Modeling and Data Analysis Report

for

Joe Pool Lake Watershed Protection Plan (WPP) Development

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Investigating Entities

Texas A&M AgriLife Research
The Trinity River Authority of Texas

Prepared by

Avay Risal, Texas A&M AgriLife Research
Shubham Jain, Texas A&M AgriLife Research
Katie Mendoza, Texas A&M AgriLife Research
R. Srinivasan, Texas A&M AgriLife Research
Heather Firn, Trinity River Authority
Webster Mangham, Trinity River Authority

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Table of Contents

List of Figures

List of Tables

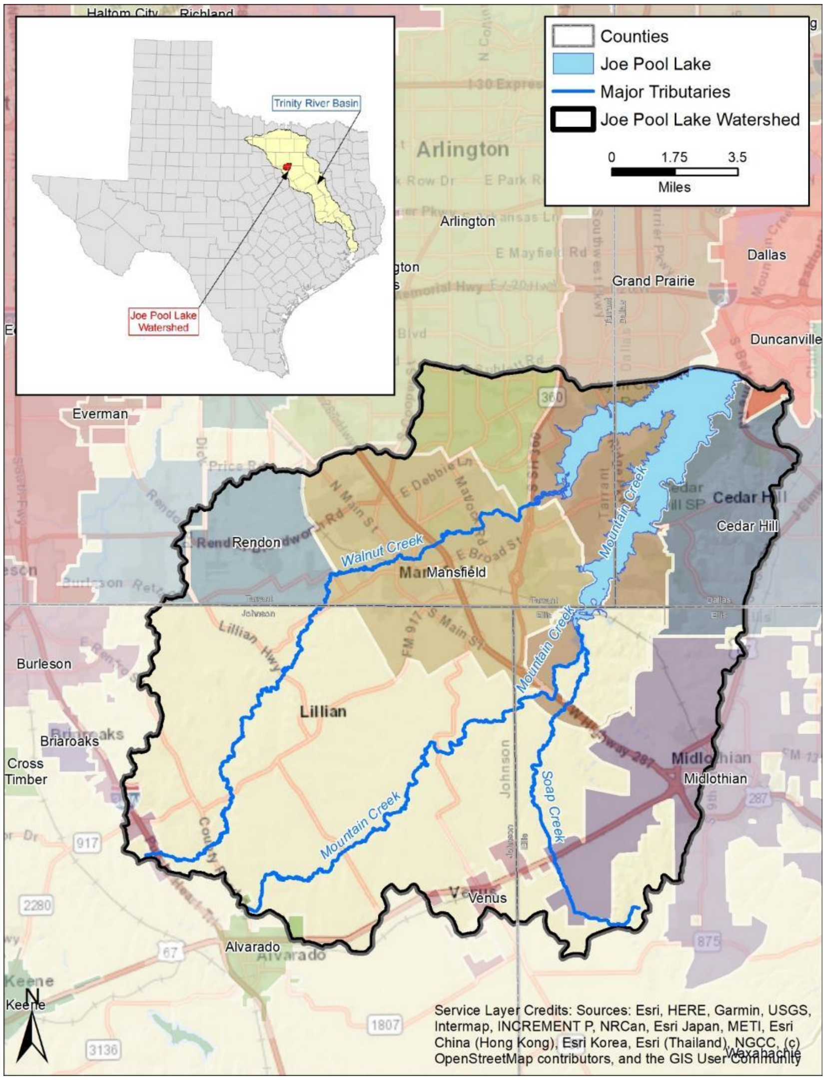
List of Acronyms

AMLE	Adjusted Maximum Likelihood Estimation
AU	assessment unit
BG	block groups
BMP	Best Management Practice
CFS	Cubic Feet Per Second
Chl-a	Chlorophyll-a
DO	Dissolved Oxygen
DFW	Dallas-Fort Worth Metroplex
DWU	Dallas Water Utilities
EC	*E.coli*
EPA	U.S. Environmental Protection Agency
E.coli	*Escherichia coli*
FC	Fecal Coliform
FDC	Flow Duration Curve
GIS	geographic information system
HH	households
HRU	Hydrologic Response Unit
HUC	Hydrologic Unit Code
I/I	inflow/infiltration
IPL	Integrated Pipeline Project
IR	TCEQ Integrated Report of Surface Water Quality
JPL	Joe Pool Lake
KGE	Kling-Gupta efficiency
LDC	Load Duration Curve
LAD	Least Absolute Deviation
LOADEST	LOAD Estimation program
LULC	Land Use and Land Cover
MLE	Maximum Likelihood Estimation
MS4	Municipal Separate Sewer System
NAAS	National Agricultural Statistics Service
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NO_2	nitrite
NO_3	nitrate
NO_X	nitrogen ($NO_3 + NO_2$)
NSE	Nash-Sutcliffe Efficiency
OP	ortho-phosphate phosphorous
OSSF	on-site sewage facility (septic system)
PBIAS	percent bias
R^2	coefficient of determination
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SSO	sanitary sewer overflow
SWAT	Soil and Water Assessment Tool
SWQM	Surface Water Quality Monitoring
TAMU	Texas A&M AgriLife
TCEQ	Texas Commission on Environmental Quality

TKN	total Kjedahl nitrogen
TMDL	total maximum daily load
TNRIS	Texas Natural Resources Information System
TP	total phosphorous
TPWD	Texas Parks and Wildlife Department
TRA	Trinity River Authority
TRWD	Tarrant Regional Water District
TSWQS	Texas Surface Water Quality Standards
USACE	U.S. Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	U.S. Geological Survey
VSS	volatile suspended solids
WPP	watershed protection plan
WWTF	wastewater treatment facility

