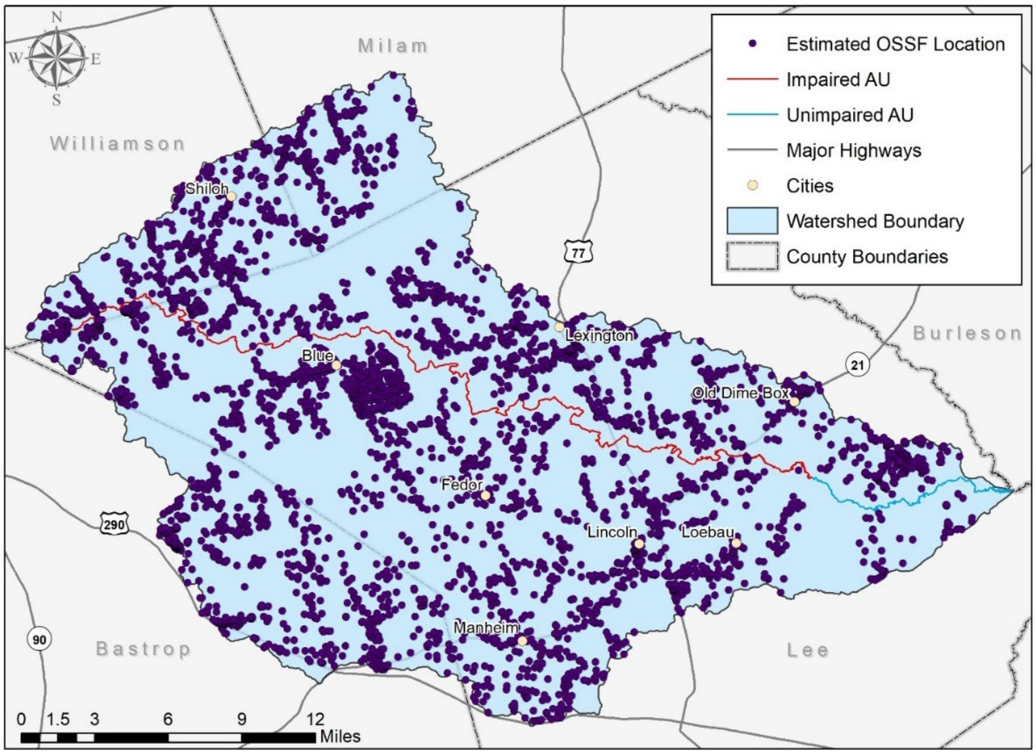

Figure 48. Estimated on-site sewage facility (OSSF) locations in the Middle Yegua Creek watershed.

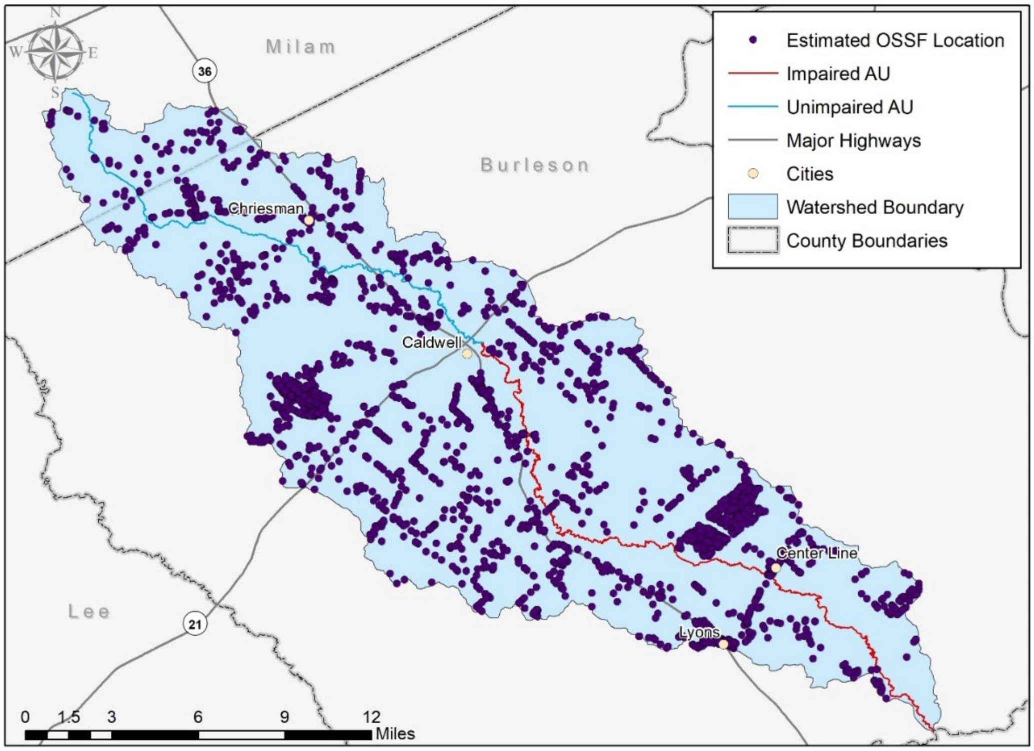

Figure 49. Estimated on-site sewage facility (OSSF) locations in the Davidson Creek watershed.

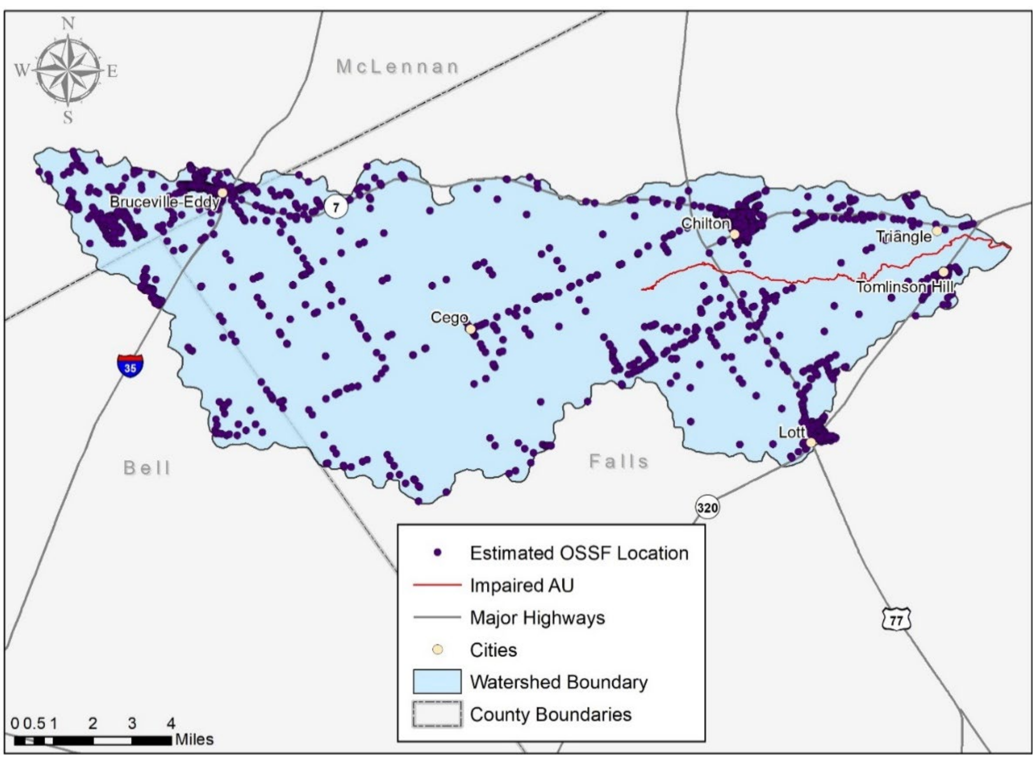

Figure 50. Estimated on-site sewage facility (OSSF) locations in the Deer Creek watershed.

Permitted Discharges

Permitted discharges are sources regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) and the National Pollutant Discharge Elimination System (NPDES) programs. Examples of permitted discharges include WWTF discharges, industrial or construction site stormwater discharges, and discharges from municipal separate storm sewer systems (MS4) of regulated cities or agencies. WWTFs treat municipal wastewater before discharging the treated effluent into a water body. WWTFs are required to test and report the levels of indicator bacteria and nutrients as a condition of their discharge permit. Plants that exceed their permitted levels may require infrastructure or process improvements to meet the permitted discharge requirements.

As of January 2020, five facilities in the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds treat domestic wastewater; one is in the Middle Yegua watershed, two are in the Davidson Creek watershed and two are in the Deer Creek watershed (Table 18; Figure 51, Figure 52, Figure 53). The City of Caldwell WWTF discharges directly into the impaired Davidson Creek segment, and the Chilton Water Supply and Sewer Service WWTF discharges directly into the impaired Deer Creek segment. Discharge for all five facilities is measured in million gallons per day (MGD). All of the WWTFs, except the Burleson County WWTF, had a history of non-compliance issues during the 12-quarter period (3 years) October 1, 2016 through September 30, 2019 (USEPA 2019). During this period, the two facilities reported exceedances in bacteria concentration discharge limits, the City of Lexington WWTF and the Chilton Water Supply and Sewer Service WWTF. None of the bacteria effluent violations were reported as “significant” non-compliance effluent violations. Compliance status is based on the period of record available through the EPA’s Enforcement and Compliance History Online (ECHO) database, which shows history of facility compliance with NPDES and TPDES permit requirements.

Table 18. Permitted wastewater treatment facilities (WWTFs) in the watersheds.

Facility Name (TPDES Permit No.)	Receiving Stream	Flow (MGD)		Bacteria (MPN/100 mL)		Number of Quarters in Violation for Exceedance from 10/2016-9/2019
		Final Permitted	Reported (3-year avg.)	Permitted (Daily Average)	Reported (3-year average)	
City of Lexington WWTF (WQ0010016-001)	Shaw Branch to Middle Yegua Creek (1212A)	0.200	0.0726	126[1]	289	**12** (3 DO monthly min., 9 BOD daily avg., 1 BOD single grab, 11 pH max., 1 pH min., 3 TSS daily avg., 1 Flow daily avg., 8 *E. coli* daily avg., 8 *E. coli* single grab)
City of Caldwell WWTF (WQ0015306-001)	Davidson Creek (1211A)	0.711	0.4431	126[1]	3.75	**4** (1 Ammonia daily avg., 1 Ammonia daily max., 4 BOD daily avg.)
Burleson County WWTF (WQ0010813-002)	Berry Creek to Davidson Creek (1211A)	0.300	N/A[2]	126[1]	N/A[2]	**0**
Chilton Water Supply & Sewer Service WWTF (WQ0010811-001)	Deer Creek (1242J)	0.105	0.0429	126[1]	25.5	**6** (3 TSS daily avg., 3 Ammonia daily avg., 2 Ammonia single grab, 1 *E. coli* daily avg., 1 *E. coli* single grab)
City of Lott WWTF (WQ0010017-001)	Bone Branch to Deer Creek (1242J)	0.080	0.0410	126[1]	34.6	**4** (2 DO monthly min., 1 BOD daily avg., 1 pH max., 1 Flow daily avg.)

[1] MPN/100 mL *E. coli*

[2] Data not available

million gallons per day, MGD; most probably number, MPN; dissolved oxygen, DO; biological oxygen demand, BOD; total suspended solids, TSS

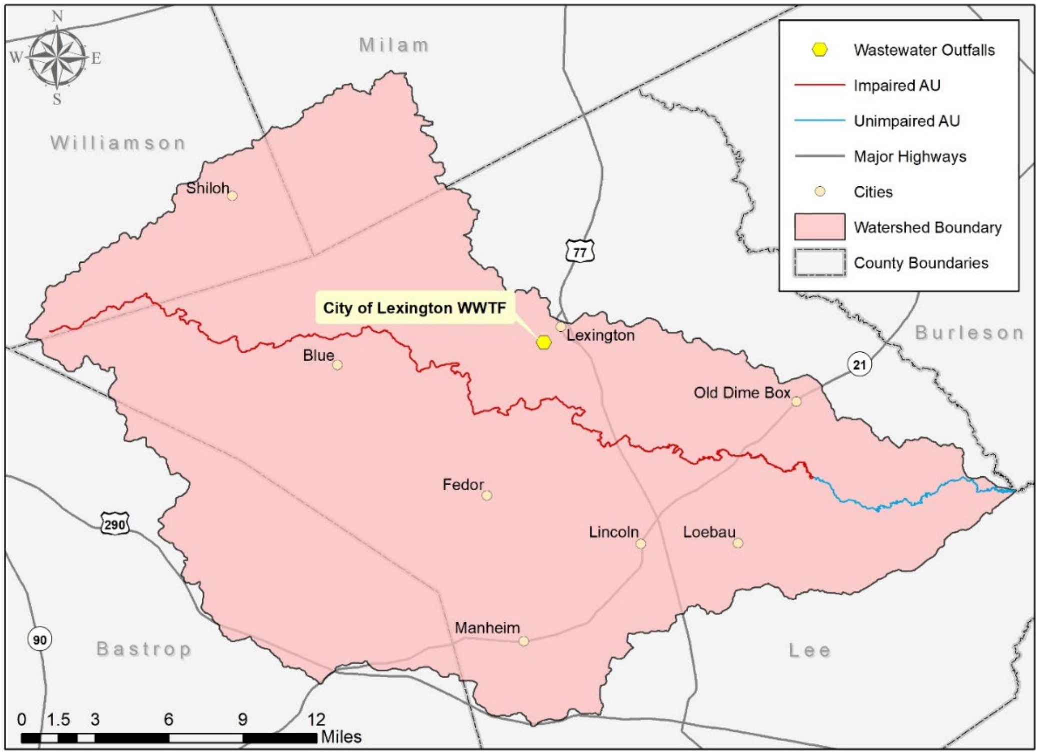

Figure 51. Active permitted wastewater discharge outfall locations for the Middle Yegua Creek watershed.

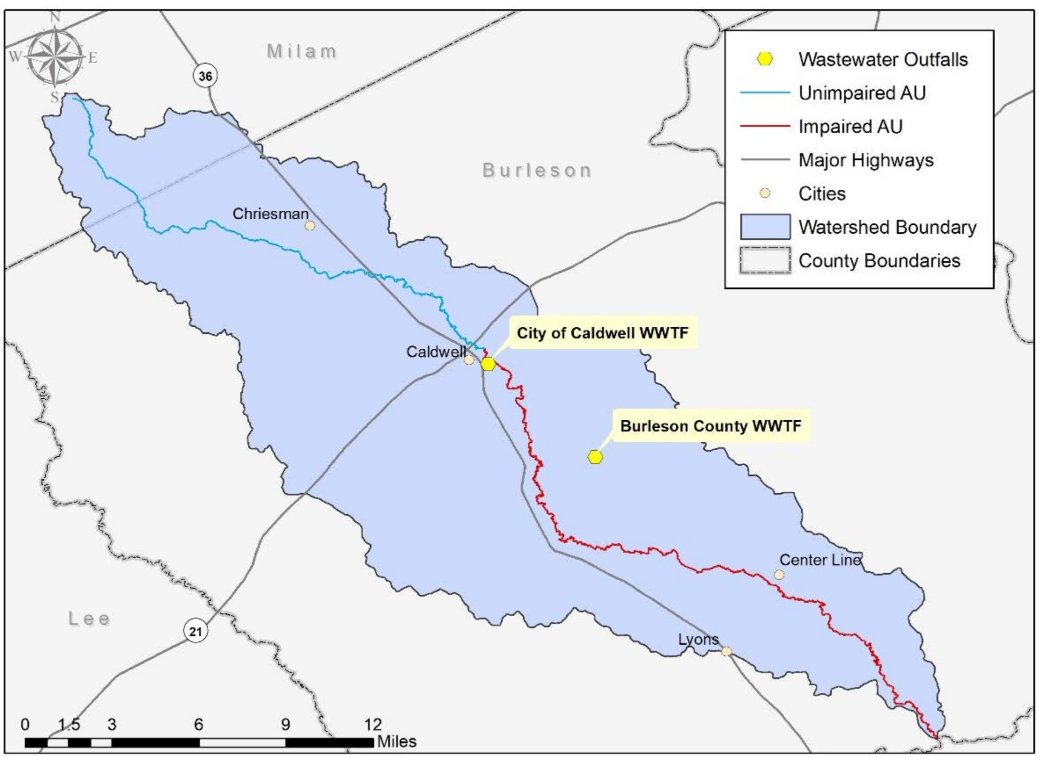

Figure 52. Active permitted wastewater discharge outfall locations for the Davidson Creek watershed.

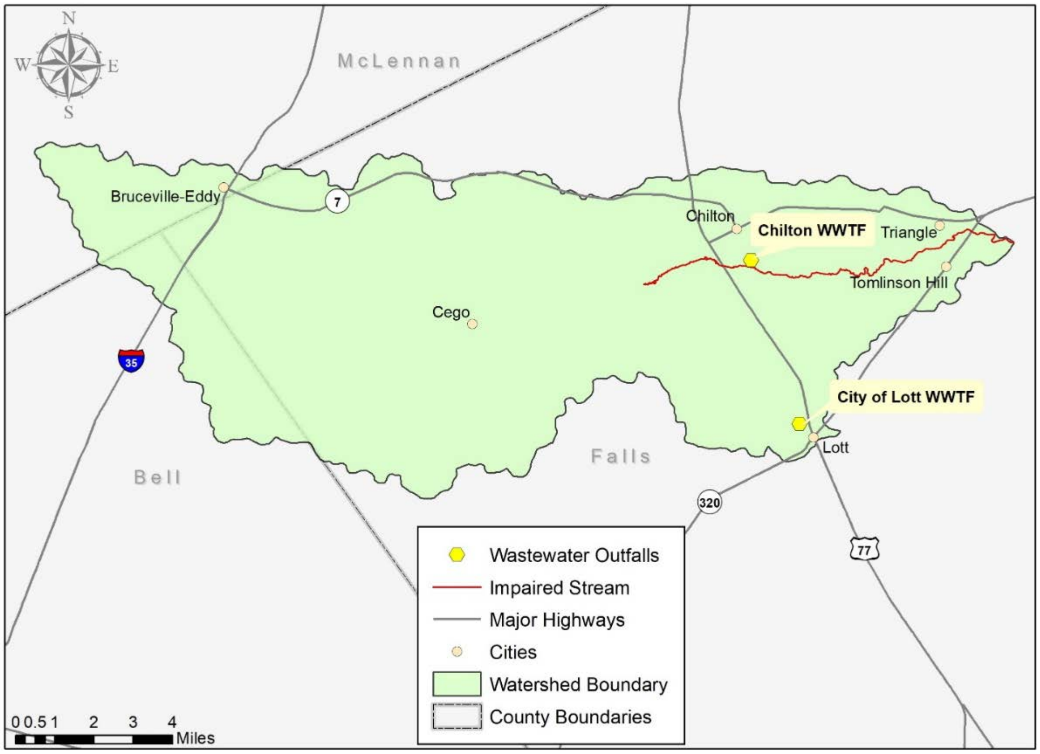

Figure 53. Active permitted wastewater discharge outfall locations for the Deer Creek watershed.

Although stormwater is generally considered a nonpoint source, stormwater is subject to regulation if it originates from a regulated MS4 or is associated with industrial and/or construction activities. MS4 permits refer to the permitting of municipal stormwater systems that are separate from sanitary sewer systems. Systems are broken down into "large" Phase I and "small" Phase II permits based on population. Further details on MS4 permitting requirements are available from TCEQ: https://www.tceq.texas.gov/permitting/stormwater/ms4. TPDES General Permits cover stormwater discharges from Phase II urbanized areas, industrial facilities and construction sites over one acre. These urban and industrial stormwater sources may contain elevated levels of bacteria or nutrients as they wash accumulated materials from roads, parking lots, buildings, parks, and other developed areas. Potential pollutants can be managed from these sites through stormwater best management practices, including structures such as detention ponds, riparian buffers, pervious pavement and low impact design.

