Technical Support Document for Five Total Maximum Daily Loads for Indicator Bacteria in the Thompsons Creek Watershed, Texas

Texas Water Resources Institute TR-545
January 2023

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make every drop count

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Prepared by:
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The U.S. Environmental Protection Agency and Texas Commission on Environmental Quality provided financial support for this study.

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Abbreviations

AU	Assessment Unit
AVMA	American Veterinary Medical Association
BMP	Best Management Practice
CCN	Certificate of Convenience and Necessity
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
cfu	Colony Forming Unit
CGP	Construction General Permit
CWA	Clean Water Act
DAR	Drainage-Area Ratio
E. coli	*Escherichia coli*
EPA	(United States) Environmental Protection Agency
FDC	Flow Duration Curve
FG	Future Growth
GAM	Generalized Additive Model
GHCN	Global Historical Climatology Network
HUC	Hydrologic Unit Code
LA	Load Allocation
LDC	Load Duration Curve
MGD	Million Gallons per Day
mL	Milliliter
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	On-Site Sewage Facility
SSO	Sanitary Sewer Overflow
SWMP	Storm Water Management Plan
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WBD	Watershed Boundary Dataset
WLA	Wasteload Allocation
WLA_{SW}	Wasteload Allocation from Regulated Stormwater
WLA_{WWTF}	Wasteload Allocation from Wastewater Treatment Facilities
WWTF	Wastewater Treatment Facility

Introduction

Background

Section 303(d) of the federal Clean Water Act (CWA) requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time but may be expressed in other ways.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The program's primary objective is to restore and maintain water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

TCEQ first identified bacteria impairments within Thompsons Creek in the *2002 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (TCEQ 2002) and within Cottonwood Branch and Still Creek in the 2006 Texas Integrated Report (TCEQ 2006). Bacteria impairments have been identified in each subsequent edition through 2020, e.g., the EPA-approved 2020 Texas Integrated Report (TCEQ 2020).

This document will consider five bacteria impairments in five assessment units (AUs) of the Cottonwood Branch, Still Creek, and Thompsons Creek. The impaired AUs and their identifying numbers are:

- Cottonwood Branch (1242B_01, 1242B_02)
- Still Creek (1242C_01)
- Thompsons Creek (1242D_01, 1242D_02)

Water Quality Standards

To protect public health, aquatic life, and the development of industries and economies throughout Texas, TCEQ established the *Texas Surface Water Quality Standards* (TCEQ 2018a). The Standards describe the limits for indicators that are monitored to assess the quality of available water for specific uses. TCEQ monitors and assesses water bodies based on these Standards and publishes the Texas Integrated Report list biennially.

The Standards are rules that do all of the following:

- Designate the uses, or purposes, for which the state's water bodies should be suitable
- Establish numerical and narrative goals for water quality throughout the state

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

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

- Aquatic life use
- Contact recreation
- Domestic water supply
- General use

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

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

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

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

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

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

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

Still Creek and Thompsons Creek are freshwater streams that have primary contact recreation 1 uses (TCEQ 2018a). The associated criterion for *E. coli* is a geometric mean of 126 cfu per 100 mL. Cottonwood Branch is a freshwater stream and has a secondary contact recreation 1 use (TCEQ 2018b), with a geometric mean criterion for *E. coli* of 630 cfu per 100 mL.

Report Purpose and Organization

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

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

Historical Data Review and Watershed Properties

Description of Study Area and Impairment Overview

The Thompsons Creek, Still Creek, and Cottonwood Branch watersheds (collectively termed Thompsons Creek watershed in this report) span nearly 33,297 acres in Brazos County (Table 1, Figure 1). Cottonwood Branch consists of a single segment (1242B) and two AUs (1242B_01 and 1242B_02). The downstream AU (AU 1242B_01) receives flows from AU 1242B_02 and an unnamed tributary (Segment 1242G) before joining Still Creek (Segment 1242C). Still Creek is a tributary of Thompsons Creek (Segment 1242D), draining largely the western part of the City of Bryan. Still Creek is composed of two AUs (1242C_01 and 1242C_02). AU 1242C_02 receives flows from the upstream portion of Still Creek and from segment 1242B. Segment 1242B is composed of two AUs (1242D_01 and 1242D_02).

The 2020 Texas Integrated Report (TCEQ 2020) has the following water body and AU descriptions:

- Segment 1242B (Cottonwood Branch) – Intermittent stream with perennial pools from the confluence with Still Creek upstream 0.95 km to the confluence with an unnamed tributary.
    - AU 1242B_01 – Portion of Cottonwood Branch from confluence with Still Creek upstream to an unnamed tributary in Brazos County.

  - AU 1242B_02 – Portion of Cottonwood Branch from confluence with unnamed tributary upstream to headwaters in Brazos County.

- Segment 1242C (Still Creek) – Perennial stream from the confluence with Thompsons Creek upstream to the headwaters in Brazos County near US 190.
  - AU 1242C_01 – Portion of Still Creek from confluence with Thompsons Creek in Brazos County upstream to confluence with unnamed tributary.
  - AU 1242C_02 – Portion of Still Creek from confluence with Cottonwood Branch upstream to headwaters in Brazos County near US 190.

- Segment 1242D (Thompsons Creek) – From the confluence of the Brazos River upstream to the confluence of Thompsons Branch, north of FM 1687.
  - AU 1242D_01 – Thompsons Creek an Appendix D perennial stream from the confluence of the Brazos River upstream to the confluence of Sill Creek in Brazos County.
  - AU 1242D_02 – Thompsons Creek an Appendix D intermittent stream with perennial pools from the confluence of Still Creek upstream to the confluence of Thompsons Branch, north of FM 1687.

- AU 1242G (Unnamed Tributary of Cottonwood Branch) – Intermittent stream with perennial pools from the confluence with Cottonwood Branch upstream to the headwaters.

- 1242G_01 – Intermittent stream with perennial pools from the confluence with Cottonwood Branch upstream to the headwaters.

In the 2020 Texas Integrated Report (TCEQ 2020), both Cottonwood Branch and Thompsons Creek AUs, and AU 1242C_02 on Still Creek are listed as impaired for bacteria. AU 1242D_02 on Thompsons Creek is impaired for dissolved oxygen (DO), whereas AU 1242C_02 has concerns for depressed DO. AUs on Cottonwood Branch have nutrient concerns for nitrate and total phosphorous. AUs on Thompsons Creek also have concerns of ammonia, chlorophyll-a, nitrate, total phosphorous, impaired fish community, and impaired microbenthic community.

This document addresses the bacteria impairment for waterbodies in the Thompsons Creek watershed. Throughout this document, the entire area drained by Thompson Creek and its tributaries will be referred to variously as the “Thompsons Creek watershed,” the “project watershed,” and occasionally just “watershed” when the area discussed is clear from context. Watersheds for individual AUs will be identified by their AU identification numbers (IDs) (e.g., AU 1242B_02 Watershed) or as TMDL watersheds. Segment IDs (e.g., 1242B Watershed) are appended when discussing segment watersheds

In the US Geological Survey's (USGS) Watershed Boundary Dataset (WBD), the Thompson Creek watershed is a 34,284-acre hydrologic unit with the hydrologic unit code (HUC)[1] 120701010702. The HUC watershed boundary includes the area covered by Lake Bryan. Using ArcGIS, the watershed boundary used in this document that excludes Lake Bryan was delineated from the most

[1] The United States is sub-divided successively into nested hydrologic units (HU). Each HU is identified by a unique hydrologic unit code (HUC).

downstream point on AU 1242D_01 using the National Hydrography Dataset (NHD) 10-meter elevation dataset (USGS 2019a).

Table 1. Segments and assessment units in the Thompsons Creek watershed.

Segment name	Segment ID	AU ID	AU length (miles)	AUs impaired for bacteria	AU watershed area (acres)	AU total contributing drainage area (acres)
Cottonwood Branch	1242B	1242B_01	0.78	1242B_01	107	4,147
		1242B_02	6.05	1242B_02	2,419	2,419
Still Creek	1242C	1242C_01	0.66	-	75	10,645
		1242C_02	8.30	1242C_02	6,423	6,423
Thompsons Creek	1242D	1242D_01	7.22	1242D_01	7,083	33,297
		1242D_02	5.38	1242D_02	15,568	15,568
Unnamed tributary of Cottonwood Branch	1242G	1242G_01	5.11	-	1,621	1,621
		Total			33,297	

AU = assessment unit
ID = identification number

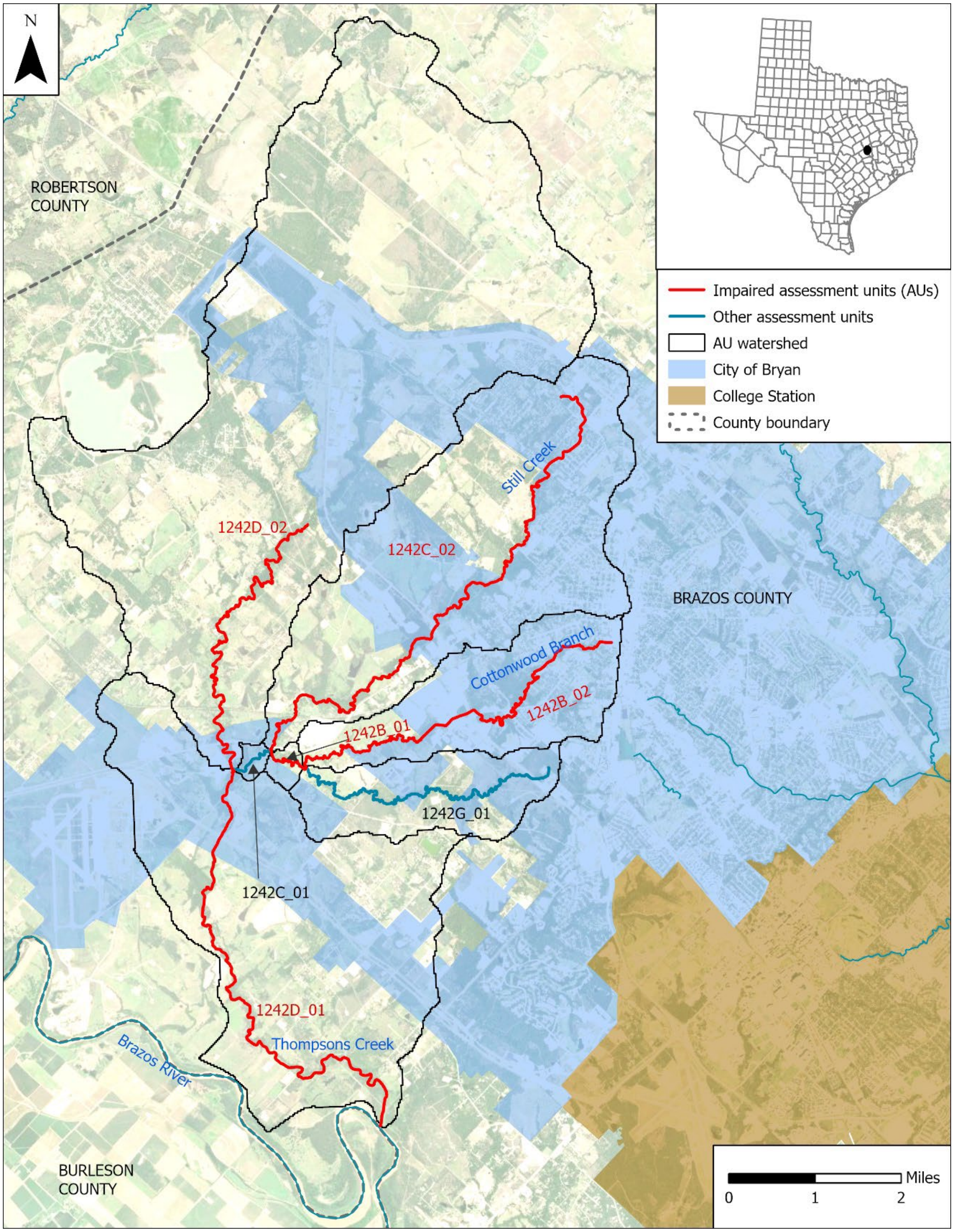


Figure 1. Overview map of the Thompsons Creek watershed.

The unnamed tributary of cottonwood Branch (AU 1242G_01) and the lower portion of Still reek below its confluence with Cottonwood Branch (AU 1242C_01) (Table 1, Figure 1) are currently not listed as impaired. Being upstream of other impaired AUs, loadings from these AU watersheds have a bearing on the water quality of downstream impaired watersheds. For TMDL assessments, and in line with previous technical reports that covered the project area (Gitter et al. 2020, Schramm et al. 2022), the AU watershed boundary for AU 1242B_01 includes AU 1242G_01. Similarly, the boundary for AU 1242D_01 includes AU 1242C_01 (Table 2, Figure 2). The configuration allows for the monitoring of stream flows from the two unmonitored assessment units (1242C_01 and 1242G_01). As shown in Figure 2, the closest downstream surface water quality monitoring (SWQM) station for monitoring flows from AU 1242G_01 watershed is SWQM station 17598 on AU 1242B_01. SWQM station 16882 is downstream of AU 1242C_01.

Table 2. Configuration of TMDL assessment units in the Thompsons Creek watershed.

TMDL Assessment unit	Watershed area (acres)	Total contributing drainage area (acres)
1242B_01	1,728	4,147
1242B_02	2,419	2,419
1242C_02	6,423	6,423
1242D_01	7,158	33,297
1242D_02	15,568	15,568

Review of Routine Monitoring Data

Analysis of Bacteria Data

E. coli data collected at SWQM stations in the watershed (Figure 2) were used to determine attainment of the primary contact recreation 1 uses for Still Creek and Thompsons Creek, and secondary contact recreation 1 use for Cottonwood Branch, as reported in the 2020 Texas Integrated Report (Table 3).

The analysis of historical routine monitoring data agrees with the 2020 Texas Integrated Report and indicates non-support of the primary contact recreation 1 use for Aus on Still Creek and Thompsons Creek. The secondary contact recreation 1 use criterion is not met for only AU 1242B_01 on Cottonwood Branch. The geometric mean value for long-term historical data (Table 4) for AU 1242B_02 is below the secondary contact recreation 1 use criterion (630 cfu/100 mL).

