Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria for North Fork Cottonwood Creek

Assessment Unit: 0841P_01

North Fork Cottonwood Creek at Sampling Station 10722

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Submitted to TCEQ November 2021

Published by the Texas Commission on Environmental Quality
AS-223

Prepared for
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087

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TR-2109
Submitted to the Texas Commission on Environmental Quality
August 2021

Published by the Texas Commission on Environmental Quality as
AS-223 February 2022

Suggested citation:
Millican, Jimmy and Todd Adams. Texas Institute for Applied Environmental Research. 2021. Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria for North Fork Cottonwood Creek. Austin: Texas Commission on Environmental Quality (AS-223).

Acknowledgements

The United States (U.S.) Environmental Protection Agency and the Texas Commission on Environmental Quality (TCEQ) provided financial support for this study. TCEQ was the study's lead agency. The administrative oversight, technical input, and review of this document by the TCEQ Project Manager, Mr. Jason Leifester, were important to the completion of this project and the development of this document.

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Abbreviations

AU	assessment unit
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming units
CGP	construction general permit
DAR	drainage area ratio
DFW	Dallas/Fort Worth
DSLP	days since last precipitation
E. coli	*Escherichia coli*
EPA	(United States) Environmental Protection Agency
FDA_{SWP}	fractional drainage area stormwater permit
FDC	flow duration curve
FG	future growth
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
MCM	minimum control measure
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NCTCOG	North Central Texas Council of Governments
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
SWMP	stormwater management program
SWQM	surface water quality monitoring
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TRA	Trinity River Authority
USCB	United States Census Bureau
USGS	United States Geological Survey
WLA	wasteload allocation
WLA_{SW}	wasteload allocation stormwater
WLA_{WWTF}	wasteload allocation wastewater treatment facilities
WWTF	wastewater treatment facility

Section 1. Introduction

1.1. Background

Section 303(d) of the federal Clean Water Act 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 its 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 the water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

TCEQ first identified the bacteria impairment within North Fork Cottonwood Creek in the EPA-approved *2020 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report, TCEQ, 2020).

This document will consider one bacteria impairment in one assessment unit (AU) of North Fork Cottonwood Creek. The impaired water body and identifying AU number are:

- North Fork Cottonwood Creek 0841P_01

1.2. Water Quality Standards

To protect public health, aquatic life, and 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 United States 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 100 mL

- 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, that 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 physical characteristics of the water body or limited public access. The geometric mean criterion for *E. coli* is 1,030 cfu per 100 mL

- Noncontact 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

North Fork Cottonwood Creek has a primary contact recreation 1 use. The associated criterion for *E. coli* is a geometric mean of 126 cfu per 100 mL

1.3. Report Purpose and Organization

The North Fork Cottonwood Creek TMDL project was initiated through a contract between TCEQ and Texas Institute for Applied Environmental Research. The tasks of this project were to (1) develop, have approved, 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 TMDL for the impaired AU. This report contains:

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

Whenever it was feasible, the data development and computations for developing the LDC and pollutant load allocation were performed in a manner to remain consistent with the previously completed *Addendum One: Total Maximum Daily Load for Indicator Bacteria in North Fork Fish Creek* (TCEQ, 2019) and the original *Four Total Maximum Daily Loads for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake* (TCEQ, 2016).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The North Fork Cottonwood Creek watershed is highly urbanized and located within Tarrant and Dallas counties. North Fork Cottonwood Creek (0841P) is a tributary of Cottonwood Creek (0841F). The watershed drains an area of 5.5 square miles (3,546 acres).

North Fork Cottonwood Creek is approximately 4.4 miles long and has only one AU (0841P_01). It is an unclassified, perennial stream that flows into Cottonwood Creek (0841F), which eventually flows into Mountain Creek Lake (0841A).

The 2020 Texas Integrated Report (TCEQ, 2020) supplies the following water body and AU description for North Fork Cottonwood Creek:

- 0841P (North Fork Cottonwood Creek; AU 0841P_01) – A 4.4 mile stretch of North Fork Cottonwood Creek running upstream from confluence with the South Fork Cottonwood Creek in Grand Prairie, Dallas County, to approximately 0.3 miles upstream of Carter Street in Arlington, Tarrant County.

Using a watershed-based approach, the entire watershed of North Fork Cottonwood Creek will be considered in this report. The watersheds of the original TMDLs (TCEQ, 2016), one addendum TMDL for North Fork Fish Creek (TCEQ, 2019), and this study of North Fork Cottonwood Creek are shown in Figure 1.

2.2. Review of Routine Monitoring Data

2.2.1. Analysis of Bacteria Data

Surface water quality monitoring has been done within the North Fork Cottonwood Creek watershed at TCEQ surface water quality monitoring (SWQM) stations 10722, 20836, and 17673 (Figure 2). *E. coli* data collected at stations 20836 and 10722 over the seven-year period of December 1, 2011, through November 30, 2018, were used in assessing attainment of the primary contact recreation 1 use as reported in the 2020 Texas Integrated Report (TCEQ, 2020) and are summarized in Table 1. The 2020 assessment data for the TMDL watershed shows non-support of the primary contact recreation 1 criterion because geometric mean concentrations exceed the *E. coli* geometric mean criterion of 126 cfu/100 mL.

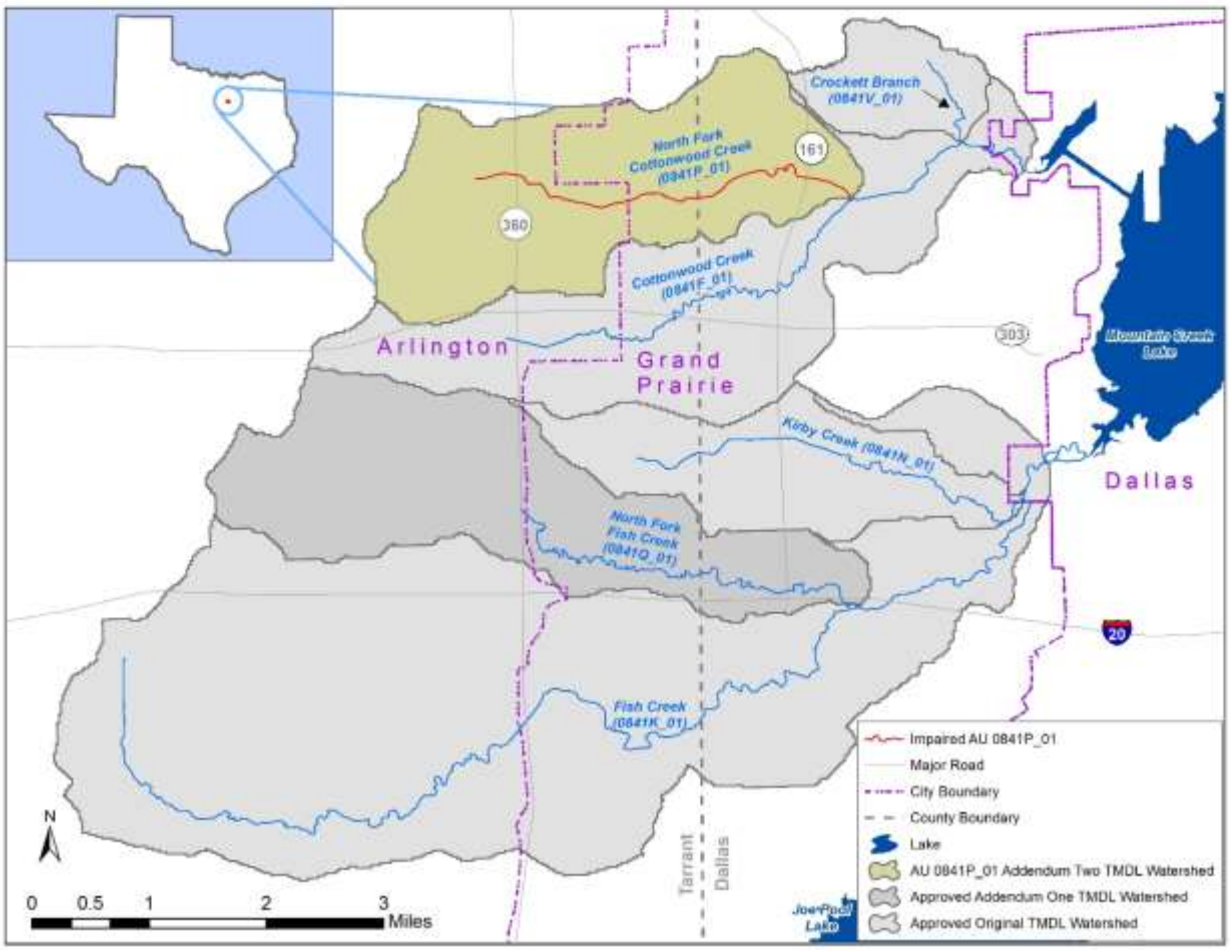

Figure 1. Map showing the previously approved, original four TMDL watersheds (TCEQ, 2016), one addendum for North Fork Fish Creek (TCEQ, 2019), and the North Fork Cottonwood Creek watershed considered in this study

Table 1. 2020 Texas Integrated Report summary for the North Fork Cottonwood Creek

Water Body Name	AU	Parameter	Stations	No. of Samples	Data Date Range	Geometric Mean (cfu/100 mL)
North Fork Cottonwood Creek	0841P_01	*E. coli*	20836 and 10722	49	2011–2018	258