A review of active stormwater general permits coverage in the Middle Yegua Creek watershed, as of February 2020, found two active industrial facilities, three active construction sites and one active concrete production facility. A review of the active stormwater general permits coverage in the Davidson Creek watershed, as of February 2020, found six active industrial facilities, one active construction site and one active concrete production facility. A review of the active stormwater general permits coverage in the Deer Creek watershed, as of February 2020, found only two active construction sites. There are no MS4s or petroleum bulk stations and terminals facilities in any of the watersheds. Based on the 2016 NLCD, only 17 square miles out of the 440-square-mile Middle

Yegua Creek watershed, 12 square miles out of the 218-square-mile Davidson Creek watershed, and 6 square miles out of the 115-square-mile Deer Creek watershed are urbanized or developed. Therefore, contributions to surface water impairments from regulated stormwater and urbanized development are assumed to be small based on the relatively low amount of stormwater permits and developed land.

Unauthorized Discharges

SSOs are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris. Inflow and infiltration (I&I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition. The TCEQ Region 9 and 11 Offices maintain a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity and a general location of the spill. The reports of SSO events that occurred within the watersheds of Middle Yegua Creek, Davidson Creek and Deer Creek between January 2015 and December 2019 are shown in Table 19. Two separate incidences were reported for two different facilities. The reported data indicate that the SSOs occurred year-round and that both durations were unknown. Overflow volumes for both incidences were one gallon.

Table 19. SSO events since 2015 for the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds.

Facility	Date	Gallons	Cause
City of Caldwell WWTF	03/09/2015	1	Unknown
City of Lexington WWTF	05/15/2015	1	I&I

wastewater treatment facility, WWTF; inflow and infiltration (I&I)

Water Quality Summary

The Middle Yegua Creek, Davidson Creek and Deer Creek watersheds are predominantly rural, characterized by vital agricultural communities. Therefore, significant portions of the watersheds have been utilized for cropland, pasture or grazing. The populations of the watersheds are projected to increase by small proportions over the next 50 years.

The primary water quality concern is bacteria impairments in the watersheds. Potential contributors to the bacteria impairments likely include some combination of (1) managed livestock/cattle; (2) unmanaged wildlife/feral hogs; (3) failing OSSFs; (4) stormwater runoff from urban areas and impervious surfaces (including contributions from household pets); and (5) permitted discharges and SSOs (Table 20).

Table 20. Summary of potential bacteria sources contributing to the impairments in the watersheds.

Pollutant Source	Pollutant Type	Potential Cause	Potential Impact
Livestock	Bacteria	- Runoff from pastures - Overgrazing - Manure transport to streams - Direct deposition into streams	Fecal material and bacteria directly deposited into stream or through runoff
Wildlife	Bacteria	- Manure transport to streams - Direct deposition into streams - Riparian degradation	Fecal material and bacteria directly deposited into stream or through runoff
OSSFs	Bacteria	- System failure - Improper design	Insufficiently or untreated water runoff to streams
Urban stormwater and domestic pets	Bacteria	- Increased runoff from impervious surface - Improper disposal of pet waste	Increased velocity and volume of stormwater quickly transport bacteria laden water to streams
Permitted dischargers/SSOs	Bacteria	-Inflow and infiltration Overloaded or aging infrastructure	Untreated waste enters water body

on-site sewage facilities, OSSFs; sanitary sewer overflows, SSOs

Pollutant Source Assessment

Introduction

Water quality sampling, described in the previous section, established that the primary water quality concern in the Middle Yegua Creek, Davidson Creek and Deer Creek watersheds is excessive fecal indicator bacteria. The current water quality standard established by TCEQ for primary contact recreation is 126 MPN/100mL for *E. coli*. The 2014 Texas Integrated Report (TCEQ 2015a) lists Davidson Creek as impaired with a geometric mean of 2,212 MPN/100 mL *E. coli*. The 2016 Texas Integrated Report (TCEQ 2019a) lists Middle Yegua Creek as impaired with a geometric mean of 749 MPN/100 mL *E. coli* and Deer Creek as impaired with a geometric mean of 459 MPN/100 mL *E. coli*. The 2016 Texas Integrated Report did not have an *E. coli* geometric mean listed for Davidson Creek, but it is still on the 303(d) list.

In order to calculate the reductions needed to meet primary contact recreation standards, the bacteria load capacity of Middle Yegua Creek, Davidson Creek and Deer Creek were calculated. The current bacterial load for all three creeks were also calculated using water quality samples and the load duration curve (LDC) method. By taking the difference between the load capacity and the current load, this characterization estimates the needed reductions to meet water quality standards.

Furthermore, this section estimates the relative load contributions from different potential fecal bacteria sources. A Geographic Information Systems (GIS) analysis, which includes the best available data, provided relative load contribution estimates. By estimating the relative potential contribution of different fecal bacteria sources across the watersheds, areas can be prioritized as to when and where future potential management measures should occur.

Source and Load Determination

Load Duration Curves

LDCs are a widely accepted methodology used to characterize water quality data across different flow conditions in a watershed. An LDC provides a visual display of streamflow, load capacity and water quality exceedance. An LDC is first developed by constructing a flow duration curve (FDC) using historical streamflow data. The historical flow measurements used to develop the FDCs for Middle Yegua Creek and Davidson Creek came from daily streamflow records at USGS gages within the watersheds. The gage used for the Middle Yegua Creek FDC was USGS stream gage 08109700 and the gage used for the Davidson Creek watershed was USGS stream gage 08110100. As previously mentioned, there was no USGS stream gage in the Deer Creek watershed. An alternative method to developing the FDC for this watershed is explained further in this section.

An FDC is a summary of the hydrology of the stream, indicating the percentage of time that a given flow is exceeded. An FDC is constructed by ranking flow measurements from highest to lowest and determining the frequency of different flow measurements at the sampling location. Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100% occur during low flow or drought conditions while values approaching 0% occur during periods of high flow or flood conditions.

The red lines on the following LDCs are the allowable load at the water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL). These lines were created by multiplying the stream flow for each gage in cfs by the geometric mean of 126 MPN/100 mL for *E. coli* and by a conversion factor (2.44658×10^{7}), which gives you a loading unit of MPN/day. The grey lines (allowable load at single sample criterion) were developed similar to the red lines, except instead of multiplying streamflow by 126 MPN/100 mL, the streamflow was multiplied by 399 MPN/100 mL. The exceedance percentages, which are identical to the value for streamflow data points, were then plotted against the geometric mean criterion for *E. coli*. The resulting curves plot each bacteria load value (y-axis) against its exceedance value (x-axis). Exceedance values along the x-axis represent the percent of days that the bacteria load was at or above the allowable load on the y-axis.

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

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of the FDC and LDC. For this characterization, three flow regimes were identified. These three intervals along the x-axis of the LDCs are: (1) 0%-25% (high flows); (2) 25%-75% (mid-range conditions); and (3) 75%-100% (lowest flows).

In total, four LDCs were produced for the three watersheds. For Middle Yegua Creek, one LDC included SWQM stations 18750 and 11840 (Figure 54). This LDC indicates the *E. coli* loadings exceed allowable loads across all flow conditions except Low Flows. A second LDC was created for SWQM station 11838 in Middle Yegua Creek because it is located in a different AU (Figure 55). Although this AU is not currently impaired, a number of samples taken exceed the 126 MPN/100 mL criterion. The LDC also indicates that exceedances are occurring generally near or below the loading criteria at all flow conditions. It is important to note that with only 14 data points, this LDC does not technically reach the threshold of data quantity to be considered valid. The third LDC was developed for Davidson Creek SWQM stations 11729, 18349 and 21420 (Figure 56). The Davidson Creek LDC indicates loads exceeding capacity under all flow conditions with nearly equal exceedances occurring at higher and lower flow conditions. While elevated loadings under high flows are indicative of nonpoint sources (NPS) of indicator bacteria due to presumed greater amounts of runoff, exceedances during lower flow conditions are generally more indicative of point sources or direct fecal deposition to streams from wildlife or domestic livestock.

The final LDC was created for Deer Creek SWQM stations 11723 and 18644 (Figure 57). With no USGS stream gages in the Deer Creek watershed, the previously mentioned DAR method (Asquith et al. 2006) was used to create a simulated naturalized streamflow for the watershed over a 10-year period. This method is used to equate the ratio of streamflow of an unknown stream location to that of a nearby drainage area with sufficient data. This method was reviewed jointly by the USGS and TCEQ using 7.8 million values of daily streamflow data from 712 USGS streamflow gages in Texas and was found to be a sufficient method in interpolating streamflow measurements. Further information regarding the DAR method used to develop the LDC for the Deer Creek watershed is in Appendix A.

For the Deer Creek DAR, USGS gage 08095300 on the Middle Bosque River was chosen. The Middle Bosque River watershed was ideal, as it is near the Deer Creek watershed, and is comparable in size, land use and land cover. The dataset for the Middle Bosque River included ten years' worth of daily streamflow records, dating back to January 2009. Most of the elevated loadings occurred during higher flow conditions while lower flow conditions loadings were typically below the exceedance line. This is indicative of loadings associated with NPS pollution or from bacteria present within stream sediments that are resuspended under increased flow.

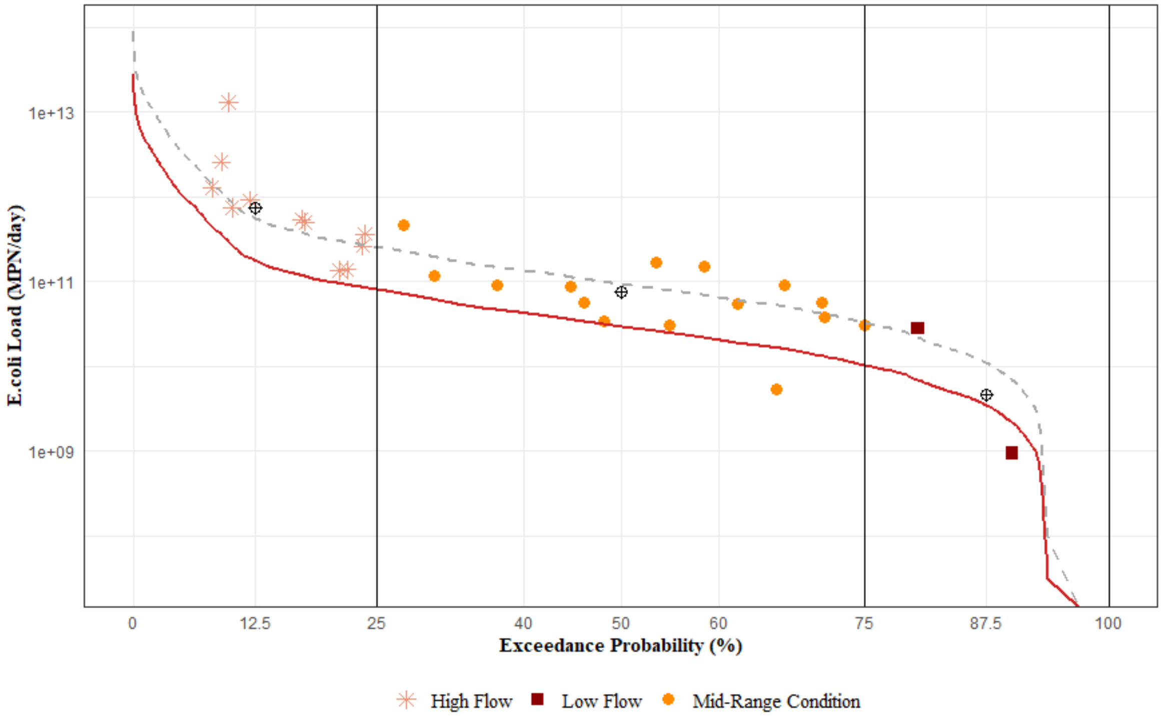

Figure 54. Load duration curve for Middle Yegua Creek Surface Water Quality Monitoring stations 18750 and 11840. The solid red line indicates the allowable load at geomean criterion (126 most probable number (MPN)/100 milliliter (mL)) and the gray dashed line is allowable load at single sample criterion (399 MPN/100mL). The black circles indicate the existing geomean load in each flow regime (MPN/day).

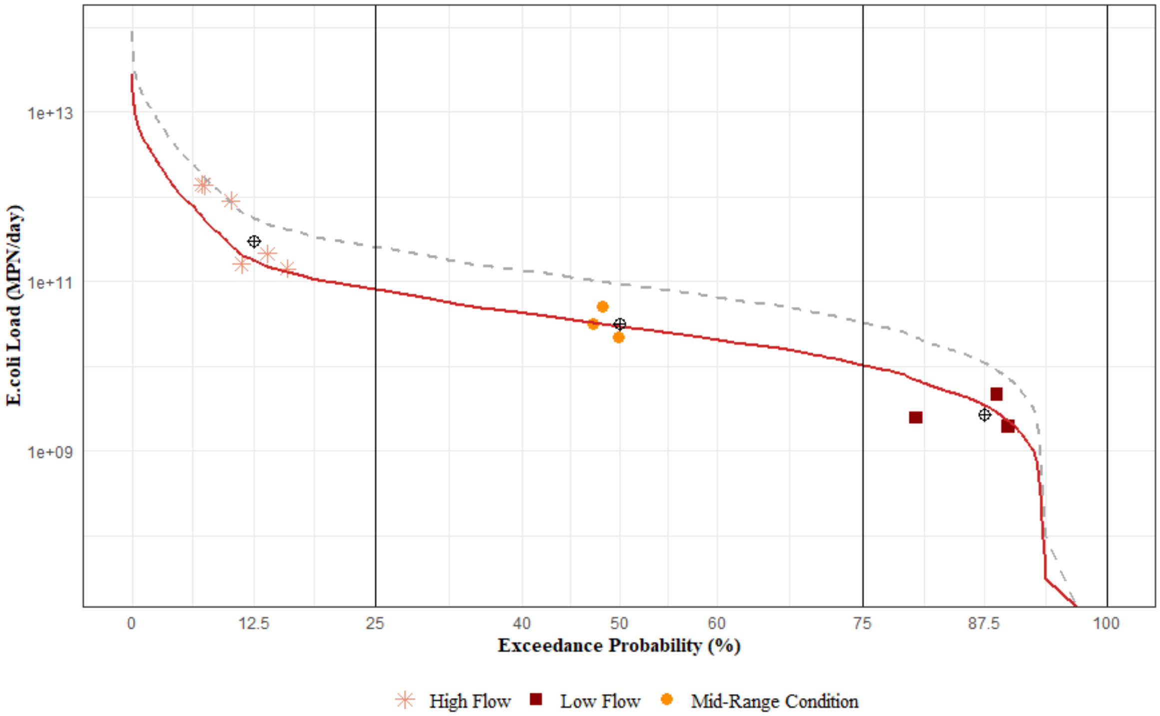

Figure 55. Load duration curve for Middle Yegua Creek Surface Water Quality Monitoring station 11838. The solid red line indicates the allowable load at geomean criterion (126 most probable number (MPN)/100 milliliter (mL)) and the gray dashed line is allowable load at single sample criterion (399 MPN/100mL). The black circles indicate the existing geomean load in each flow regime (MPN/day).

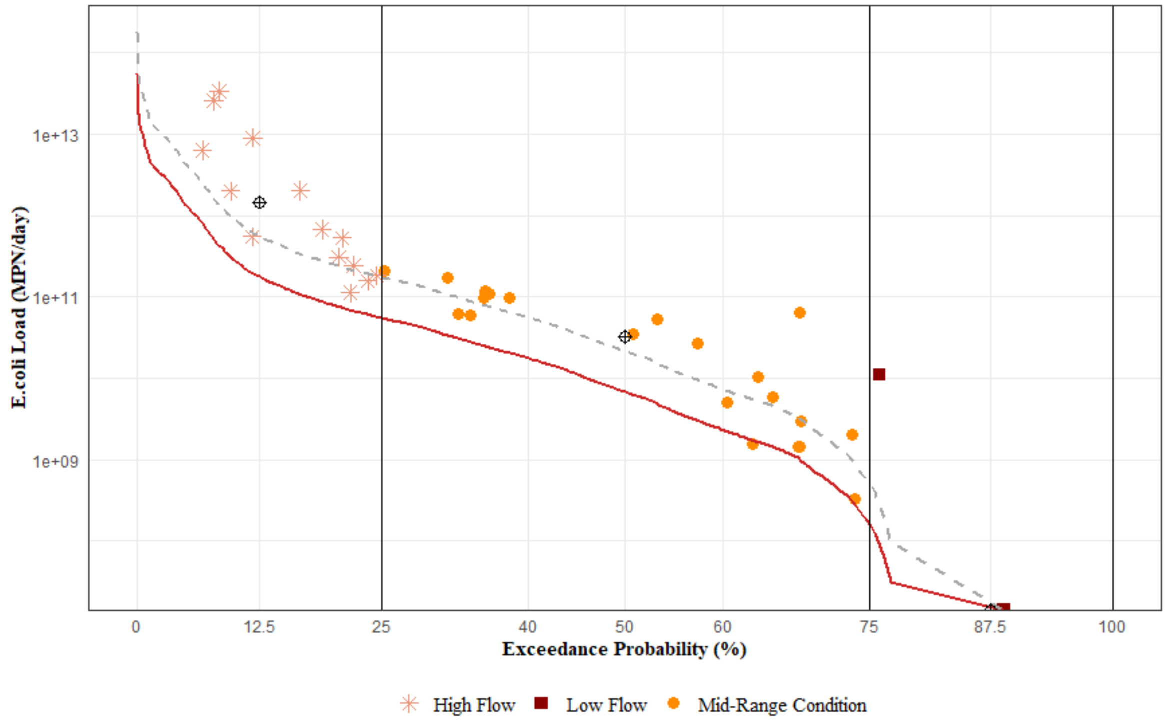

Figure 56. Load duration curve for Davidson Creek Surface Water Quality Monitoring stations 11729, 18349 and 21420. The solid red line indicates the allowable load at geomean criterion (126 most probable number (MPN)/100 milliliter (mL)) and the gray dashed line is allowable load at single sample criterion (399 MPN/100mL). The black circles indicate the existing geomean load in each flow regime (MPN/day).

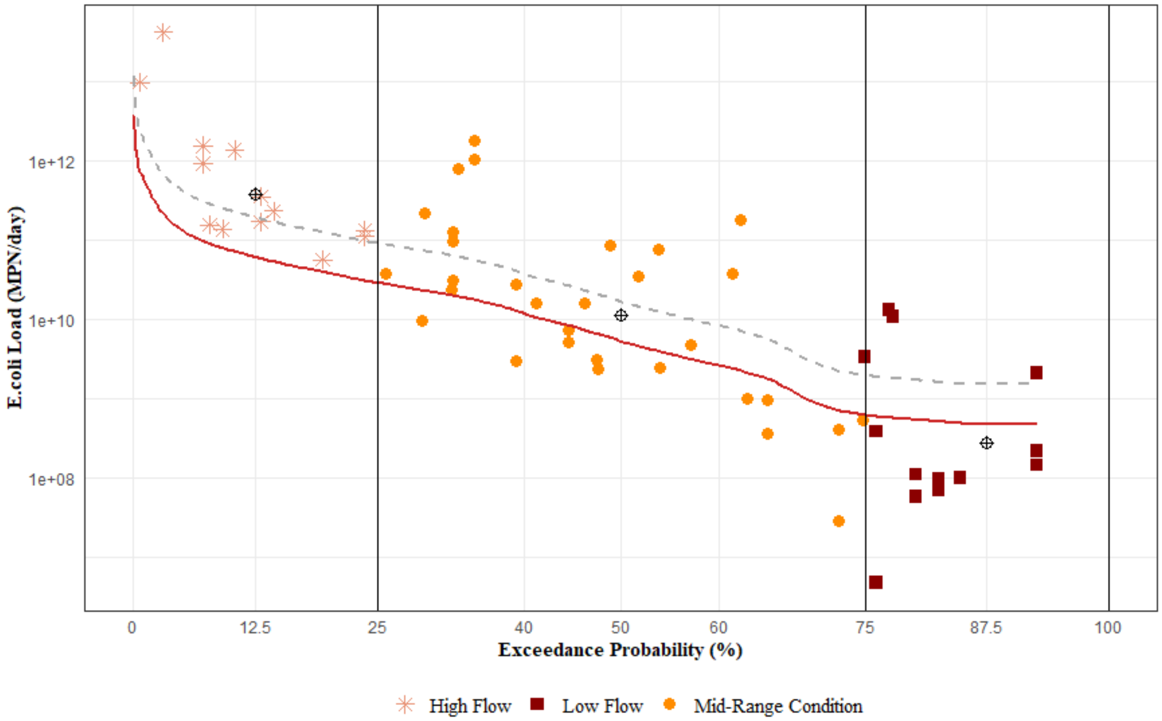

Figure 57. Load duration curve for Deer Creek Surface Water Quality Monitoring stations 11723 and 18644. The solid red line indicates the allowable load at geomean criterion (126 most probable number (MPN)/100 milliliter (mL)) and the gray dashed line is allowable load at single sample criterion (399 MPN/100mL). The black circles indicate the existing geomean load in each flow regime (MPN/day).