1.0 Introduction

This technical report was prepared as part of an effort to address the growing water quality concerns associated with the rapid development expected within the Joe Pool Lake (JPL) watershed in recent and coming years. Drinking water from JPL is utilized by over forty-thousand people in the city of Midlothian and the communities of Venus, Rockett, Mountain Peak, Sardis, and parts of southern Grand Prairie. Additionally, JPL is expected to be further developed by the cities of Cedar Hill, Duncanville, and Grand Prairie for their own municipal use. JPL has also been designated as a potential terminal storage reservoir for the Tarrant Regional Water District (TRWD) and Dallas Water Utilities (DWU) Integrated Pipeline Project (IPL), which seeks to connect three reservoirs in east Texas (Richland Chambers, Cedar Creek, and Lake Palestine) to other reservoirs in the Dallas-Fort Worth (DFW) metroplex to enhance the future water supply of the region and to provide for redundancy in the water supply system (Figure 1-1). This project will identify sources, quantify load reduction targets, and result in the creation of a watershed protection plan (WPP) document. The WPP will provide best management practice (BMP) recommendations to achieve those targets to local stakeholder groups who will implement those recommended BMPs to mitigate water quality concerns throughout the watershed. These recommendations will be based on targeted water quality sampling, analysis, and modeling for water quality constituents including, but not limited to, *Escherichia coli* (*E.coli*), Nitrite (NO_2), Nitrate (NO_3), Total Kjedahl Nitrogen (TKN), Total Phosphorous (TP), and Ortho-phosphate Phosphorous (OP).



Basemap: ESRI; Stream data source: NHD
Figure 1-1. JPL watershed.

1.1 Problem Statement

Portions of JPL and Mountain Creek have experienced elevated levels of nitrate and *E.coli*. Walnut Creek, one of Joe Pool's two main tributaries, was listed on the 2014 Texas Commission on Environmental Quality (TCEQ) Texas Water Quality Inventory and 303(d) List due to elevated levels of *E.coli*, with its first listing occurring in 2006. Most of the impaired segment flows through the city limits of Mansfield. As of the 2018 TCEQ Integrated Report of Surface Water Quality (IR) Walnut Creek has been delisted. Additionally, the Mountain Creek arm of JPL was listed on the 2014 Water Quality Inventory—Water Bodies with Concerns for Use Attainment and Screening Levels for general use concerns due to elevated levels of nitrate. The Cities of Cedar Hill, Grand Prairie, and Mansfield all border this segment of concern. As of the 2018 TCEQ IR, the Mountain Creek arm of JPL has been removed as a concern for nitrate. The WPP will be integral to keep both Walnut Creek and Mountain Creek off the TCEQ IR list as the region is further developed.

1.2 Pollutant Source Assessment and Load Evaluation

To ensure that a thorough characterization of the watershed's status was achieved, several assessment methods were employed so that a clearer picture of the water quality impacts in the watershed could be obtained. Pollutant loadings were assessed using a variety of methods utilizing both empirical data and estimations based on literature values from multiple sources. The methods used in this study included routine and flow-biased water quality data analysis, the Load Estimation program (LOADEST), Load Duration Curve (LDC) analysis based on collected data for multiple pollutants, Flow Duration Curves (FDCs), spatial analysis of potential *E.coli* sources using the Spatially Explicit Load Enrichment Calculation Tool (SELECT) analysis, and hydrological modeling using the Soil and Water Assessment Tool (SWAT).

Water Quality Monitoring

The Trinity River Authority (TRA) of Texas conducted routine water quality monitoring and targeted high flow monitoring in JPL and its tributaries in partnership with the cities of Cedar Hill, Duncanville, Grand Prairie, and Midlothian. Monitoring data for Nitrite and Nitrate Nitrogen (mg/L), Total Kjedahl Nitrogen (mg/L), Total Phosphorous (mg/L), Orthophosphate Phosphorous (mg/L), *E.coli* (MPN/100ml) as well as field and flow parameters were collected bi-monthly between 2019 and 2020 at three lake sites, fifteen tributary sites, and two intake sites. TRA obtained historical data from monitoring events held quarterly since November 2013.

Trends in water quality data from 20 sites collected from June 2019 to May 2020 were analyzed. Analysts related these trends to water quantity, considering influences from natural precipitation, groundwater inputs, and anthropogenically-driven sources. The influences from climatic conditions, land use and land cover (LULC) conditions, lake storage levels, and water withdrawals were also considered. Geometric means for concentrations were calculated for the parameters of interest and compared to relevant water quality indicators. These geometric means were then analyzed at temporal scales at each station and between stations during the same sampling event, with more intense analysis when unexpected data values or other events of interest were apparent.

Introduction

LOADEST

The Load Estimation program is a modeling tool used to estimate constituent loads in streams for missing observations using the observed flow and constituent concentrations (Runkel, Crawford and Cohn, 2004). It was developed by U.S. Geological Survey (USGS) and has been extensively used for the estimation of daily constituent loads for several water quality parameters(Gao et al., 2021). It generates a regression model using available streamflow and constituent concentration with the help of three statistical methods, Adjusted Maximum Likelihood Estimation (AMLE), Maximum Likelihood Estimation (MLE), and Least Absolute Deviation (LAD). Based on the regression model developed, it estimates constituent load over a time interval specified by the user.