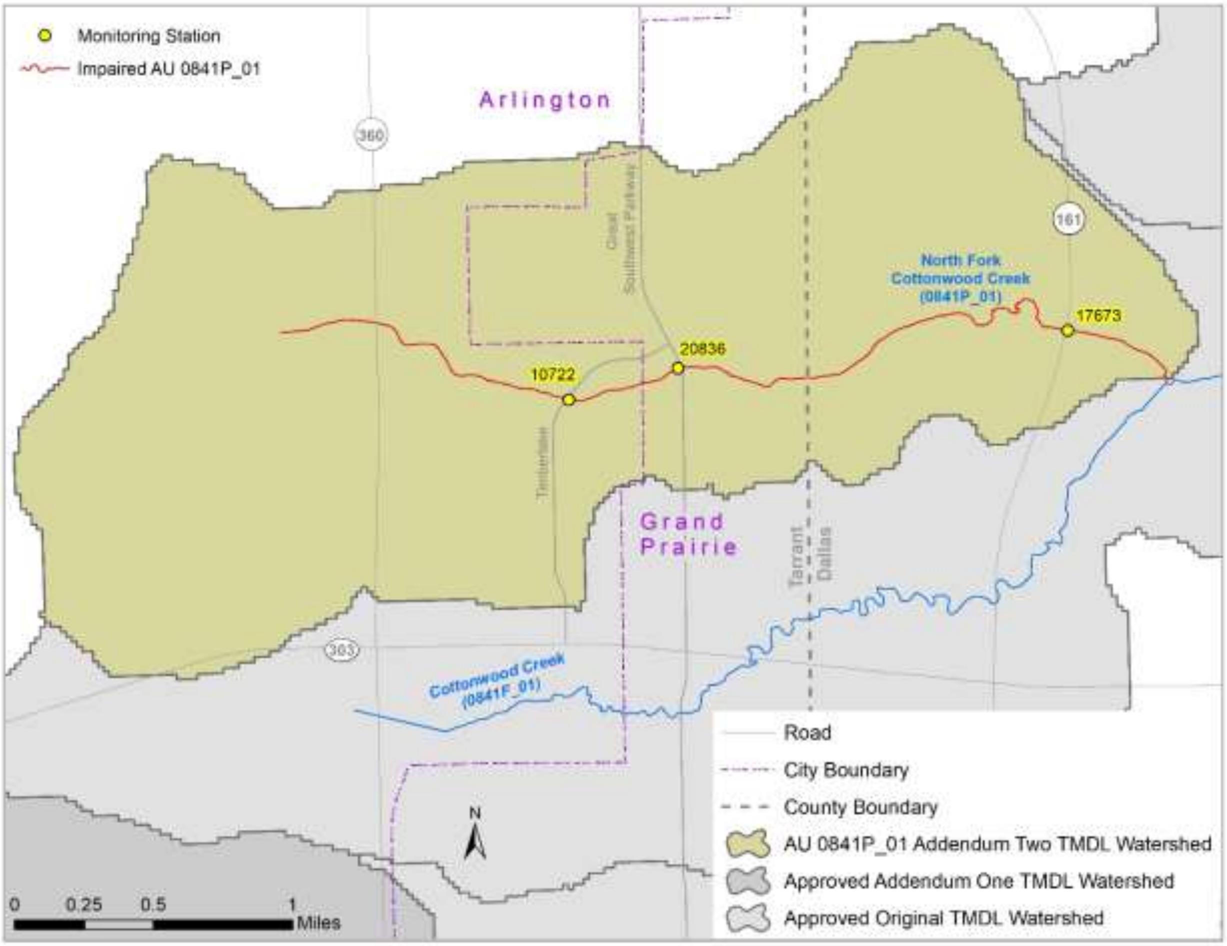

Figure 2. North Fork Cottonwood Creek watershed showing locations of the TCEQ SWQM stations

2.3. Climate and Hydrology

The North Fork Cottonwood Creek watershed is near the center of the Dallas/Fort Worth (DFW) metroplex, which has a humid subtropical climate (NOAA, 2009). Typically, the DFW area has mild winters with the first frost occurring in late November and the last frost in mid-March; however, brief periods of extreme cold do occur. Summers in the DFW area are hot and temperatures frequently exceeding 100˚F are typically combined with fair skies and westerly winds. Annual precipitation predominately occurs in the form of thunderstorms that are typically brief in nature and are recurrent in the spring.

For the Arlington Municipal Airport weather station located in the western portion of the Fish Creek (0841K) watershed, the average high temperatures typically peak in August (96.8 ˚F) with highs above 100 ˚F occurring June through August (Figure 3; NOAA, 2021). During winter, the average low temperature generally bottoms out at 35.6 ˚F in January (NOAA, 2021).

Weather data obtained from the National Climatic Data Center for the Arlington Municipal Airport station spanning a period from 1999 through 2019 indicate the wettest month is typically May (4.4 inches) while August (1.6 inches) is normally the driest month, with rainfall occurring throughout the year (Figure 3; NOAA, 2021). Average annual rainfall for the twenty-year period was 34.3 inches.

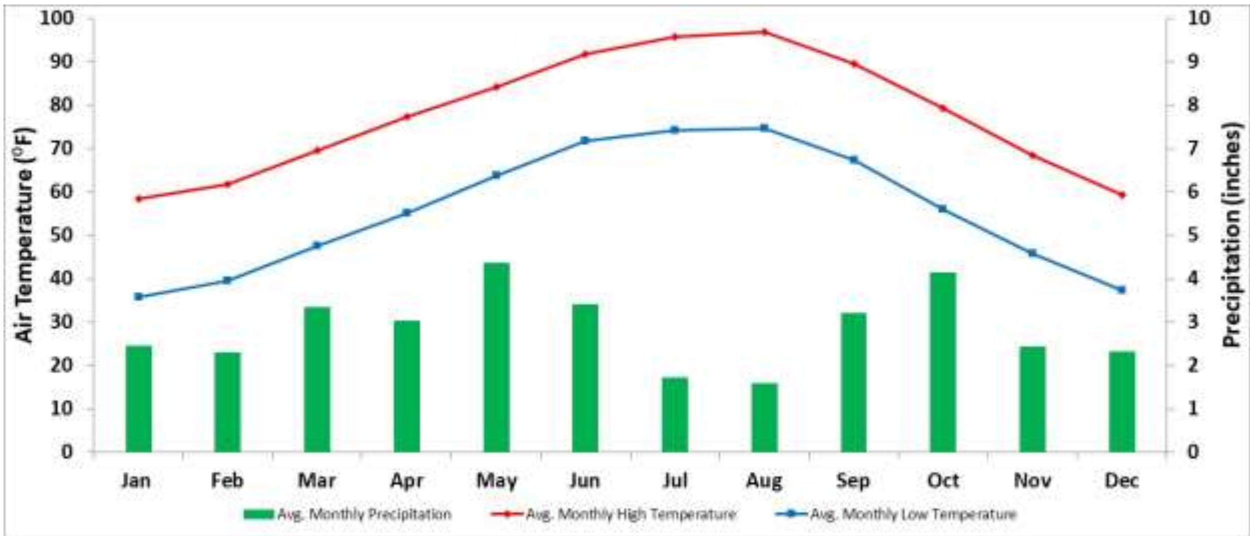

Figure 3. Average minimum and maximum air temperature and total precipitation by month from Jan 1999–Dec 2019 for Arlington Municipal Airport

2.4. Population and Population Projections

As shown in Figure 1, the North Fork Cottonwood Creek watershed is geographically located within the municipal boundaries of Arlington and Grand Prairie. Population estimates were developed using 2010 U.S. Census Block data allocated to the area within the TMDL watershed. Population projections for the year 2045 were developed by the North Central Texas Council of Governments (NCTCOG) by using traffic survey zone allocations. Traffic survey zones are planning areas used by NCTCOG to provide for more analysis at a local scale. NCTCOG modeled the 2045 projected populations using inputs such as number of households, household populations, land cover changes, and future land use plans. The projected population increase was then estimated based on the increase from the 2010 population to the projected 2045 population. This predicts that the population within the watershed will increase by 38.4%. (Table 2; USCB 2010 and NCTCOG, 2017a).

Table 2. Population projections

Water Body Name	AU	2010 U.S Census Population	2045 Population Projection	Projected Population Increase (2010–2045)	Percentage Change
North Fork Cottonwood Creek	0841P_01	32,252	44,643	12,391	38.4%

2.5. Land Cover

The land cover data for the North Fork Cottonwood Creek watershed were obtained from the NCTCOG (2017b) and represent land cover estimates for 2015. The land cover is represented by the following categories and definitions:

- Commercial/Industrial: land occupied by office, retail, industrial (manufacturing, warehouses, salvage yards, quarries, mines), utilities (sewage/water treatment plants, power infrastructure), stadiums, communication (radio, television, cable, and phone infrastructure), construction sites, and parking.
- Group Quarters: land occupied by nursing homes, dormitories, jails, military personnel quarters, and hotels/motels.
- Residential: land occupied by single family, multi-family, and mobile home residences.
- Institution: land occupied by churches, schools, museums, hospitals, medical clinics, libraries, government facilities, and military bases.
- Transit: land occupied by roads, rail lines, rail stations, bus lines and bus facilities.
- Dedicated: land occupied by public and private parks, golf courses, tennis courts, pools, campgrounds, amusement parks, and cemeteries.
- Vacant: land that is undeveloped with the potential to be developed or reserved for recreational use.
- Ranch/Farmland: land occupied by livestock or crops.
- Timberland: land covered by trees.
- Water: covered by lakes, rivers, and ponds.

The 2015 land cover data from the NCTCOG is provided in Figure 4. A summary of the land cover data is provided in Table 3 and shows that residential is the dominant land cover comprising approximately 34.76% of the total land cover.