Based on the LDCs developed for Middle Yegua Creek, a total reduction of 5.90×10^{13} MPN/year (yr) is required at SWQM stations 18750 and 11840 (Table 21) as well as a total reduction 1.15×10^{13} MPN/yr at SWQM station 11838 (Table 22) to reach primary contact recreation standards. Appendix B details the calculations used to develop the annual load reduction estimates.

A total reduction of 1.22×10^{14} MPN/yr is required at the Davidson Creek SWQM stations 11729, 18349, and 21420 (Table 23). The largest reduction is needed during higher flows where NPSs of bacteria are a primary concern.

For Deer Creek SWQM stations 11723 and 18644, a total reduction of 3.06×10^{13} MPN/yr is required (Table 24). Similar to Middle Yegua Creek and Davidson Creek, the largest reduction is needed during the higher flows.

Table 21. Bacteria load reductions required to meet water quality goals in Middle Yegua Creek for Surface Water Quality Monitoring stations 18750 and 11840.

	Flow Conditions		
	High	**Mid-Range**	**Low**
Days per year	91.25	182.5	91.25
Median Flow (cubic feet per second)	56.4	9.45	1.1
Existing Geomean Concentration (MPN/100 mL)	528	322	170
Allowable Daily Load (Billion MPN)	173.88	29.13	3.39
Allowable Annual Load (Billion MPN)	15,866.81	5,317.07	309.46
Existing Daily Load (Billion MPN)	728.67	74.47	4.58
Existing Annual Load (Billion MPN)	66,491.31	13,591.33	417.90
Annual Load Reduction Needed (Billion MPN)	50,624.51	8,274.26	108.44
Percent Reduction Needed	76.14%	60.88%	25.95%
Total Annual Load (Billion MPN)	80,500.54		
Total Annual Load Reduction (Billion MPN)	59,007.20		
Total Percent Reduction	73.30%		

most probable number, MPN

Table 22. Bacteria load reductions required to meet water quality goals in Middle Yegua Creek for Surface Water Quality Monitoring station 11838.

	Flow Conditions		
	High	Mid-Range	Low
Days per year	91.25	182.5	91.25
Median Flow (cubic feet per second)	56.4	9.45	1.1
Existing Geomean Concentration (MPN/100 mL)	214	135	100
Allowable Daily Load (Billion MPN)	173.88	29.13	3.39
Allowable Annual Load (Billion MPN)	15,866.81	5,317.07	309.46
Existing Daily Load (Billion MPN)	295.87	31.16	2.69
Existing Annual Load (Billion MPN)	26,998.44	5,687.29	245.70
Annual Load Reduction Needed (Billion MPN)	11,131.63	370.22	0
Percent Reduction Needed	41.23%	6.51%	0%
Total Annual Load (Billion MPN)	32,931.43		
Total Annual Load Reduction (Billion MPN)	11,501.86		
Total Percent Reduction	34.93%		

most probable number, MPN

Table 23. Bacteria load reductions required to meet water quality goals in Davidson Creek for Surface Water Quality Monitoring stations 11729, 18349 and 21420.

	Flow Conditions		
	High	Mid-Range	Low
Days per year	91.25	182.5	91.25
Median Flow (cubic feet per second)	57.7	2.19	0
Existing Geomean Concentration (MPN/100 mL)	1,034	599	498
Allowable Daily Load (Billion MPN)	177.89	6.75	0
Allowable Annual Load (Billion MPN)	16,232.53	1,232.21	0
Existing Daily Load (Billion MPN)	1,459.91	32.12	0
Existing Annual Load (Billion MPN)	133,216.34	5,862.77	0
Annual Load Reduction Needed (Billion MPN)	116,983.81	4,630.56	0
Percent Reduction Needed	87.81%	78.98%	0%
Total Annual Load (Billion MPN)	139,079.11		
Total Annual Load Reduction (Billion MPN)	121,614.37		
Total Percent Reduction	87.44%		

most probable number, MPN

Table 24. Bacteria load reductions required to meet water quality goals in Deer Creek for Surface Water Quality Monitoring stations 11723 and 18644.

	Flow Conditions		
	High	Mid-Range	Low
Days per year	91.25	182.5	91.25
Median Flow (cubic feet per second)	19.53	1.68	0.16
Existing Geomean Concentration (MPN/100 mL)	801	276	73
Allowable Daily Load (Billion MPN)	60.21	5.18	0.48
Allowable Annual Load (Billion MPN)	5,494.30	945.26	43.89
Existing Daily Load (Billion MPN)	382.70	11.36	0.28
Existing Annual Load (Billion MPN)	34,921.66	2,073.47	25.44
Annual Load Reduction Needed (Billion MPN)	29,427.36	1,128.21	0
Percent Reduction Needed	84.27%	54.41%	0%
Total Annual Load (Billion MPN)	37,020.57		
Total Annual Load Reduction (Billion MPN)	30,555.57		
Total Percent Reduction	82.54%		

most probable number, MPN

Pollutant Source Load Estimates

GIS Analysis

To aid in identifying potential areas of *E. coli* contributions within the watersheds, a GIS analysis was applied using the methodology employed by the Spatially Explicit Load Enrichment Calculation Tool (SELECT) (Borel et al. 2012). The best available information was used to identify likely NPSs of bacteria and calculate potential loadings.

Using this GIS 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, if at all. As such, these analyses represent worst case scenarios that do not represent the actual *E. coli* loadings expected to enter the creeks. Potential loads for identified sources are summarized for each of the subwatersheds (Figure 58, Figure 59, Figure 60) found in all three watersheds.

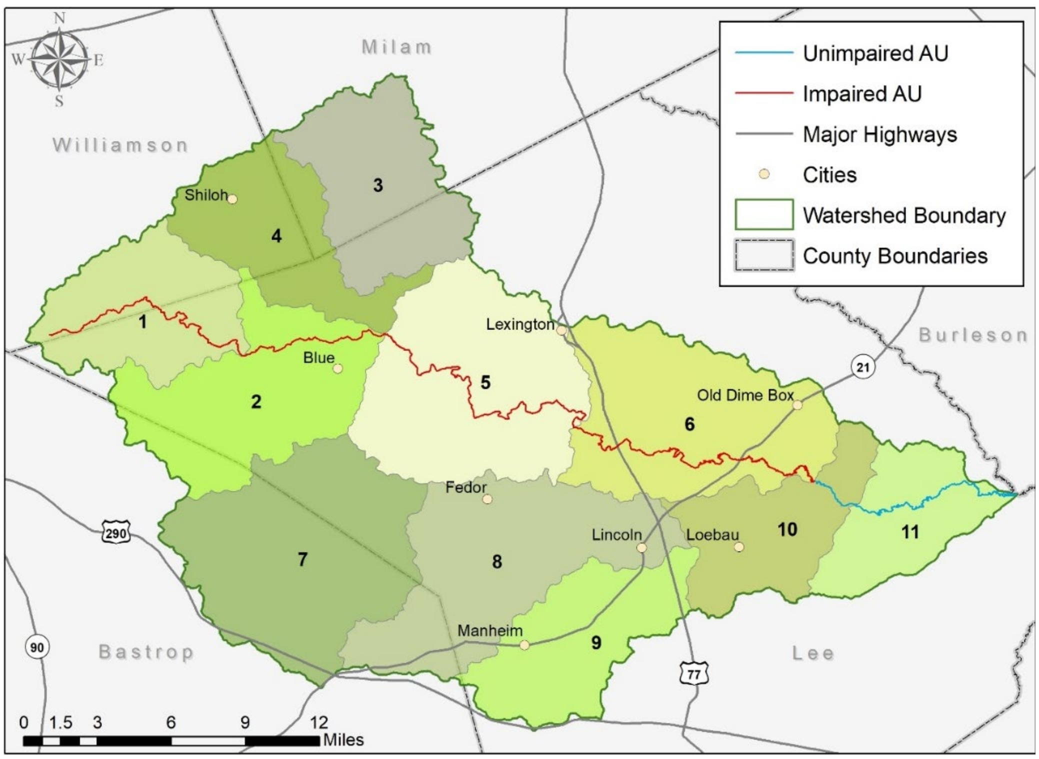

Figure 58. Middle Yegua Creek subwatersheds.

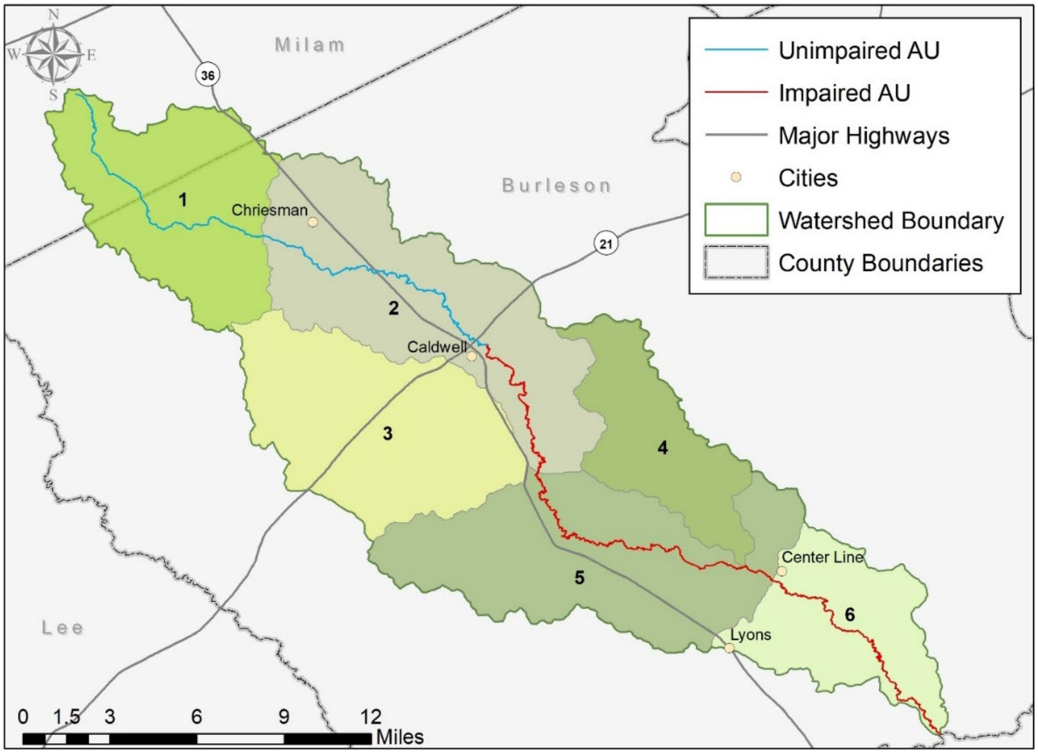

Figure 59. Davidson Creek subwatersheds.

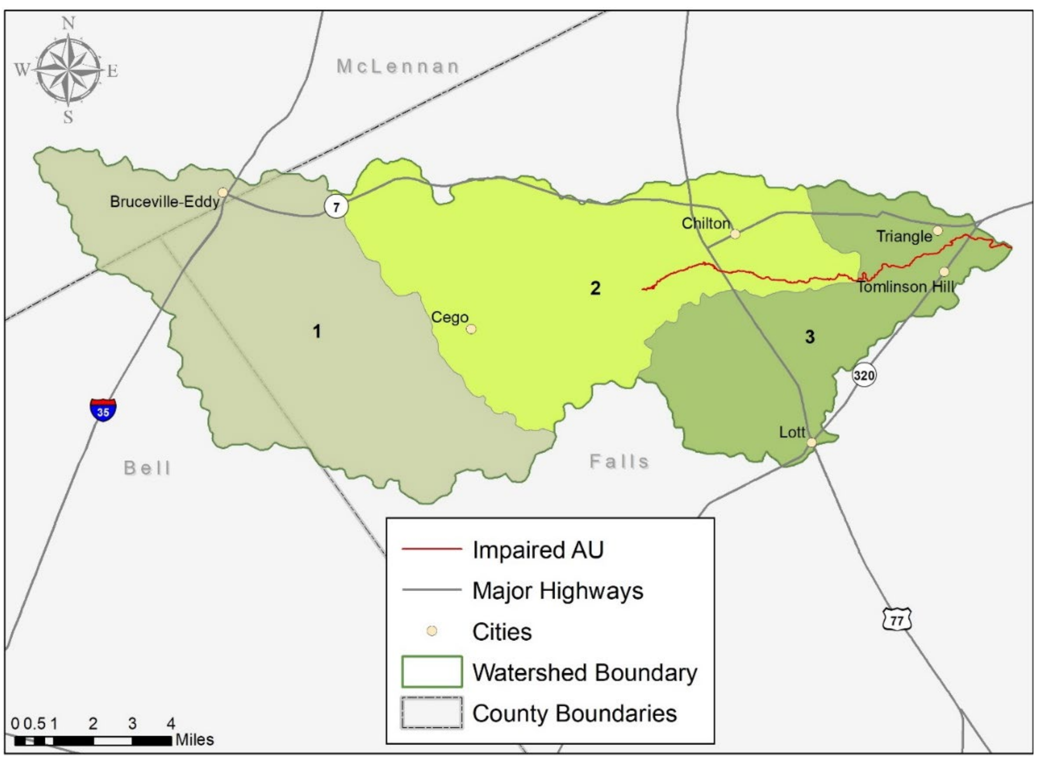

Figure 60. Deer Creek subwatersheds.

Livestock: Cattle

Cattle can contribute to *E. coli* bacteria loading in two ways. First, they can contribute through the direct deposition of fecal matter into streams while wading. Second, runoff from pasture and rangeland can contain elevated levels of *E. coli*, which in turn can increase bacteria loads in the stream. Improved grazing practices and land stewardship can dramatically reduce runoff and bacteria loadings. For example, recent research in Texas watersheds 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 significantly reduce the amount of time cattle spend in and near streams, thus resulting in improved water quality (Wagner et al. 2013; Clary et al. 2016).

Based on the best available data, it was estimated that there are approximately 54,389 cattle animal units across the entire Middle Yegua Creek watershed. Appendix C describes the assumptions and equations used to estimate potential bacteria loading in all three watersheds. GIS analysis indicated the highest potential annual loading for Middle Yegua Creek occur in subwatersheds 9 and 10 (Figure 61). Across the watershed, the estimated potential annual load due to cattle is 1.07×10^{17} colony forming units (cfu) per year.

For the Davidson Creek watershed, it was estimated that there are approximately 27,103 cattle animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 62). Across the watershed, the estimated potential annual load due to cattle is 5.33×10^{16} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 6,911 cattle animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 63). Across the watershed, the estimated potential annual load due to cattle is 1.36×10^{16} cfu/yr.

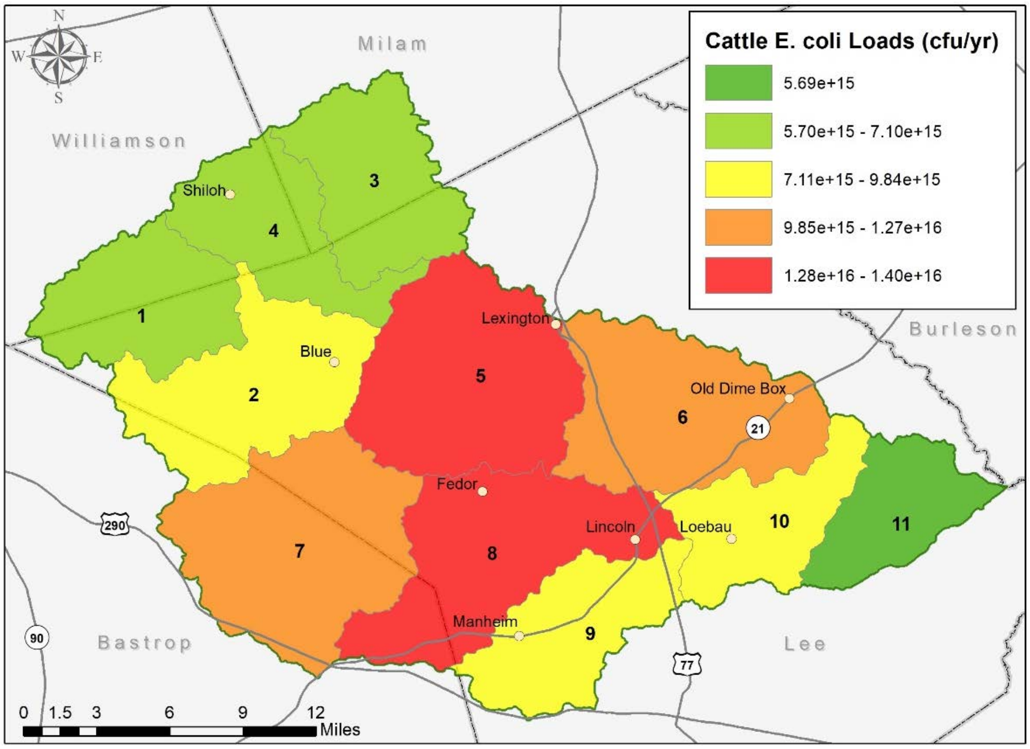

Figure 61. Potential annual bacteria loadings from cattle in the Middle Yegua Creek watershed. colony forming unit, cfu

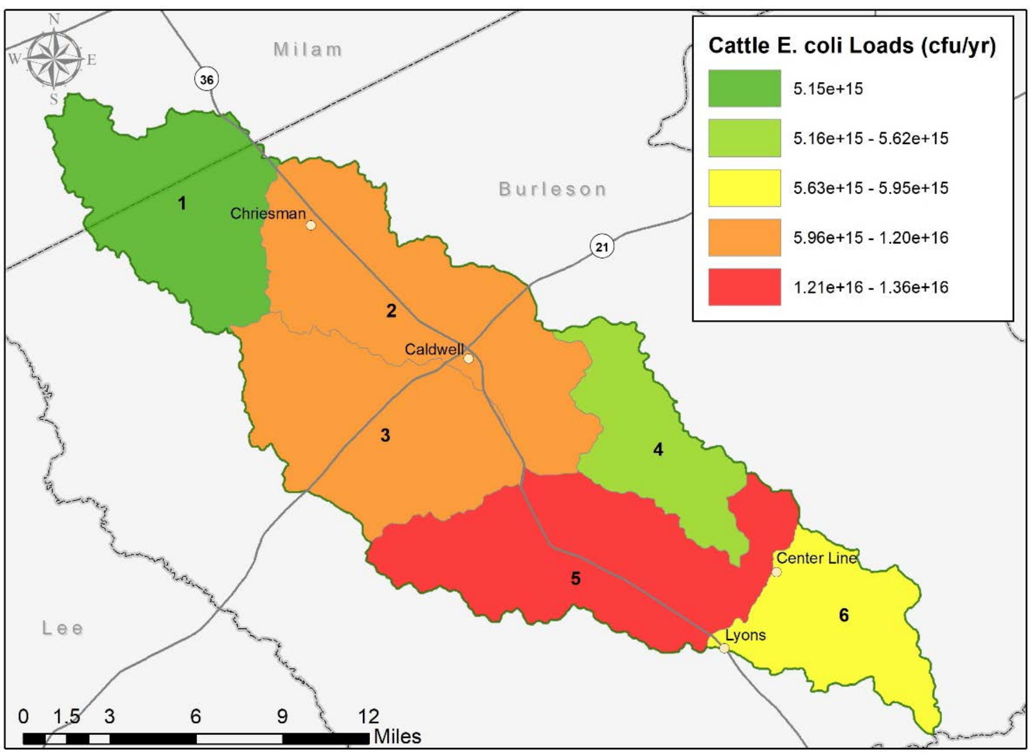

Figure 62. Potential annual bacteria loadings from cattle in the Davidson Creek watershed. colony forming unit, cfu