Table 3. 2020 Texas Integrated Report summary for *E .coli* concentrations in the Thompsons Creek watershed.

Segment name	AU ID	Criteria cfu/100mL)	Number of samples	Period of analysis	Geometric mean (cfu/100 mL)
Cottonwood Branch	1242B_01	630	9	12/01/11 – 11/30/18	1294.96
	1242B_02	630	10	12/01/11 – 11/30/18	130.40
Still Creek	1242C_02	126	18	12/01/11 – 11/30/18	277.04
Thompsons Creek	1242D_01	126	27	12/01/11 – 11/30/18	924.55
	1242D_02	126	-	12/01/11 – 11/30/18	-

AU = assessment unit
ID = identification number
cfu/100 mL = colony forming units per 100 milliliters

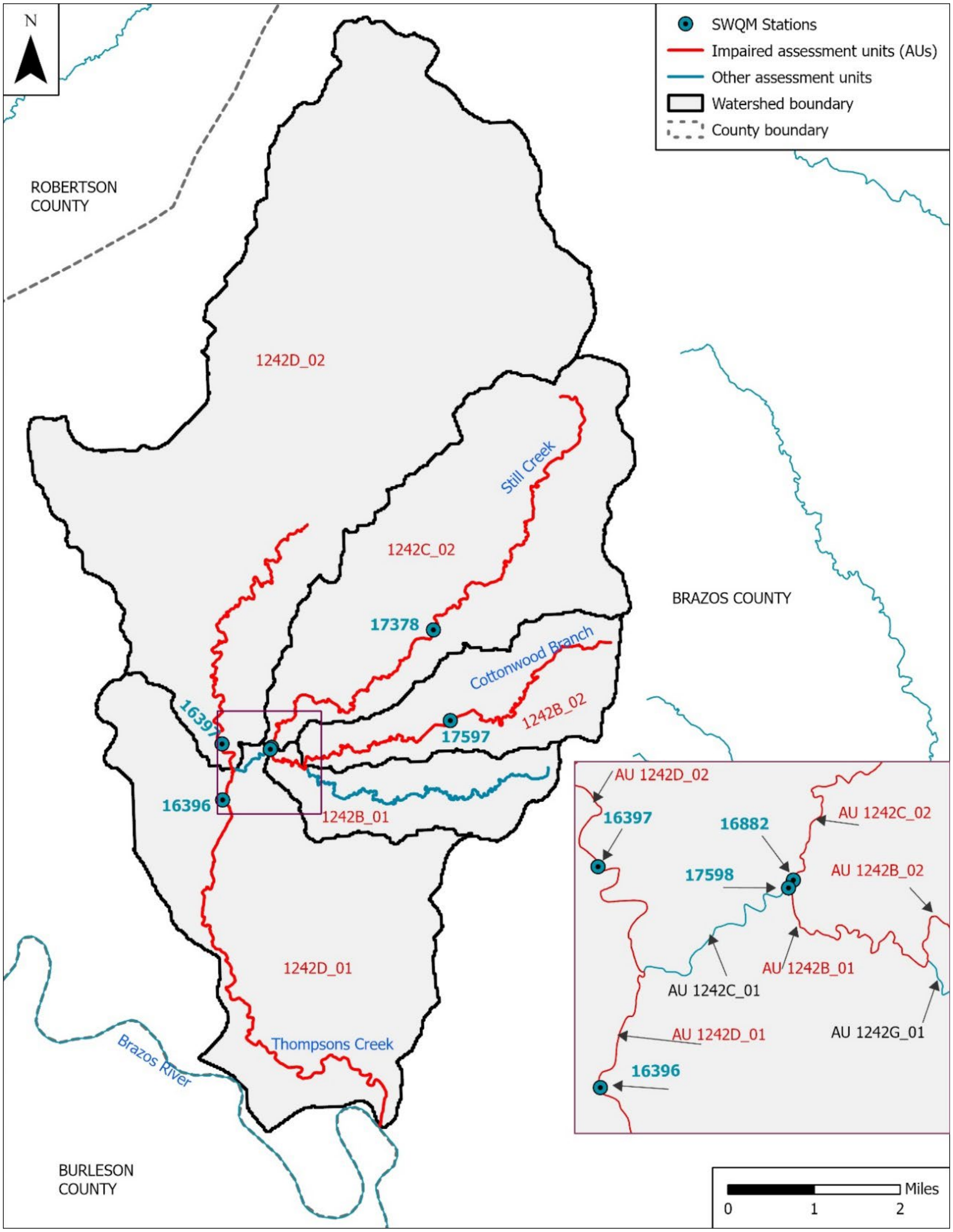


Figure 2. Surface water monitoring (SWQM) stations and TMDL assessment unit boundaries in the Thompsons Creek watershed.

Table 4. *E. coli* sampling history and analysis in the Thompsons Creek watershed (2003-2021).

Assessment unit	SWQM station	Number of samples	Period of analysis	Geometric mean (cfu/100 mL)
1242B_01	17598	51	01/01/03 – 06/30/21	1408
1242B_02	17597	45	01/01/03 – 06/30/21	157
1242C_02	16882	52	01/01/03 – 06/30/21	375
1242D_01	16396	86	01/01/03 – 06/30/21	1042
1242D_02	16397	30	01/01/03 – 06/30/21	357

cfu/100 mL = colony forming units per 100 milliliters
SWQM = surface water quality monitoring

Watershed Climate

The National Oceanic and Atmospheric Administration (NOAA) station located in the watershed with long-term climatic data, the Global Historical Climatology Network (GHCN) daily Station US1TXBZS088 (Bryan 3.5 NNW, TX US), and the adjacent GHCN station in College Station; USW00003904 (College Station Easterwood Field, TX US) were used for retrieving climatic data.

The Bryan 3.5 NNW Station was used for precipitation data as it is located within the Thompsons Creek watershed and has consistent records of precipitation data (but no temperature data) from 2014 through 2021. The College Station Easterwood Field Station is the only station in the area with consistent long-term temperature data records. Both daily summaries of temperature and rainfall data were retrieved from the GHCN-daily dataset (Menne et al. 2012) for the 2014 through 2020 period.

The average monthly low temperatures range from 41.0^{o}F (January) to 75.5^{o}F (July), and the monthly average highs range from 61.8^{o}F (January) to 95.9^{o}F (August). The average monthly precipitation ranges from 2.0 to 7.9 inches, with the greatest precipitation occurring in May and the lowest precipitation occurring in February (Figure 3). From 2014 through 2021, the average annual precipitation was 47.1 inches, with a low of 37.6 inches occurring in 2014 and a high of 54.1 occurring in 2018 (Figure 4).

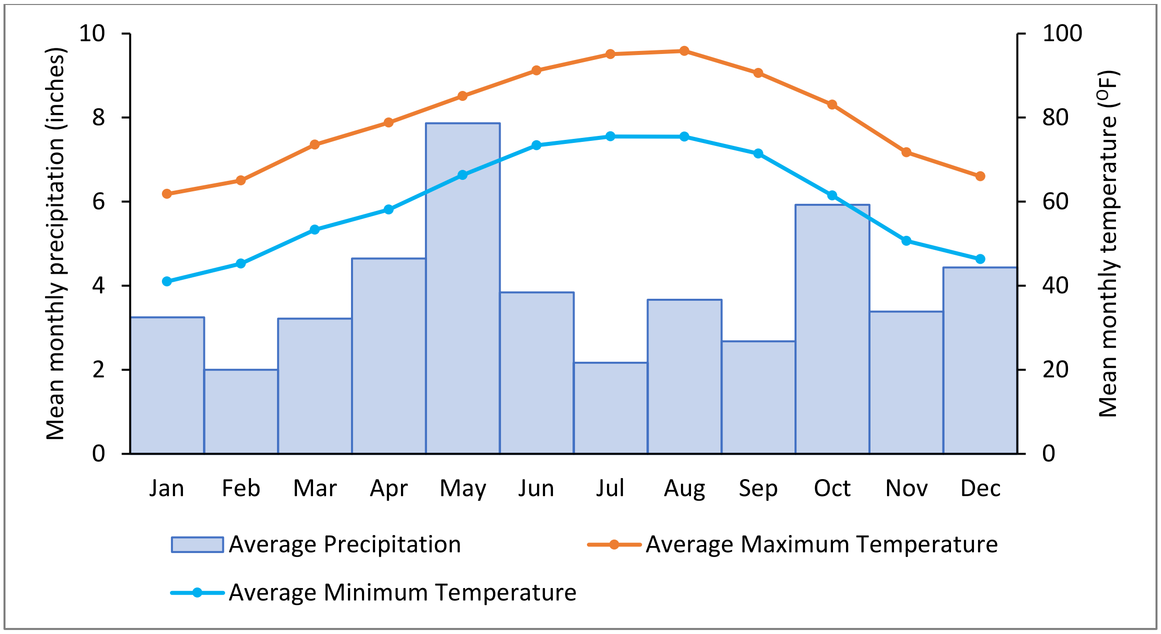


Figure 3. Average monthly temperature and precipitation (2014–2021) in Bryan/College Station area, Texas.

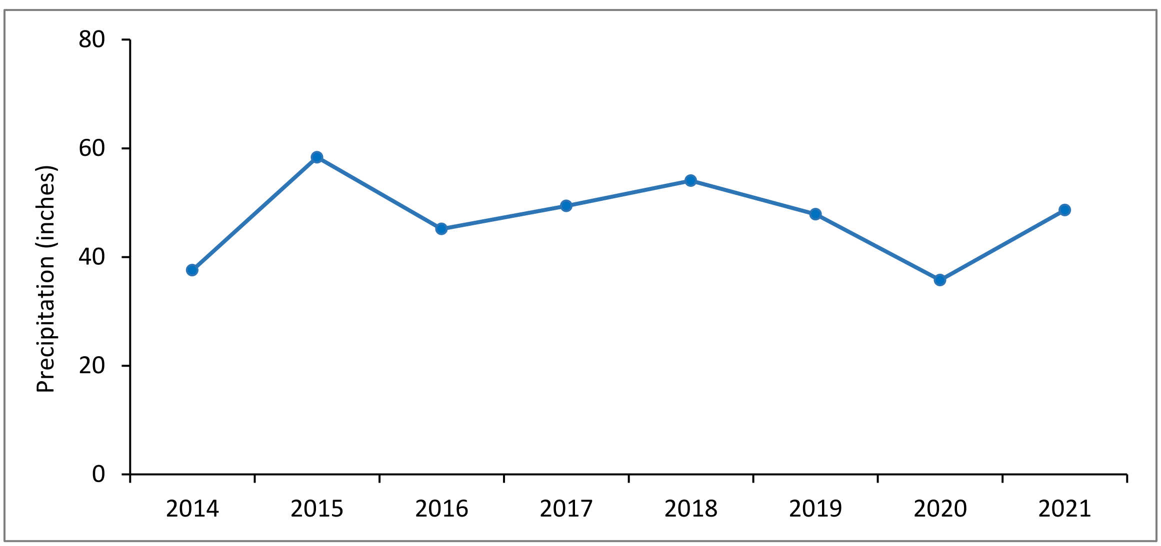


Figure 4. Annual precipitation totals (2014–2021) at Global Historical Climatology Network Daily Station US1TXBZS08, Bryan, Texas.

Land Cover

Land cover data was derived from the 2019 National Land Cover Database (NLCD) (USGS 2019b). The NLCD is a nationwide data set classifying all lands into several LULC categories. Table 5 lists the land cover types represented in the database for the Thompsons Creek watershed.

Table 5. Description of National Land Cover Database (NLCD) land cover level II classes found in the Thompsons Creek watershed.

Classification	Description
Open water	Areas of open water, generally with less than 25% cover of vegetation or soil
Developed, open space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes
Developed, low intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.
Developed, medium intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of total cover. These areas most commonly include single-family housing units.
Developed, high intensity	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, rowhouses, and commercial/industrial. Impervious surfaces account for 80% to 100% of 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 five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change
Evergreen forest	Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the species maintain their leaves all year. Canopy is never without green foliage
Mixed forest	Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrub/scrub	Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
Grasslands/ herbaceous	Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing
Hay/pasture	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Woody wetlands	Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent herbaceous wetlands	Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil substrate is periodically saturated with or covered with water.

Spatial analysis of the dataset found that within the project area watershed, the dominant landcover is pasture/hay (Figure 5, Table 6). Pasture/hay landcover type accounts for over half of the watershed area (52.7%). AUs 1242B_02 and 1242C_02 drain parts of the City of Bryan and their watersheds are predominantly developed lands (67.1% and 44.3%, respectively). The primary land cover in AUs 1242B_01, 1242D_01, and 1242d_02 is Pasture/Hay (Table 6).