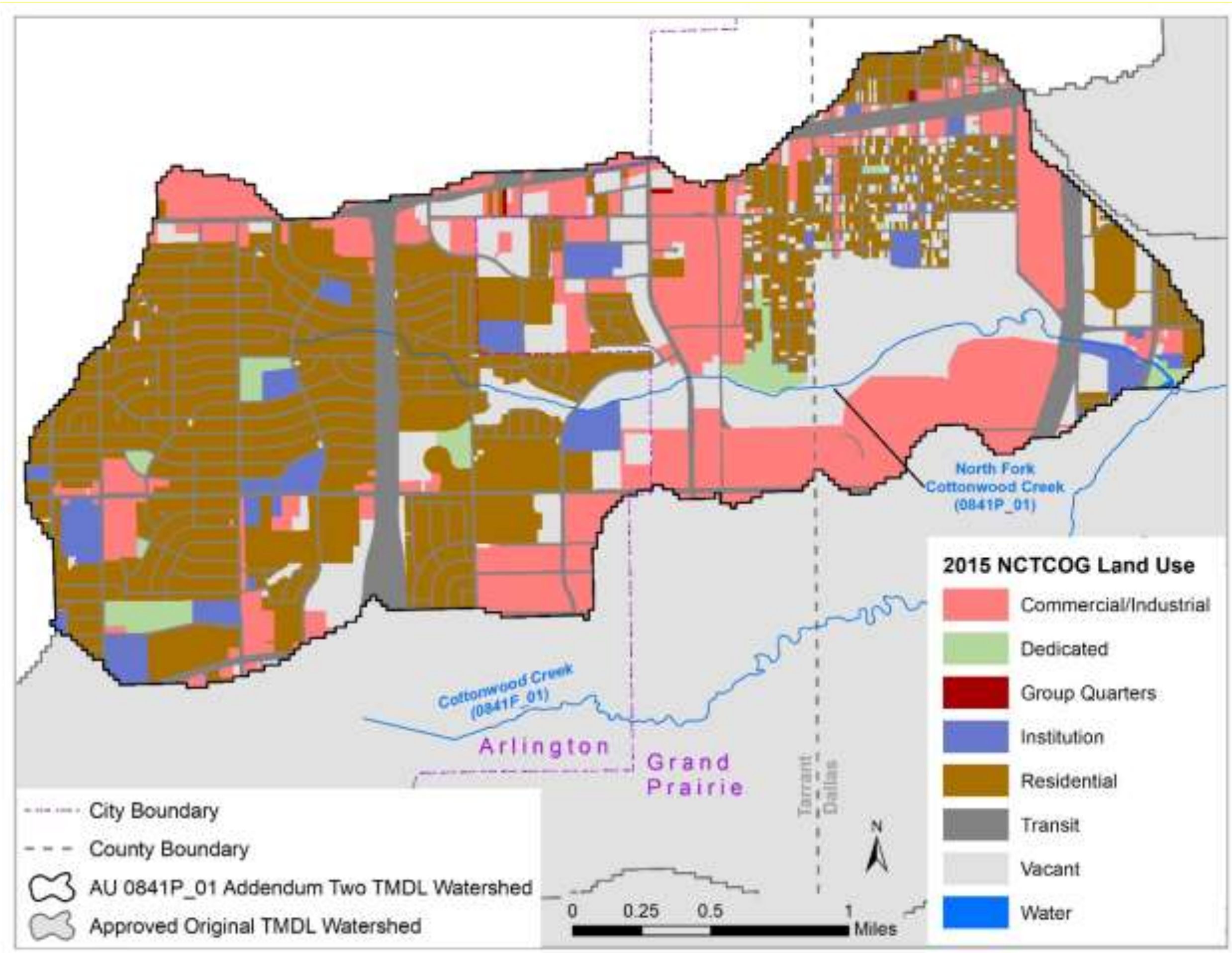

Figure 4. Land cover map showing classifications as of 2015

Table 3. 2015 land cover by area and percentage

Classification	Area (acres)	Percentage of Total
Commercial/Industrial	776.9	21.91%
Group Quarters	2.7	0.08%
Residential	1,232.6	34.76%
Institution	163.7	4.62%
Transit	657.9	18.56%
Dedicated	76.4	2.15%
Vacant	633.4	17.86%
Water	2.0	0.06%
Total	**3,545.6**	**100%**

2.6. 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. Wastewater treatment facilities (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 source in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permits.

With the exception of 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.

2.6.1. Regulated Sources

Regulated sources are controlled by permit under the TPDES program. Stormwater discharges from industrial sites, regulated construction activities, and municipal separate storm sewer systems (MS4s) represent the potential regulated sources in the TMDL watershed.

2.6.1.1. Domestic and Industrial Wastewater Treatment Facilities

No permitted WWTFs exist in the TMDL study area. Domestic wastewater is collected by and transported to the Trinity River Authority (TRA) Central Regional Wastewater System, which is outside the study area (Figure 5).

2.6.1.2. TCEQ/TPDES General Wastewater Permits

Certain types of activities must be covered by one of several TCEQ/TPDES 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)

A review of active general permits (TCEQ, 2021a) in the North Fork Cottonwood Creek watershed as of February 25, 2021, found two permittees authorized by the general pesticide permit. The pesticide management areas do not have bacteria reporting requirements or limits in their permits. Pesticide application in the pesticide management areas is assumed to contain inconsequential amounts of indicator bacteria; therefore, it was unnecessary to allocate bacteria loads to them. No other active general wastewater permit authorizations were found.

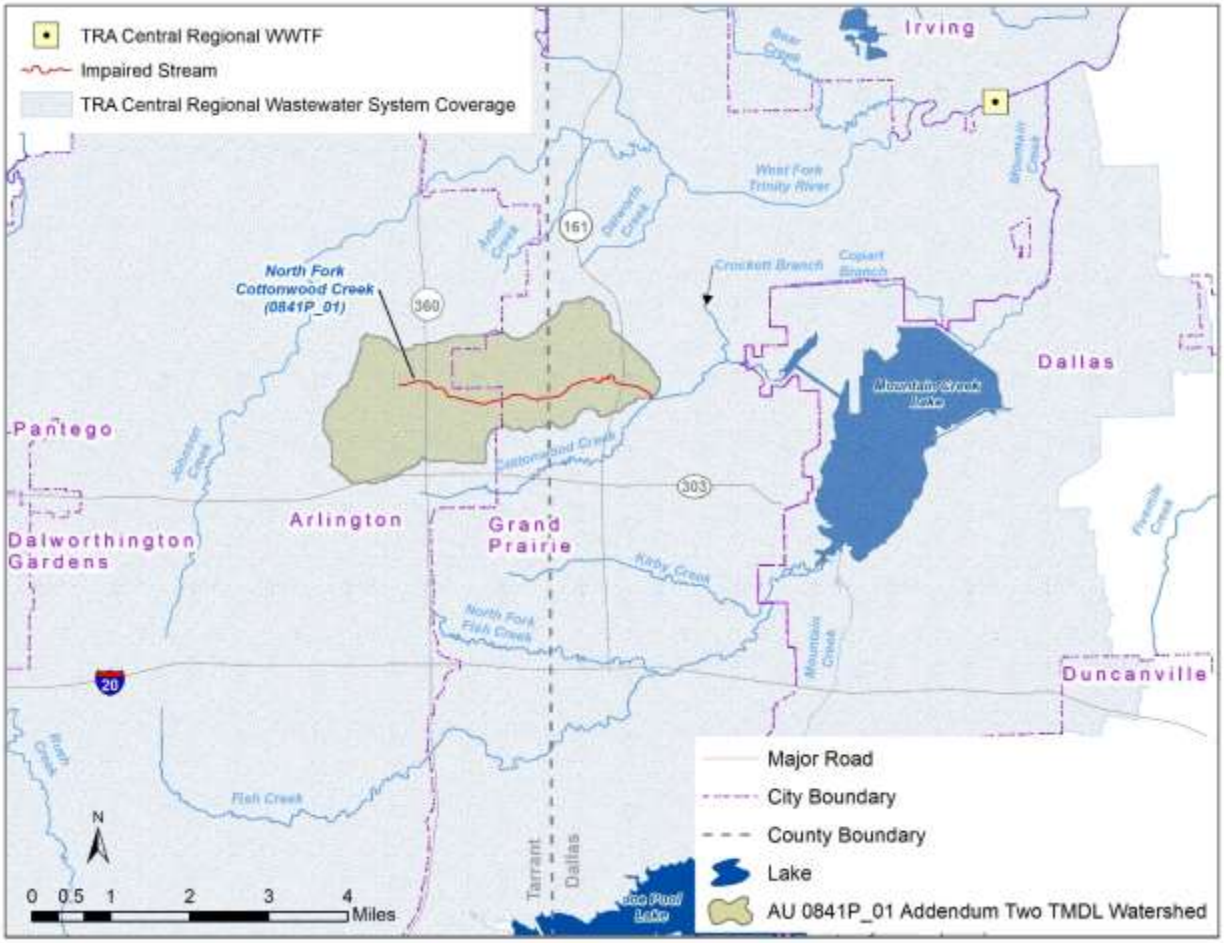

Figure 5. Coverage area of the TRA Central Regional Wastewater System within the TMDL study area

2.6.1.3. 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:

1. Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated MS4s and stormwater discharges associated with regulated industrial and construction activities.
2. 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 MS4s with populations of 100,000 or more based on the 1990 United States Census, while the Phase II general permit regulates small MS4 within a United States Census Bureau (USCB) defined urbanized area.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that the SWMPs specify the best management practices 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 measures 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 those for Phase II permits, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program. The Phase I MCMs include all of these activities:

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

Three MS4 permits currently cover 100% of the TMDL study area (Table 4 and Figure 6).