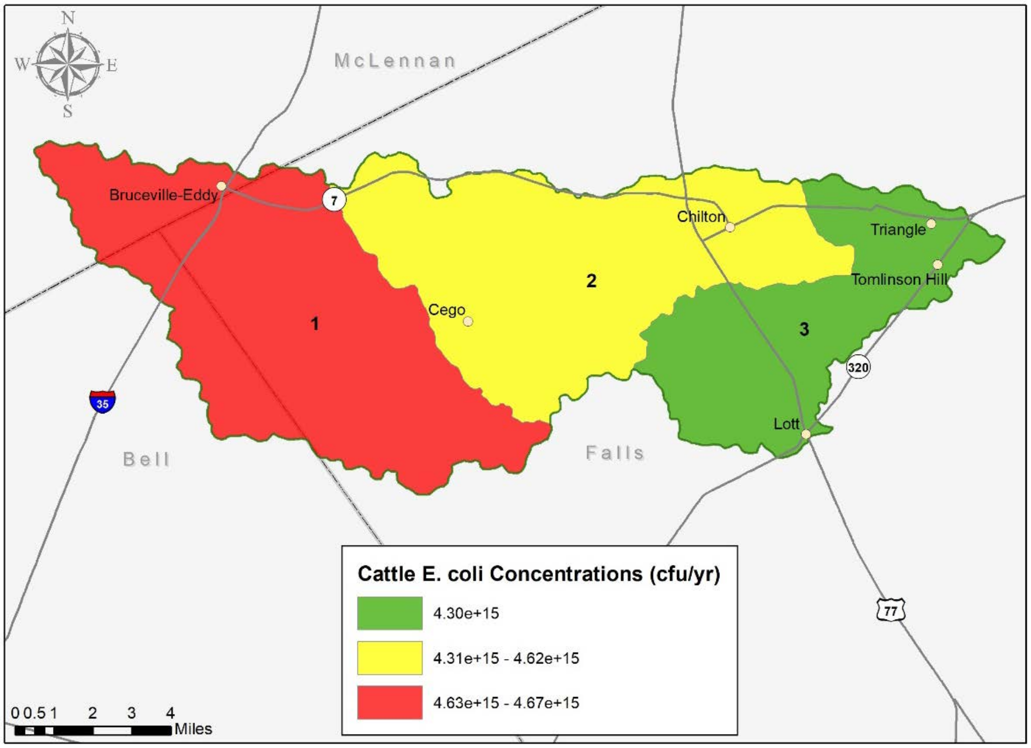

Figure 63. Potential annual bacteria loadings from cattle in the Deer Creek watershed. colony forming unit, cfu

Livestock: Horses

A total of 1,149 animal units of horses in the Middle Yegua Creek watershed were evenly distributed over shrub/scrub, grassland/herbaceous and pasture/hay. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 5, 6, 7 and 8 (Figure 64). Across the watershed, the estimated potential annual load due to horses is 9.61×10^{13} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 456 horse animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 65). Across the watershed, the estimated potential annual load due to horses is 3.81×10^{13} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 247 horse animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 66). Across the watershed, the estimated potential annual load due to horses is 2.07×10^{13} cfu/yr.

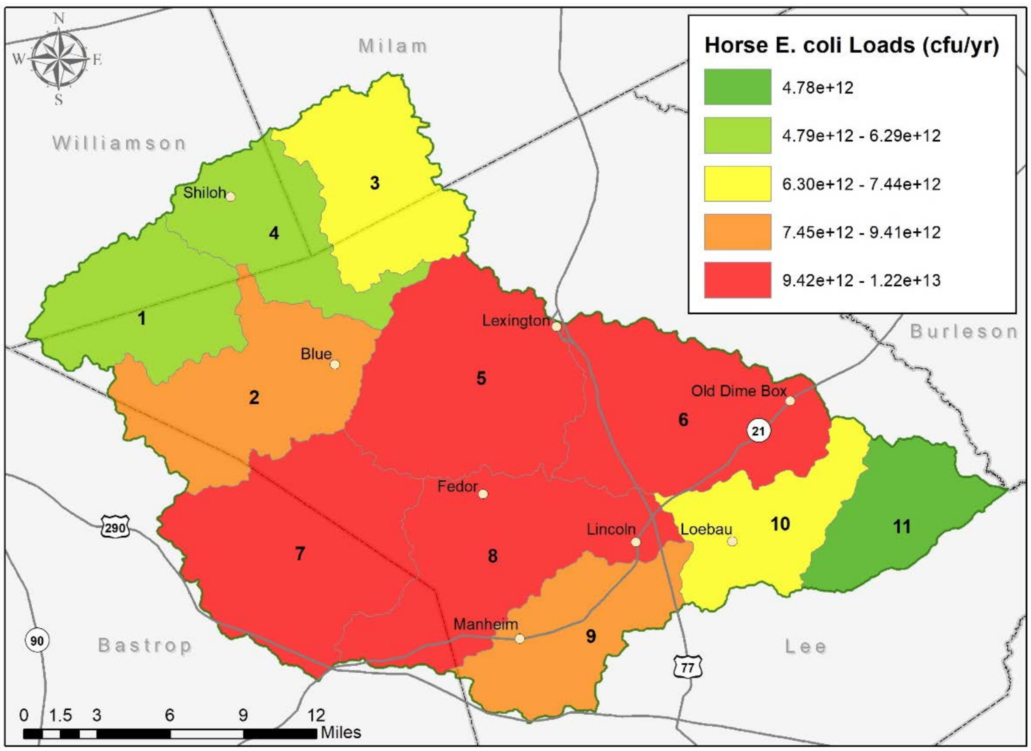

Figure 64. Potential annual bacteria loadings from horses in the Middle Yegua Creek watershed. colony forming unit, cfu

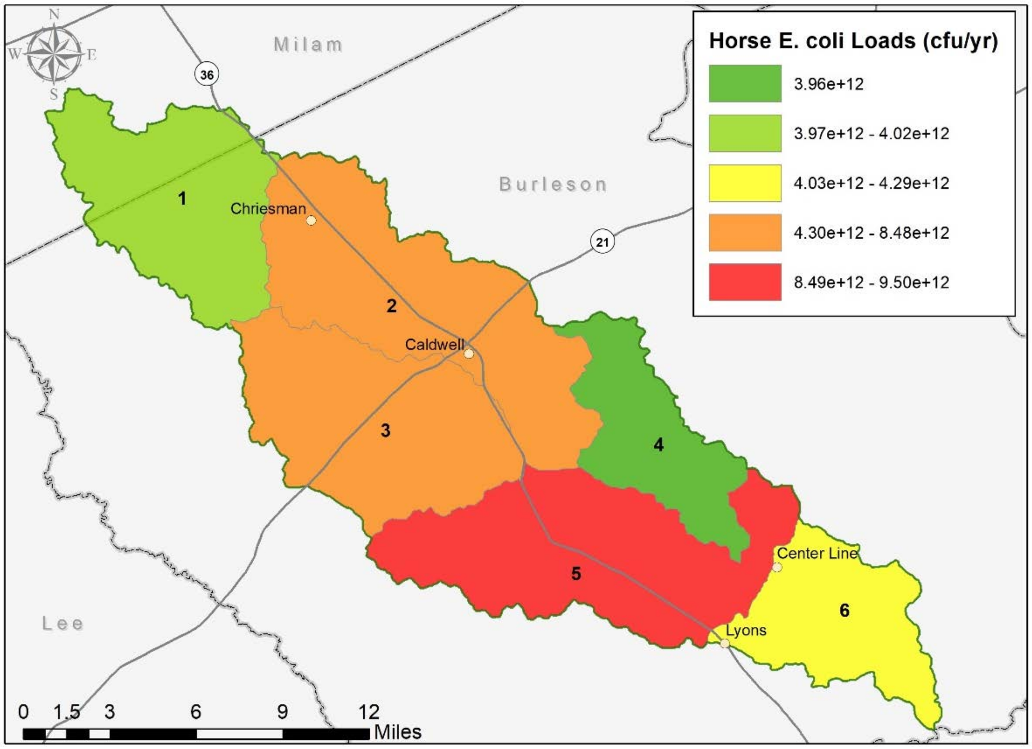

Figure 65. Potential annual bacteria loadings from horses in the Davidson Creek watershed. colony forming unit, cfu

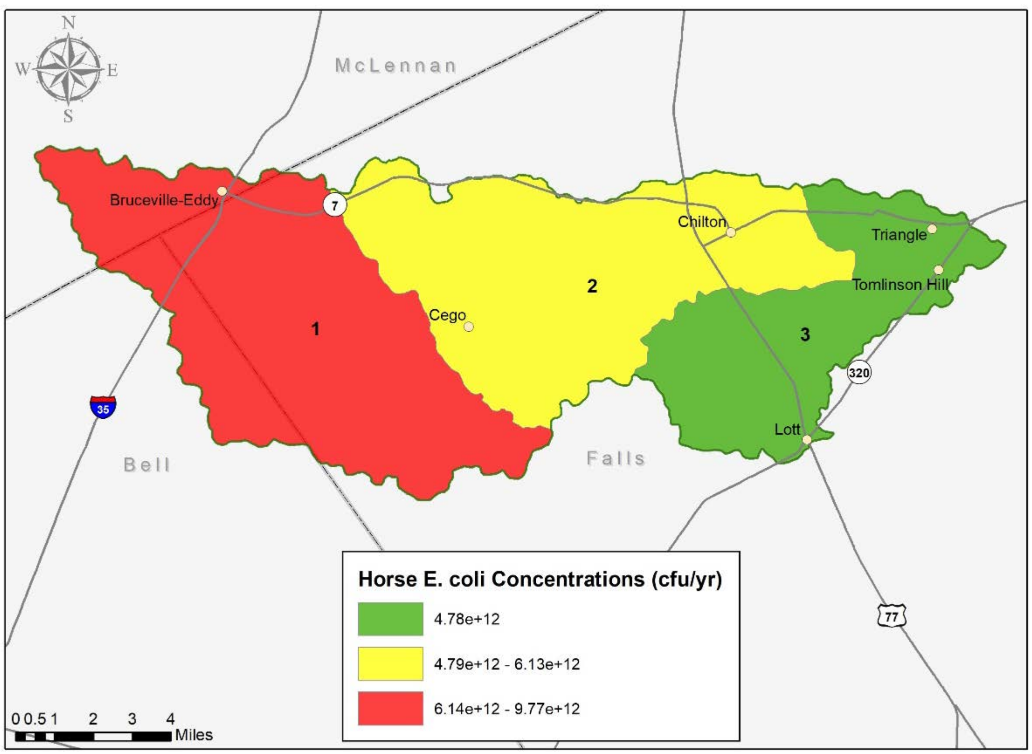

Figure 66. Potential annual bacteria loadings from horses in the Deer Creek watershed. colony forming unit, cfu

Livestock: Goats

A total of 1,268 animal units of goats in the Middle Yegua Creek watershed were evenly distributed over shrub/scrub, grassland/herbaceous and pasture/hay. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 5, 6, 7 and 8 (Figure 67). Across the watershed, the estimated potential annual load due to goats is 1.26×10^{15} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 419 goat animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 68). Across the watershed, the estimated potential annual load due to goats is 4.17×10^{14} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 305 goat animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 69). Across the watershed, the estimated potential annual load due to goats is 3.03×10^{14} cfu/yr.

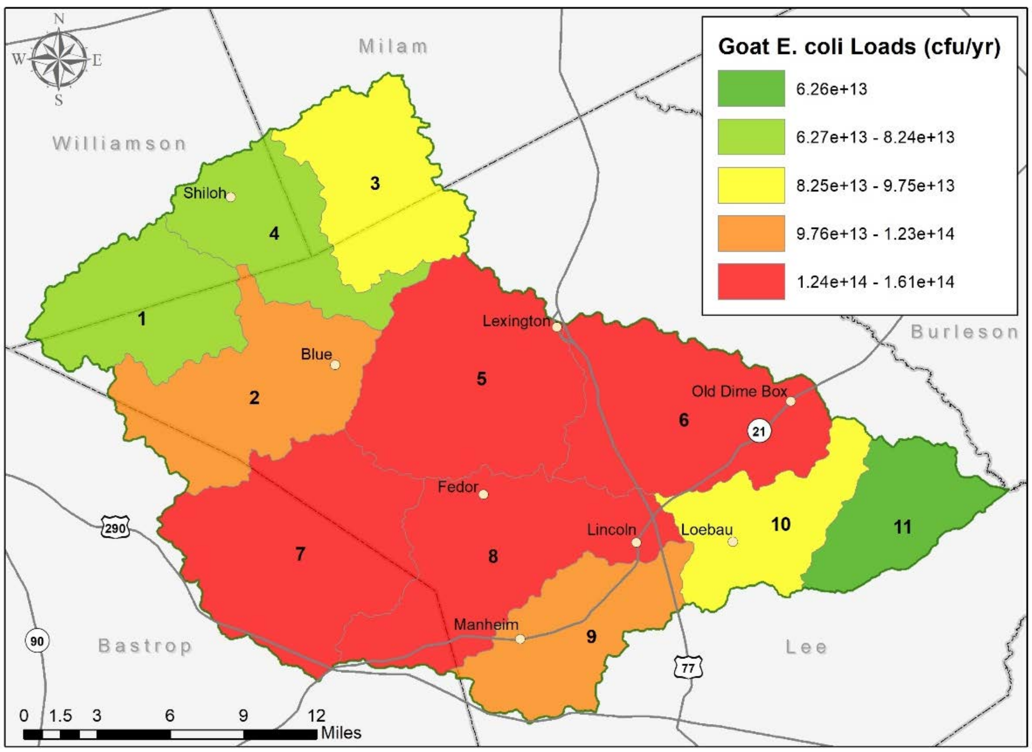

Figure 67. Potential annual bacteria loadings from goats in the Middle Yegua Creek watershed. colony forming unit, cfu

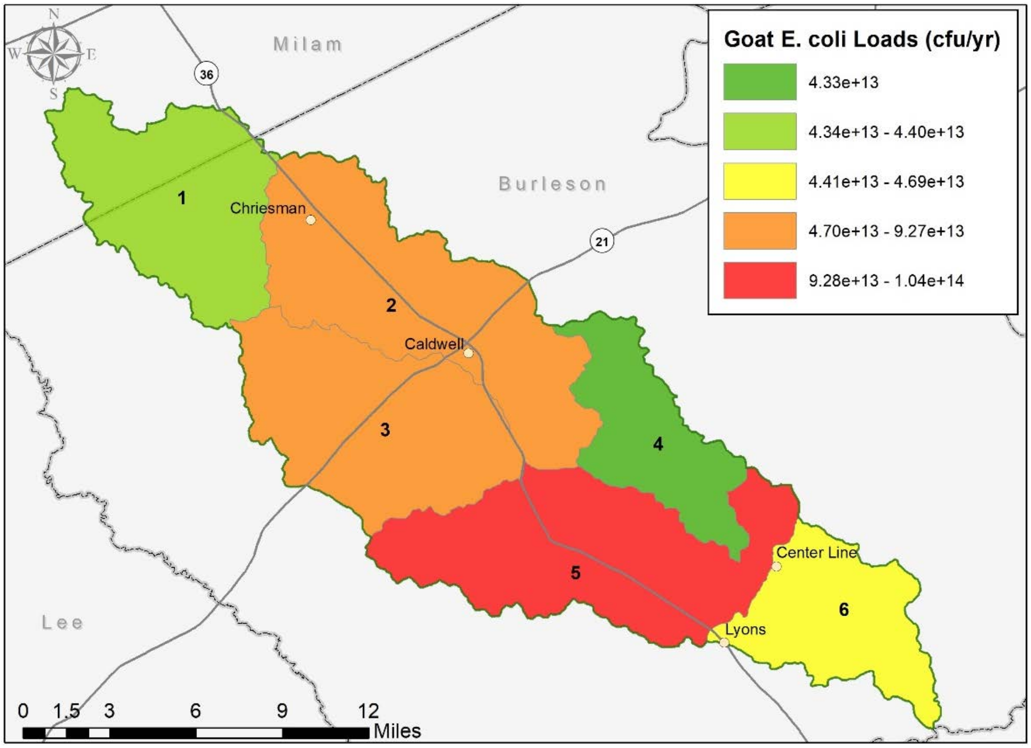

Figure 68. Potential annual bacteria loadings from goats in the Davidson Creek watershed. colony forming unit, cfu

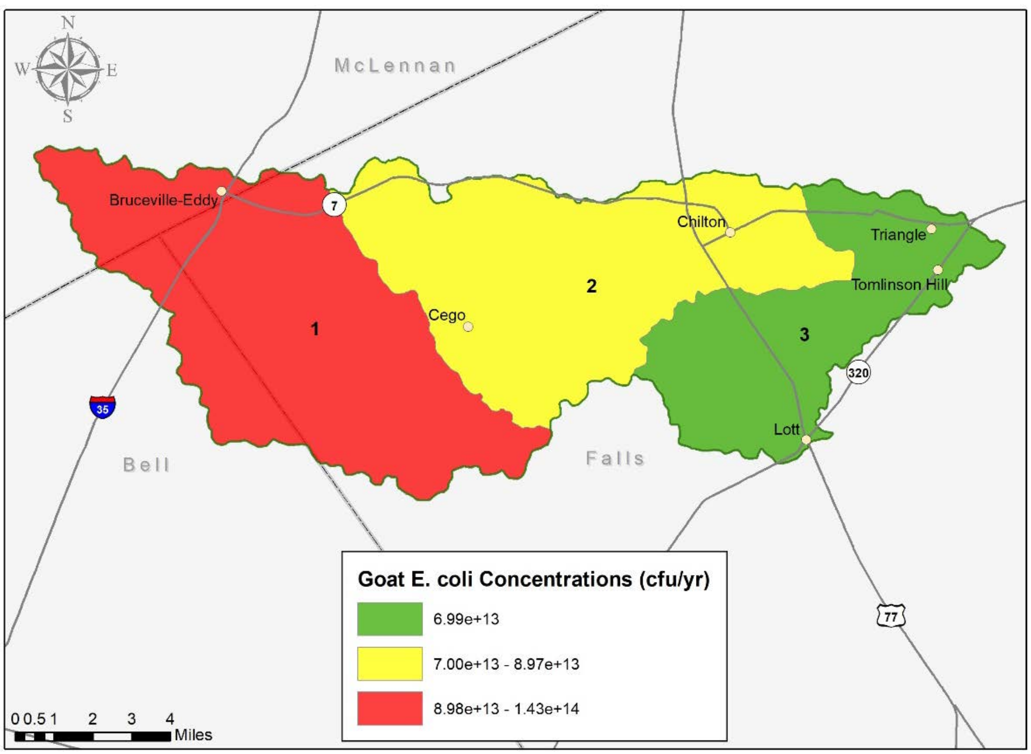

Figure 69. Potential annual bacteria loadings from goats in the Deer Creek watershed. colony forming unit, cfu

Livestock: Sheep

A total of 804 animal units of sheep in the Middle Yegua Creek watershed were evenly distributed over shrub/scrub, grassland/herbaceous and pasture/hay. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 5, 6, 7 and 8 (Figure 70). Across the watershed, the estimated potential annual load due to sheep is 1.07×10^{16} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 290 sheep animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 71). Across the watershed, the estimated potential annual load due to sheep is 3.86×10^{15} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 378 sheep animal units. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 72). Across the watershed, the estimated potential annual load due to sheep is 5.04×10^{15} cfu/yr.