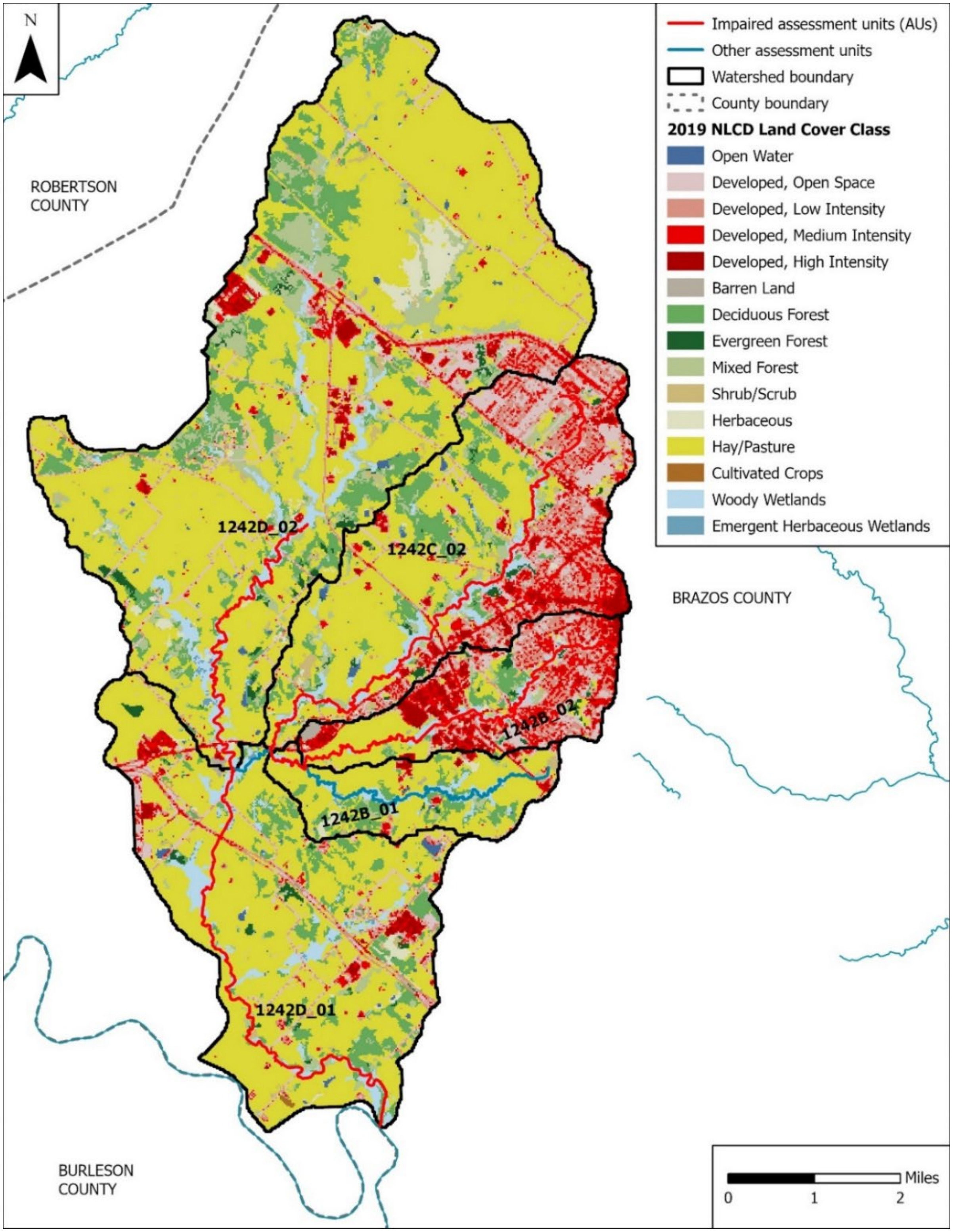


Figure 5. Land use and land cover classifications in the Thompsons Creek watershed, Texas, in 2019.

Table 6. Acreage for land cover classes in the Thompsons Creek watershed in 2019.

Land cover category	Assessment unit land cover area (percent acreage)					
	1242B_01	1242B_02	1242C_02	1242D_01	1242D_02	Total
Open Water	0.36	0.01	0.47	0.59	0.35	0.40
Developed, Open Space	2.18	14.45	12.92	5.68	4.73	7.09
Developed, Low Intensity	3.03	20.50	16.02	4.56	3.48	7.34
Developed, Medium Intensity	3.53	23.10	12.36	3.14	2.85	6.26
Developed, High Intensity	1.49	9.09	3.02	1.29	1.09	2.11
Barren Land	0.24	1.11	0.15	0.21	0.18	0.25
Deciduous Forest	14.27	4.45	8.37	9.51	10.62	9.69
Evergreen Forest	0.33	1.35	1.09	1.05	0.77	0.91
Mixed Forest	3.09	2.75	4.26	2.01	7.87	5.30
Shrub/Scrub	1.32	0.62	1.04	0.40	0.91	0.83
Grasslands/ Herbaceous	1.96	0.62	0.39	0.98	2.57	1.64
Hay/Pasture	57.04	17.42	34.40	63.49	60.40	52.75
Cultivated Crops	0.00	0.00	0.00	0.11	0.00	0.02
Woody Wetlands	10.80	4.44	5.25	6.62	3.92	5.15
Emergent Herbaceous Wetlands	0.35	0.08	0.26	0.36	0.25	0.27
Total	100.00	100.00	100.00	100.00	100.00	100.00

Soils

Soil data was obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) gridded Soil Survey Geographic (gSSURGO) database (Soil Survey Staff 2021). The SSURGO data assigns different soils to one of seven possible runoff potential classifications or hydrologic groups. These classifications are based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The four main groups are A, B, C, and D, with three dual classes (A/D, B/D, C/D). The gSSURGO database defines the classifications below.

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

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

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

Soils within the Thompsons Creek watershed are primarily categorized as group D soils (Figure 6, Table 7). In each of the assessment unit watersheds, group D soils cover over 70% of the watershed area. When wet, group D soils have a higher runoff potential, and water movement is restricted in the soils. Therefore, given the high percent coverage of group D soils in the watershed, runoff generation potential across the watershed is high.

Table 7. Summary of the hydrologic soil groups in the Thompsons Creek watershed.

Soil group	Assessment unit soil group area (percent acreage)					
	1242B_01	1242B_02	1242C_02	1242D_01	1242D_02	Total
A	1.53	0.57	8.32	3.65	6.42	5.51
B	3.06	0.00	1.07	10.17	3.08	3.99
C	8.58	11.07	28.90	15.12	17.64	18.32
D	86.83	88.36	61.71	71.06	72.86	72.17
Total	100.00	100.00	100.00	100.00	100.00	100.00

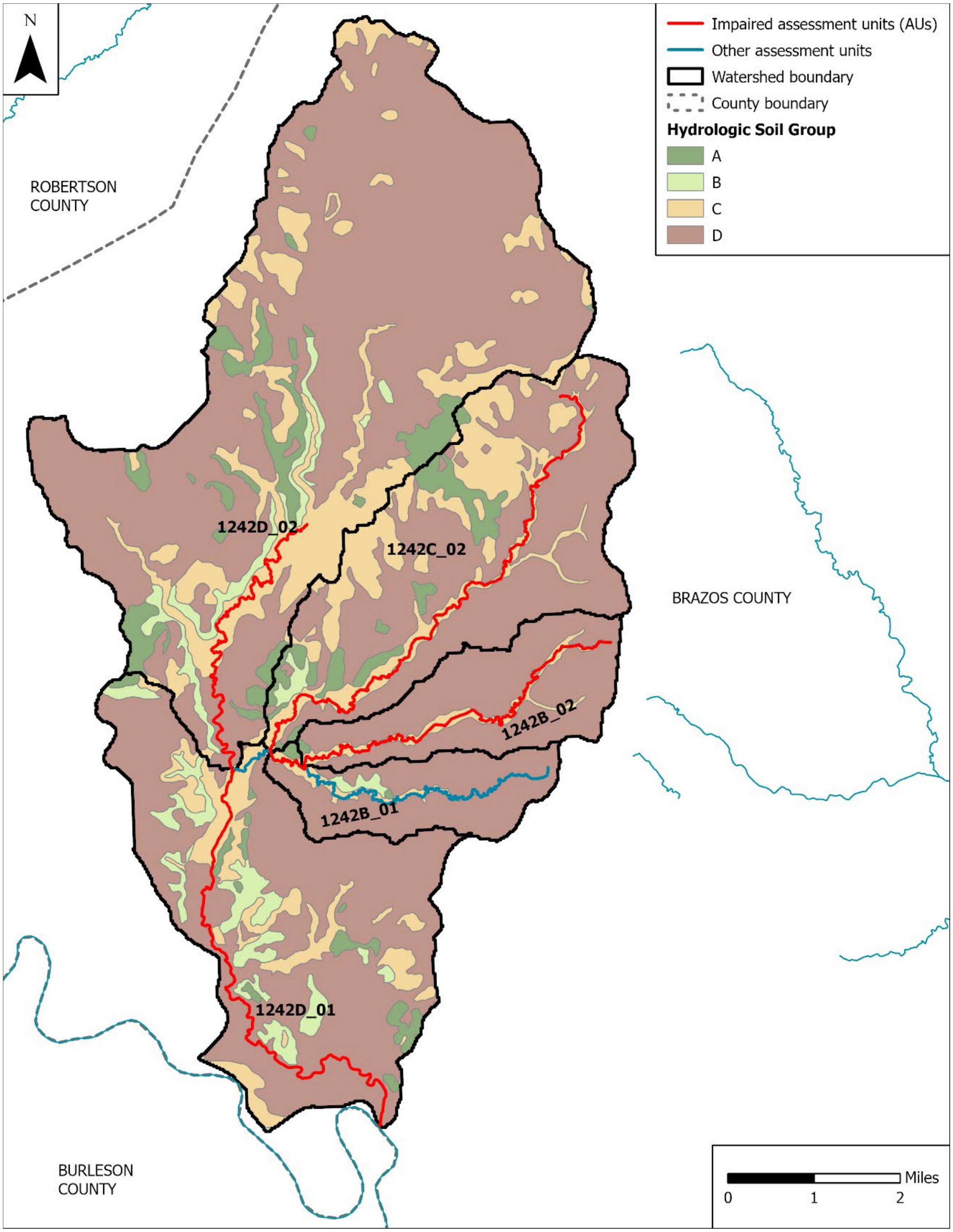


Figure 6. Spatial distribution of hydrologic soil groups in the Thompsons Creek watershed.

Population and Population Projections

Watershed population estimates were developed using the United States Census Bureau (USCB) 2020 census blocks data (USCB 2020a) and 2020 decennial population data (USCB 2020b). Census blocks are the smallest geographic units used by USCB to tabulate population data. The Thompsons Creek project area includes 669 census blocks located entirely or partially within the watershed. The population was estimated for those census blocks partially located in the watershed by multiplying the census block population and the percentage of each block within the watershed. It was assumed for this estimation that the population was evenly distributed within a census block. These estimated partial census block populations were then summed with populations from the census blocks located entirely within the watershed. Following this approach, the population in the Thompsons Creek watershed was estimated to be about 25,399 in 2020 (Table 8). Population density is highest in the eastern parts of Cottonwood Branch and Still Creek watersheds located in the City of Bryan (Figure 7). With approximately 7,600 occupied households in the watershed, the number of people per household in the watershed was estimated to be 3.35.

Table 8. Population estimates and distribution in the Thompsons Creek watershed in 2020.

Assessment unit	1242B_01	1242B_02	1242C_02	1242D_01	1242D_02	Total
Watershed area (square miles)	2.70	3.78	10.04	11.19	24.33	52.03
Population	542	7,638	12,717	1,074	3,428	25,399
Population per square mile	201	2,020	1,267	96	141	488*

* Average value

The Texas Water Development Board (TWDB) regional water plan population and water demand projections (TWDB 2021) provide decadal population projections for counties within Texas from 2020 through 2070. The Thompsons Creek watershed is fully located within Brazos County; thus, the county population growth rates for Brazos County (Table 9) were presumed to be appropriate for the project area. Decadal population percentage increase rates based on published TWDB population projections were applied to the 2020 decennial census population estimates to determine future population projections for the project area (Table 9).

Table 9. Population projections for Thompsons Creek watershed, 2020–2070.

	2020	2030	2040	2050	2060	2070
TWDB population projections, Brazos County	227,654	282,453	342,487	401,051	433,781	484,546
Decadal population increase (percent), Brazos County	-	24	21	17	8	12
Population estimates, AU 1242B_01	542*	672	813	951	1,028	1,151
Population estimates, AU 1242B_02	7,638*	9,471	11,460	13,408	14,481	16,219
Population estimates, AU 1242C_02	12,717*	15,769	19,081	22,324	24,110	27,003
Population estimates, AU 1242D_01	1,074*	1,332	1,611	1,885	2,036	2,281
Population estimates, AU 1242D_02	3,428*	4,251	5,143	6,018	6,499	7,279
Population estimates, Thompsons Creek watershed	25,399	31,495	38,109	44,587	48,154	53,933

* 2020 population estimates for Thompson Creek are based on the 2020 decennial census population estimates

AU: Assessment unit

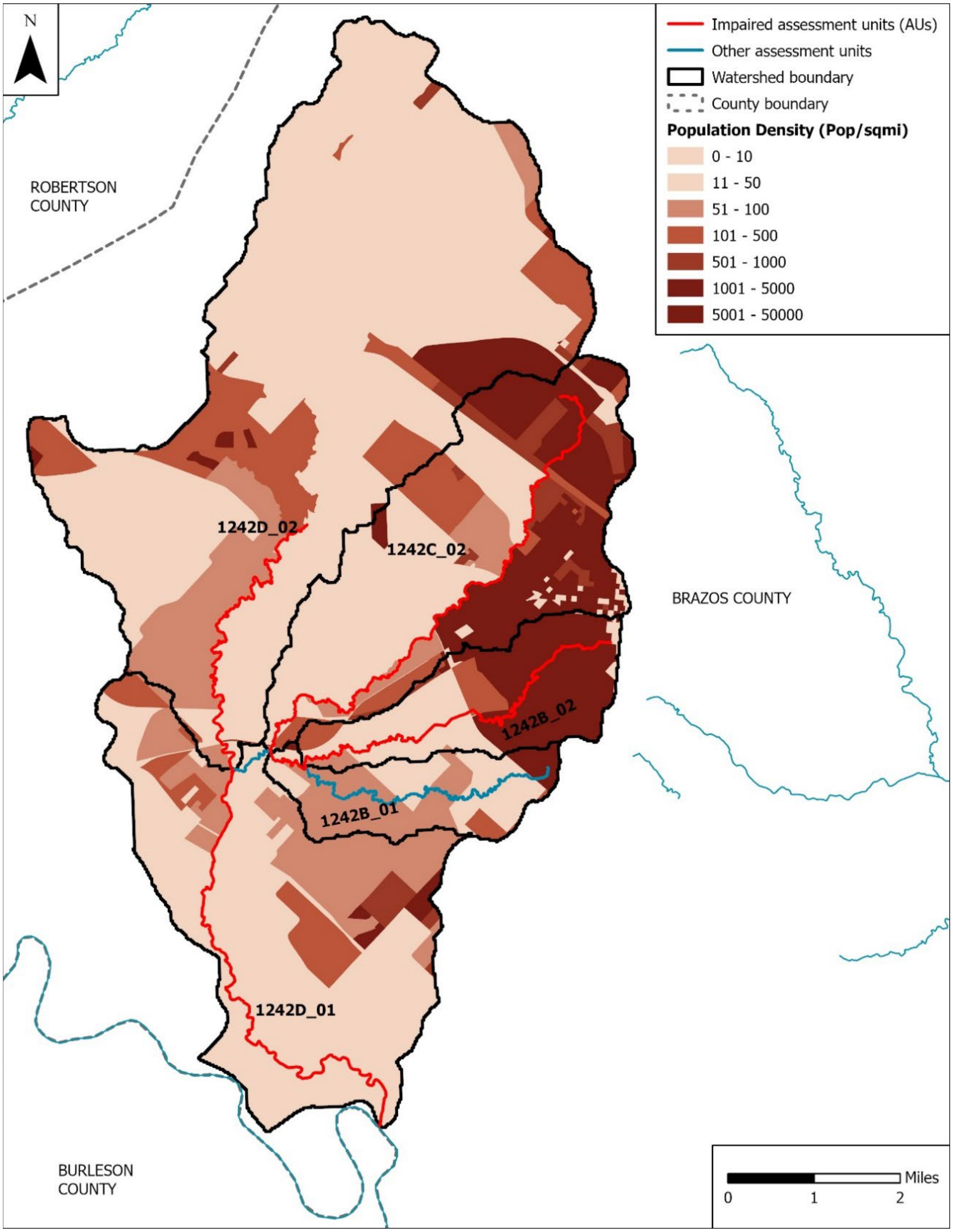


Figure 7. Population density (population per square mile, pop/sqmi) in the Thompsons Creek watershed.