Table 4. TPDES MS4 permits

Regulated Entity	TPDES Permit/ NPDES[a] Permit	Permit Type
City of Arlington	WQ0004635000/ TXS000301	Phase I
Texas Department of Transportation	WQ0005011000/ TXS002101	Combined Phase I/II

Regulated Entity	TPDES Permit/ NPDES[a] Permit	Permit Type
City of Grand Prairie	General Permit (TXR040000)/ TXR040065	Phase II

[a] National Pollutant Discharge Elimination System

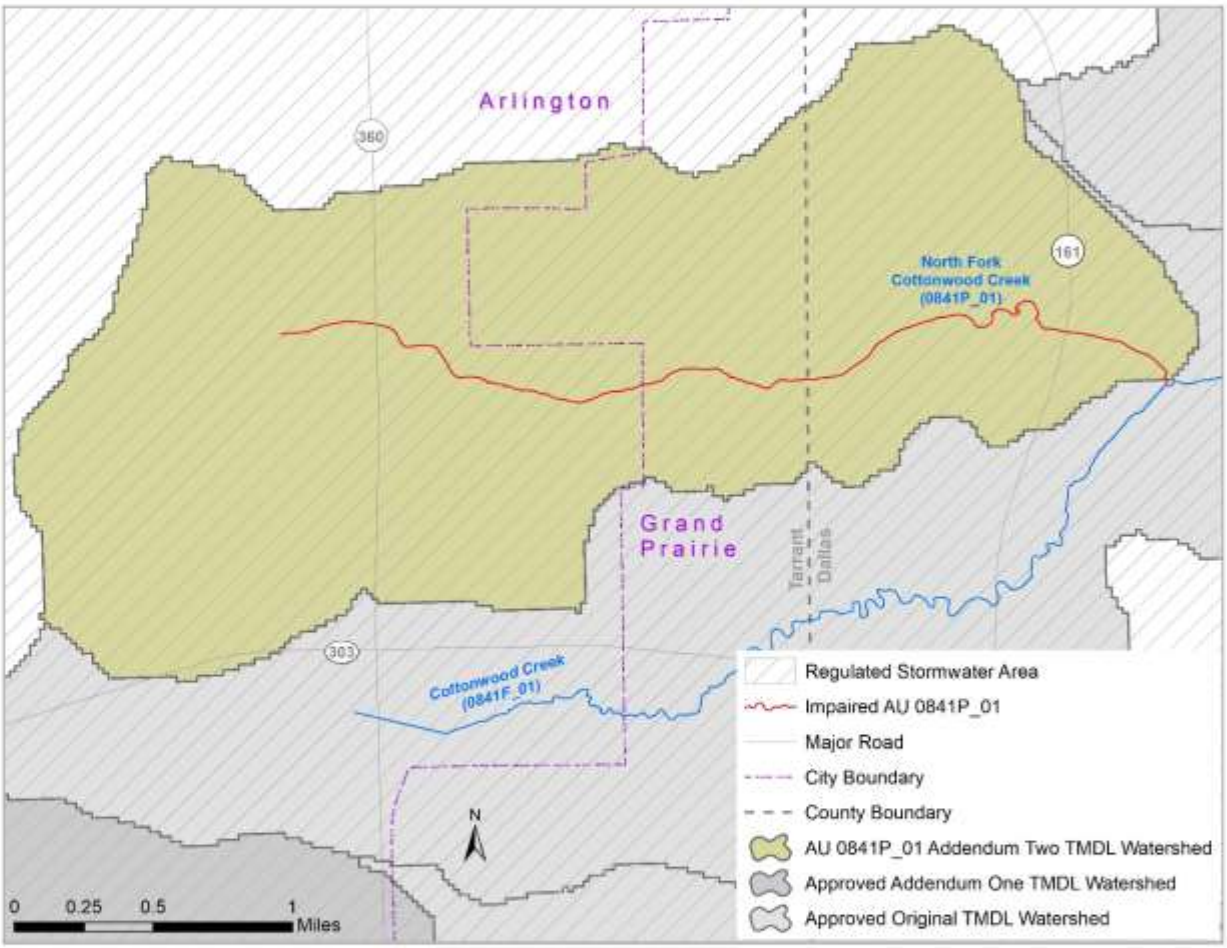

Figure 6. Regulated stormwater area based on Phase I and Phase II MS4 permits

2.6.1.3.1 TPDES General Stormwater Permits

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
- 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

A review of active stormwater general permit coverage as of March 30, 2021 (TCEQ, 2021a), found one MSGP authorization, one Phase II MS4 authorization, and several CGP authorizations located within the North Fork Cottonwood Creek watershed. The areas covered by the MSGP and CGP authorizations are not discussed further, since MS4 permits cover 100% of the watershed area.

2.6.1.4. 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 are typical causes of overflows under conditions of high flow in the WWTF system. Blockages in the line may worsen the inflow and infiltration problem. Other causes, such as a collapsed sewer line, may occur under any condition.

Information about reported SSO incidents in the North Fork Cottonwood Creek watershed were acquired through the NCTCOG for incidents that occurred from 2010 to 2019. The SSO data were originally collected by TCEQ Region 4 and were refined by NCTCOG by assigning latitude and longitude coordinates to each SSO event. Table 5 summarizes the SSO data. Figure 7 shows the locations of reported incidents.

Table 5. Summary of SSO incidents from 2010–2019

No. of Incidents	Total Volume (gallons)	Average Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)
37	17,074	461	7	5,560

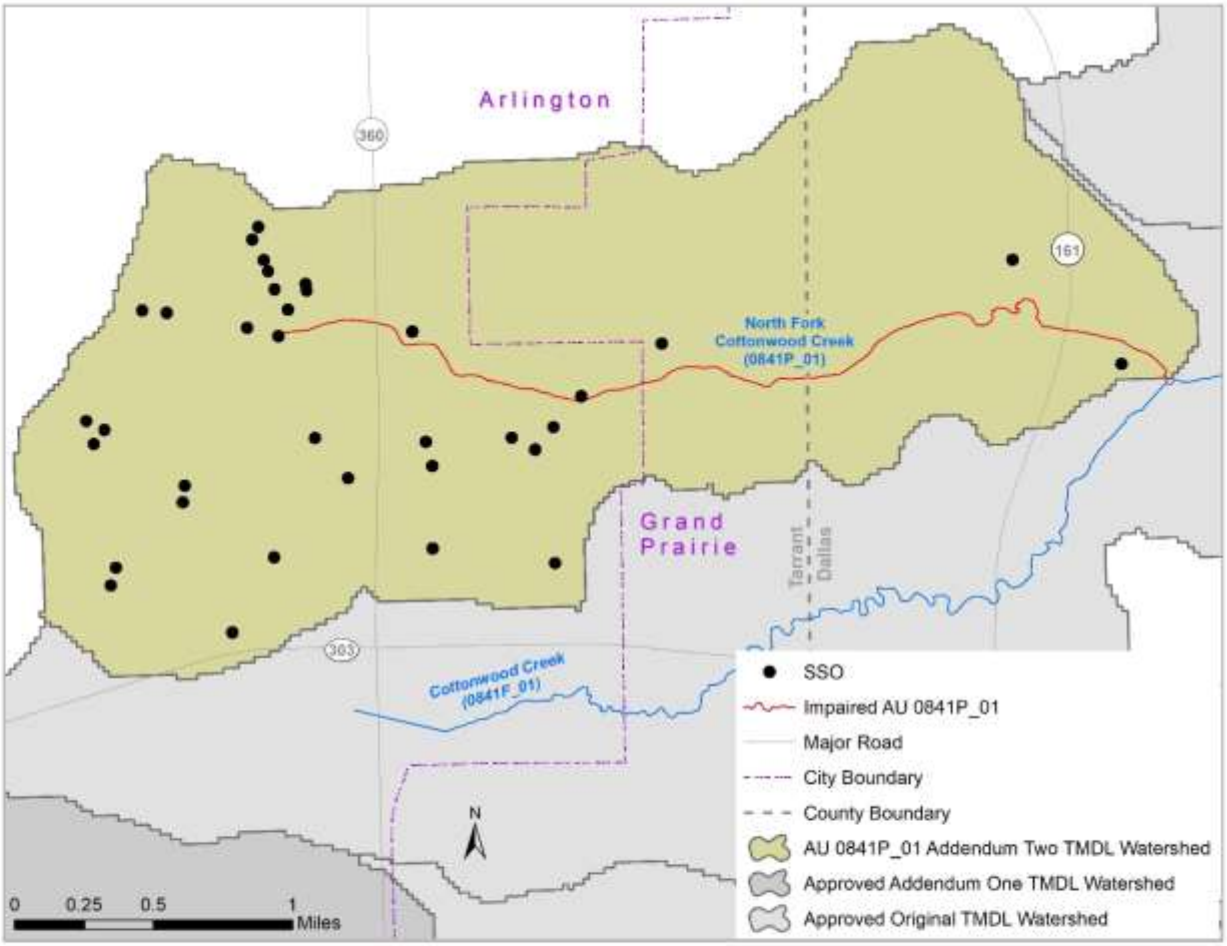

Figure 7. SSOs from 2010–2019

2.6.1.5. 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 the following.

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.

2.6.2. 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, and domestic pets.

2.6.2.1. Wildlife and Unmanaged Animals

Fecal bacteria are common inhabitants of the intestines of all warm-blooded animals, including feral hogs and 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 *E. coli* contribution from feral hogs and wildlife in the North Fork Cottonwood Creek watershed cannot be determined based on existing information; however, due to its urbanized nature, it is assumed that the contribution would be minimal.

2.6.2.2. Unregulated Agricultural Activities and Domesticated Animals

Due to the highly urbanized nature of the TMDL study area, livestock are not a major source of bacteria loading.

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 6 summarizes the estimated number of dogs and cats within the TMDL watershed. 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 2017–2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the watershed was estimated using 2010 USCB data (USCB, 2010). The actual contribution and significance of bacteria loads from pets reaching the water body is unknown.

Table 6. Estimated distribution of dog and cat populations

Watershed	Households	Dogs	Cats
North Fork Cottonwood Creek	10,056	6,175	4,596

2.6.2.3. On-Site Sewage Facilities

Failing on-site sewage facilities (OSSFs), commonly referred to as septic systems, are not a major source of bacteria loading in the North Fork Cottonwood Creek watershed, because the entire watershed area is served by a wastewater collection and treatment system. A review of OSSF information received from NCTCOG indicates that no OSSFs are known to exist in the TMDL study area.

2.6.2.4. 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 for North Fork Cottonwood Creek.

Section 3. 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.

3.1. Tool Selection

For consistency between this TMDL and the previously completed TMDLs located upstream of Mountain Creek Lake, the pollutant load allocation activities for North Fork Cottonwood Creek used the LDC method. The LDC method has been previously used on TCEQ-adopted and EPA-approved TMDLs for the *Four Total Maximum Daily Loads for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake* (TCEQ, 2016) as well as in *TMDL Addendum One: One TMDL for Indicator Bacteria in North Fork Fish Creek* (TCEQ, 2019).

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 supports application of the LDC method within their three-tiered approach to TMDL development (Jones et al., 2009). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion and can give indications of broad sources of the bacteria, that is, point source and nonpoint source.

3.2. Data Resources

Successful application of the LDC method requires two basic types of data: continuous daily streamflow data and historical bacteria data for the relevant indicator bacteria, which in this case is *E. coli*.