SWAT

The Soil and Water Assessment Tool, the most widely used hydrological model in the world, simulates flow and watershed potential pollutant loadings under various scenarios. SWAT is a physically based, deterministic, continuous, watershed-scale simulation model developed by USDA Agricultural Research Service (Arnold et al., 1998) and tested for a wide range of regions, conditions, practices, and time scales (Gassman et al., 2007). SWAT model subdivides a basin/watershed into subwatersheds connected by a stream network, and further delineates hydrologic response units (HRUs) consisting of unique combinations of land cover and soils in each subbasin. The HRU is the smallest landscape component of SWAT used for simulating hydrologic processes. Hydrological processes are divided into two phases - land phase and channel/floodplain phase. The land phase calculates the upland loadings of flow, sediment, nutrients, and pesticides from each HRU, which are then area-weighted to subwatershed level. The channel/floodplain phase calculates the routing from the upland loadings from each subwatershed through the channel/stream and dam/reservoirs network.

The SWAT model requires spatial (e.g., digital elevation model, land use, soil) and temporal (e.g., weather and streamflow) data to simulate various biophysical processes in the watershed that generate streamflow. Land management and dam characteristics/operation data are also important for capturing the impacts of various management interventions. The outputs from the SWAT model will provide information to develop LDCs and load reduction strategies.

LDC

The Load Duration Curve analysis takes the traditional water quality data analysis a step further by combining each parameter’s concentration by the instantaneous flow value collected, resulting in an estimated total annual pollutant load for each parameter of interest. In other words, LDCs convert discrete sample concentrations to load, for example, milligrams per liter (mg/L) to tons per day (ton/day). These measurements are useful for providing a realistic representation of the existing amount of a pollutant within a waterbody, especially if a lake or other water storage facility is the endpoint of the system where these pollutant loads can accumulate. Furthermore, pollutant load reductions are also the accepted metric used by the TCEQ and the U.S. Environmental Protection Agency (EPA) for determining the success of both total maximum daily load (TMDL) and WPP projects. The development of LDC analyses is beneficial for tracking progress on these projects.

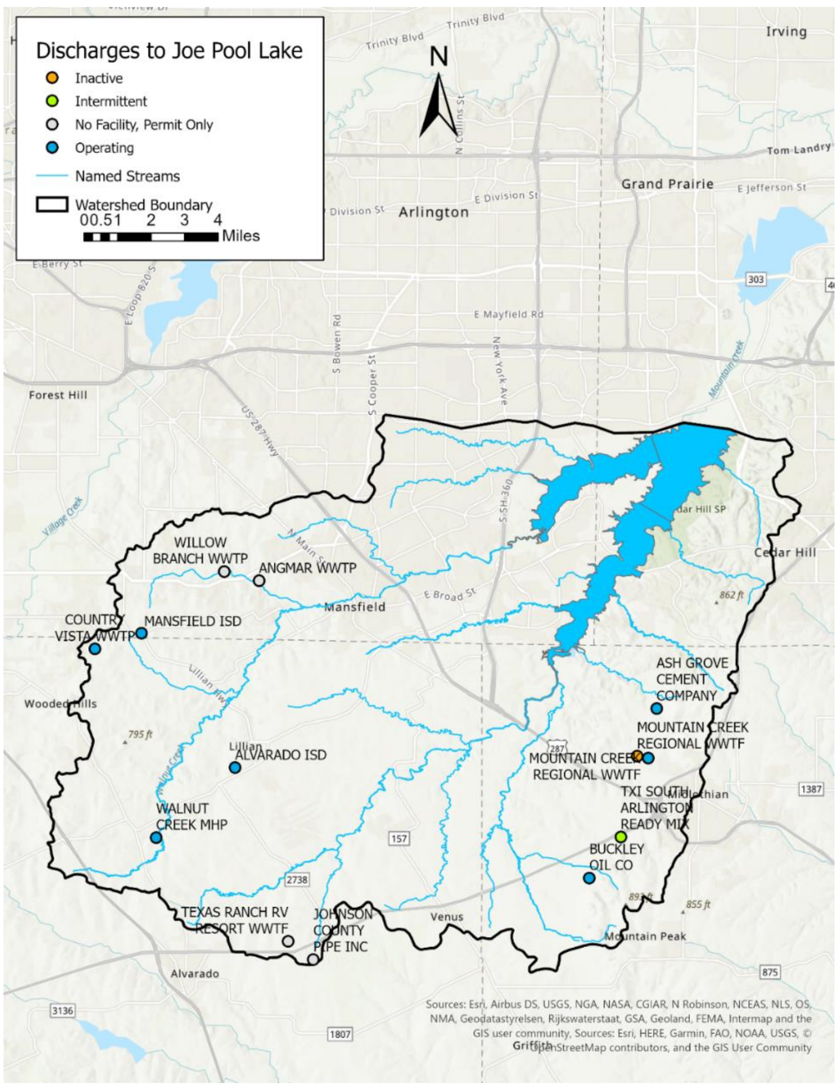
SELECT

Constituent loads can be related to potential pollutant sources within the watershed using the Spatially Explicit Load Enrichment Calculation Tool. SELECT uses the LULC classes and estimated populations of humans, pets, farm animals, and various other animals to estimate a subwatersheds potential loading of fecal bacteria. SELECT spatially references the sources, then calculates and allocates potential pathogen loadings to a stream from various sources within a watershed. As a result, all loads will be spatially referenced. Allocation of the bacteria loads throughout the JPL watershed were made by estimating source contributions from various sources identified during the watershed characterization process. This in turn allows the sources and locations to be ranked according to their potential contribution for each sub-watershed. The populations of agricultural animals, wildlife, and domestic pets were calculated and distributed throughout each watershed according to appropriate land use. Human influences, such as inputs from wastewater infrastructure and on-site sewage facilities (OSSF), were also considered. Septic system contribution was estimated based on criteria including distance to a stream, soil type, failure rate, and age of system. Once the watershed profile was developed for each potential source, the information was aggregated to the subwatershed level to identify the top contributing areas in the watershed.