Potential Sources of Fecal Indicator Bacteria

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are controlled by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. WWTFs and stormwater discharges from industrial sites, regulated construction activities, and the separate storm sewer systems of cities are considered point sources of pollution.

Unregulated sources are typically nonpoint sources in origin, meaning the pollutants originate from multiple locations, and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permits.

Except for WWTFs, which receive individual wasteload allocations (WLAs) (see the "WLA" section), the regulated and unregulated sources in this section are presented to give a general account of the various sources of bacteria expected in the watershed. These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the Thompsons Creek watershed include WWTF outfalls, stormwater discharges from industrial and regulated construction sites, and concrete production.

Domestic and Industrial Wastewater Treatment Facilities

As of December 2021, there are three facilities with individual TPDES permits that discharge within the Thompsons Creek project area (TCEQ 2022b). The Riverside WWTF and the Still Creek WWTF treat domestic wastewater with discharge limits of 0.045 million gallons per day (MGD) and 4.0 MGD, respectively. Sanderson Farms, Inc. treats industrial wastewater associated with poultry processing and has a discharge limit of 1.678 MGD (Table 10).

Table 10. Summary of permitted wastewater treatment facilities in the Thompsons Creek watershed.

Receiving assessment unit	TPDES/NPDES Number	Facility	Outfall number	Bacteria limits (cfu/100 ml)	Primary discharge type	Daily average flow – permitted discharge (mgd)	Daily average flow – recent discharge (mgd)
1242D_01	WQ0011778001/ TX0071145	Riverside WWTF	001	126	Treated domestic wastewater	0.045	0.018
1242C_02	WQ0010426002/ TX0025071	Still Creek WWTF	001	126	Treated domestic wastewater	4.000	1.72
1242B_01	WQ0003821000/ TX0113603	Sanderson Farms, Inc.	001	126	Poultry processing wastewater	1.678	0.925

TPDES: Texas Pollutant Discharge Elimination System
NPDES: National Pollutant Discharge Elimination System
MGD: million gallons per day

Recent average discharges (MGD) between January 1, 2017–December 31, 2021

General Wastewater Permits

In addition to the individual wastewater discharge permits, certain types of activities must be covered by one of several TCEQ/TPDES wastewater general permits:

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

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

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

A review of active general permits (TCEQ 2022d) in the Thompsons Creek watershed, as of December 2021, found four general authorizations for concrete production facilities (Table). These facilities do not have bacteria requirements or limits in their permits. The permits authorize the discharge of stormwater and are implicitly included in the regulated stormwater allocations. No other active general permits with a potential bacteria loading were found for the Thompsons Creek watershed

Table 11. Active stormwater general permits in the Thompsons Creek watershed.

TCEQ permit number	Permittee	Facility Name	Authorization Type	Receiving Segment
TXG111340	TXI Operations, LP	TXI Bryan Independence Ready Mix	Concrete Production	Cottonwood Branch
TXG111947	Boyd Ready Mix, Inc.	BRM 4/Bryan Plant	Concrete Production	Thompsons Creek
TXG112144	Texcrete, Inc.	Bryan CBP	Concrete Production	Thompsons Creek
TXG112963	Knife River Corporation – South	Bryan Material Yard	Concrete Production	Cottonwood Branch

TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES-regulated discharge permit and stormwater originating from areas not under a TPDES -regulated discharge permit.

Stormwater discharges fall into two categories:

- Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated municipal separate storm sewer system (MS4) entities, stormwater discharges associated with regulated industrial activities, and construction activities
- Stormwater runoff not subject to regulation.

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

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

- Public education, outreach, and involvement
- Illicit discharge detection and elimination
- Construction site stormwater runoff control
- Post-construction stormwater management in new development and redevelopment
- Pollution prevention and good housekeeping for municipal operations
- Industrial stormwater sources

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

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

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

As of December 2021, TCEQ Central Registry indicates there is one active Phase II MS4 permit held by the City of Bryan, one pending Phase II MS4 permit by Brazos County, and 35 MSGP permits (Table 12) (TCEQ 2022d). The area of regulated stormwater is approximately

12.39 square miles or 23.8% of the Thompsons Creek watershed. Due to the short-term and economy-driven nature of construction permits, a search of active, terminated, and expired CGPs was conducted from January 2019 to December 2021.

Table 12. Summary of permitted wastewater treatment facilities in the Thompsons Creek watershed.

TPDES Permit Number	Permittee	Facility	Authorization Type	Receiving Segment	Status
TXR040336	City of Bryan	N/A	MS4	Cottonwood Branch	Active
TXR040663	Brazos County	N/A	MS4	Still Creek	Pending
TXR05AA03	Brazos Valley Solid Waste Management Agency, Inc.	City of Bryan Composting Facility	MSGP	Still Creek	Active
TXR05AL43	Olegario Cruz	Cruz Salvage Yard	MSGP	Still Creek	Active
TXR05AL68	Knife River Corporation – South	Bryan Material Yard	MSGP	Cottonwood Branch	Active
TXR05AZ74	Bryan Iron & Metal, Ltd.	Bryan Iron & Metal	MSGP	Still Creek	Active
TXR05BF57	S-CON, Inc.	S-CON	MSGP	Thompsons Creek	Active
TXR05BI60	Machine Works, Incorporated	Machine Works Inc	MSGP	Cottonwood Branch	Active
TXR05BI74	LiquidPower Specialty Products Inc.	Phillips Specialty Products	MSGP	Cottonwood Branch	Active
TXR05BJ53	Cobra Protective Coatings, LLC	Cobra Protective Coatings	MSGP	Still Creek	Active
TXR05BL97	Toyo Ink International Corporation	Bryan Industrial Park	MSGP	Thompsons Creek	Active
TXR05BP47	C&J Well Services, Inc.	C&J Bryan	MSGP	Thompsons Creek	Active
TXR05BQ31	City of Bryan	Thompsons Creek WWTP	MSGP	Thompsons Creek	Active
TXR05BQ65	G M Y, Ltd.	Brickyard Metal Recycling	MSGP	Still Creek	Active
TXR05BY60	Enterprise Crude Oil, LLC	Enterprise Crude Oil – Bryan	MSGP	Still Creek	Active
TXR05BZ67	Alenco Extrusion Management, LLC	New Alenco Extrusion	MSGP	Thompsons Creek	Active
TXR05CH71	Axis Pipe and Tube Inc.	Axis Pipe and Tube	MSGP	Thompsons Creek	Active
TXR05CQ98	Brazos Paving, Inc.	BPI Yard	MSGP	Thompsons Creek	Active
TXR05CT98	Bryan Auto Recycling, Sales, & Glass, LLC	Bryan Auto Recycling Sales & Glass	MSGP	Thompsons Creek	Active
TXR05CU02	Terrabon Research Company, LLC	Demonstration Plant	MSGP	Thompsons Creek	Active
TXR05CU78	Kelly Burt Dozer	Kelly Burt Dozer Inc	MSGP	Thompsons Creek	Active
TXR05CW25	Axis Pipe and Tube Inc.	Axis Pipe and Tube	MSGP	Thompsons Creek	Active

TPDES Permit Number	Permittee	Facility	Authorization Type	Receiving Segment	Status
TXR05DA29	Saint-Gobain Ceramics & Plastics, Inc.	Bryan Ceramics Plant	MSGP	Cottonwood Branch	Active
TXR05DL05	Honeywell Electronic Chemicals LLC	Honeywell Electronic Chemicals Bryan Plant	MSGP	Thompsons Creek	Active
TXR05DO75	Coca-Cola Southwest Beverages LLC	Bryan Distribution Center	MSGP	Thompsons Creek	Active
TXR05DR86	Texas Commercial Waste, L.L.C.	M Lipsitz and Company Texas Commercial Waste	MSGP	Still Creek	Active
TXR05EM64	Mid South Baking Company LLC	Mid South Baking	MSGP	Thompsons Creek	Active
TXR05EP01	Rod And Tubing Services, LLC	Rod And Tubing Services	MSGP	Still Creek	Active
TXR05EV81	Texcrete, Inc.	College Station CBP	MSGP	Still Creek	Active
TXR05EV82	Texcrete, Inc.	Bryan CBP	MSGP	Still Creek	Active
TXR05EW11	Hasa, Inc.	HASA	MSGP	Thompsons Creek	Active
TXR05EY16	City of Bryan	Thompson Creek WWTP	MSGP	Thompsons Creek	Active
TXR05EY17	City of Bryan	Still Creek WWTP	MSGP	Still Creek	Active
TXR05M769	Sanderson Farms, Inc. (Production Division)	Sanderson Farms	MSGP	Cottonwood Branch	Active
TXR05Q530	City of Bryan	Still Creek WWTP	MSGP	Still Creek	Active
TXR05W509	North America Packaging Corporation	North America Packaging	MSGP	Cottonwood Branch	Active
TXR05Z618	Texas Steel Conversion, Inc.	Texas Steel Conversion Bryan Plant	MSGP	Cottonwood Branch	Active
TXR15013P	Collier Construction, LLC	Brazos County Juvenile Justice Center	Construction	Still Creek	Terminated
TXR1507AB	Legend Classic Homes, Ltd.	Leonard Crossing Subdivision	Construction	Cottonwood Branch	Active
TXR1510DD	Stylecraft Builders, INC.	Pleasant Hill	Construction	Still Creek	Active
TXR15118Z	Stephenson Dirt Contracting, L.L.C.	Wastewater Lagoon - Sanderson Farms	Construction	Cottonwood Branch	Terminated
TXR1514AB	Legend Classic Homes, Ltd.	Alamosa Springs Subdivision	Construction	Thompsons Creek	Active
TXR15152O	Larry Young Paving, Inc.	West 26th Street Rehabilitation	Construction	Still Creek	Terminated
TXR15153O	Larry Young Paving, Inc.	Old Hearne Rd Wilkes Street Rehab	Construction	Still Creek	Terminated
TXR1518BB	Continental Homes of Texas, L.P.	Pleasant Hill, Phase 1, and Section 2 Phase 2	Construction	Still Creek	Active
TXR1521CI	Madison Construction, L.P.	Boys and Girls Club of Brazos Valley	Construction	Cottonwood Branch	Active

TPDES Permit Number	Permittee	Facility	Authorization Type	Receiving Segment	Status
TXR1522EV	Bartlett Cocke General Contractors, LLC	Blinn-Rellis Phase II Building	Construction	Thompsons Creek	Active
TXR15233O	Camillo Properties Ltd.	Camillo-Oakwood Forest	Construction	Thompsons Creek	Terminated
TXR15284H	Stylecraft Builders, INC.	Porters Meadow	Construction	Still Creek	Terminated
TXR1529BS	Stylecraft Builders, INC.	Connors Cove	Construction	Still Creek	Active
TXR1530DW	D & S Contracting, Inc.	The Reserve at Cottonwood Creek	Construction	Cottonwood Branch	Active
TXR1532DB	Larry Young Paving, Inc.	Palasota Dr - Phase I	Construction	Cottonwood Branch	Active
TXR15341W	NAVCON GROUP LLC	NTA	Construction	Thompsons Creek	Terminated
TXR1534BT	Larry Young Paving, Inc.	Woodville Road Improvements	Construction	Thompsons Creek	Terminated
TXR1534FN	Cervantez Construction, LLC	Sage Meadows	Construction	Still Creek	Active
TXR15359W	Cervantez Construction, LLC	Connors Cove	Construction	Still Creek	Terminated
TXR1538BA	J.T. Vaughn Construction, LLC	Innovative Technologies Development Complex and Infrastructure	Construction	Thompsons Creek	Active
TXR15403X	Marek Brothers Construction, Inc.	Parking Grading and Drng Upgrades Rellis Campus	Construction	Thompsons Creek	Active
TXR15419B	J.T. Vaughn Construction, LLC	Rellis Central Utility Plant and Site Infrastructure	Construction	Thompsons Creek	Terminated
TXR1542AQ	Liquidpower Specialty Products Inc.	Liquidpower Specialty Products	Construction	Cottonwood Branch	Active
TXR1542EA	Cervantez Construction, LLC	Bonham Trace	Construction	Still Creek	Active
TXR1543BQ	WBW Construction, LLC	Pleasant Hill Section 2	Construction	Still Creek	Active
TXR1545DP	Max Foote Construction Company, L.L.C.	Water Treatment Plant Sanderson Farms Bryan	Construction	Cottonwood Branch	Terminated
TXR1547BO	Civil Constructors, Inc.	W 28th Street	Construction	Cottonwood Branch	Active
TXR1547DX	Palasota Contracting, LLC	Foxwood Crossing Subdivision	Construction	Thompsons Creek	Active
TXR1551GR	WJH LLC	Foxwood Crossing Subdivision	Construction	Thompsons Creek	Active
TXR1552DX	Jacody Construction, LP	The Reserve at Cottonwood Creek	Construction	Cottonwood Branch	Terminated
TXR15638V	WBW Construction, LLC	Pleasant Hill	Construction	Still Creek	Active
TXR1566FR	Blackrock Builders, LLC	Heritage Meadows	Construction	Still Creek	Active

TPDES Permit Number	Permittee	Facility	Authorization Type	Receiving Segment	Status
TXR15686X	Honeywell Electronic Chemicals LLC	Honeywell Electronic Chemicals Bryan Plant	Construction	Thompsons Creek	Active
TXR15734O	Kelly Burt Dozer, Inc.	Leonard Road Substation	Construction	Cottonwood Branch	Terminated
TXR1574CD	Civil Constructors, Inc.	Hope Subdivision	Construction	Still Creek	Terminated
TXR1574FR	Aggieland Construction, LLC	Rellis Administrative Complex Extension	Construction	Thompsons Creek	Active
TXR15765W	Camillo Properties Ltd.	Camillo - Leonard Crossing	Construction	Cottonwood Branch	Active
TXR1582GB	Drymalla Construction Company, LLC	Bryan Intermediate School3	Construction	Still Creek	Active
TXR15836A	CTX Development Company	Porters Meadow	Construction	Still Creek	Terminated
TXR1583FJ	Jim Cooper Construction Company, Inc.	Fedex Distribution Facility	Construction	Thompsons Creek	Active
TXR1583GB	Legend Classic Homes, Ltd.	Hope Crossing	Construction	Still Creek	Active
TXR1586EG	Palasota Contracting, LLC	Bryan Still Creek Culverts	Construction	Still Creek	Active
TXR1587FV	Bartlett Cocke General Contractors, LLC	Tamus Rellis Campus Infrastructure Phase 3a	Construction	Thompsons Creek	Active
TXR1589CK	First Omega Partners, Ltd.	Pleasant Hill	Construction	Still Creek	Active
TXR1593DS	Glenn Fuqua, Inc.	Leonard Road Substation	Construction	Thompsons Creek	Terminated
TXR15940X	Bartlett Cocke General Contractors, LLC	Rellis Agriculture and Workforce Education Center	Construction	Thompsons Creek	Terminated
TXR15950C	Bartlett Cocke General Contractors, LLC	TTI Headquarters Building	Construction	Still Creek	Terminated

Sanitary Sewer Overflows

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

TCEQ Central Office in Austin provided statewide data on SSO incidents from January 2016 through December 2021 (TCEQ 2022e). Table 13 summarizes the number of SSO incidents reported by regulated entities operating within the watershed.