Hydrologic data in the form of daily streamflow records were unavailable for the North Fork Cottonwood Creek watershed; however, streamflow records were available for the nearby Walnut Creek watershed. Streamflow records for Walnut Creek are collected and made readily available by the United States Geological Survey (USGS; USGS, 2020), which operates the streamflow gauge (Table 7, Figure 8). USGS streamflow gauge 080497000 is located along the mainstem of Walnut Creek and serves as the primary source for streamflow records used in this document. The Walnut Creek streamflow gauge served as the source of streamflow records used in the existing four TMDLs to which the North Fork Cottonwood Creek TMDL will be added.

The drainage area ratio (DAR) approach was applied to the streamflow records for Walnut Creek as explained in more detail in Section 3.3.3.

Table 7. Basic information on Walnut Creek USGS streamflow gauge

Gauge No.	Site Description	Drainage Area (acres)	Daily Streamflow Record (beginning & end date)
08049700	Walnut Creek near Mansfield, Texas	40,179	Oct. 1960 – present

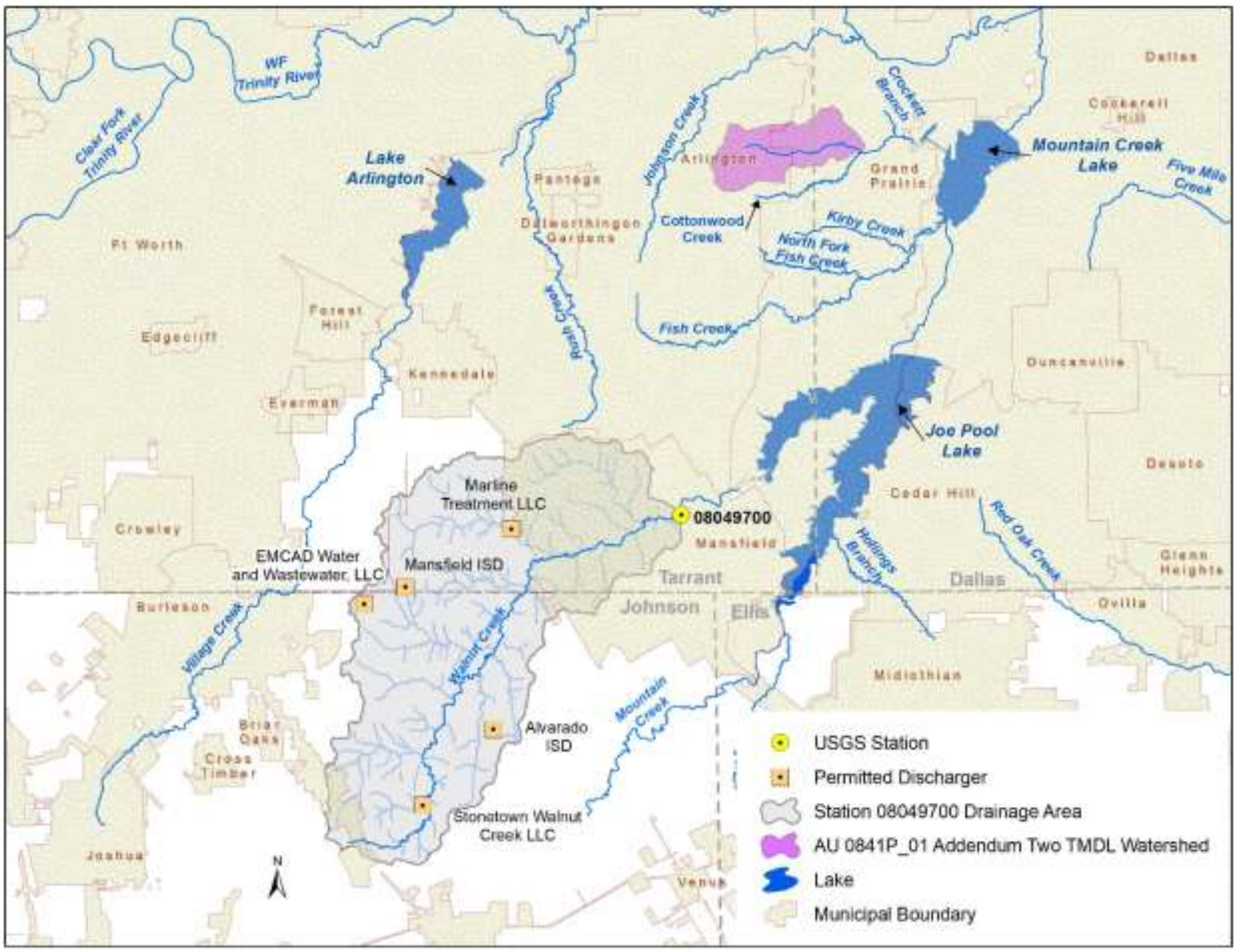

Figure 8. TMDL study area, Walnut Creek watershed, and USGS Station 08049700 location near Mansfield, Texas

Ambient *E. coli* data were retrieved from the TCEQ Surface Water Quality Monitoring Information System on November 12, 2020 for three stations along North Fork Cottonwood Creek (Table 8 and Figure 2).

Table 8. Summary of historical data set of *E. coli* concentrations

Station	Station Location	No. of *E. coli* Samples	Data Date Range
10722	At Timberlake Drive, Arlington, Texas	62	Jan 2002 – May 2019
20836	At South Great Southwest Parkway, Grand Prairie, Texas	64	May 2009 – Sep 2014
17673	At West Freeway, Grand Prairie, Texas	72	Dec 2001 – May 2008

3.3. 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 series of 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 DAR parameter estimates.
- Step 4: Develop daily streamflow record at the desired stream location.
- Step 5: Develop an FDC at the desired stream location, segmented into discrete flow regimes.
- Step 6: Develop the allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- Step 7: Superimpose historical bacteria data on each allowable bacteria LDC.

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

3.3.1. Step 1: Determine Hydrologic Period

A 60-year daily hydrologic (streamflow) record was available for USGS gauge 08049700 located on nearby Walnut Creek (Table 7, Figure 8). Optimally, the period of record to develop FDCs should include as much data as possible in order to capture extremes of high and low streamflow and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the *E. coli* data were collected. Therefore, a 25-year record of daily streamflow from January 1995 through December 2019 was selected to develop the FDC at the sampling station location This period also includes the collection dates of all available *E. coli* data at the time this work effort was undertaken. A 25-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent and current conditions in the watershed. A 25-year hydrologic period was also used in the previously completed TMDL *Addendum One: One TMDL for Indicator Bacteria in North Fork Fish Creek* (TCEQ, 2019) and the original TMDL *Four Total Maximum Daily Loads for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake* (TCEQ, 2016), which maintains consistency of the North Fork Cottonwood Creek TMDL with the previous TMDLs.

3.3.2. Step 2: Determine Desired Stream Locations

When using the LDC method, the best location for developing the pollutant load allocation is a currently monitored SWQM station located near the outlet of the watershed. While Station 17673 is relatively near the outlet, this station has not been monitored since 2008. The lack of recent monitoring at Station 17673 required the development of an additional LDC at the watershed outlet. The FDCs and LDCs developed for the three SWQM stations within the TMDL watershed are used only to provide additional information. The LDC developed at the watershed outlet was the basis for developing the pollutant load allocations for North Fork Cottonwood Creek.

3.3.3. Step 3: Develop Drainage Area Ratio Parameter Estimates

Once the hydrologic period of record and stream locations were determined, the next step was to develop the 25-year daily streamflow records from extant USGS records.

The method to develop the necessary streamflow record for the FDC/LDC location (SWQM station locations and watershed outlet) involved a DAR approach. The DAR approach involves multiplying a USGS gauging station daily streamflow value by a factor to estimate the flow at a desired SWQM station location. The factor is determined by dividing the drainage area upstream of the desired SWQM station by the drainage area upstream of the USGS gauge (Table 9).

Because an assumption of the DAR approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land cover, point source derived flows from within the USGS gauge watershed should first be removed from the flow record prior to application of the ratio. There are five active WWTF discharges above the USGS gauge on Walnut Creek (Figure 8); however, each of these discharges is small (largest permitted discharge of 0.04 million gallons per day [MGD]) and all are greater than 10 stream miles from the gauge location. The combination of the small size of the discharges, their distance from the gauge and the fact that the USGS gauge location for the 25-year period of record experienced zero streamflow 8% of the time and flow less than 0.05 cubic feet per second (cfs) 15% of the time lead to the assumption that the existing discharges are not significantly impacting the gauged streamflow record. Therefore, no adjustments for WWTF discharges were made to the Walnut Creek USGS gauge record prior to application of the DARs.

3.3.4. Step 4: Develop Daily Streamflow Records at Desired Locations

In addition to the WWTF discharges, surface water diversions associated with water rights permits have the potential of impacting stream hydrology and application of the

DAR approach. A spatial query of water rights features (diversions, withdrawals, return flows) showed that the TMDL watershed did not contain any active water rights authorizations; however, there was one active water-right authorization located in the Walnut Creek watershed. A review of the Texas Water Rights Viewer (TCEQ, 2021b) indicates that only one user, located above the USGS gauge 08049700, reported diversions from 2013 through 2019. The impact of the monthly diversions was investigated by applying the diversion amounts to the streamflow record and found to have no significant impact on streamflow calculations and ultimately no impact on TMDL calculations. Therefore, diversions associated with water rights permits were not considered in the development of the streamflow record.

The DARs for locations within the TMDL study area are presented in Table 9. The computation of the daily streamflow record at a location was performed by multiplying each daily streamflow in the 25-year Walnut Creek gauged record by the appropriate DAR for that station.

Table 9. DARs based on the drainage area of the Walnut Creek USGS gauge

Gauge/Station	Drainage Area (acres)	DAR
USGS Gauge 08049700	40,179	1.0
SWQM Station 10722	1,549	0.0386
SWQM Station 20836	2,196	0.0547
SWQM Station 10722	3,309	0.0824
Watershed Outlet	3,546	0.0883

3.3.5. Steps 5–7: 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. To develop an FDC for a location, all of the following steps were taken in the order shown.

- 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 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 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 allowable daily loadings for the geometric mean criterion. The next step was to plot the sampled *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.