1.3 Study Area Description

JPL is a 11.2 mi^2 (7,145 acres) reservoir in the southern part of the DFW metroplex. The construction of JPL started in 1981, impoundment started in 1986, and the reservoir was filled by 1989. It is a source of municipal water supply and a recreational destination. The dam is operated by the U.S. Army Corps of Engineers (USACE) with the water rights held by the TRA. The total drainage area of the JPL watershed is 223.6 mi^2 (143,091 acres). The watershed is divided into two major subwatersheds, Mountain Creek and

Walnut Creek, that span Johnson, Ellis, Tarrant, and Dallas counties in Texas (Table 2-13). The headwaters of Walnut Creek are located south of Burleson and drain to the northeast. The headwaters of Mountain Creek are located north of Alvarado, draining northward to form JPL (Figure 1-1). Mountain Creek and Walnut Creek tributaries have multiple branches that regularly contribute flow, and multiple smaller creeks feed directly into the lake from both the east and the west. JPL receives natural flow mixed with stormwater runoff and treated wastewater effluent from Mountain Creek Regional wastewater treatment facility (WWTF) and several smaller domestic sewage discharges within the watershed (Figure 1-2) (USACE, 2019).



Basemap: ESRI World Street Map; Stream data source: NHD; station data: EPA ECHO
Figure 1-2. Discharges to JPL watershed.

Introduction

The JPL watershed is generally located within the Grand Prairie physiographic province according to the Physiographic Map of Texas (BEG, 1996). A physiographic province has similar geomorphology that is significantly different than adjacent areas. The majority of the watershed is underlain by units from the Austin Chalk, Eagle Ford (undivided), and Woodbine groups, with some fluviatile terrace deposits and alluvial floodplain deposits in areas underlying or near larger waterbodies.

Soils in the vicinity of the lake are composed mainly of fine sandy loams and silty clays. Some of the more common upland soil groups in the watershed include Crosstell fine sandy loams, Heiden clays, Houston black clays, and Rader fine sandy loams. Several hydric soils occupy the bottom land areas of the watershed, with Trinity clays, Tinn clays, and Pulexas fine sandy loams being most common.

Land Use and Land Cover (LULC)

LULC characteristics govern many of the operations within both the data collection and data analysis tasks. Regarding data collection activities, water quality monitoring stations should not only be well-distributed geographically throughout the watershed, but should also be representative of all the major LULC conditions found within the watershed boundary. This distribution will provide reasonable assurance that effort has been made to account for a variety of pollutant sources during characterization, such as those from rural, urban, and industrial areas. When interpreting the results from these stations, data analysts must be mindful of LULC conditions in the upstream contributing watershed, whether analyzing individual sampling event results, relating multiple sampling events at a specific station, or aggregating multiple sampling events and multiple stations to develop LDCs for the watershed. In doing so, analysts can make more informed decisions by relating water quality impairments or concerns to possible pollutant sources that are typical to specific LULC characteristics. Knowledge of LULC conditions and their potential water quality influences are also an important consideration within the scope of the SELECT analysis. SELECT uses the LULC classes from digitized maps and relates them to estimated populations of humans, pets, farm animals, and various other warm-blooded organisms to estimate the amount of fecal bacteria produced in the watershed. SELECT then uses a variety of techniques to estimate the amount that is likely to end up in the various water bodies in the watershed. For these reasons, it is important for water quality analysts to ensure that they are using the most up-to-date version of LULC maps in their analyses. It may also be useful to perform in-field ground truthing surveys to verify LULC conditions, especially in areas with widespread, ongoing urban development.