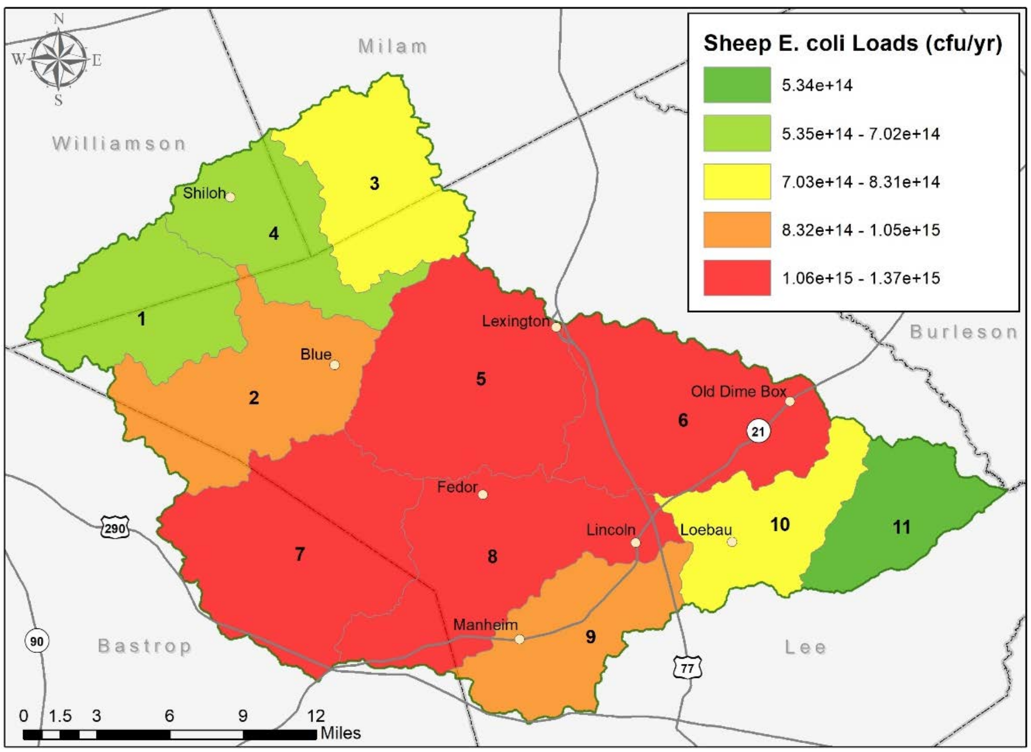

Figure 70. Potential annual bacteria loadings from sheep in the Middle Yegua Creek watershed. colony forming unit, cfu

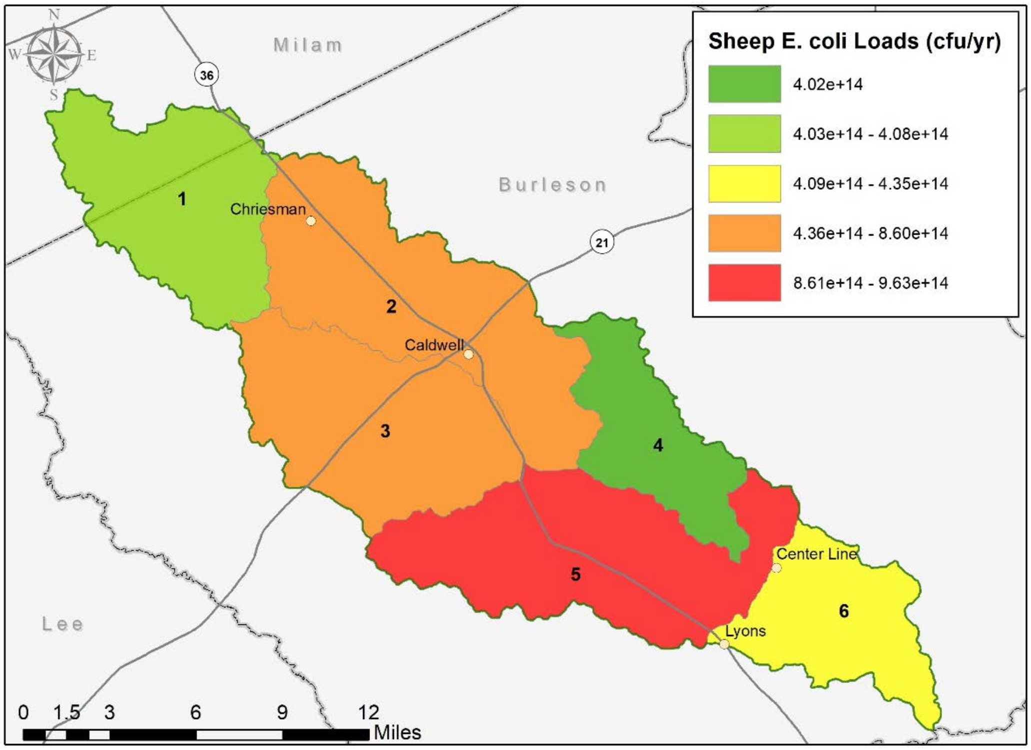

Figure 71. Potential annual bacteria loadings from sheep in the Davidson Creek watershed. colony forming unit, cfu

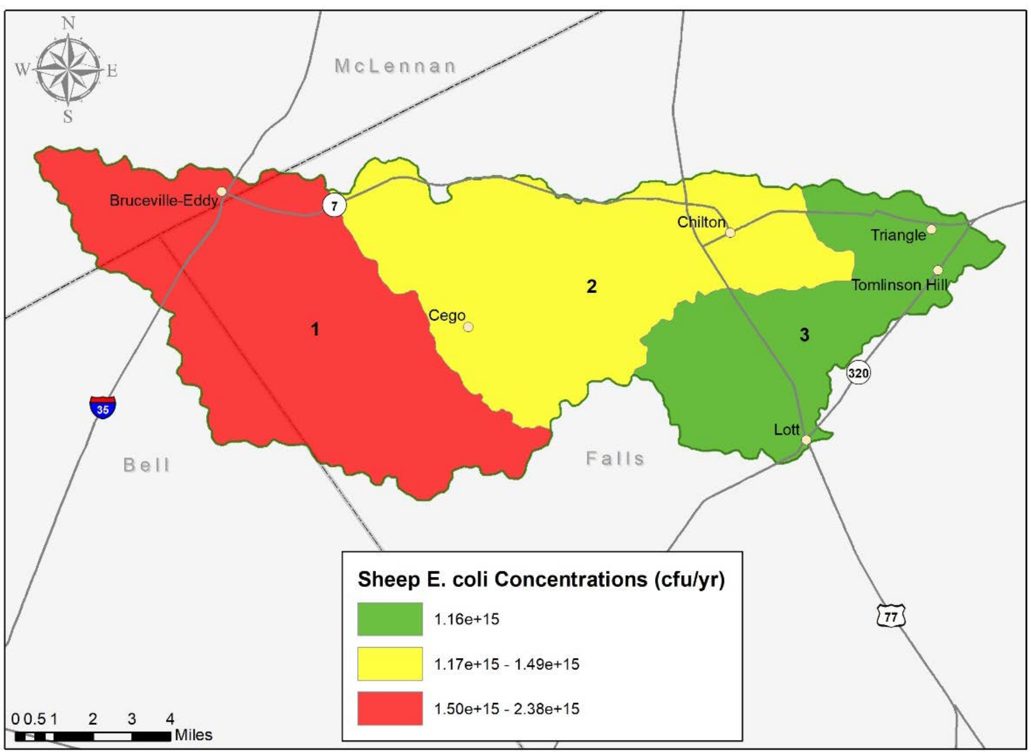

Figure 72. Potential annual bacteria loadings from sheep in the Deer Creek watershed. colony forming unit, cfu

Wildlife: Deer

Wildlife is another *E. coli* and nutrient source in the watershed. Riparian areas provide the most suitable wildlife habitat in the watershed, leading most wildlife to spend the majority of their time in these areas. The amount of fecal deposition is directly related to time spent in a given area, thus wildlife feces are considered a major source in the watershed. Deer populations were estimated using annual deer density estimates from TPWD surveys conducted in and near the watershed.

For the Middle Yegua Creek watershed, a deer population of 6,438 animals was estimated. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 5 and 7 (Figure 73). Across the watershed, the estimated potential annual load due to deer is 2.49×10^{15} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 3,144 deer with a density of 41.65 animals per acre. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 2 and 5 (Figure 74). Across the watershed, the estimated potential annual load due to deer is 1.21×10^{15} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 2,602 deer with a density of 26.69 animals per acre. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 75). Across the watershed, the estimated potential annual load due to deer is 1.01×10^{15} cfu/yr.

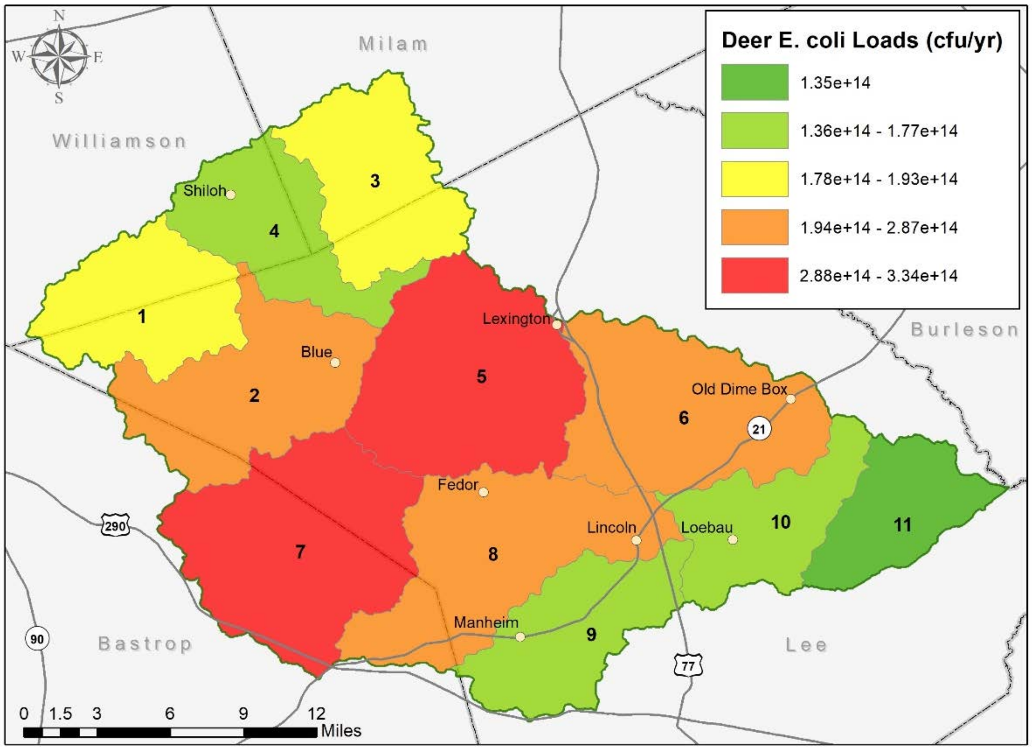

Figure 73. Potential annual bacteria loadings from deer in the Middle Yegua Creek watershed. colony forming unit, cfu

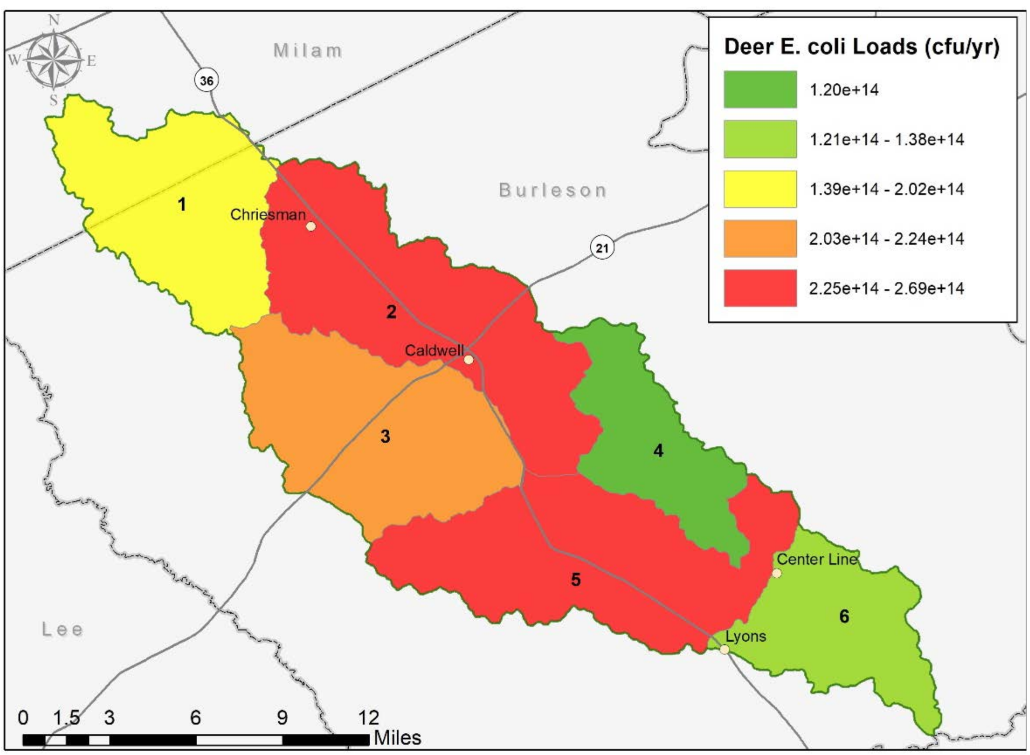

Figure 74. Potential annual bacteria loadings from deer in the Davidson Creek watershed. colony forming unit, cfu

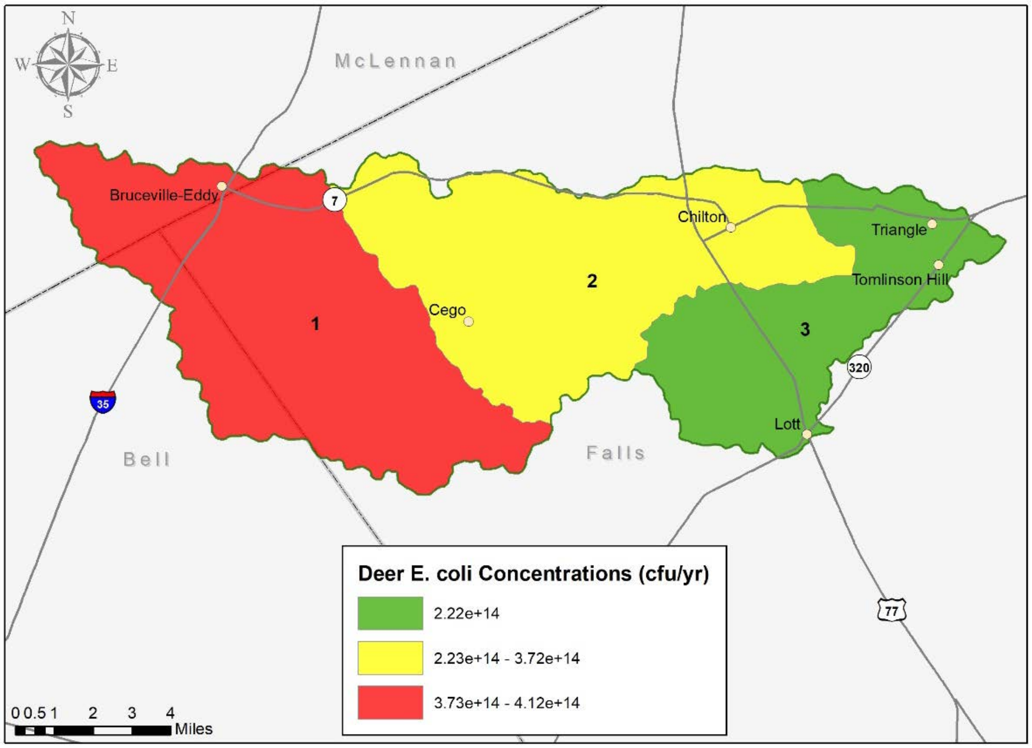

Figure 75. Potential annual bacteria loadings from deer in the Deer Creek watershed. colony forming unit, cfu

Wildlife: Feral Hogs

Feral hogs (Sus scrofa) are an introduced, non-native and invasive species. Early settlers released some of the first domestic hogs in the Texas landscape as early as the 1680s, with many of these hogs becoming feral over time as animals were left to fend for themselves (Mayer 2009; Mapston 2010). Documented introductions of Eurasian wild boar occurred in the early 1920s through the 1940s along the Texas Central Coast, including at the St. Charles Ranch in what is now the nearby Aransas National Wildlife Refuge (Mayer 2009). Current population estimates of feral hogs in Texas alone range from 1 to 3 million individuals (Mayer 2009; Mapston 2010).

Feral hogs contribute to *E. coli* bacteria loadings through the direct deposition of fecal matter into streams while wading or wallowing in riparian areas. Riparian areas provide ideal habitats and migratory corridors for feral hogs as they search for food. While complete removal of feral hog populations is unlikely, habitat management and trapping programs can limit populations and associated damage.

For the Middle Yegua Creek watershed, a watershed-wide estimate of 8,053 hogs was produced. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 5 and 7 (Figure 76). Across the watershed, the estimated potential annual load due to feral hogs is 2.80×10^{14} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 3,932 feral hogs within the watershed. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 2 and 5 (Figure 77). Across the watershed, the estimated potential annual load due to feral hogs is 1.37×10^{14} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 2,085 feral hogs within the watershed. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 78). Across the watershed, the estimated potential annual load due to feral hogs is 7.25×10^{13} cfu/yr.