3.4. Flow Duration Curves

FDCs were developed for three SWQM stations within North Fork Cottonwood Creek as well for as the outlet of the watershed (Figure 9). The FDCs were developed by applying the DAR method using the Walnut Creek USGS gauge 25-year period of record described in the preceding sections. Flow exceedances less than 10% typically represent streamflow influenced by storm runoff, while higher flow exceedances represent receding hydrographs after a runoff event and base flow conditions.

3.5. Load Duration Curves

A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curve. This approach can aid in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0–10% (high flows); (2) 10–40% (moist conditions); (3) 40–60% (mid-range flows); (4) 60–90% (dry conditions); and (5) 90–100% (low flows).

For this TMDL watershed, streamflow distribution was divided into three flow regimes: high, mid-range, and low flow (Table 10), which maintains consistency with the previously completed TMDLs (TCEQ, 2016 and 2019). High flows correspond to large storm-induced runoff events. Mid-range flows typically represent periods of medium base flows but can also represent small runoff events and periods of flow recession following large storm events. Conditions within the low flow regime represent relatively low flow conditions, resulting from extended periods of little or no rainfall.

The selection of the flow regime intervals was based on general observations of the LDCs. The selected flow regime intervals also provide consistency with the original TMDLs for the watershed upstream of Mountain Creek Lake (TCEQ, 2016).

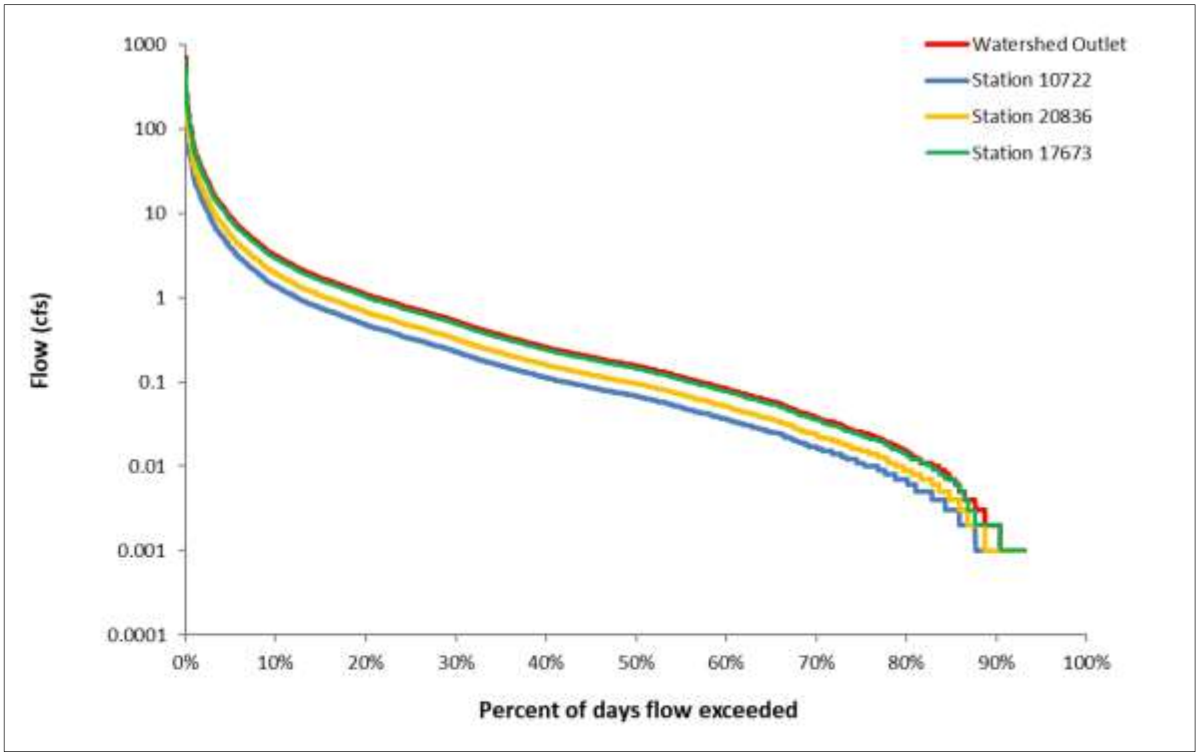

Figure 9. FDCs for North Fork Cottonwood Creek (AU 0841P_01)

Table 10. Flow regime classifications

Flow Regime Classification	Flow Exceedance Percentile
High Flows	0 – 10%
Mid-Range Flows	10 – 60%
Low Flows	60 – 100%

The LDCs for North Fork Cottonwood Creek, showing these three flow regimes, are provided in Figures 10–13. The LDCs for the three SWQM stations were developed for informational purposes, while the LDC for the watershed outlet was constructed for developing the TMDL allocation for North Fork Cottonwood Creek. There is no sampling station located at the watershed outlet so there are no bacteria data available to be plotted on the watershed outlet LDC. Geometric mean loadings for the data points within each flow regime have also been distinguished on the figure to aid interpretation. The LDCs for the SWQM stations provide a means of identifying the streamflow conditions under which exceedances in *E. coli* concentrations have occurred. The LDC depicts the allowable loading under the geometric mean criterion

(126 cfu/100 mL) and shows that existing loadings often exceed the criterion. In addition, the LDC also presents the allowable loading under the single sample criterion (399 cfu/100 mL).

On the graph, the measured *E. coli* data are associated with a "wet weather event" or a "non-wet weather event." A sample was determined to be influenced by a wet weather event based on the reported "days since last precipitation" (DSLP), as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic and hydrologic conditions. A sample taken with a DSLP ≤ 2 days was defined as a wet weather event. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