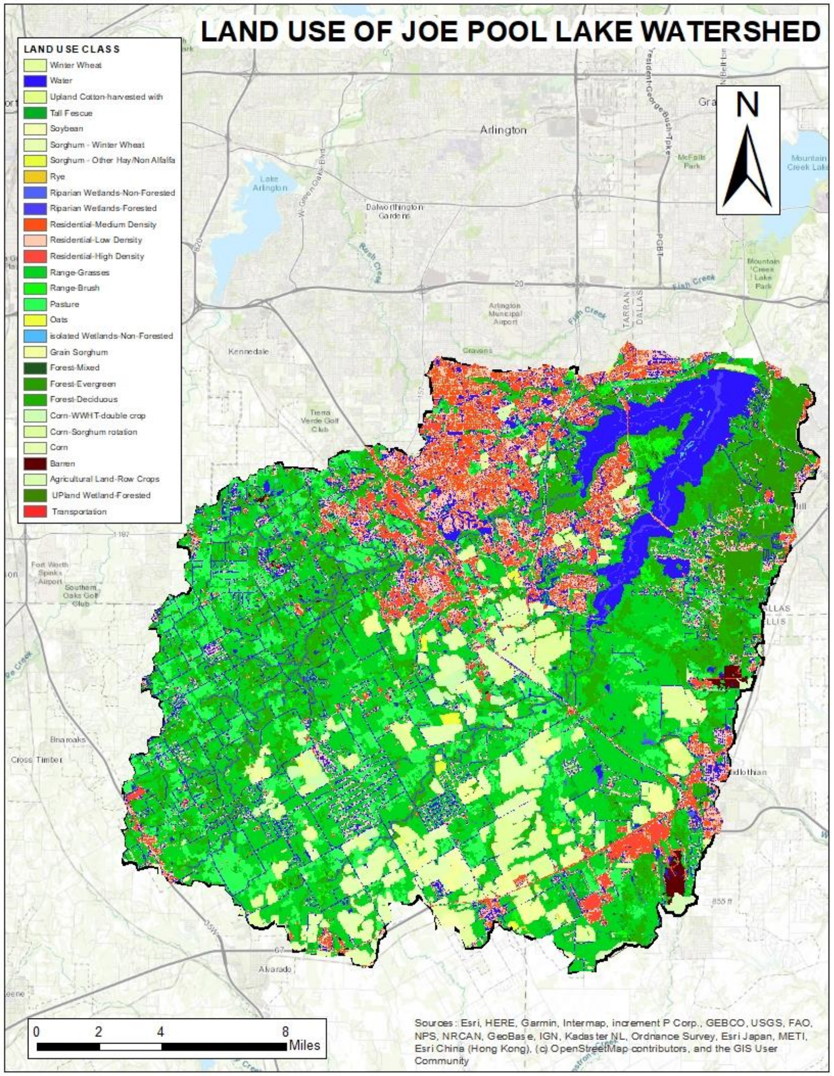
Introduction

The northcentral and southeastern regions of the JPL watershed are urbanized, while the upstream, southwestern regions of the watershed have remained generally rural, dominated by herbaceous cover, with some pastureland and row-crop agriculture. Cedar Hill State Park is located east of the lake and dominated by forest land. Loyd Park and Lynn Creek Park are located on the western edge of the lake and Estes Park is located on the peninsula; all are popular recreation centers within the watershed. Major population centers include Midlothian and suburbs in southwest DFW, which include Mansfield, Arlington, Grand Prairie, and Cedar Hill. These population centers comprise most of the developed land. JPL Land Use is shown in Figure 1-3. Land cover within the watershed is depicted in Figure 1-4, which relates a use category (residential, industrial, undeveloped, etc.) to the land use information. The urban centers in the JPL watershed are defined as low and medium density urban land made up of 90% single family homes, but the majority of the industrial complexes within the basin appear in the vicinity of Midlothian, with smaller complexes near the center of the watershed. Outside of the urbanized areas, ranch land is dominant, with pockets of farmland and undeveloped open lots.

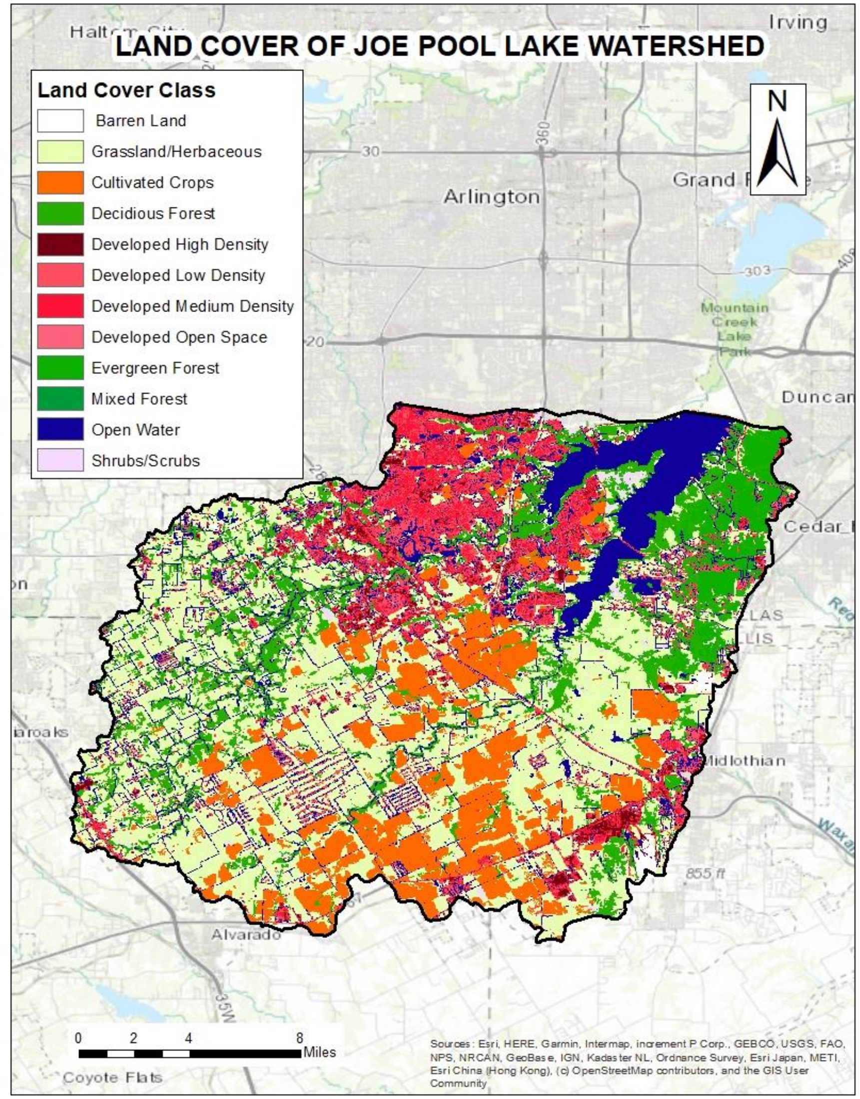
About 41% of the watershed is covered by rangelands and pasturelands, 17% by forest, 25% by urban, 6% by open water and wetlands, and 10% by agricultural lands. The amount of land cover by categories are shown in Table 1-1.

Table 1-1. Summary of Land use for the JPL watershed from 2019 LiDAR.