Table 13. Summary of reported sanitary sewer overflow events from 2016 through 2021 in the Thompsons Creek watershed.

Assessment Unit	Estimated Incidents	Total Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)
1242B_01	2	630	30	600
1242B_02	1	1,000	1,000	1,000
1242C_01	39	45,115,023	1	45,000,000
1242D_01	6	100,581	1	100,000
1242D_02	2	11,500	1500	10,000

Dry Weather Discharges/Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions. The term "illicit discharge" is defined in TPDES General Permit TXR040000 for Phase II or small MS4s as "Any discharge to a municipal separate storm sewer system that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges included in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC 2003) include:

- Direct Illicit Discharges:
  - Sanitary wastewater piping that is directly connected from a home to the storm sewer.
  - Materials that have been dumped illegally into a storm drain catch basin.
  - A shop floor drain that is connected to the storm sewer.
  - A cross-connection between the sanitary sewer and storm sewer systems.
- Indirect Illicit Discharges:
  - An old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line.
  - A failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing on-site sewage facilities (OSSFs), and domestic pets.

Wildlife and Unmanaged Animals

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

The Texas Parks and Wildlife Department (TPWD) provides deer population-density estimates by Resource Management Unit and Ecoregion in the state. The Thompsons Creek project area lies in the Resource Management Unit 19, with an average deer density of 25.3 acres per deer in 2019 (TPWD 2020). Suitable NLCD classes for deer habitat classified in the 2019 NLCD include Shrub/Scrub, Grassland/Herbaceous, Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, Emergent Herbaceous Wetlands, and Pasture/Hay. Thompsons Creek (1242D_02) had the greatest amount of suitable habitat, with 13,618 acres, which corresponds to an estimated 538 deer (Table 14).

Texas A&M AgriLife Extension (2012) estimates one hog per 39 acres as a statewide average density for feral hogs. The density was applied to appropriate NLCD classes for feral hogs in the watershed, which includes Pasture/Hay, Shrub/Scrub, Grassland/Herbaceous, and Emergent Herbaceous Wetlands. Thompsons Creek (1242D_02) had the greatest feral hog population with 257 hogs (Table 14).

Table 14. Summary of permitted wastewater treatment facilities in the Thompsons Creek watershed.

Assessment unit	Feral hogs		White-tailed deer	
	Suitable habitat (acres)	Estimated population	Suitable habitat (acres)	Estimated population
1242B_01	1,057	27	1,541	61
1242B_02	448	11	762	30
1242C_02	2,327	60	3,540	140
1242D_01	4,690	120	6,050	239
1242D_02	10,027	257	13,618	538

Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. Activities, such as livestock grazing close to water bodies and the use of manure as fertilizer, can contribute *E. coli* to nearby water bodies. Litter produced by commercial poultry operations can be another source of bacteria pollution in the Thompsons Creek project area if appropriate measures for litter management are not practiced.

Watershed livestock populations were estimated using county-level data available from the 2017 Census of Agriculture (USDA 2019). The Brazos county-level data was refined to reflect acres of grazeable land within each AU watershed. The refinement was determined by the grazeable area of Brazos County and the grazeable acres of the AU watersheds. The ratio was the grazeable area (defined as an aggregate of Pasture/Hay and Grassland/Herbaceous NLCD classifications) of the AU watershed divided by the total grazeable area of the county. Poultry appears to be the dominant livestock in the watershed and among all AU watersheds (Table 15).

Table 15. Estimated livestock populations in the Thompsons Creek watershed.

Assessment unit	Cattle and calves	Hogs and pigs	Poultry	Goats and sheep	Horses
1242B_01	350	8	23,344	14	0
1242B_02	147	3	9,787	6	0
1242C_02	763	18	50,909	30	0
1242D_01	1,577	37	105,153	61	0
1242D_02	3,349	78	223,325	129	0

Fecal matter from dogs and cats is transported to water bodies by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 16 summarizes the estimated number of dogs and cats in the TMDL watersheds. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association (AVMA) 2017–2018 U.S. Pet Statistics (AVMA 2018). The number of households in the watershed was estimated using 2020 Census data (USCB 2020a). The actual contribution and significance of bacteria loads from pets reaching the water bodies is unknown.

Table 16. Estimated households and pet populations in the Thompsons Creek watershed.

Assessment unit	Estimated households	Estimated dog population	Estimated cat population
1242B_01	249	153	114
1242B_02	2,468	1,515	1,128
1242C_02	4,070	2,499	1,860
1242D_01	418	257	191
1242D_02	1,144	702	523

On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on the physical conditions of the local soils. Typical designs consist of (i) one or more septic tanks and a drainage or distribution field (anaerobic system) and (ii) aerobic systems that have an aerated holding tank and often an above-ground sprinkler system for distributing the liquid. In simplest terms, household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system, which may consist of buried perforated pipes or an above-ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs contribute virtually no fecal bacteria to surface waters. For example, Weiskel et al. (1996) reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system. Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The Thompsons Creek watershed is located within the Region 4 area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

Estimates of the number of OSSFs in the Thompsons Creek watershed were determined using 911 address data to identify residence locations that were visually validated with aerial imagery data. Residential and business addresses that were found to be outside of city boundaries, the area covered by the Certificates of Convenience and Necessity (CCN), and outside of the city's sewer system were assumed to have an OSSF (Public Utilities Commission of Texas 2017). A regional approach to evaluate the CCNs was undertaken, which included reviewing all wastewater services in Brazos County in the vicinity of the Thompsons Creek project area. Data from these sources indicate that there are 507 OSSFs located within the Thompsons Creek watershed. Most of the OSSFS are in the AU 1242D_02 and AU 1242D_01 watersheds (Table 17).

Table 17. Estimated onsite sewage facilities and potential failing rates in the Thompsons Creek watershed.

Assessment unit watershed	Estimated OSSFs	Failure rate (percent)	Estimated failing OSSFs
1242B_01	28	12	3
1242B_02	10	12	1
1242C_02	39	12	5
1242D_01	113	12	14
1242D_02	317	12	38

Bacteria Survival and Die-off

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

Bacteria Tool Development

This section describes the rationale for selecting the bacteria tool used for TMDL development and details the procedures and results of LDC development.

Tool Selection

The TMDL allocation process for bacteria involves assigning bacteria, e.g., *E. coli*, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for the impaired AU in the TMDL watershed considered the availability of data and other information necessary for the supportable application of the selected tool and guidance in the Texas bacteria task force report (Jones et al. 2009). Mechanistic models and empirically derived LDCs are the two approaches commonly used for bacteria TMDLs in Texas.

Mechanistic models, also referred to as process models, are based on theoretical relationships that numerically describe the physical processes that determine streamflows and bacteria concentrations, in addition to other related response variables. Information and data resources that allow adequate definition of many of the physical and biological processes influencing instream bacteria concentrations for mechanistic model application in the TMDL watersheds are unavailable. These limitations became an important consideration in the allocation tool selection process.

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

The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations, often associated with bacteria TMDLs that constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by TCEQ, and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the LDC method within their three-tiered approach to TMDL development (Jones et al. 2009).

The LDC method was used in this project to estimate differences in bacteria loads and relevant criterion and to give indications of broad sources of the bacteria (point and nonpoint sources).

Data Sources

Streamflow Data

Hydrologic data in the form of daily streamflow records were unavailable in the TMDL watersheds. To better understand the hydrology of Thompsons Creek and its tributaries, TWRI, in cooperation with TCEQ, measured continuous streamflow data from March 2020 to March 2021. Continuous flow data measurements were made at three SWQM stations: 16396 on Thompsons Creek (AU 1242D_01), 16397 on Thompsons Creek (AU 1242D_02), and 16882 on Still Creek (AU 1242C_02).

Measured continuous data was used to develop discharge-stage rating relationships, which were then used to develop daily streamflow data at the three stations. Long-term daily flows for the 2003–2021 period for the three stations were then generated using a calibrated and validated daily lumped catchment water balance model. The methodology used to derive the 2003–2021 long-term daily flows for stations 16396, 16397, and 16882 is detailed in Schramm et al. (2022).

Flows at three additional SWQM stations: 17378 on Still Creek (AU 1242C_02), 17598 on Cottonwood Branch (AU 1241B_01), and 17597 on Cottonwood Branch (AU 1242B_02) were estimated using the drainage-area ratio (DAR) method. Kikoyo et al., 2022 describes how the DAR methodology was used to derive flows at additional unmonitored stations in the Thompsons Creek watershed.

Water Quality Data

Historical ambient *E. coli* data used for the development of LDCs was obtained through TCEQ SWQMIS database (TCEQ 2019). An analysis of water quality data for SWQM stations in the project watershed is presented in Appendix A and further discussed in Kikoyo et al., 2022.

Methodology for Flow Duration and Load Duration Curve Development

To develop the flow duration curves (FDCs) and LDCs, the previously discussed data resources were used in the following sequential steps:

- Step 1: Determine the hydrologic period of record to be used in developing the FDC.
- Step 2: Determine the stream location for which FDC and LDC development is desired.
- Step 3: Develop daily streamflow record at desired location.
- Step 4: Develop FDC at the desired stream location, segmented into discrete flow regimes.
- Step 5: Develop allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 6: Superimpose historical bacteria data on the allowable bacteria LDC.

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

Step 1: Determine Hydrologic Period

Daily hydrologic (streamflow) records were estimated for the impaired waterbodies at all six SWQM stations in the project watershed. Optimally the period of record to develop FDCs should include as much data as possible to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years. The period of record selected should also be representative of conditions experienced when the *E. coli* data were collected. Table 18 shows periods when *E.coli* data was collected in the watershed and periods with estimated daily streamflow data.

Table 18. Periods of record for historical bacteria data and streamflow estimates for surface water quality monitoring (SWQM) stations in the Thompsons Creek watershed.

SWQM station	Assessment unit watershed	Period with *E.coli* data records	Period with streamflow estimates
17598	1242B_01	5/2002-3/2022	1/2003-6/2021
17597	1242B_02	10/2002-3/2022	1/2003-6/2021
16882	1242C_02	9/2001-3/2022	1/2003-6/2021
17378	1242C_02	8/2002-3/2022	1/2003-6/2021
16396	1242D_01	9/2001-3/2022	1/2003-6/2021
16397	1242D_02	9/2001-3/2002	1/2003-6/2021

For LDC development, a 17½ -year period from January 2003 to June 2021 was selected. This period of record captures a reasonable range of extreme high and low streamflow and represents a period when *E. coli* data were collected at all SWQM stations in the watershed.

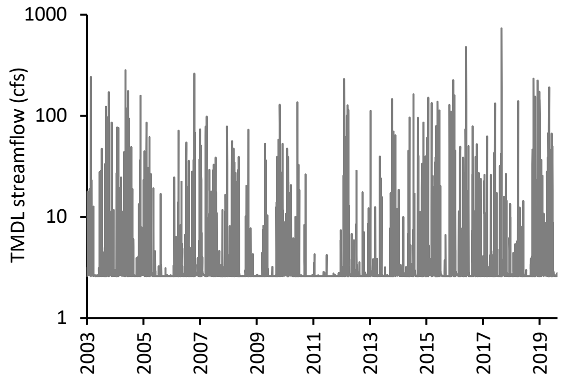
Step 2: Determine Desired Stream Location

The SWQM stations that were located within the impaired waterbody, for which adequate *E. coli* data were available, determined the stream location for which FDCs and LDCs were developed.

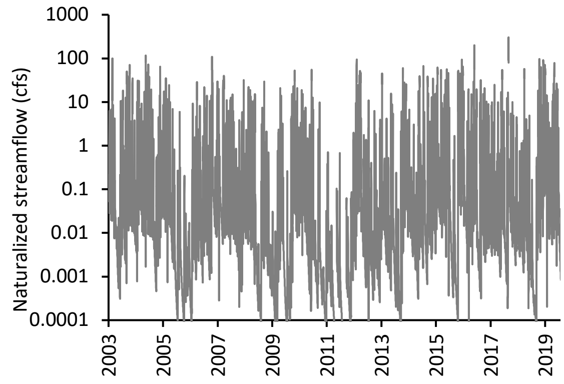
Streamflow and *E. coli* records at stations 16396, 16397, 16882, 17598, and 17597, located on impaired AUs 1242D_01, 1242D_02, 1242C_02, 1242B_01, and 1242B_02 respectively, were used for FDCs and LDCs development. SWQM station 16396 is located on the portion of Thompsons Creek downstream of the confluence with Still Creek, 16397 is on the portion of Thompsons Creek above the confluence with Still Creek, 16882 is on the portion of Still Creek below the City of Bryan Wastewater Treatment Plant (WTTP), 17598 is on the portion of Cottonwood Branch downstream of Sanderson Farms, and 17597 is on the Cottonwood Branch upstream of Sanderson Farms. Station 17378 is not considered for FDC development since it is located on the same AU as Station 16882, which gives a good representation of streamflow and water quality conditions in the AU watershed.