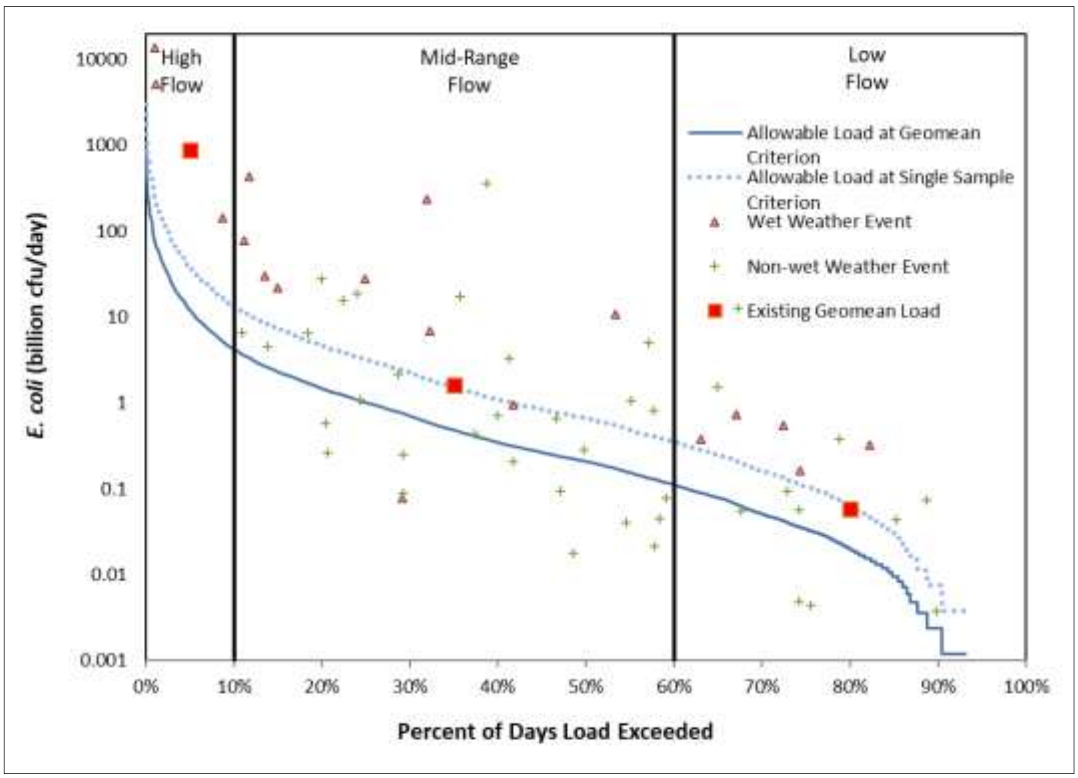

Figure 10. LDC at SWQM Station 10722

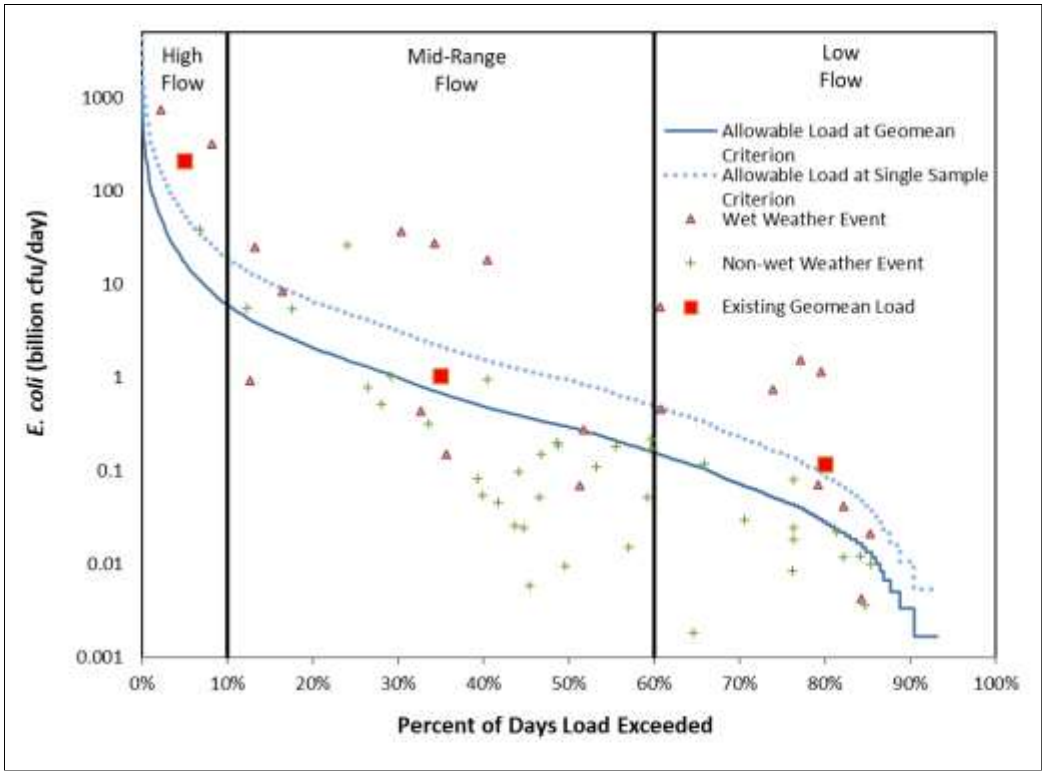

Figure 11. LDC at SWQM Station 20836

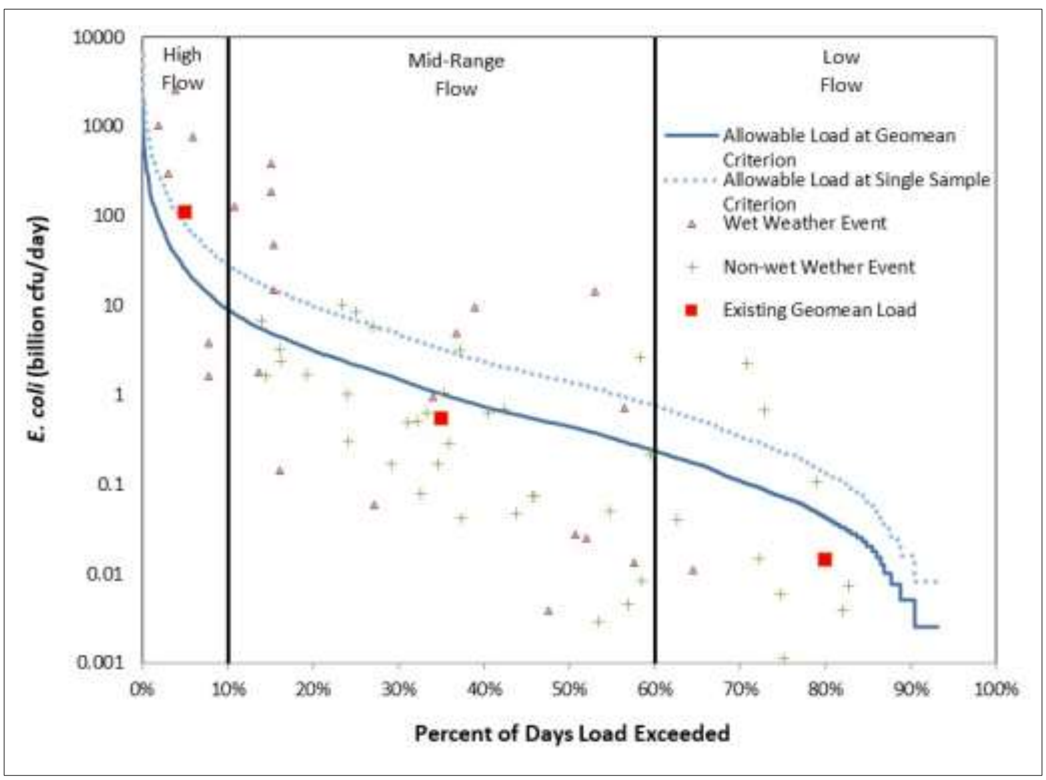

Figure 12. LDC at SWQM Station 17673

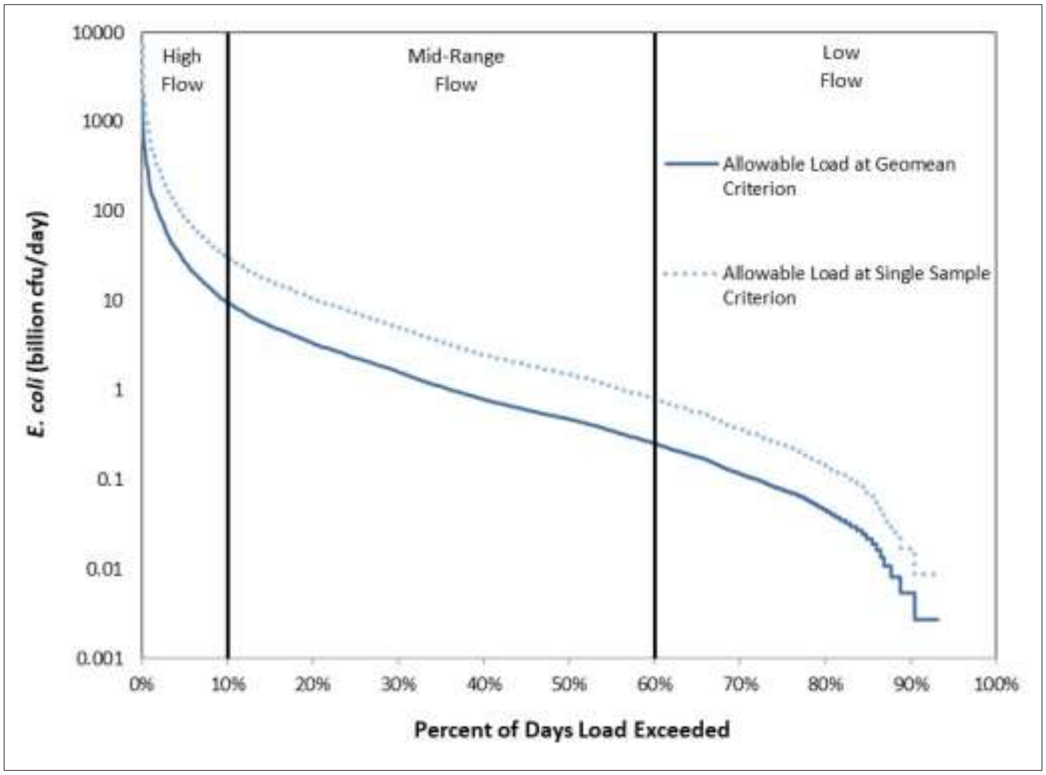

Figure 13. LDC for the outlet of North Fork Cottonwood Creek

Section 4. TMDL Allocation Analysis

4.1. 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.

4.2. Seasonal Variation

Seasonal variations or seasonality 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 three SWQM stations (10722, 20836, and 17673). 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. This analysis of *E. coli* data indicated that there was no significant difference (α=0.05) in indicator bacteria between cool and warm weather seasons for North Fork Cottonwood Creek.

4.3. 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 flow 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 and 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 also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7). 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.

4.4. 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 is 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 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 hydrologic 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 LDCs developed for the three SWQM station locations with historical *E. coli* data added to the graph (Figures 10–12) and Section 2.6 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. For this TMDL watershed, historical *E. coli* data show that elevated bacteria loadings occur under all three flow regimes. The geometric means of the measured data exceed the geomean criterion under all three flow regimes for SWQM Stations 10722 and 20836 (Figures 10 and 11). Geometric means measured at SWQM Station 17673 (Figure 12) indicate a slight moderation of the elevated loadings under mid-range and low flow conditions; however, this may not represent current conditions since data has not been collected at this station in over 10 years.

4.5. 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 in the TMDL using either of the following two methods:

1. Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
2. 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%.

4.6. Load Reduction Analysis

While the TMDL for North Fork Cottonwood Creek was developed using an LDC and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percentage load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical *E. coli* data obtained from the SWQM stations within AU 0841P_01.

For each flow regime the percentage reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 126 cfu/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 11).

Table 11. Percent reduction calculations

Flow Regime	Station	Number of Samples	Geometric Mean by Flow Regime (cfu/100 ML)	Percentage Reduction by Flow Regime
High Flow (0–10%)	10722	3	9,340	98.7%
Mid-Range Flow (10–60%)	10722	39	423	70.2%
Low Flow (60–100%)	10722	20	365	65.5%
High Flow (0–10%)	20836	3	1,561	91.9%
Mid-Range Flow (10–60%)	20836	36	191	34.1%
Low Flow (60–100%)	20836	25	521	75.8%
High Flow (0–10%)	17673	6	540	76.7%
Mid-Range Flow (10–60%)	17673	48	66	0%
Low Flow (60–100%)	17673	18	41	0%

4.7. 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:

$$TMDL = WLA + LA + FG + MOS \qquad \text{(Equation 1)}$$

Where:

WLA = wasteload allocation, the amount of pollutant allowed by regulated dischargers

LA = load allocation, the amount of pollutant allowed by unregulated sources

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

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.

4.7.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDL for AU 0841P_01 was developed as a pollutant load allocation based on information from the LDC for the outlet of the TMDL watershed (Figure 13). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* criterion (126 cfu/100 mL) 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:

TMDL (cfu/day) = Criterion * Flow (cfs) * Conversion Factor (Equation 2)

Where:

Criterion = 126 cfu/100 mL (*E. coli*)

Conversion Factor (to billion cfu/day) = (283.1685 100 mL/cubic feet (ft^3) * 86,400 seconds/day (s/d) ÷ 1,000,000,000

The allowable loading of *E. coli* that the water body can receive daily was determined using Equation 2 based on the median value within the high flow regime of the FDC (or 5% flow exceedance value) for the watershed outlet (Table 12).

Table 12. Summary of allowable loading calculation

Water Body Name	AU	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/day)	TMDL (Billion cfu/day)
North Fork Cottonwood Creek	0841P_01	8.918	2.749E+10	27.492

4.7.2. 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:

MOS = 0.05 * TMDL (Equation 3)

Using the value of TMDL for AU 0841P_01 provided in Table 12, the MOS may be readily computed by proper substitution in Equation 3 (Table 13).

Table 13. MOS calculations

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS
North Fork Cottonwood Creek	0841P_01	27.492	1.375

[a] TMDL from Table 12.

4.7.3. Waste Load Allocations

The 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}).