Class Name	Area (acres)	% of Watershed Area
Open Water	7,145	5.0
Developed, Open Space	11,258	7.9
Developed, Low Density	12,917	9.0
Developed, Medium Density	9,414	6.6
Developed, High Density	2,376	1.7
Barren Land	708	0.5
Deciduous Forest	19,622	13.7
Evergreen Forest	4252	3.0
Mixed Forest	369	0.3
Shrub/Scrub	1,679	1.2
Herbaceous	45,670	31.9
Hay/Pasture	12,943	9.0
Cultivated Crops	14,167	9.9
Woody Wetlands	161	0.1
Emergent Herbaceous Wetlands	408	0.3
Total	**145,091**	**100%**



Basemap: ESRI World Street Map; land data: USGS NLCD and USDA-NASS-CDL
Figure 1-3. Land Use across the JPL watershed.



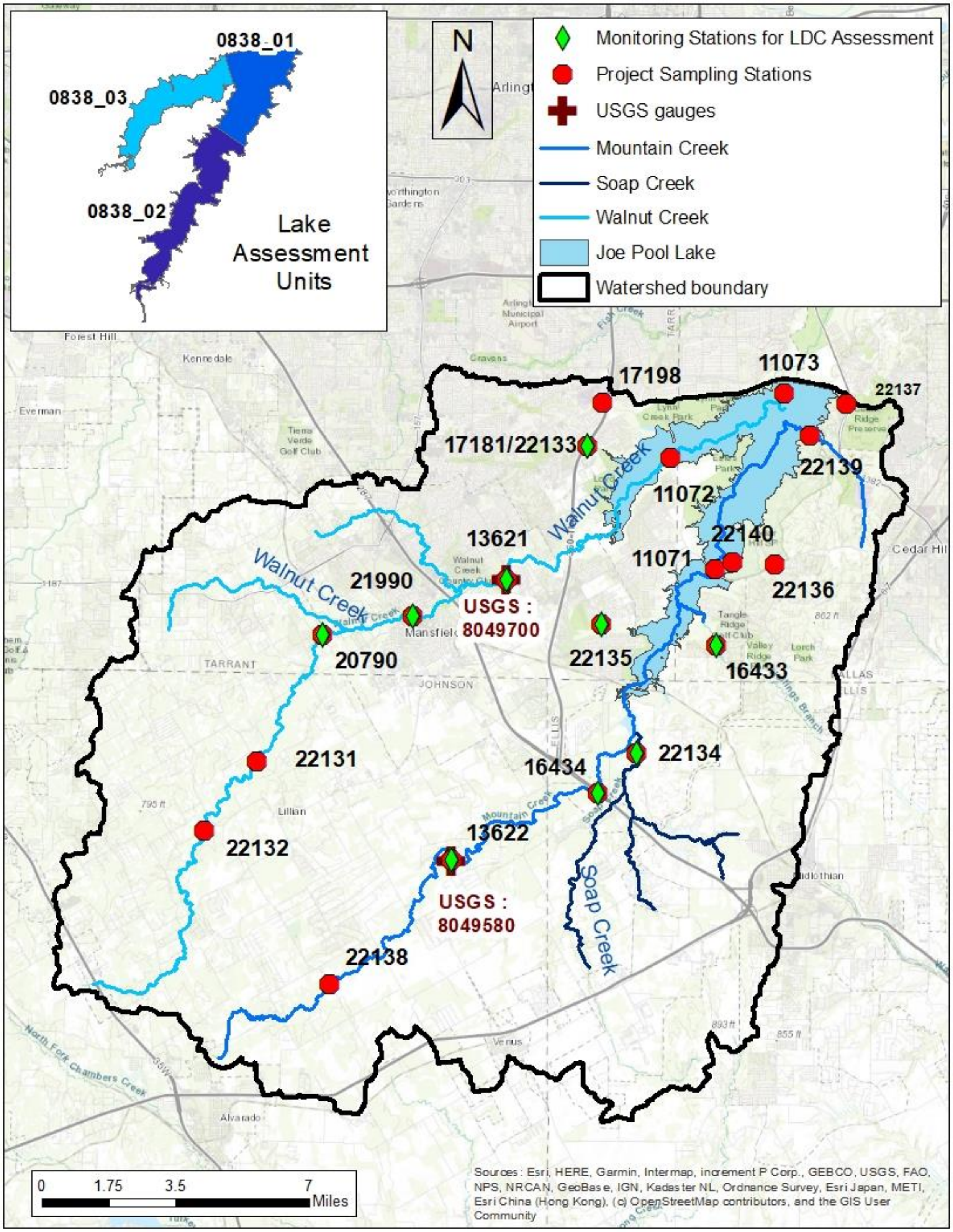
Basemap: ESRI World Street Map; Land data: USGS NLCD 2016
Figure 1-4. Land cover across the JPL watershed.

2.0 Methods

2.1 Data Collection Activities

The data analyzed in this report includes both routinely-collected and flow-targeted water quality sampling for several parameters, including *E.coli*, NO_2, NO_3, TKN, TP, and OP. The monitoring regime was designed to facilitate the creation of a WPP, using the collected data to inform this and other reports developed as part of this project, which will evaluate annual and seasonal trends, spatial patterns, hydrologic characteristics (*i.e.,* flow characterization), and other relational patterns that will help identify how and when *E.coli* and other pollutants are entering the system. A fully-detailed account of the data collection activities is provided in the Data Collection Report for this project (TRA, 2020).