Step 3: Develop Daily Streamflow Record at Desired Location

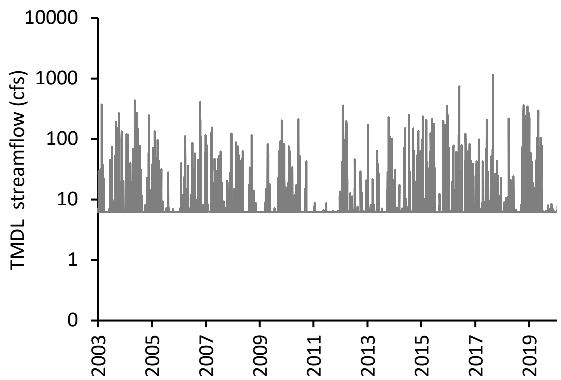
Once the hydrologic period of record and the station location determined, the next step was to develop the daily streamflow records for the station. The methodology used for estimating long-term streamflow records at SWQM stations 16396, 16397, and 16882 is discussed in Schramm et al. (2022). Streamflow estimation using the drainage area ratio method for SWQM stations 17597 and 17598 is discussed in Kikoyo et al., 2022, Figure 8 shows daily mean streamflow time-series plots at the above stations in the project watershed.



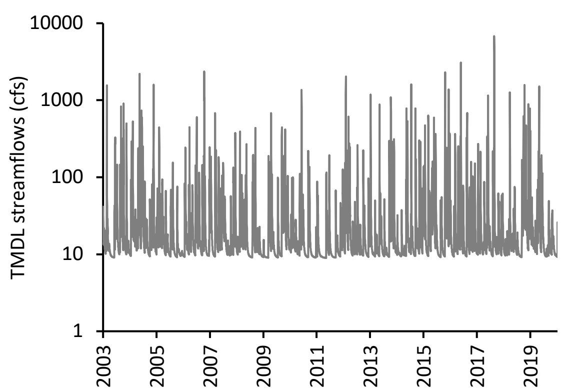
(a) SWQM Station 17598



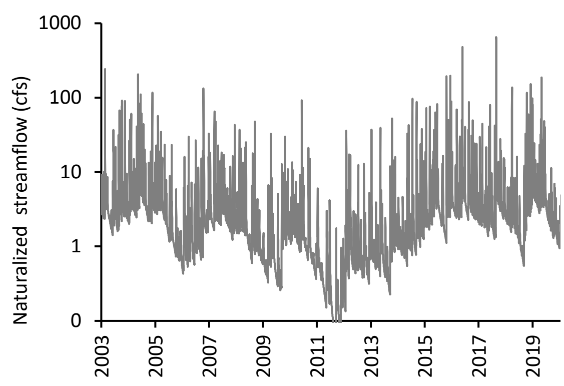
(b) SWQM Station 17597



(c) SWQM station 16882



(d) SWQM Station 16396



(e) SWQM Station 16397

Figure 8. Timeseries plot of daily mean streamflow at water quality monitoring (SWQM) station (a) 17598 on assessment unit (AU) 1242B_01, (b) 17597 on AU 1242B_02, (c) 16882 on AU 1242C_02, (d) 16396 on AU 1242D_01, and (e) 16397 on 1242D_02.

Steps 4–6: Flow Duration and Load Duration Curves

FDCs and LDCs are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. The following steps were taken to develop an FDC for a location:

- Order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (one for the highest flow, two for the second highest flow, and so on).
- Compute the percentage of days each flow was exceeded by dividing each rank by the total number of data points plus one.
- Plot the corresponding flow data against exceedance percentages.

Further, when developing an LDC:

- Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 cfu/100 mL or 1.26 cfu/mL) and by a conversion factor (2.44658×10^9), which gives you a loading unit of cfu/day.
- Plot the exceedance percentages, which are identical to the value for the streamflow data points, against the geometric mean criterion for *E. coli*.

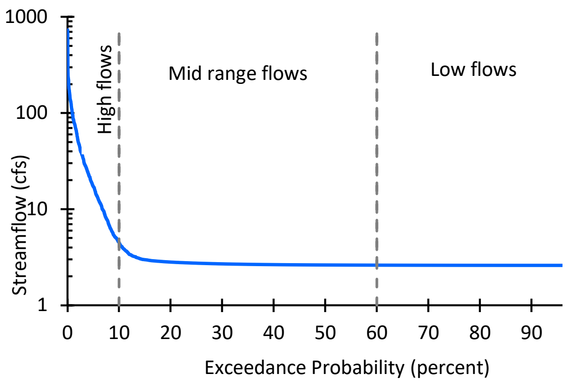
The resulting curve represents the maximum daily allowable loadings for the geometric mean criterion. The next step was to plot the measured *E. coli* data on the developed LDC using the following steps:

- Compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^9).
- Plot on the LDC for each SWQM station the load for each measurement at the exceedance percentage for its corresponding streamflow.

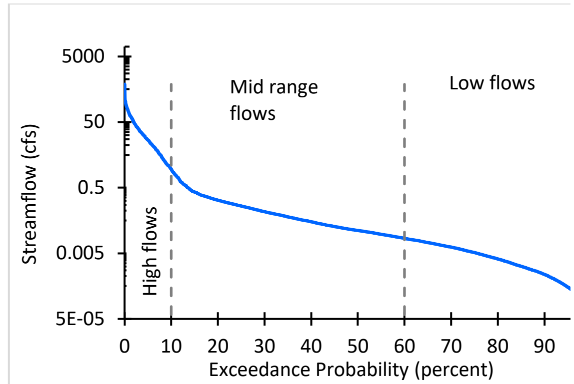
The plots of the LDC with the measured loads (*E. coli* concentrations times daily streamflow) display the frequency and magnitude at which measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an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

Flow Duration Curves

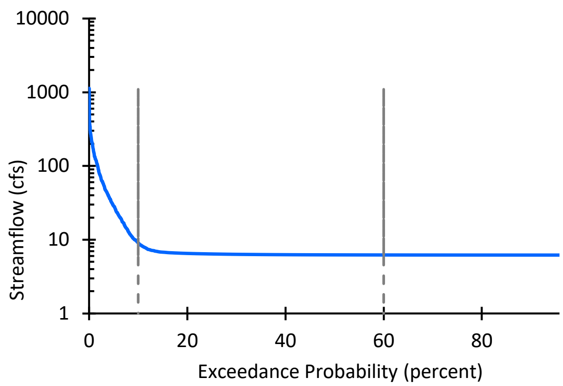
FDCs were developed for the five SWQM stations in the project watershed, as described in the previous section. Figure 9 shows plots of streamflow versus the percent of days a particular flow was exceeded. The curves were divided into three flow regimes to assist in determining streamflow conditions under which exceedances occurred. Flows were divided into high flow (0-10% flow exceedance), mid-range flow (10-60% flow exceedance), and lowest flows (60-100% flow exceedance).



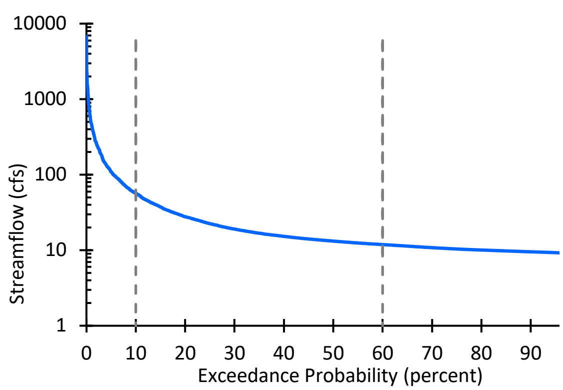
(a) SWQM Station 17598



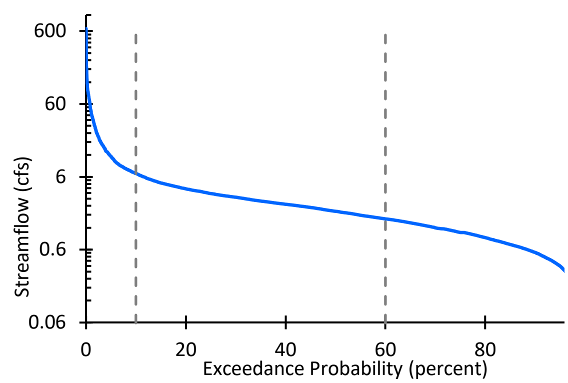
(b) SWQM Station 17597



(c) SWQM station 16882



(d) SWQM Station 16396

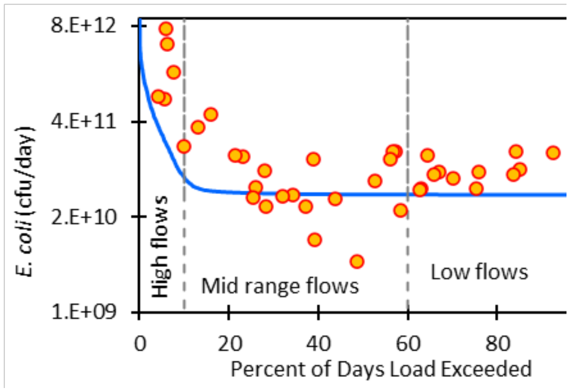


(e) SWQM Station 16397

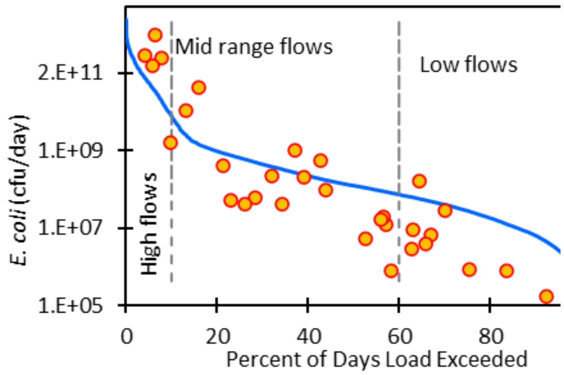
Figure 9. Flow duration curves at water quality monitoring (SWQM) stations (a) 17598 on assessment unit (AU) 1242B_01, (b) 17597 on AU 1242B_02, (c) 16882 on AU 1242C_02, (d) 16396 on AU 1242D_01, and (e) 16397 on 1242D_02.

Load Duration Curves

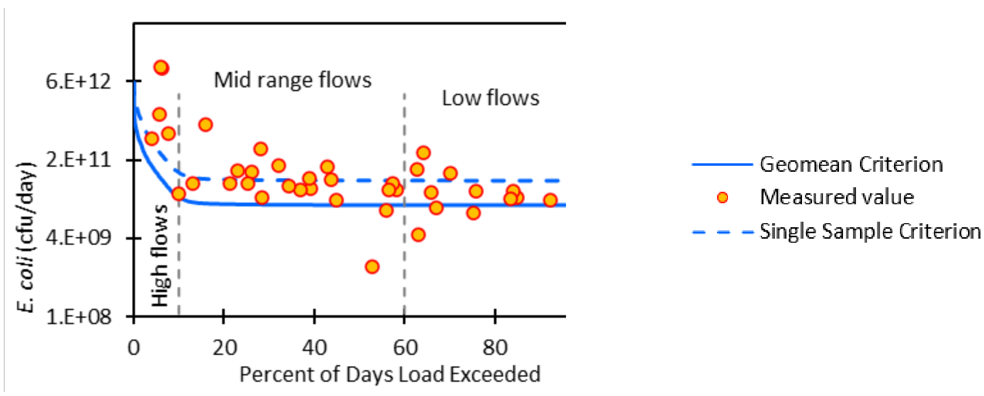
LDCs were developed for the five SWQM stations in the project watershed using *E. coli* data from the TCEQ SWQMIS database. Figure 10 shows LDCs for the five SWQM stations in the project watershed.



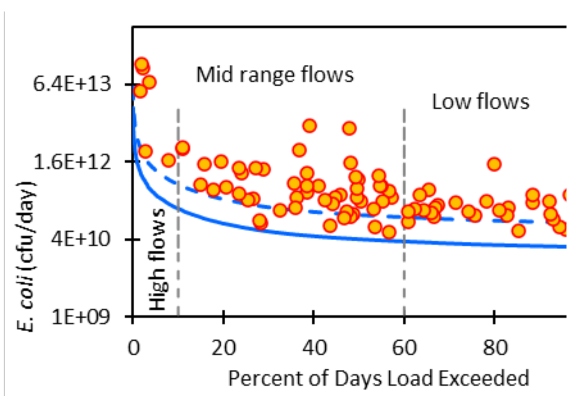
(a) SWQM Station 17598



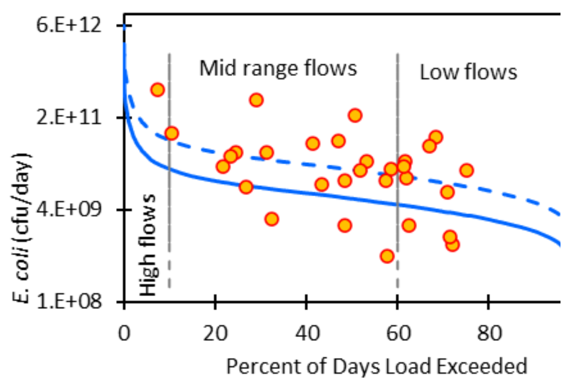
(b) SWQM Station 17597



(c) SWQM station 16882



(d) SWQM Station 16396



(e) SWQM Station 16397

Figure 10. Load duration curves at water quality monitoring (SWQM) stations (a) 17598 on assessment unit (AU) 1242B_01, (b) 17597 on AU 1242B_02, (c) 16882 on AU 1242C_02, (d) 16396 on AU 1242D_01, and (e) 16397 on 1242D_02.

TMDL Allocation Analysis

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work needed and as a criterion against which to evaluate future conditions.