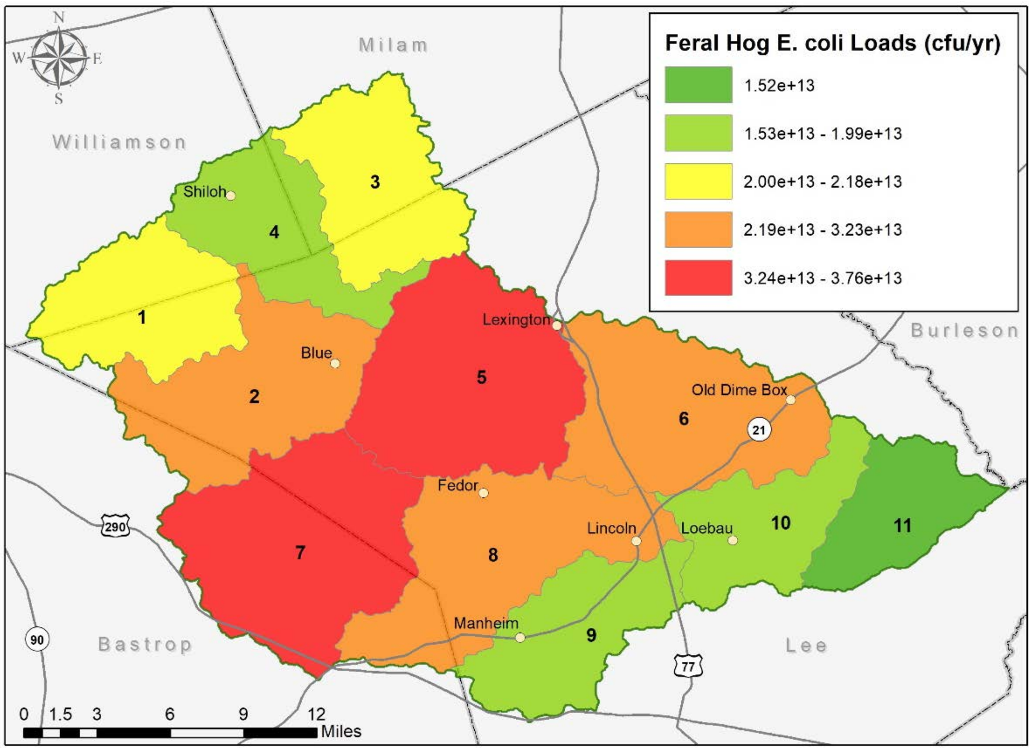

Figure 76. Potential annual bacteria loadings from feral hogs in the Middle Yegua Creek watershed. colony forming unit, cfu

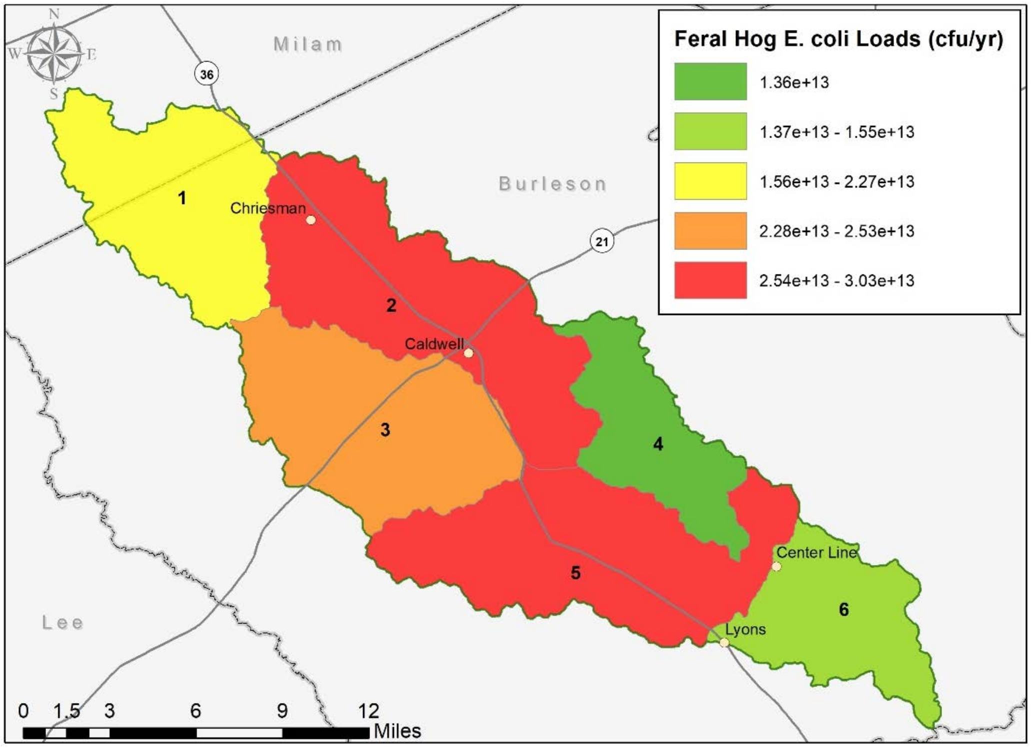

Figure 77. Potential annual bacteria loadings from feral hogs in the Davidson Creek watershed. colony forming unit, cfu

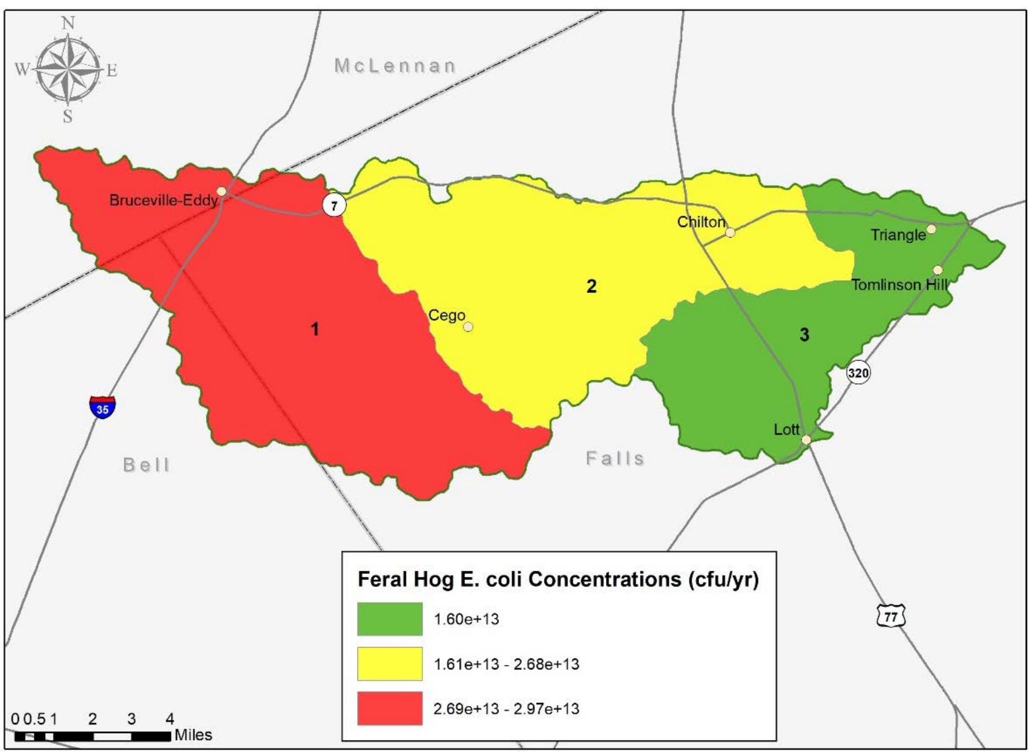

Figure 78. Potential annual bacteria loadings from feral hogs in the Deer Creek watershed. colony forming unit, cfu

OSSFs

Failing or unmaintained OSSFs can contribute to bacteria loads in water bodies, particularly those where effluent is released near the water bodies. Within all three watersheds, approximately 15% of OSSFs are assumed to fail in a given year. For the Middle Yegua Creek watershed, it was estimated that there are approximately 3,953 OSSFs within the watershed based on the most recently available 911 address data. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 79). Across the watershed, the estimated potential annual load due to OSSFs is 7.93×10^{15} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 2,408 OSSFs within the watershed. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 3 and 5 (Figure 80). Across the watershed, the estimated potential annual load due to OSSFs is 4.79×10^{15} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 1,685 OSSFs within the watershed. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 81). Across the watershed, the estimated potential annual load due to OSSFs is 3.85×10^{15} cfu/yr.

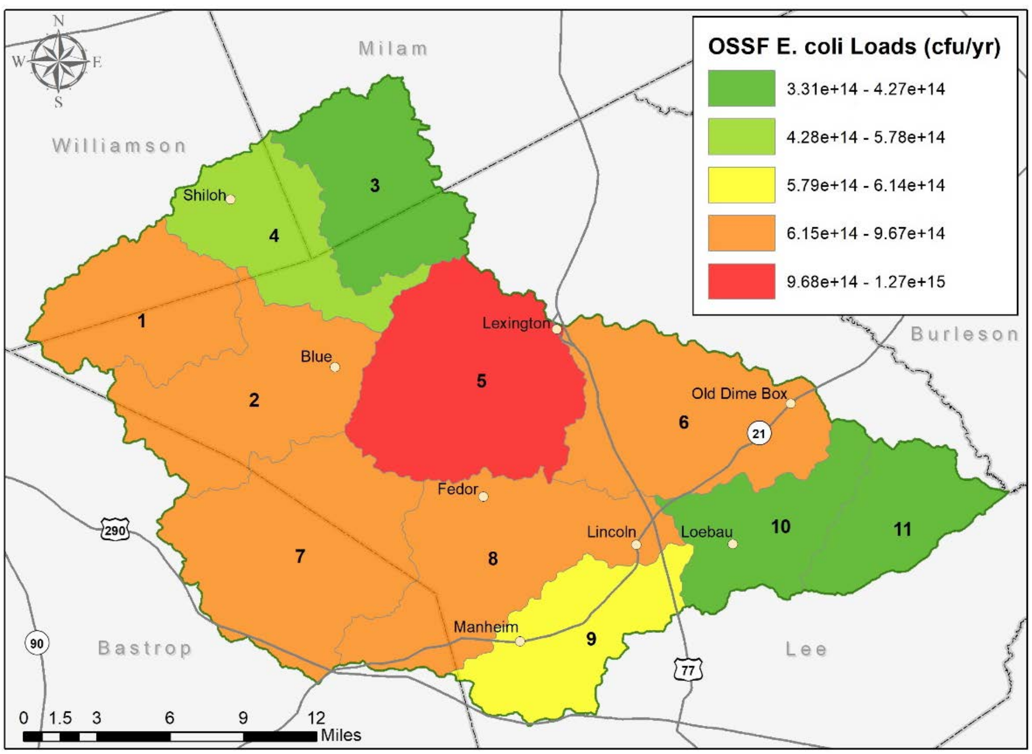

Figure 79. Potential annual bacteria loadings from on-site sewage facilities (OSSFs) in the Middle Yegua Creek watershed. colony forming unit, cfu

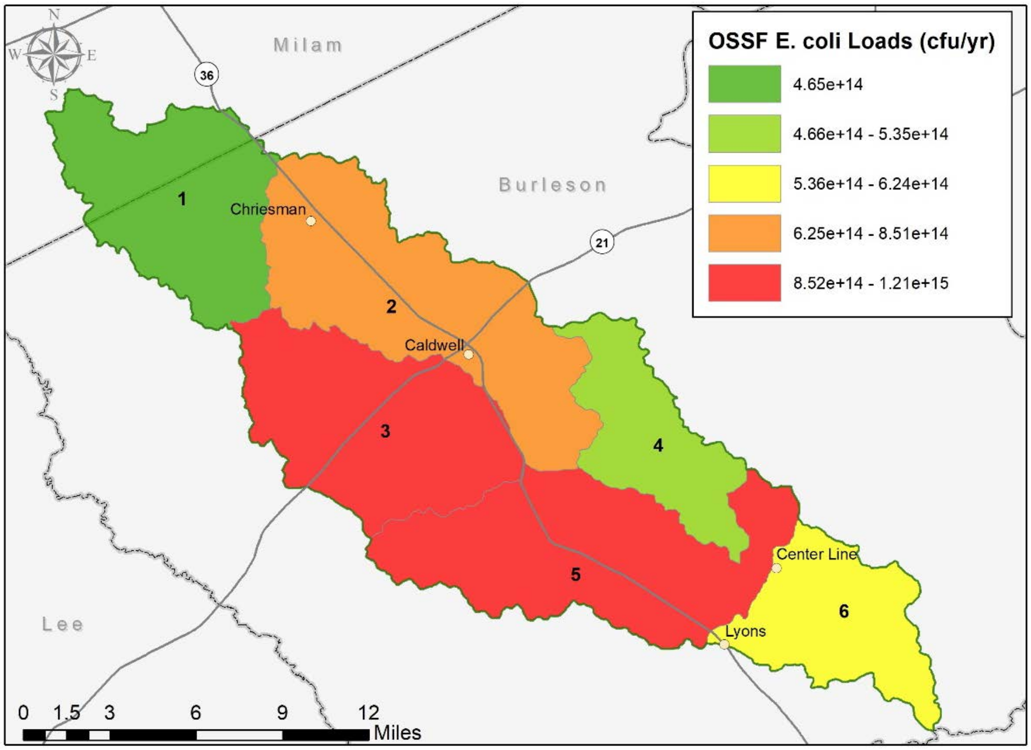

Figure 80. Potential annual bacteria loadings from on-site sewage facilities (OSSFs) in the Davidson Creek watershed. colony forming unit, cfu

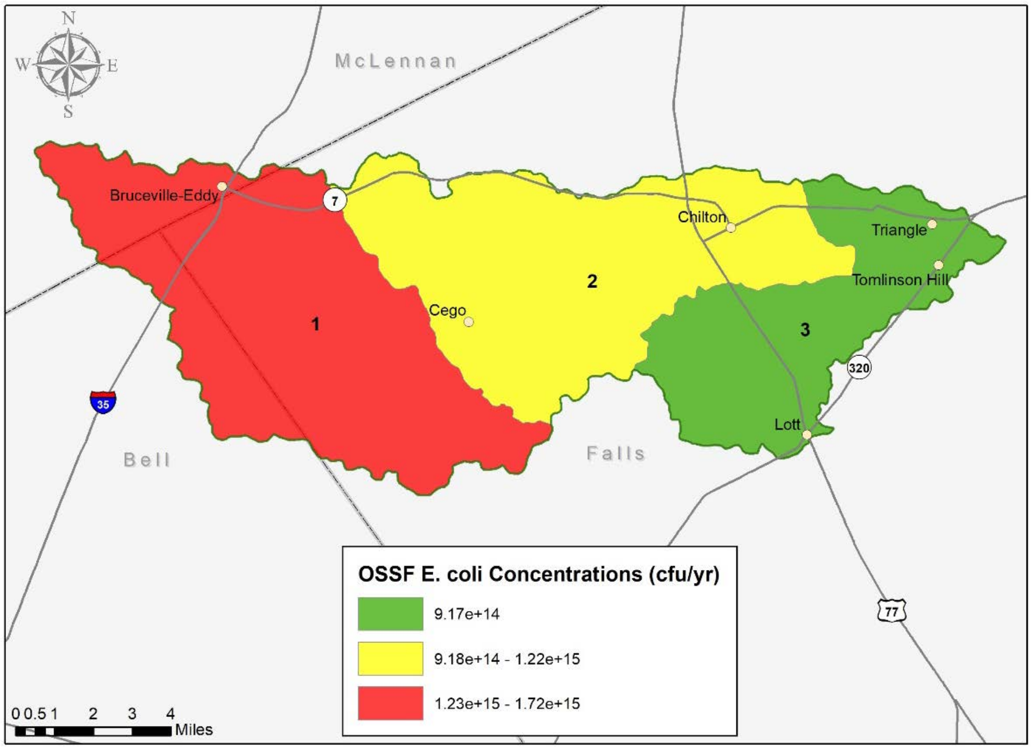

Figure 81. Potential annual bacteria loadings from on-site sewage facilities (OSSFs) in the Deer Creek watershed. colony forming unit, cfu

Domestic Pets: Dogs

Domestic pets, particularly dogs, can contribute to bacteria loadings when pet waste is not disposed of and subsequently washes into nearby water bodies during rain and storm events. The highest potential loads from domestic pets are anticipated to occur in developed and urbanized areas. For the Middle Yegua Creek watershed, it was estimated that there are approximately 2,256 dogs within the watershed. GIS analysis indicated the highest potential annual loading occurs in subwatershed 5 (Figure 82). Across the watershed, the estimated potential annual load due to dogs is 2.59×10^{15} cfu/yr. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that there are approximately 2,435 dogs within the watershed. GIS analysis indicated the highest potential annual loadings occur in subwatersheds 2 and 3 (Figure 83). Across the watershed, the estimated potential annual load due to dogs is 2.80×10^{15} cfu/yr.

For the Deer Creek watershed, it was estimated that there are approximately 1,003 dogs within the watershed. GIS analysis indicated the highest potential annual loading occurs in subwatershed 1 (Figure 84). Across the watershed, the estimated potential annual load due to dogs is 1.15×10^{15} cfu/yr.

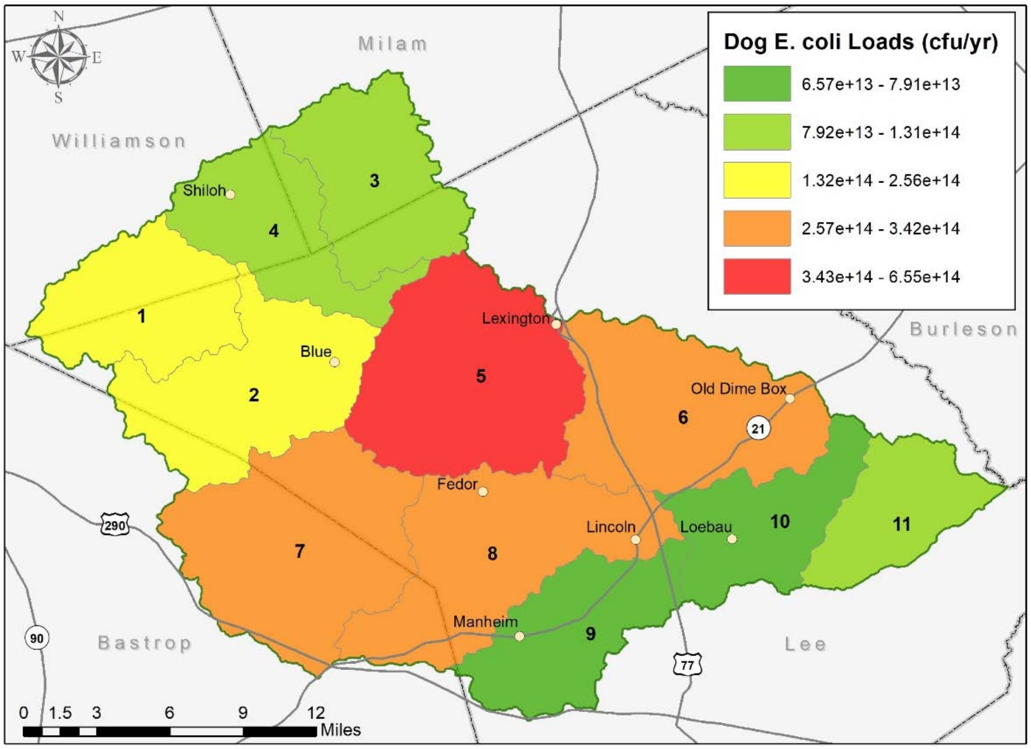

Figure 82. Potential annual bacteria loadings from dogs in the Middle Yegua Creek watershed. colony forming unit, cfu

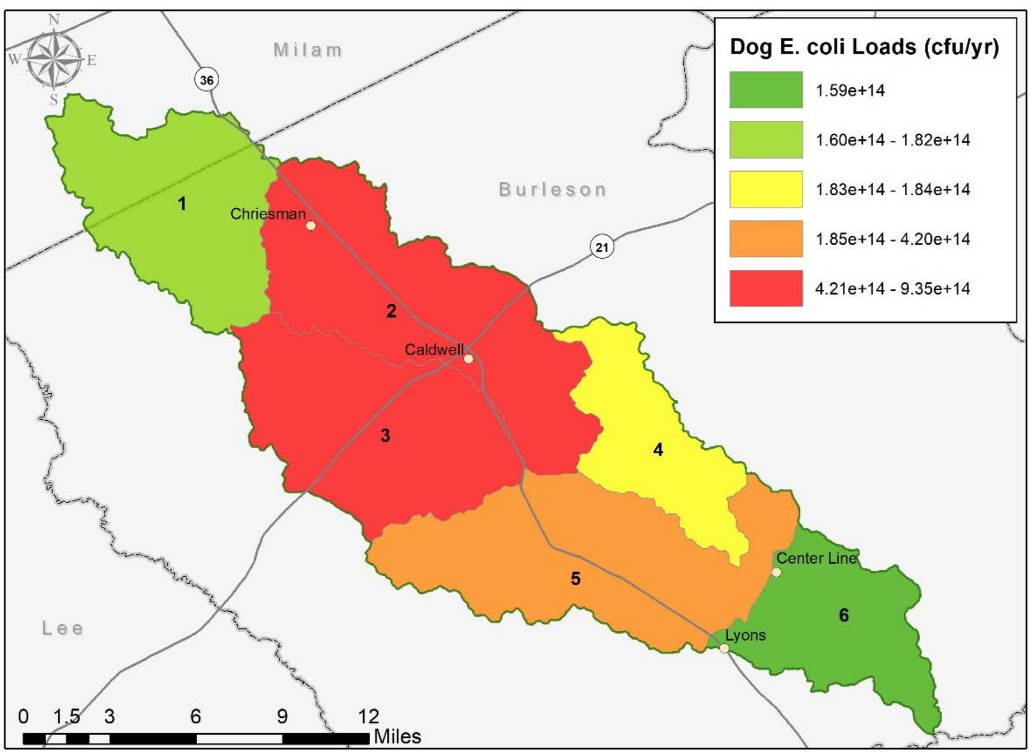

Figure 83. Potential annual bacteria loadings from dogs in the Davidson Creek watershed. colony forming unit, cfu

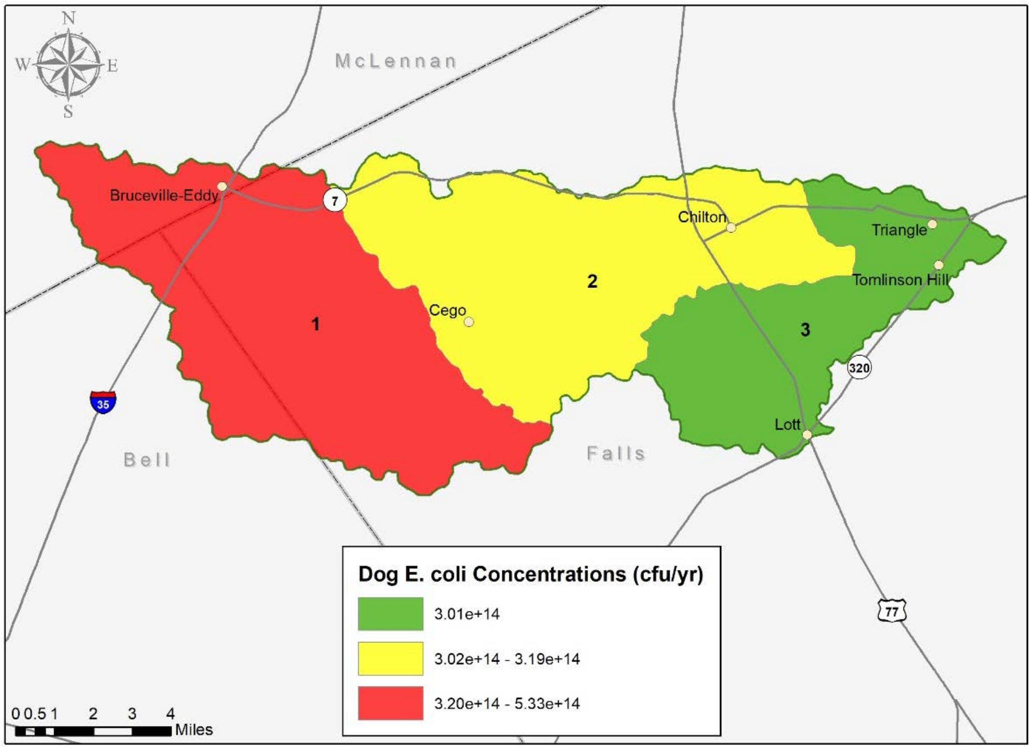

Figure 84. Potential annual bacteria loadings from dogs in the Deer Creek watershed. colony forming unit, cfu

WWTFs

According to TCEQ and NPDES data, there is one permitted wastewater discharger in the Middle Yegua Creek watershed, two in the Davidson Creek watershed and two in the Deer Creek watershed. These wastewater discharges are regulated by TCEQ and the dischargers are required to report 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. Total potential bacteria loads based on maximum permitted discharges across the Middle Yegua Creek watershed is 3.46×10^{11} cfu/yr (Figure 85), and the highest potential load occurs in subwatershed 6. Appendix C describes the equations and assumptions used to generate potential annual loads.