The monitoring data for water quality parameters, NO_2, NO_3, TKN, TP, OP, and *E.coli* collected from twenty different monitoring stations were used for water quality analysis. Of these sites, eight drain into the Mountain Creek arm of JPL, seven drain into the Walnut Creek arm of JPL, and 5 sites are within the body of the lake. Sites were selected based on the following criteria: safety, access to the stream, access to the centroid of flow, location of stream confluences, location of potential sources of pollution, and placement at downstream locations to maximize watershed capture. The location of JPL watershed, JPL subbasins, USGS gages, monitoring stations, and stream network is presented in Figure 2-1. The land cover distribution above each monitoring station is shown in Figure 2-2 with a detailed description found in Table 2-1.



Basemap: ESRI World Street Map; Stream data source: NHD; gauge data: USGS NWIS
Figure 2-1. JPL watershed, its subbasins, USGS gages, monitoring stations, and stream network.

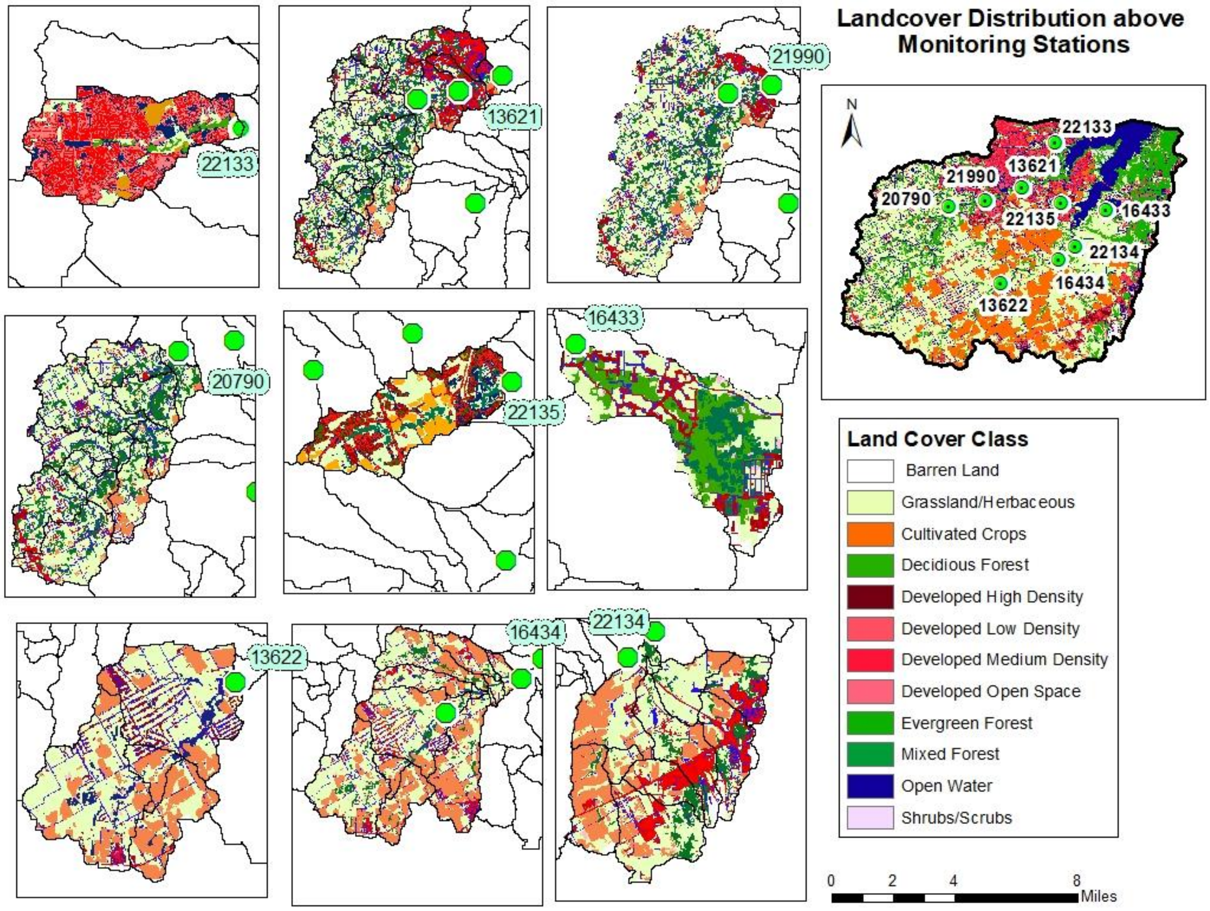


Figure 2-2. Land Cover Distribution upland of monitoring stations across the JPL watershed.

Table 2-1. Percent of land cover upstream from each monitoring stations across the JPL watershed.

Monitoring Station	Forest	Rangeland	Urban	Agriculture	Water
22133	3%	6%	64%	12%	15%
13621	19%	49%	16%	3%	13%
21990	20%	55%	10%	3%	12%
20790	21%	58%	6%	4%	11%
22135	7%	35%	41%	5%	12%
16433	49%	34%	11%	0%	6%
13622	5%	54%	6%	27%	8%
16434	5%	52%	7%	29%	7%
22134	9%	45%	14%	26%	6%

Methods

A list of the water quality data monitoring stations, the site description, their locations, and period of record for the data are presented in Table 2-2.

Table 2-2. List of monitoring stations, site description, location, and data period of record.