The endpoint for the TMDL is to maintain the concentration of *E. coli* below the geometric mean criterion of;

- 126 cfu/100 mL, which is protective of the primary contact recreation 1 use in freshwater for Still and Thompsons creeks, and
- 630 cfu/100 mL, which is protective of the secondary contact recreation 1 use in freshwater for Cottonwood Branch.

Seasonal Variation

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

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing available *E. coli* concentrations obtained from routine monitoring at the five SWQM monitoring stations (16396, 16397, 16882, 17597, and 17598). Differences in *E. coli* concentrations were evaluated by performing a Wilcoxon Rank Sum test. *E. coli* concentrations during warmer months (May – September) were compared against those during the cooler months (November – March). April and October are considered transitional periods between warm and cool seasons and therefore were excluded from the analysis. The test was considered significant at the $\alpha=0.05$ level.

The analysis of *E. coli* data indicated that there was no significant difference (p value = 0.31 was greater than $\alpha = 0.05$) in indicator bacteria between cool and warm weather seasons in the watershed. Mean and median values of *E. coli* concentrations across seasons were nearly similar (Figure 11).

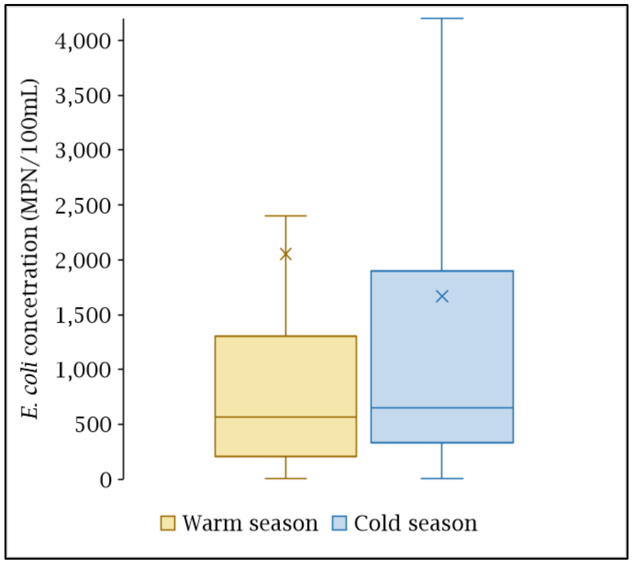


Figure 11. Distribution of *E. coli* concentrations by season in the Thompsons Creek watershed.

Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flows in the absence of runoff events, the main contributing sources are likely to be point sources and direct deposition (such as direct fecal deposition into the water body). During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in size, the impact of point sources like direct deposition is typically diluted and would, therefore, be a smaller part of the overall concentrations.

Bacteria load contributions from regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, can carry bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline as runoff washes fecal bacteria from the land surface, and the volume of runoff decreases following the rain event.

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

Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and they are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. An LDC is a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. The LDC method does not require any assumptions about loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of this approach to characterize pollutant sources. In addition, many other states are using this method to develop TMDLs.

The weaknesses of this method include the limited information it provides about the magnitude or specific origin of the various sources. Information gathered about point, and nonpoint sources in the watershed are limited. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

The LDC method allows for the estimation of existing and TMDL loads by using the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland 2003). In addition to estimating stream loads, this method allows for the determination of the hydrological conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater), and provides a means to allocate allowable loadings.

Based on the derived LDCs (Figure 10) and the analysis of potential sources of fecal bacteria, the following broad linkage statements can be made.

- Cottonwood Branch AU 1242B_02 watershed, historical *E. coli* data indicate that elevated bacteria loading primarily occurs under high flow, moist conditions, and mid-range flows. However, bacteria loads are most elevated under the highest flow conditions. Under the dry conditions and lowest flow conditions, most loadings are below the geometric mean criterion. AU 1242B_02 is predominantly an urban watershed. The majority of high flow- and moist condition-related loadings are likely attributed to regulated stormwater that comprises a majority of the watershed. Within the watershed, there are no WWTFs to contribute point source loadings under dry and low flow conditions; however, SSOs are periodic events that may contribute to bacteria loadings within the watershed under wet weather conditions.

- Cottonwood Branch AU 1242B_01 watershed, historical *E. coli* data indicate that elevated bacteria loading occurs under both high and low flow conditions. AU1242B_01 is downstream of AU 124B_02 and as such receives loadings from AU 1242B_02, potentially from regulated stormwater water and SSOs. Also, the AU 1242B_01 portion of the Cottonwood Branch is downstream of the Sandersons' WWFT effluent outfall. The WWTF contributes point source loadings under both high and low flow conditions.

- Still Creek AU 1242C_02 watershed, historical *E. coli* data indicate that elevated bacteria loading occurs under both flow conditions. AU 1242C_02 on the Still Creek segment is located downstream of the City of Bryan WWTF and receives point sources loadings from the facility under both high and low flow conditions. Additionally, Still Creek drains a large part of the City of Bryan urban area. High flow condition-related loadings are, therefore, partly attributed to regulated stormwater and SSOs from the City.

- Thompsons Creek AU 1242D_02 watershed, historical *E. coli* data indicate that elevated bacteria loading occurs majorly at low to median flow conditions. Of all AUs in the project area, this watershed has the highest density of OSSFs. OSSF failures in the watershed likely contribute to a substantial amount of bacteria loadings in the AU. Additionally, the comparatively high populations of livestock and wildlife in the watershed are potential sources of loadings.

- Thompsons Creek AU 1242D_01 watershed, historical *E. coli* data indicate that elevated bacteria loading occurs under both flow conditions. This AU is downstream of all the impaired streams in the watershed. In addition to potential loadings from its watershed, it accumulates bacteria loads from upstream impaired AUs.

Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA 1991), the MOS can be incorporated into the TMDL using either of the following two methods:

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

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

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

Load Reduction Analysis

While the TMDLs for the project watershed will be developed using load allocations, additional insight may be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each flow regime was determined using the historical *E. coli* data obtained from the stations in the impaired watersheds (Table 19).

The estimated existing load in each flow regime was calculated with the geometric mean concentration in each flow category and the median flow in each flow category (excluding days with zero flow), estimated using equation 1.

Existing bacteria load at the median flow for flow category FC (cfu/day)	=	*Median flow for flow category FC* *x Geometric mean of bacteria (cfu E. coli/mL) samples for flow category FC* *x Conversion factor (28,316.8 mL/cubic feet × 86,400 seconds/day)*	*Equation 1*

The allowable load was calculated using equation 2.

Allowable bacteria load at the median flow for flow category FC (cfu/day)	=	*Median flow for flow category FC* *x Criterion (cfu E. coli/mL)* *x Conversion factor (28,316.8 mL/cubic feet × 86,400 seconds/day)*	*Equation 2*

Percent reduction for each flow category was then calculated using equation 3 as below:

Percent reduction for flow category FC	=	*100 x (Existing bacteria load for flow category - Allowable bacteria load for flow category)* *÷ Existing bacteria load*	*Equation 3*

Table 19. Percent daily load reductions needed to meet water quality standards in the project watershed.

Assessment Unit	Flow Regime	Median Flow (cfs)	Existing Load (Billion cfu/day)	Allowable Load (Billion cfu/day)	Percent Reduction Required
1242B_01	High Flows	17.26	2249.472	266.035	88
	Moist Conditions	2.74	67.796	42.233	38
	Mid-Range Flows	2.63	50.217	40.537	19
	Dry Conditions	2.61	77.185	40.229	48
	Low Flows	2.6	104.167	40.075	62
1242B_02	High Flows	6.09	380.164	93.868	75
	Moist Conditions	0.06	0.547	0.925	-
	Mid-Range Flows	0.01	0.025	0.154	-
	Dry Conditions	0.002	0.003	0.031	-
	Low Flows	0.0002	0.0003	0.003	-
1242C_02	High Flows	28.74	1607.832	88.596	94
	Moist Conditions	6.41	79.165	19.760	75
	Mid-Range Flows	6.23	26.198	19.205	27
	Dry Conditions	6.2	33.929	19.113	44
	Low Flows	6.19	46.531	19.082	59
1242D_01	High Flows	108.81	15521.299	335.426	98
	Moist Conditions	22.5	644.836	69.360	89
	Mid-Range Flows	13.21	309.941	40.722	87
	Dry Conditions	10.39	187.372	32.029	83
	Low Flows	9.29	147.295	28.638	81
1242D_02	High Flows	11.46	678.232	35.328	95
	Moist Conditions	3.53	30.290	10.882	64
	Mid-Range Flows	2.01	16.139	6.196	62
	Dry Conditions	1.03	8.254	3.175	62
	Low Flows	0.36	-	1.11	-

cfu/day = colony forming units per day

Pollutant Load Allocation

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

Total maximum daily load (TMDL)	=		*Wasteload allocation (WLA), the amount of pollutant allowed by regulated dischargers*	*Equation 4*
		+	*Load allocation (LA), the amount of pollutant allowed by unregulated sources*	
		+	*Loadings associated with future growth from potential regulated facilities (FG)*	
		+	*Margin of safety load (MOS)*	

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

Assessment Unit-Level TMDL Calculations

The bacteria TMDL for each water body was developed as a pollutant load allocation based on information from the LDC for the SWQM stations located within the watershed. As discussed previously, the bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* criterion and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the "Allowable Load" displayed in the LDC at 5% exceedance (the median value of the high flow regime) is the TMDL. The allowable loading of *E. coli* that the impaired water body can receive on a daily basis was determined using Equation 5 based on the median value within the high-flow regime of the FDC (or 5% flow exceedance value) for the SWQM stations (Table 20).

Total maximum daily load (TMDL) (cfu/day)	=		*Median flow for high the flow regime (5% flow exceedance value)*	*Equation 5*
		x	*Criterion (cfu E. coli/mL)*	
		x	*Conversion factor (28,316.8 mL/cubic feet × 86,400 seconds/day)*	

Table 20. Allowable loadings in each of the impaired waterbodies in the Thompsons Creek watershed.

Assessment unit	5% exceedance flow (cfs)	Total maximum daily load (billion cfu/day)
1242B_01	17.26	266.035
1242B_02	6.09	93.868
1242C_02	28.74	88.596
1242D_01	108.81	335.426
1242D_02	11.46	35.328

Margin of Safety Allocation

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

Margin of Safety (MOS) (cfu/day)	=		*Total maximum daily load (TMDL) (cfu/day)*	*Equation 6*
		x	*0.05 (Margin of safety factor)*	

Using values of TMDLs for the AUs provided in Table 20, the computed margins of safety for respective AUs are shown in Table 21.

Table 21. Margin of safety loads for impaired waterbodies in the Thompsons Creek watershed.

Assessment unit	Total maximum daily load (billion cfu/day)	Margin of safety (billion cfu/day)
1242B_01	266.035	13.302
1242B_02	93.868	4.693
1242C_02	88.596	4.430
1242D_01	335.426	16.771
1242D_02	35.328	1.766

Wasteload Allocations

The wasteload allocation (WLA) consists of two parts—the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

Wasteload allocation (WLA) = *Wasteload allocations for permitted wastewater facilities (WLAWWTF)* + *Wasteload allocations for regulated stormwater dischargers (WLASW).* *Equation 7*

Wasteload Allocations for Permitted Wastewater Facilities

TPDES-permitted WWTFs are allocated a daily wasteload calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion (Equation 8). The water quality criterion is used as the WWTF target to provide instream and downstream load capacity.

Wasteload allocations for permitted wastewater facilities (cfu/day) = *Target criterion (cfu/mL)* x *Full permitted flow (gallon/day)* x *Conversion factor (3785.41 mL/gallon)* *Equation 8*

Using this equation, each WWTF's allowable loading was calculated using the permittee's full permitted flow. The individual results were summed for each AU. The criterion was applied based on the indicator bacteria designated for the segment. Table 22 presents the wasteload allocations for permitted facilities in the Thompsons Creek watershed.

Table 22. Wasteload allocations for permitted facilities in the Thompsons Creek watershed.

Assessment unit	Full permitted flow (MGD)	Target criterion (cfu/100 mL)	Wasteload allocations for permitted wastewater facilities (billion cfu/day)
1242B_01	1.678	630	40.017
1242B_02	-	630	-
1242C_02	4.0	126	19.078
1242D_01	5.723	126	27.297
1242D_02	-	126	-

MGD: million gallons per day
mL: milliliters
cfu/day: colony forming units per day

Wasteload Allocations for Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges. A simplified approach was used to estimate the WLA for these areas to develop this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of the land area that is under the jurisdiction of stormwater permits in the TMDL watershed was used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

Wasteload allocations for regulated stormwater (WLA_{SW})	=	*{Total maximum daily load (TMDL)*	*Equation 9*
		- *Wasteload allocations for permitted wastewater facilities (WLA_{WWTF})*	
		- *Future growth (FG)*	
		- *Margin of safety (MOS)}*	
		x *fractional proportion of drainage area under the jurisdiction of stormwater permits (FDA_{SWP})*	

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under-regulated stormwater permits for each AU (Table 23).

Table 23. Computation of the drainage area under the jurisdiction of the municipal separate storm sewer system (MS4) permits in the Thompsons Creek watershed.

Assessment unit	Total contributing area (acres)	Total contributing area under the jurisdiction of MS4 permits (acres)	Fraction of contributing drainage area under the jurisdiction of MS4 permits
1242B_01	4,147.44	2060.99	0.497
1242B_02	2,419.43	1,910.28	0.790
1242C_02	6,422.77	4,393.08	0.684
1242D_01	33,296.97	7931.89	0.238
1242D_02	15,568.31	1301.65	0.084

The daily allowable loading of *E. coli* assigned to WLA_{SW} was determined based on the combined area under-regulated stormwater permits. To calculate the WLA_{SW} (Equation 12), the FG term must be known. The calculation for that term is presented in the next section, but the results are included here for continuity. Table 24 provides the information needed to compute WLA_{SW}.

Table 24. Regulated stormwater load allocations.