$WLA = WLA_{WWTF} + WLA_{SW}$ (Equation 4)

4.7.3.1. Wastewater

TPDES-permitted WWTFs are allocated a daily wasteload calculated as their full permitted discharge flow rate multiplied by one-half the instream geometric criterion. One-half of the water quality criterion (63 cfu/100mL) is used as the WWTF target to provide instream and downstream load capacity, and to be consistent with previously developed TMDLs. Thus, WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \quad \text{(Equation 5)}$$

Where:

Target= 63 cfu/100 mL

Flow = full permitted flow in MGD

Conversion Factor (to billion cfu/day) = 37,854,000 mL/MGD

Due to the absence of any permitted dischargers in the North Fork Cottonwood Creek watershed, the WLA_{WWTF} is zero.

4.7.3.2. 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 for estimating the WLA for these areas was used in the development of 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}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Equation 6)}$$

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

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. As described in Section 2.6.1.3, the North Fork Cottonwood Creek watershed is covered completely by MS4 Phase I and II permits. However, even in highly urbanized areas such as this one, there remain small areas of potential direct deposition of bacteria loadings from unregulated sources such as wildlife. To account for these small unregulated areas, the stream length based on the TCEQ definition of AU 0841P_01 and average channel width as calculated based on recent aerial imagery was used to compute an area of unregulated stormwater contribution (Table 14)

Table 14. Basis of unregulated stormwater area and computation of FDA_{SWP} term

Water Body Name	AU	Total Area (acres)	Stream Length (feet)	Estimated Average Channel Width (feet)	Estimated Stream Area (acres)	Fraction Unregulated Area	FDA_{SWP}
North Fork Cottonwood Creek	0841P_01	3,546	23,232	74	39.5	0.011	0.989

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 6), the FG term must be known. As noted previously in section 2.6.1.1, the North Fork Cottonwood Creek watershed is entirely within the collection system area of the TRA Central Regional WWTF. There are no WWTFs within the North Fork Cottonwood Creek watershed and there are no plans to build a new one within the watershed (TRA, 2021). Consequently, the FG term is zero. Table 15 provides the information needed to compute WLA_{SW}.

Table 15. Regulated stormwater WLA calculations

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	FG[d]	FDA_{SWP}[e]	WLA_{SW}[f]
North Fork Cottonwood Creek	0841P_01	27.492	1.375	0	0	0.989	25.830

[a] TMDL from Table 12

[b] MOS from Table 13

[c] WLA_{WWTF} = 0 due to an absence of any WWTFs in the TMDL watershed

[d] FG = 0 since the establishment of WWTFs within the TMDL watershed is highly unlikely

[e] FDA_{SWP} from Table 14

[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Eq. 6)

4.7.4. Future Growth

The FG 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 assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

Thus, the FG is calculated as follows:

$$FG = WWTF_{FP} * \text{conversion factor} * \text{target} \quad \text{(Equation. 7)}$$

Where:

$WWTF_{FP}$ = full permitted discharge (MGD) of potential future WWTF

Conversion factor = (37,854,000 100mL/MGD) ÷ 1,000,000,000

Target = 63 cfu/100 mL

As stated earlier, due to the absence of any existing WWTFs and the fact that it is highly unlikely that any new WWTFs will be established within the watershed (TRA, 2021), the FG component is zero.

4.7.5. Load Allocations

Within the North Fork Cottonwood Creek watershed, a small area not regulated by stormwater permits was assigned, as detailed in Table 14. The LA is the load from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \quad \text{(Equation 8)}$$

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 16.

Table 16. LA calculation

Load units expressed as billion cfu/day *E. coli*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	FG[e]	LA[f]
North Fork Cottonwood Creek	0841P_01	27.492	1.375	0	25.830	0	0.287

[a] TMDL from Table 12

[b] MOS from Table 13

[c] WLA_{WWTF} = 0 due to an absence of any WWTFs in the TMDL watershed

[d] WLA_{SW} from Table 15

[e] FG = 0 since the establishment of WWTFs within the TMDL watershed is highly unlikely

[f] LA = TMDL – WLA_{WWTF} – $WLAS_{W}$ – FG – MOS (Eq. 8)

4.8. Summary of TMDL Calculations

Table 17 summarizes the TMDL calculation for the North Fork Cottonwood Creek watershed. The TMDL was calculated based on the median flow in the 0–10 percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for the outlet of the North Fork Cottonwood Creek watershed. Allocations are based on the current geometric mean criterion for *E. coli* of 126 cfu/100 mL for each component of the TMDL. The TMDL allocation summary for the North Fork Cottonwood Creek TMDL watershed is summarized in Table 17.

Table 17. TMDL allocation summary

Load units expressed as billion cfu/day *E. coli*

AU	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
0841P_01	27.492	1.375	0	25.830	0.287	0

[a] TMDL = from Table 12

[b] MOS = from Table 13

[c] WLA_{WWTF} = 0 due to an absence of any WWTFs in the TMDL watershed

[d] WLA_{SW} = from Table 15

[e] LA = from Table 16

[f] FG = 0 since the establishment of WWTFs within the TMDL watershed is highly unlikely

The final TMDL allocations (Table 18) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the $WLA_{WWTF.}$

Table 18. Final TMDL allocations

Load units expressed as billion cfu/day *E. coli*

AU	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA
0841P_01	27.492	1.375	0	25.830	0.287

Section 5. References

AVMA (American Veterinary Medical Association). 2018. 2017–2018 U.S. Pet Ownership Statistics. Retrieved April 29, 2021 from www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics.

Cleland, B. 2003. TMDL Development From the "Bottom Up" - Part III: Duration Curves and Wet-Weather Assessments. Retrieved April 29, 2021 from engineering.purdue.edu/mapserve/ldc/pldc/help/TMDL_Development_from_the_Bottom_UP_PartIV.pdf.

EPA. 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. Retrieved April 29, 2021 from Office of Water: Total Maximum Daily Loads (303d) from www.epa.gov/sites/production/files/2018-10/documents/guidance-water-tmdl-process.pdf.

EPA. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. www.epa.gov/sites/production/files/2015-07/documents/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf.

Jones, C. A., Wagner, K., Di Giovanni, G., Hauck, L., Mott, J., Rifai, H., Srinivasan, R., Ward, G., Wythe, K. 2009. Bacteria Total Maximum Daily Load Task Force Final Report (No. TR-341). Texas Water Resources Institute. Retrieved April 29, 2021 from www.researchgate.net/publication/26903717_Bacteria_Total_Maximum_Daily_Load_Task_Force_Report.

NCTCOG. 2017a. Traffic Survey Zones. Retrieved March 9, 2021, from the Regional Data Center at data-nctcoggis.opendata.arcgis.com/datasets/2045-nctcog-demographic-forecast-tsz/explore.

NCTCOG. 2017b. 2015 Land Use. Retrieved March 30, 2021, from the Regional Data Center at data-nctcoggis.opendata.arcgis.com/datasets/2015-land-use/explore?location=32.606035%2C-97.213450%2C9.00.

NEIWPCC (New England Interstate Water Pollution Control Commission). 2003. Illicit Discharge Detection and Elimination Manual.

NOAA (National Oceanic and Atmospheric Administration). 2009. Dallas/Fort Worth Climate Narrative. Retrieved January 14, 2021, from National Weather Service Forecast Office from www.weather.gov/fwd/dnarrative.

NOAA. 2021. Station USW00053907, Arlington Municipal Airport, Arlington Texas, US Retrieved January 14, 2021, from the National Climatic Data Center at www.ncdc.noaa.gov/cdo-web/search.

TCEQ. 2016. Four TMDLs for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake. Retrieved April 29, 2021 fromwww.tceq.texas.gov/assets/public/waterquality/tmdl/66trinitybact/66F-MtCreekLakeTMDL-Adopted.pdf..

TCEQ. 2018a. 2018 Texas Surface Water Quality Standards. 2018 Chapter 307 Rule Amendment. Retrieved, April 29, 2021 from texreg.sos.state.tx.us/public/readtac%24ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=307&rl=Y.

TCEQ. 2018b. Preserving & Improving Water Quality: The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. Retrieved April 29, 2021 from www.tceq.texas.gov/assets/public/comm_exec/pubs/gi/gi-351.pdf.

TCEQ. 2019. Addendum One to Four Total Maximum Daily Loads for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake: One Total Maximum Daily Load for Indicator Bacteria in North Fork Fish Creek. Retrieved April 29, 2021 from www.tceq.texas.gov/assets/public/waterquality/tmdl/66trinitybact/66-nffc-addendum-oct2019.pdf.

TCEQ. 2020. 2020 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). Retrieved April 29, 2021 from www.tceq.texas.gov/waterquality/assessment/20twqi/20txir.

TCEQ. 2021a. Water Quality and General Permits & Registration Search. Retrieved April 15, 2021 from www2.tceq.texas.gov/wq_dpa/index.cfm.

TCEQ. 2021b. Texas Water Rights Viewer. Retrieved November 22, 2021 from tceq.maps.arcgis.com/home/item.html?id=44adc80d90b749cb85cf39e04027dbdc.

TRA. 2021. Personal communication, Glenn Clingenpeel, Manager, Technical Services and Basin Planning, via email on future growth for WWTFs within the North Cottonwood Creek watershed on April 20, 2021.

USCB. 2010. 2010 Census Block Shapefiles from www.census.gov/cgi-bin/geo/shapefiles/index.php. Tabular data from: 2010 Census Block Households and Families. Retrieved March 9, 2021, from American FactFinder at data.census.gov/cedsci/.

USGS. 2020. USGS Streamflow Data for Station 08049700, Walnut Creek near Mansfield, Texas. Retrieved November 12, 2020 from waterdata.usgs.gov/tx/nwis/current/?type=flow.

Appendix A. Method Used to Determine Population Projections

The following steps detail the method used to estimate the 2010 and projected 2045 populations in the North Fork Cottonwood Creek watershed.

1) Obtained U.S. Census data at the block level.

2) Developed 2010 watershed populations using the block level data for the portion of the census blocks located within the watershed.

3) Obtained population projections for the year 2045 from the NCTCOG traffic survey zone allocations.

4) Developed population projections using traffic survey zone data for the portion of the traffic survey zones located within the watershed.

5) Subtracted the 2010 watershed population from the 2045 population projection to determine the projected population increase. Subsequently, the projected population increase was divided by the 2010 watershed population to determine the percent population increase for the North Fork Cottonwood Creek watershed.