For the Davidson Creek watershed, it was estimated that the total potential bacteria loads based on maximum permitted discharges is 1.75×10^{12} cfu/yr (Figure 86), and the highest potential load occurs in subwatershed 2.

For the Deer Creek watershed, it was estimated that the total potential bacteria loads based on maximum permitted discharges is 3.20×10^{11} cfu/yr (Figure 87), and the highest potential load occurs in subwatershed 2.

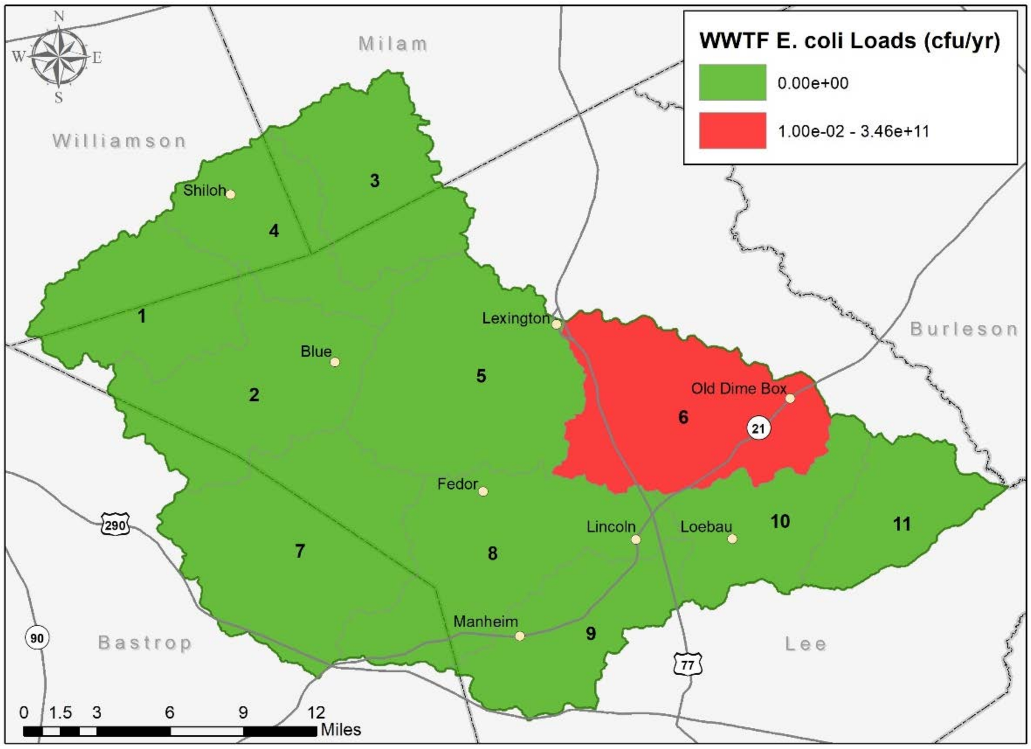

Figure 85. Potential annual bacteria loadings from wastewater treatment facilities (WWTFs) in the Middle Yegua Creek watershed. colony forming unit, cfu

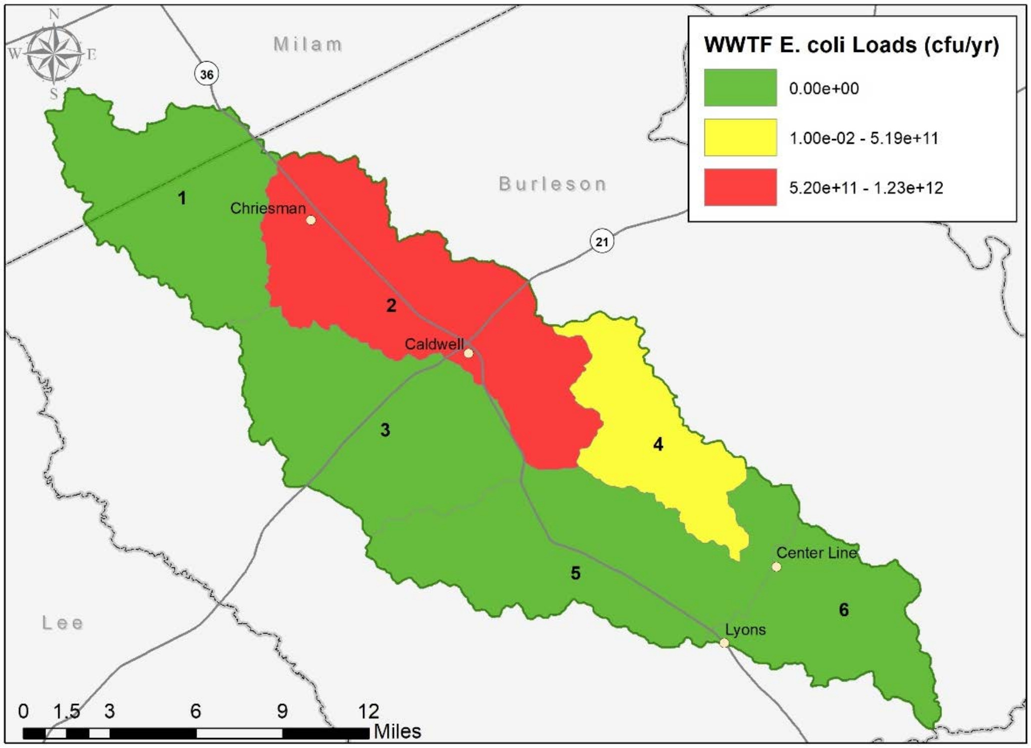

Figure 86. Potential annual bacteria loadings from wastewater treatment facilities (WWTFs) in the Davidson Creek watershed. colony forming unit, cfu

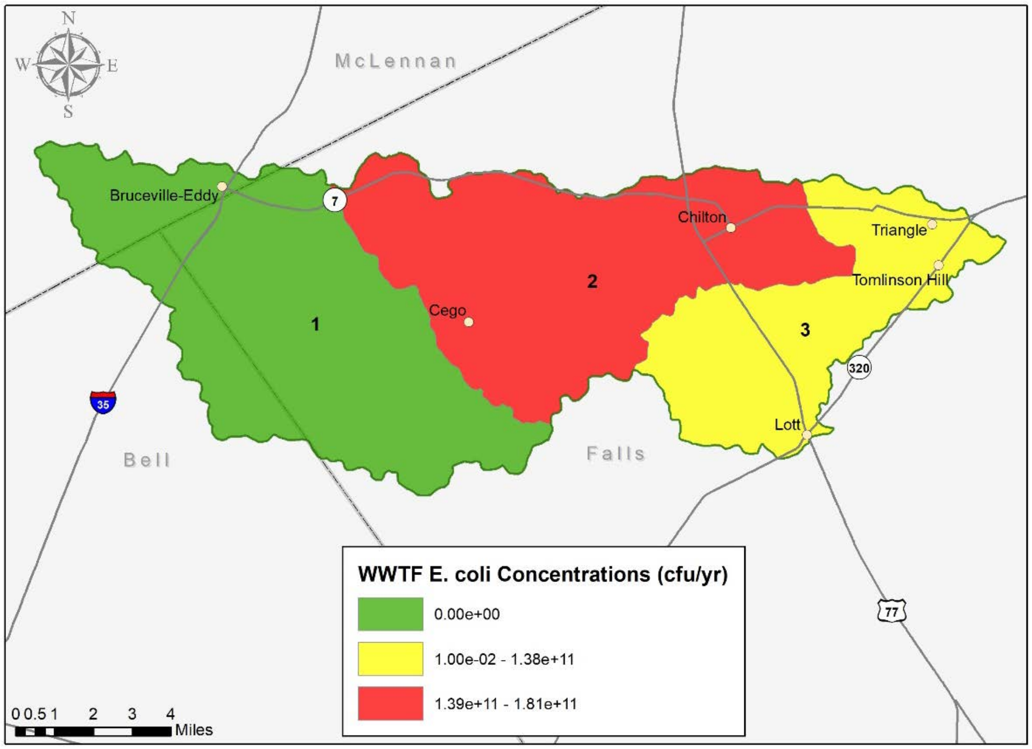

Figure 87. Potential annual bacteria loadings from wastewater treatment facilities (WWTFs) in the Deer Creek watershed. colony forming unit, cfu

Load Reduction and Sources Summary

The LDCs provided in the first half of this section indicate that the amount of *E. coli* bacteria entering Middle Yegua Creek, Davidson Creek and Deer Creek exceeds the capacities of those water bodies under all flow conditions except for low flows in Deer Creek and low flows in part of Middle Yegua Creek. Based on these curves, it can be assumed that *E. coli* is entering water bodies under both higher flow and lower flow conditions. Using the LDC approach, a total reduction of 5.90×10^{13} MPN/yr was estimated as needed to meet primary contact recreation standards at the Middle Yegua Creek SWQM stations 18750 and 11840. A reduction of 1.15×10^{13} MPN/yr was also estimated for Middle Yegua Creek SWQM station 11838. For Davidson Creek a reduction of 1.22×10^{14} MPN/yr was estimated to meet primary contact recreation standards at SWQM stations 11729, 18349 and 21420. For Deer Creek a reduction of 3.06×10^{13} MPN/yr was estimated to meet primary contact recreation standards at SWQM stations 11723 and 18644.

Given the relatively good compliance of permitted dischargers in the watersheds with the exception of the Lexington WWTF in the Middle Yegua Creek watershed, bacteria loading exceedances during low flow conditions are likely attributable to direct deposition from livestock and wildlife in addition to discharges from unregulated failing and faulty OSSFs in riparian zones. Bacteria in runoff are likely to contribute to exceedances during higher flow conditions. Sources of bacteria-laden runoff might include runoff from rangeland and pastures and drainage fields of faulty OSSFs. Although reported SSO events are extremely uncommon in the watersheds, I&I during heavy rainfall events and resulting SSOs or unauthorized discharges may also contribute to elevated loads during some high flow events.

Based on the GIS analysis, bacteria loadings from cattle and livestock are likely to be relatively high compared to other sources (Table 25). Estimated total potential loads are likely conservative because most wildlife sources of fecal bacteria are not included in the analysis.

Identifying where grazed pasture and rangeland in the watersheds are the most concentrated helps to highlight important areas to address and implement potential improvements in pasture and rangeland runoff. GIS analysis suggests relatively high potential for loadings from dogs in subwatersheds that encompass the cities of Lexington, Caldwell and Bruceville-Eddy; it will be important to address pet waste and stormwater runoff from impervious surfaces in these areas. OSSFs and feral hogs have moderate potential for *E. coli* loading as compared to other sources. WWTFs and urban stormwater indicated the lowest relative potential for loadings amongst sources assessed.

Table 25. Summary of potential source loads.

Source	Middle Yegua Creek		Davidson Creek		Deer Creek	
	Potential Load/yr	Highest Priority Subwatersheds	Potential Load/yr	Highest Priority Subwatersheds	Potential Load/yr	Highest Priority Subwatersheds
Cattle	1.07×10^{17}	5 & 8	5.33×10^{16}	5	1.36×10^{16}	1
Horses	9.61×10^{13}	5, 6, 7 & 8	3.81×10^{13}	5	2.07×10^{13}	1
Goats	1.26×10^{15}	5, 6, 7 & 8	4.17×10^{14}	5	3.03×10^{14}	1
Sheep	1.07×10^{16}	5, 6, 7 & 8	3.86×10^{15}	5	5.04×10^{15}	1
Deer	2.49×10^{15}	5 & 7	1.21×10^{15}	2 & 5	1.01×10^{15}	1
Feral Hogs	2.80×10^{14}	5 & 7	1.37×10^{14}	2 & 5	7.25×10^{13}	1
OSSFs	7.93×10^{15}	5	4.79×10^{15}	3 & 5	3.85×10^{15}	1
Dogs	2.59×10^{15}	5	2.80×10^{15}	2 & 3	1.15×10^{15}	1
WWTFs	3.46×10^{11}	6	1.75×10^{12}	2	3.20×10^{11}	2
Totals	1.32×10^{17}		6.65×10^{16}		2.50×10^{16}	

on-site sewage facilities, OSSFs; wastewater treatment facilities, WWFs

References

Asquith, W., Roussel, M.C., and Vrabel, J. 2006. Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas. U.S. Geological Survey Scientific Investigations Report 2006-5286.

AVMA (American Veterinary Medical Association). 2018. 2017-2018 U.S. Pet Ownership & Demographics Sourcebook. https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx

Borel, K., Gregory, L., Karthikeyan, R. 2012. Modeling Support for the Attoyac Bayou Bacteria Assessment using SELECT. College Station, Texas: Texas Water Resources Institute. TR-454. http://twri.tamu.edu/reports/2012/tr454.pdf

Borel, K. E., Karthikeyan, R., Berthold, T. A., & Wagner, K. 2015. Estimating *E. coli* and *Enterococcus* loads in a coastal Texas watershed. Texas Water Journal 6(1): 33–44.

Clary, C. R., Redmon, L., Gentry, T., Wagner, K., Lyons, R. 2016. Nonriparian shade as a water quality best management practice for grazing-lands: a case study. Rangelands 38(3): 129-137. https://doi.org/10.1016/j. rala.2015.12.006

Griffith, G., Bryce, S., Omernik, J., and A. Rogers. 2007. Ecoregions of Texas. U.S. Geological Survey. https://tpwd.texas.gov/publications/pwdpubs/pwd_pl_w7000_1187a/media/1.pdf

Mapston, M. E. 2010. Feral Hogs in Texas. Texas Cooperative Extension. Texas Wildlife Services. B-6149 03-07. http://feralhogs.tamu.edu/files/2010/05/B-6149-FeralHogs-in-Texas.pdf

Mayer, J. J. 2009. Biology of wild pigs: taxonomy and history of wild pigs in the United States. In Wild pigs: biology, damage, control techniques and management, edited by J. J. Mayer and I. L. Brisbin Jr., 5-23. Savannah River National Laboratory, Aiken, South Carolina. http://sti.srs.gov/fulltext/SRNL-RP-2009-00869.pdf

NOAA (National Oceanic and Atmospheric Administration). 2016. Climate Data Online. National Climatic Data Center. http://www.ncdc.noaa.gov/cdo-web/

NRCS (Natural Resources Conservation Services), USDA (U.S. Department of Agriculture). 2019. Web Soil Survey. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

PRISM Climate Group at Oregon State University. 2012. 30-Year Normals. 30-Year Normal Precipitation Spatial Data. http://www.prism.oregonstate.edu/normals/

Reed, Stowe & Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas. http://www.

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

TCEQ (Texas Commission on Environmental Quality). 2002. 2002 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/02twqi/02_303d.pdf

TCEQ. 2008. 2006 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/06twqi/2006_303d.pdf

TCEQ. 2011. 2010 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/10twqi/2010_303d.pdf

TCEQ. 2015a. 2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/waterquality/assessment/14twqi/14txir

TCEQ. 2015b. 2014 Guidance for Assessing and Reporting Surface Water Quality in Texas. https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/14txir/2014_guidance.pdf

TCEQ. 2019a. 2016 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/16txir/2016_303d.pdf

TCEQ. 2019b. 2018 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/18txir/2018_303d.pdf

TWDB (Texas Water Development Board). 2016. Population and Water Demand Projections. https://www.twdb.texas.gov/waterplanning/data/projections/

USCB (United States Census Bureau). 2010. Census Data. https://data.census.gov/cedsci/

USEPA (United States Environmental Protection Agency). 2001. Protocol for Developing Pathogen TMDLs First Edition, (January), 132. https://doi.org/EPA 841-R-00-002

USEPA. 2019. Enforcement and Compliance History Online (ECHO). Available online at: http://echo.epa.gov/

USGS (United States Geological Survey). 2013. National Elevation Database (NED). http://nationalmap.gov/viewer.html

NLCD. 2016. National Land Cover Database 2016. Multi-resolution Land Characteristics Consortium (MRLC). USGS. https://www.mrlc.gov/data/nlcd-2016-land-cover-conus

Wagner, K. L. and Moench, E. 2009. Education Program for Improved Water Quality in Copano Bay. Task Two Report. College Station, Texas: Texas Water Resources Institute. TR-347. http://twri.tamu.edu/reports/2009/ tr347.pdf

Wagner, K. L., Redmon, L. A., Gentry, T. J., Harmel, R. D. 2012. Assessment of cattle grazing effects on *E. coli* runoff. Transactions of the ASABE 55(6): 2111-2122.

Wagner, K. L., Redmon, L. A., Gentry, T. J., Harmel, R. D., Knight, R., Jones, C. A., Foster, J. L. 2013. Effects of an off-stream watering facility on cattle behavior and instream *E. coli* levels. Texas Water Journal 4(2): 1-13.

Appendix A: DAR Method Used for LDC Development

Hydrologic data in the form of daily streamflow records were unavailable for the Deer Creek watershed. However, streamflow records were available for the nearby Middle Bosque River watershed of similar land cover characteristics. There were also some instantaneous streamflow records from 2010-2011 at SWQM station 11723 in the watershed. Due to the absence of flow records within the impaired watershed, the naturalized flow was constructed using the DAR approach.

Both sets of flow data, instantaneous flows at SWQM station 11723 and USGS gaged daily streamflow in the Middle Bosque River near McGregor, Texas (USGS Gage 08095300) were used to estimate the DAR parameters. The watershed boundaries were delineated above the SWQM station in the Deer Creek watershed and the USGS gage in the Middle Bosque River watershed, using 10-meter digital elevation models. The influence of the discharge from the City of Crawford WWTF in the Middle Bosque watershed was removed by subtracting the full permitted flow from the gaged record so that the reference flow is considered to be naturalized flow. Prior to the estimation of DAR parameters, zero flows were removed in order for the log transformation to be applied (Asquith et al. 2006).