Assessment unit	Total maximum daily load (billion cfu/day)	Margin of safety (billion cfu/day)	Wasteload allocations for permitted wastewater facilities (billion cfu/day)	Future growth (billion cfu/day)	Fraction of contributing drainage area under the jurisdiction of MS4 permits	Wasteload allocations for regulated stormwater (billion cfu/day)
1242B_01	266.035	13.302	40.017	44.939	0.497	83.373
1242B_02	93.868	4.693	0.000	0.000	0.790	70.409
1242C_02	88.596	4.430	19.078	21.425	0.684	29.865
1242D_01	335.426	16.771	27.297	30.654	0.238	62.104
1242D_02	35.328	1.766	0.000	0.000	0.084	2.806

cfu/day: colony forming units per day
MS4: municipal separate storm sewer system

Future Growth

The future growth component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of water bodies increases as the amount of flow increases. The allowance for future growth will result in the protection of existing uses and conform to Texas' antidegradation policy.

The future growth component (Table 25) was based on population projections and currently permitted wastewater dischargers. The permitted flows were increased by the expected population growth per AU between 2020 and 2070 to determine the estimated future flows.

Thus, the future growth component was calculated as follows:

Future growth allocation (cfu/day) = *Full permitted flow (gallon/day)*
x Estimated percentage increase in population between 2020 and 2070
x Target criterion (cfu/mL)
x Conversion factor (3785.41 mL/gallon)
Equation 11

Table 25. Future growth load allocation

Assessment unit	Full permitted flow (MGD)	Percent Population increase (2020-2070)	Increase inflow due to future growth (MGD)	Future growth (*E. coli* billion cfu/day)
1242B_01	1.678	112.3%	1.884	44.939
1242B_02	-	-	-	-
1242C_02	4.0	112.3%	4.492	21.425
1242D_01	5.723	112.3%	6.427	30.654
1242D_02	-	-	-	-

Load Allocation from unregulated sources

The load allocation is the load from unregulated sources and is calculated as:

Load allocation from unregulated sources	=	*Total maximum daily load* - *Wasteload allocations for permitted wastewater facilities* - *Wasteload allocations for regulated stormwater dischargers* - *Future growth* - *Margin of safety*	*Equation 12*

The calculation results are shown in Table 26. Although ideally, load allocations should be assigned to individual nonpoint sources, this is not practical; hence, the load allocation category covers all unregulated sources in the watershed. Even though the CWA provides no federal authority for requiring nonpoint sources to reduce their loadings of pollutants to the nation's waters, the act does require states (and authorized territories and tribes) to develop TMDLs for waters where nonpoint sources are significant sources of pollutants. Regarding nonpoint sources, TMDLs are a source of information that, for a given water body, should answer the following questions:

- Are nonpoint sources a significant contributor of pollutants to this water body?
- What are the approximate total current loads of a particular pollutant from all nonpoint sources in the watershed?
- What fraction of total loads of the pollutant of concern comes from nonpoint sources vs. point sources?
- How much do the loads from nonpoint sources need to be reduced to achieve the water quality standards for the water body?

An analysis of TMDL load allocations shows that unregulated sources contribute significant bacteria loads in assessment units 1242D_01 and 1242D_02. The percent of loads that is from unregulated sources is in AU 1242D_02 (87 percent), whereas the least contribution is in AU 1242B_01 (9 percent).

Table 26. Load allocation for unregulated sources.

Assessment unit	Total maximum daily load	Margin of safety	Wasteload allocations for permitted wastewater facilities	Wasteload allocations for regulated stormwater dischargers	Future growth	Load allocation for unregulated sources
1242B_01	266.035	13.302	40.017	83.373	44.939	84.403
1242B_02	93.868	4.693	0.000	70.409	0.000	18.766
1242C_02	88.596	4.430	19.078	29.865	21.425	13.798
1242D_01	335.426	16.771	27.297	62.104	30.654	198.6
1242D_02	35.328	1.766	0.000	2.806	0.000	30.756

All loads are in billion colony forming units per day.

Summary of TMDL Calculations

Table 27 summarizes the TMDL allocations for the Thompsons Creek watershed. The future growth component is included in the wasteload allocations for permitted wastewater facilities to comply with the requirements of 40 CFR 130.7.

Table 27. Total maximum daily load allocation summary for the Thompsons Creek watershed.

Assessment unit	Total maximum daily load	Margin of safety allocation	Wasteload allocations for permitted wastewater facilities	Wasteload allocations for regulated stormwater dischargers	Load allocation for unregulated sources
1242B_01	266.035	13.302	84.956	83.373	84.403
1242B_02	93.868	4.693	0.000	70.409	18.766
1242C_02	88.596	4.430	40.504	29.865	13.798
1242D_01	335.426	16.771	57.951	62.104	198.6
1242D_02	35.328	1.766	0.000	2.806	30.756

All loads are in billion colony forming units per day.
Wasteload allocations for permitted wastewater facilities include future growth component.

Public Participation

EPA's regulations require public involvement in developing TMDLs, however. Public participation affords stakeholders (those that have an interest or stake in an issue, such as individuals, interest groups, and communities) in the watershed the opportunity to influence the decision-making process. Depending on the form of participation sought, public participation makes use of a variety of tools and techniques to inform the public, generate public input, and, in some cases, and build consensus..

A robust stakeholder involvement program process was undertaken to develop partnerships and gain insight into local stakeholders' preferences for managing impairments in the Thompsons Creek watershed. Stakeholders consulted included representatives from the Brazos River Authority, Texas A&M University, Brazos County offices, local Soil and Water Conservation District, and the City of Bryan. Stakeholders highlighted the need for implementing integrated management measures that address all the impairments in the watershed. Because of the rapid urbanization and increased population pressures in the watershed, stakeholders proposed that a more dynamic and voluntary stakeholder-driven approach would be more suited for addressing environmental challenges in the watershed.

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Appendix A. Review and analysis of water quality data in Thompsons Creek watershed, 2003–2022.

Analysis of *E. coli* Monitoring Data

All available ambient *E. coli* data records were obtained from the SWQMIS database. The data analyzed represents all historical *E. coli* data collected in the project area from 2003 to date (March 2022) (Figure A-1). The analysis of recorded *E. coli* loads shows that:

- The geomean value for measured *E. coli* concentrations on AU 1242B_02, Cottonwood Branch is below the criterion for secondary contact recreation 1 use. Only 13 out of the 53 measurements (25%) made from 2003 to date were above the criterion.
- The geomean value for measured *E. coli* concentrations on AU 1242B_01, Cottonwood Branch is above the criterion for secondary contact recreation 1 use. Most of the measurements (50 out of the total 59 measurements) made from 2003 to date were above the criterion.
- The geomean value for measured *E. coli* concentrations on AU 1242C_02, Still Creek is above the criterion for primary contact recreation 1 use. At the most downstream SWQM on the AU (Station 16882), most of the measurements (55 out of the total 60 measurements) made from 2003 to date were above the criterion.
- The geomean value for measured *E. coli* concentrations on AU 1242D_02, Thompsons Creek is above the criterion for primary contact recreation 1 use. Most of the measurements (29 out of the total 38 measurements) made from 2003 to date were above the criterion.
- The geomean value for measured *E. coli* concentrations on AU 1242D_01, Thompsons Creek is above the criterion for primary contact recreation 1 use. All measurements (95 measurements) made from 2003 to date were above the criterion.

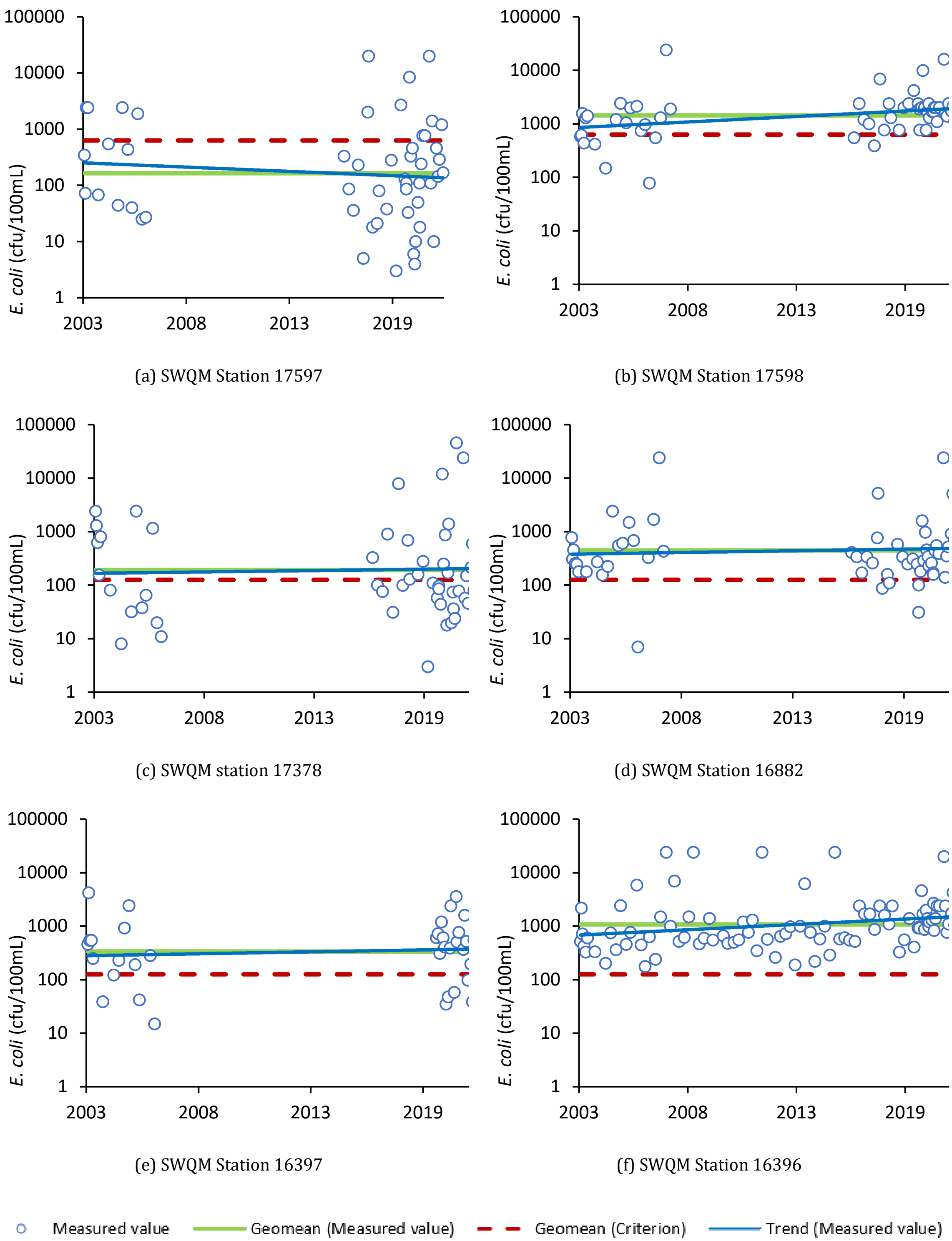

Figure A-1. Plot of historical bacteria data for surface water quality monitoring (SWQM) stations (a) 17597 on assessment unit (AU) 1242B_02, (b) 17598 on AU 1242B_01, (c) 17378 and (d) 17378 on AU 1242C_02, (e) 16397 on AU 1242D_02, and (e)16396 on 1242D_01.

Other Water Quality Parameters in the Watershed

Water quality monitoring data were drawn from the TCEQ's SWQMIS for SWQM stations in the watershed. Table A-1 shows summary statistics of water quality parameters in the SWQMIS database. Summary statistics are only presented for parameters that were also measured during the 2021-2022 TWRI monitoring activity.

Table A- 1. Summary statistics of water quality parameters at surface water quality monitoring (SWQM) stations in the watershed from January 2003-March 2022.

SWQM station	Parameter Name	Parameter Code	Number of Samples	Minimum Value	Mean Value	Maximum Value
17597	Temperature, Water (Degrees Celsius)	10	49	8.1	20.6	34.4
	Transparency, Secchi Disc (meters)	78	42	0.1	0.5	1.2
	Specific Conductance, Field (µS/cm @ 25 °C)	94	49	224.0	831.6	2352.0
	Oxygen, Dissolved (mg/L)	300	49	0.6	8.8	19.6
	pH (Standard Units)	400	48	6.8	7.6	8.5
17598	Temperature, Water (Degrees Celsius)	10	55	8.7	21.1	30.4
	Transparency, Secchi Disc (meters)	78	46	0.0	0.2	1.0
	Specific Conductance, Field (µS/cm @ 25 °C)	94	55	296.0	2044.1	3000.0
	Oxygen, Dissolved (mg/L)	300	55	2.1	8.2	13.6
	pH (Standard Units)	400	54	7.0	8.2	9.1
17378	Temperature, Water (Degrees Celsius)	10	49	7.5	19.3	31.7
	Transparency, Secchi Disc (meters)	78	43	0.1	0.5	1.2
	Specific Conductance, Field (µS/cm @ 25 °C)	94	49	110.0	584.6	1780.0
	Oxygen, Dissolved (mg/L)	300	49	0.8	6.7	24.6
	pH (Standard Units)	400	48	6.9	7.4	8.3
16882	Temperature, Water (Degrees Celsius)	10	57	10.1	21.3	31.1
	Transparency, Secchi Disc (meters)	78	48	0.1	0.6	1.2
	Specific Conductance, Field (µS/cm @ 25 °C)	94	57	223.0	1145.0	1440.0
	Oxygen, Dissolved (mg/L)	300	57	4.2	7.7	13.1
	pH (Standard Units)	400	56	7.4	8.0	8.6
16397	Temperature, Water (Degrees Celsius)	10	47	5.9	20.5	27.6
	Transparency, Secchi Disc (meters)	78	47	0.1	0.2	0.8
	Specific Conductance, Field (µS/cm @ 25 °C)	94	47	211.0	510.5	1180.0
	Oxygen, Dissolved (mg/L)	300	47	0.6	4.0	11.4
	pH (Standard Units)	400	46	6.5	7.2	8.1
16396	Temperature, Water (Degrees Celsius)	10	94	7.5	21.3	29.8
	Transparency, Secchi Disc (meters)	78	85	0.0	0.3	1.0
	Specific Conductance, Field (µS/cm @ 25 °C)	94	94	103.0	1353.1	2010.0
	Oxygen, Dissolved (mg/L)	300	93	5.9	8.3	12.6
	pH (Standard Units)	400	93	7.0	8.2	9.2

cfs = cubic feet per second
µS/cm @ 25 °C = microsiemens per centimeter at 25 degrees Celsius
mg/L = milligrams per liter
µg/L = micrograms per liter