A generalized DAR method with two parameters ϕ (exponent) and κ (bias correction factor) was applied to simulate flows on days that instantaneous flows were measured (Asquith et al. 2006). A simulation evaluation coefficient, the NSE (Nash-Sutcliffe) was calculated by comparing simulated flow and observed (instantaneous) flow at each exceedance probability. Table 26 provides the DAR used to develop streamflows at SWQM station 11723. Further information and equations used to calculate the DAR for the Deer Creek watershed are in Aquith et al. 2006.

Table 26. Drainage area ratios used to develop daily streamflow records.

Water body	Station	Area (square miles)	κ	ϕ
Middle Bosque River	USGS 08095300	179.61	NA	NA
Deer Creek	SWQM 11723	113.38	1.61346	5.240959
NSE	0.73	-	-	-

Nash-Sutcliffe, NSE

Appendix B: Annual Bacteria Load Reductions

LDCs and measured loads are summarized by range of flows (high, wet, mid-range and low). The generalized loading capacity for each of the three flow categories was computed by using the median daily loading capacity within that flow regime (12.5%, 50% and 87.5% load exceedances). The required daily load reduction was calculated as the difference between the median loading capacity and the geometric mean of observed *E. coli* loading within each flow category. To estimate the needed annual bacteria load reductions, the required daily load was multiplied by the number of days per year in each flow condition. Table 27 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 27. Bacteria load reduction calculations by flow condition.

	Flow Conditions		
	High	**Mid-Range**	**Low**
Days per year	25% × 365	50% × 365	25% × 365
Median Flow (cubic feet per second)	Median observed or median estimated flow in each flow category		
Existing Geomean Concentration (MPN/100 mL)	Geometric mean of observed *E. coli* samples in each flow category		
Allowable Daily Load (Billion MPN)	Median Flow × 126 MPN/100 mL × 283.2 100mL/cubic foot × 86400 seconds/day		
Allowable Annual Load (Billion MPN)	Allowable Daily Load × Days per year		
Existing Daily Load (Billion MPN)	Median Flow × Existing Geomean Concentration × 283.2 100mL/cubic foot × 86,400 seconds/day		
Existing Annual Load (Billion MPN)	Existing Daily Load × Days per year		
Annual Load Reduction Needed (Billion MPN)	Existing Annual Load – Allowable Annual Load		
Percent Reduction Needed	(Existing Annual Load – Allowable Annual Load)/Existing Annual Load × 100		
Total Annual Load (Billion MPN)	Sum of Existing Annual Loads		
Total Annual Load Reduction (Billion MPN)	Sum of Annual Load Reductions Needed		
Total Percent Reduction	Total Annual Load Reduction/Total Annual Load × 100		

most probable number, MPN; milliliter, mL; *Escherichia coli, E. coli*

Appendix C: Potential Bacteria Loading Calculations

The SELECT geospatial analysis (Borel et al. 2012) methodology was used to estimate potential bacteria loads in the watersheds and their respective subwatersheds. This approach estimates potential loads by subwatershed. This geospatial approach also provides an easy method to understand relative contributions and spatial distribution across the watersheds without relying on data intense (and expensive) modelling approaches.

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

Livestock Bacteria Loading Estimates

Cattle populations were estimated across the watershed based on remote-sensed land use data (Homer et al., 2015). The assumptions used in this method are documented in Wagner and Moench (2009) and Borel et al. (2015) (Table 28, Table 29, Table 30).

Table 28. Bacteria loading assumptions for cattle in the Middle Yegua Creek watershed.

Assumptions	
Acres of unimproved rangeland	21,710 acres
Acres of improved pasture	156,655 acres
Cattle stocking density on unimproved pasture	10 acres per animal unit
Cattle stocking density on improved pasture	3 acres per animal unit
Cattle on unimproved range	2,171 animal units
Cattle on improved range	52,218 animal units
Total cattle in the watershed	54,389 animal units
Animal unit conversion factor	1 (Wagner and Moench 2009)
Fecal coliform production rate	8.55×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per CFU fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 29. Bacteria loading assumptions for cattle in the Davidson Creek watershed.

Assumptions	
Acres of unimproved rangeland	4,176 acres
Acres of improved pasture	80,055 acres
Cattle stocking density on unimproved pasture	10 acres per animal unit
Cattle stocking density on improved pasture	3 acres per animal unit
Cattle on unimproved range	418 animal units
Cattle on improved range	26,685 animal units
Total cattle in the watershed	27,103 animal units
Animal unit conversion factor	1 (Borel et al. 2015)
Fecal coliform production rate	8.55×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per CFU fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 30. Bacteria loading assumptions for cattle in the Deer Creek watershed.

Assumptions	
Acres of unimproved rangeland	26,434 acres
Acres of improved pasture	12,803 acres
Cattle stocking density on unimproved pasture	10 acres per animal unit
Cattle stocking density on improved pasture	3 acres per animal unit
Cattle on unimproved range	2,643 animal units
Cattle on improved range	4,268 animal units
Total cattle in the watershed	6,911 animal units
Animal unit conversion factor	1 (Borel et al. 2015)
Fecal coliform production rate	8.55×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

We then calculate potential annual loadings as:

$$\textit{Number of cattle} \times \textit{fecal coliform loading rate} \times \textit{animal unit conversion} \times \textit{factor conversion rate} \times 365 \textit{ days/yr}$$

While cattle are the predominate livestock found throughout the counties, some contributions from horses and goats are expected (other livestock are present in the watersheds, but population estimates assume these to be extremely minor). The numbers of these livestock were estimated using NASS Agricultural census counts and the ratio of nonurban county land in the watersheds to the ratio of nonurban land in the counties. Wagner and Moench (2009) and Borel et al. (2015) document the assumptions used in potential daily load calculations for other livestock (Table 31, Table 32, Table 33). Based on these assumptions, potential bacteria load from cattle for the Middle Yegua Creek watershed is 1.07×10^{17} cfu/yr. For the Davidson Creek watershed, the potential bacteria load from cattle is 5.33×10^{16} cfu/yr and for the Deer Creek watershed, the potential bacteria load from cattle is 1.36×10^{16} cfu/yr.

Table 31. Bacteria loading assumptions for other livestock in the Middle Yegua Creek watershed.

Assumptions	
Total number of horses in the watershed	1,149 horses
Total number of goats in the watershed	1,268 goats
Total number of sheep in the watershed	804 sheep
Animal unit conversion factor for horses	1.25 (Borel et al. 2015)
Animal unit conversion factor for goats	0.17 (Borel et al. 2015)
Animal unit conversion factor for sheep	0.2 (Borel et al. 2015)
Fecal coliform production rate for horses	2.91×10^{8} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform production rate for goats	2.54×10^{10} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform production rate for sheep	2.90×10^{11} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 32. Bacteria loading assumptions for other livestock in the Davidson Creek watershed.

Assumptions	
Total number of horses in the watershed	456 horses
Total number of goats in the watershed	419 goats
Total number of sheep in the watershed	290 sheep
Animal unit conversion factor for horses	1.25 (Borel et al. 2015)
Animal unit conversion factor for goats	0.17 (Borel et al. 2015)
Animal unit conversion factor for sheep	0.2 (Borel et al. 2015)
Fecal coliform production rate for horses	2.91×10^{8} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)

Assumptions	
Fecal coliform production rate for goats	2.54×10^{10} cfu/animal-day (Borel et al, 2015; Wagner and Moench 2009)
Fecal coliform production rate for sheep	2.90×10^{11} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 33. Bacteria loading assumptions for other livestock in the Deer Creek watershed.

Assumptions	
Total number of horses in the watershed	247 horses
Total number of goats in the watershed	305 goats
Total number of sheep in the watershed	378 sheep
Animal unit conversion factor for horses	1.25 (Borel et al, 2015)
Animal unit conversion factor for goats	0.17 (Borel et al. 2015)
Animal unit conversion factor for sheep	0.2 (Borel et al., 2015)
Fecal coliform production rate for horses	2.91×10^{8} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform production rate for goats	2.54×10^{10} cfu/animal-day (Borel et al, 2015; Wagner and Moench 2009)
Fecal coliform production rate for sheep	2.90×10^{11} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

We then calculate potential annual loadings as:

$$\textit{Number of livestock} \times \textit{fecal coliform loading rate} \times \textit{animal unit conversion} \times \textit{factor conversion rate} \times 365\ \textit{days/yr}$$

Based on these assumptions, the annual potential load from horses for the Middle Yegua Creek watershed is 9.61×10^{13} cfu/yr, from goats is 1.26×10^{15} cfu/yr, and from sheep is 1.07×10^{16} cfu/yr. For the Davidson Creek watershed, the annual potential load from horses is 3.81×10^{13} cfu/yr, from goats is 4.17×10^{14} cfu/yr, and from sheep is 3.86×10^{15} cfu/yr. For the Deer Creek watershed, the annual potential load from horses is 2.07×10^{13} cfu/yr, from goats is 3.03×10^{14} cfu/yr, and from sheep is 5.04×10^{15} cfu/yr.

Dog Bacteria Loading Estimates

The dog populations in the watersheds were estimated using American Veterinary Medical Association statistics for average number of dogs per household and an estimate of number of households derived from Census block data (Table 34, Table 35, Table 36). The potential annual bacteria load from household pets is:

Average number of dogs per home × number of homes × dog fecal coliform loading rate × conversion rate × 365 days/yr

Table 34. Bacteria loading assumptions for dogs in the Middle Yegua Creek watershed.

Assumptions	
Average dogs per home	0.614 dogs (American Veterinary Medical Association, 2018)
Number of homes	3,675 homes
Estimated number of dogs	2,256 dogs
Fecal coliform production rate for dogs	5.0×10^9 cfu/dog/day (Borel et al. 2015)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench, 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 35. Bacteria loading assumptions for dogs in the Davidson Creek watershed.

Assumptions	
Average dogs per home	0.614 dogs (American Veterinary Medical Association, 2018)
Number of homes	3,965 homes
Estimated number of dogs	2,435 dogs
Fecal coliform production rate for dogs	5.0×10^9 cfu/dog/day (Borel et al. 2015)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 36. Bacteria loading assumptions for dogs in the Deer Creek watershed.

Assumptions	
Average dogs per home	0.614 dogs (American Veterinary Medical Association 2018)
Number of homes	1,633 homes
Estimated number of dogs	746 dogs
Fecal coliform production rate for dogs	5.0×10^{9} cfu/dog/day (Borel et al. 2015)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

The annual potential bacteria load from dogs for the Middle Yegua Creek watershed is 2.59×10^{15} cfu/yr. For the Davidson Creek watershed, the annual potential bacteria load from dogs is 2.80×10^{15} cfu/yr. For the Deer Creek watershed, the annual potential bacteria load from dogs is 1.15×10^{15} cfu/yr.

OSSF Bacteria Loading Estimates

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 15%. Loadings were calculated using the SELECT methodology with the assumptions outlined in Table 37, Table 38 and Table 39. Different numbers of people per household were assigned to different subwatersheds based on available census block data. The potential annual bacteria load from OSSFs is:

Number of OSSFs × failure rate × average people per household × sewage discharge rate × fecal coliform concentration in sewage × mL to gallon (gal) conversion × conversion rate × 365 days/yr

Table 37. Bacteria loading assumptions for on-site sewage facilities (OSSFs) in the Middle Yegua Creek watershed.

Assumptions	
Subwatershed 1 Number of OSSFs	444
Subwatershed 2 Number of OSSFs	389
Subwatershed 3 Number of OSSFs	189
Subwatershed 4 Number of OSSFs	288
Subwatershed 5 Number of OSSFs	632
Subwatershed 6 Number of OSSFs	447
Subwatershed 7 Number of OSSFs	482
Subwatershed 8 Number of OSSFs	398
Subwatershed 9 Number of OSSFs	306
Subwatershed 10 Number of OSSFs	165
Subwatershed 11 Number of OSSFs	213

Assumptions	
Failure rate	15% (NRCS 2019)
Average number of people per household in the watershed	2.21 (USCB 2010)
Sewage discharge rate	70 gal/person/day (Borel et al. 2015)
Fecal coliform concentration in sewage	1.0×10^{6} cfu/100mL (USEPA 2001)
Conversion from mL to gal	3,758.2 mL/gal
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

gallon, gal; colony forming units, cfu; milliliter, mL; *Escherichia coli, E. coli*

Table 38. Bacteria loading assumptions for on-site sewage facilities (OSSFs) in the Davidson Creek watershed.

Assumptions	
Subwatershed 1 Number of OSSFs	234
Subwatershed 2 Number of OSSFs	428
Subwatershed 3 Number of OSSFs	610
Subwatershed 4 Number of OSSFs	269
Subwatershed 5 Number of OSSFs	553
Subwatershed 6 Number of OSSFs	314
Failure rate	15% (NRCS 2019)
Average number of people per household in the watershed	2.19 (USCB 2010)
Sewage discharge rate	70 gal/person/day (Borel et al. 2015)
Fecal coliform concentration in sewage	10×10^{6} cfu/100mL (USEPA 2001)
Conversion from mL to gal	3,758.2 mL/gal
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

gallon, gal; colony forming units, cfu; milliliter, mL; *Escherichia coli, E. coli*

Table 39. Bacteria loading assumptions for on-site sewage facilities (OSSFs) in the Deer Creek watershed.

Assumptions	
Subwatershed 1 Number of OSSFs	752
Subwatershed 2 Number of OSSFs	532
Subwatershed 3 Number of OSSFs	401
Failure rate	15% (NRCS 2019)
Average number of people per household in the watershed	2.52 (USCB 2010)

Assumptions	
Sewage discharge rate	70 gal/person/day (Borel et al. 2015)
Fecal coliform concentration in sewage	1.0×10^{6} cfu/100mL (USEPA 2001)
Conversion from mL to gal	3,758.2 mL/gal
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

gallon, gal; colony forming units, cfu; milliliter, mL; *Escherichia coli, E. coli*

The annual potential bacteria load from OSSFs for the Middle Yegua Creek watershed is 7.93×10^{15} cfu/yr. For the Davidson Creek watershed, the annual potential bacteria load from OSSFs is 4.79×10^{15} cfu/yr. For the Deer Creek watershed, the annual potential bacteria load from OSSFs is 3.85×10^{15} cfu/yr.

Feral Hog and Wildlife Bacteria Loading Estimates

Feral hog populations were estimated based on an assumed population density of 33.3 acres/hog (Wagner and Moench 2009) and acres of available habitat identified in the NLCD for each watershed. Potential bacteria loadings from feral hogs were estimated and the assumptions are in Table 40, Table 41 and Table 42. The potential annual bacteria load from feral hogs is:

$$\textit{Number of feral hogs} \times \textit{animal unit conversion} \times \textit{fecal coliform loading rate} \times \textit{conversion rate} \times \textit{365 days/yr}$$

Table 40. Bacteria loading assumptions for feral hogs in the Middle Yegua Creek watershed.

Assumptions	
Number of feral hogs in the watershed	8,053
Animal unit conversion factor for feral hogs	0.125
Fecal coliform production rate for feral hogs	1.21×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 41. Bacteria loading assumptions for feral hogs in the Davidson Creek watershed.

Assumptions	
Number of feral hogs in the watershed	3,932
Animal unit conversion factor for feral hogs	0.125
Fecal coliform production rate for feral hogs	1.21×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 42. Bacteria loading assumptions for feral hogs in the Deer Creek watershed.

Assumptions	
Number of feral hogs in the watershed	2,085
Animal unit conversion factor for feral hogs	0.125
Fecal coliform production rate for feral hogs	1.21×10^{9} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

The annual potential bacteria load from feral hogs for the Middle Yegua Creek watershed is 2.80×10^{14} cfu/yr. For the Davidson Creek watershed, the annual potential bacteria load from feral hogs is 1.37×10^{14} cfu/yr. For the Deer Creek watershed, the annual potential bacteria load from feral hogs is 7.25×10^{13} cfu/yr.

White-tailed deer populations were estimated from an assumed population density of 41.65 deer per 1,000 acres of suitable habitat for the Middle Yegua and Davidson Creek watersheds (data provided from TPWD). For the Deer Creek watershed, the assumed population density was 26.69 deer per 1,000 acres of suitable habitat. Potential bacteria loadings were estimated, and the assumptions are in Table 43, Table 44 and Table 45. The potential annual bacteria load from white-tailed deer is:

Number of white-tailed deer × animal unit conversion × fecal coliform loading rate × conversion rate × 365 days/yr

Table 43. Bacteria loading assumptions for white-tailed deer in the Middle Yegua Creek watershed.

Assumptions	
Number of white-tailed deer in the watershed	6,438
Animal unit conversion factor for white-tailed deer	0.112
Fecal coliform production rate for white-tailed deer	1.50×10^{10} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 44. Bacteria loading assumptions for white-tailed deer in the Davidson Creek watershed.

Assumptions	
Number of white-tailed deer in the watershed	3,144
Animal unit conversion factor for white-tailed deer	0.112
Fecal coliform production rate for white-tailed deer	1.50×10^{10} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

Table 45. Bacteria loading assumptions for white-tailed deer in the Davidson Creek watershed.

Assumptions	
Number of white-tailed deer in the watershed	2,602
Animal unit conversion factor for white-tailed deer	0.112
Fecal coliform production rate for white-tailed deer	1.50×10^{10} cfu/animal-day (Borel et al. 2015; Wagner and Moench 2009)
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform (Wagner and Moench 2009)

colony forming units, cfu; *Escherichia coli, E. coli*

The annual potential bacteria load from white-tailed deer for the Middle Yegua Creek watershed is 2.49×10^{15} cfu/yr. For the Davidson Creek watershed, the annual potential bacteria load from white-tailed deer is 1.21×10^{15} cfu/yr. For the Deer Creek watershed, the annual potential bacteria load from white-tailed deer is 1.01×10^{15} cfu/yr.

WWTF Bacteria Loading Estimates

Currently, one permitted WWTF operates in the Middle Yegua Creek watershed, two in the Davidson Creek watershed and two in the Deer Creek watershed. All are permitted to discharge wastewater effluent from treated household sewage and are required to monitor bacteria levels in their discharge. The bacteria loads were estimated at a worst-case scenario of full permitted discharge at 126 cfu/100mL *E. coli* (Table 46, Table 47, Table 48). The potential annual bacteria load from WWTFs is:

Maximum permitted discharge × bacteria concentration in sewage × conversion from mL to gal × conversion from gal to MGD × 365 days/yr

Table 46. Bacteria loading assumptions for wastewater treatment facilities in the Middle Yegua Creek watershed.

Assumptions	
Subwatershed 6 treated wastewater effluent discharged per day	0.2 MGD (USEPA 2019)
E. coli concentration in sewage	126 cfu/100mL
Conversion from mL to gal	3,758.2 mL/gal
Conversion from gal to MGD	10^6 gal/MGD

million gallons per day, MGD; colony forming units, cfu; milliliter, mL; gallon, gal

Table 47. Bacteria loading assumptions for wastewater treatment facilities in the Davidson Creek watershed.

Assumptions	
Subwatershed 2 treated wastewater effluent discharged per day	0.711 MGD (USEPA 2019)
Subwatershed 4 treated wastewater effluent discharged per day	0.3 MGD (USEPA 2019)
E. coli concentration in sewage	126 cfu/100mL
Conversion from mL to gal	3,758.2 mL/gal
Conversion from gal to MGD	10^6 gal/MGD

million gallons per day, MGD; colony forming units, cfu; milliliter, mL; gallon, gal

Table 48. Bacteria loading assumptions for wastewater treatment facilities in the Deer Creek watershed.

Assumptions	
Subwatershed 2 treated wastewater effluent discharged per day	0.105 MGD (USEPA 2019)
Subwatershed 3 treated wastewater effluent discharged per day	0.08 MGD (USEPA 2019)
E. coli concentration in sewage	126 cfu/100mL
Conversion from mL to gal	3,758.2 mL/gal
Conversion from gal to MGD	10^6 gal/MGD

million gallons per day, MGD; colony forming units, cfu; milliliter, mL; gallon, gal

The annual potential bacteria load from WWTFs for the Middle Yegua Creek watershed is 3.46×10^{11} cfu/yr. For the Davidson Creek watershed, the annual potential bacteria load from white-tailed deer is 1.75×10^{12} cfu/yr. For the Deer Creek watershed, the annual potential bacteria load from white-tailed deer is 3.20×10^{11} cfu/yr.