Station ID	Period of Record	Site Description	Latitude	Longitude
11071	2019-2020	Mountain Creek arm at Lakeridge pkwy	32.58417	-97.02310
11072	2019-2020	JPL Walnut Creek arm at Lake Ridge Parkway	32.61972	-97.04000
11073	2013-2020	JPL mid lake at dam	32.64028	-96.99670
13621	2013-2020	Walnut Creek at Matlock road	32.58086	-97.10214
13622	2019-2020	Mountain Creek at FM 157 north of Venus	32.49132	-97.12315
16433	2013-2020	Hollings branch at Tangle ridge road	32.56000	-97.02278
16434	2013-2020	Mountain Creek at US 287	32.51278	-97.06756
17198	2019-2020	Lynn Creek downstream of Webb Lynn road	32.63722	-97.06561
20790	2019-2020	Walnut Creek at Retta Road	32.56340	-97.17204
21990	2019-2020	Walnut Creek at Katherine rose park foot bridge	32.56931	-97.13768
22131	2019-2020	Walnut Creek at CR 2738 northwest of Lillian	32.52291	-97.19673
22132	2019-2020	Walnut Creek at CR 519 west of Lillian	32.50090	-97.21668
22133	2013-2020	Bowman branch at South SH 360	32.62338	-97.07134
22134	2013-2020	Soap Creek upstream of Mountain Creek	32.52540	-97.05278
22135	2019-2020	Low branch at South Holland Road	32.56664	-97.06613
22136	2019-2020	Baggett Branch at Mansfield Road in Cedar Hill	32.58577	-97.00044
22137	2019-2020	Mountain Creek Trib2 at FM 1382/belt line road	32.63711	-96.97309
22138	2019-2020	Mountain Creek at CR 2738 northwest of Venus	32.45158	-97.16903
22139	2019-2020	JPL at Intake in Cedar Hill State Park	32.62698	-96.98700
22140	2019-2020	JPL intake near Lakeridge pkwy	32.58664	-97.01640

2.1.1 Texas Surface Water Quality Standards

Site-specific numeric water quality criteria, based on the Texas Surface Water Quality Standards (TSWQS) for JPL (Segment 0838), Mountain Creek (Segment 0838A), Sugar Creek (Segment 0838B), Walnut Creek (Segment 0838C), Hollings Branch (Segment 0838D), Soap Creek (Segment 0838E), and an unnamed tributary (Segment 0838F) are presented in Table 2-3, along with the designated uses associated with each criteria parameter (TCEQ, 2018). All parameters must be evaluated with a minimum of 10 samples (excluding *E.coli*, which requires 20) from a seven-year period to determine whether a designated use is being met (TCEQ, 2018).

Table 2-3. Designated uses and site-specific water quality standards for segments in the watershed.

Parameter	Seg 0838	Seg 0838	Seg 0838	Seg 0838A	*Seg 0838B	Seg 0838C	Seg 0838D	Seg 0838E	Seg 0838F	Designated Use
Station ID	11073	11072	11071	16434	*17680	13621	16433	22134	22135	
DO 24-hour ave/min (mg/l)	5/35	5/35	5/35	3/23	3/23	3/23	2/1.52	2/1.52	2/1.52	Aquatic Life
E.coli (MPN/100 ml)	126	126	126	126	126	126	126	126	126	Recreation
SO_4 (mg/l)	250	250	250							General Use
pH	9-6.5	9-6.6	9-6.7							General Use
Temp (°C)	32.2	32.2	32.2							General Use
Chloride (mg/L)	100	100	100							
TDS (mg/L)	500	500	500							

*Segment 0838B not sampled under this project. Data available on TCEQ SWQMIS from 2002-2014.

2.1.2 Nutrient Screening Levels and Reference Criteria

TCEQ Screening Level

Currently, no numeric standards exist for nutrients in streams in the state of Texas. However, TCEQ continues to screen for parameters such as nitrogen, phosphorus, and chlorophyll-a (chl-a) as preliminary indicators for waterbodies of possible concern for 303(d) impairments. To support this effort, nutrient screening levels are often used to compare a waterbody to screening levels that are set at the 85th percentile for those parameters of interest seen in similar waterbodies (Table 2-4). The Texas Nutrient Screening Levels are based on statistical analyses of Surface Water Quality Monitoring (SWQM) data (TCEQ, 2019b).

Table 2-4. TCEQ Water Quality Screening Criteria for different constituents.

Parameter		TCEQ Screening Levels		EPA Reference Criteria				Other Sources
		Lake/Reservoir	Stream	Lake/Reservoir		Stream		
TKN	(mg/L)	-	-	0.38[a]	0.41[b]	0.3[a]	0.4[b]	
NH_3	(mg/L)	0.11	0.33	-	-	-	-	
NO_2^-	(mg/L)	-	-	-	-	-	-	0.02[c]
NO_3^-	(mg/L)	0.37	1.95	-	-	-	-	
NO_2^-+NO_3^-	(mg/L)	-	-	0.017[a]	0.01[b]	0.125[a]	0.078[b]	
TP	(mg/L)	0.20	0.69	0.02[a]	0.019[b]	0.037[a]	0.038[b]	
OP[d]	(mg/L)	0.05	0.37	-	-	-	-	
Chlorophyll-a[e]	(µg/L)	26.7	14.1	5.18[a]	2.875[b]	0.93[a]	1.238[b]	

(a) Reference conditions for aggregate Ecoregion IX waterbodies, upper 25th percentile of data from all seasons, 1990-1999.
(b) Reference conditions for level III Ecoregion 29 waterbodies, upper 25th percentile of data from all seasons.
(c) For nitrite, concentrations above 0.02 mg/L (ppm) usually indicate polluted waters (Mesner, N., J. Geiger. 2010). Understanding Your Watershed: Nitrogen. Utah State University, Water Quality Extension.
(d) OP is no longer used for TCEQ screening purposes, as of the 2014 Texas Integrated Report.
(e) Chlorophyll-a, as measured by Spectrophotometric method with acid correction.

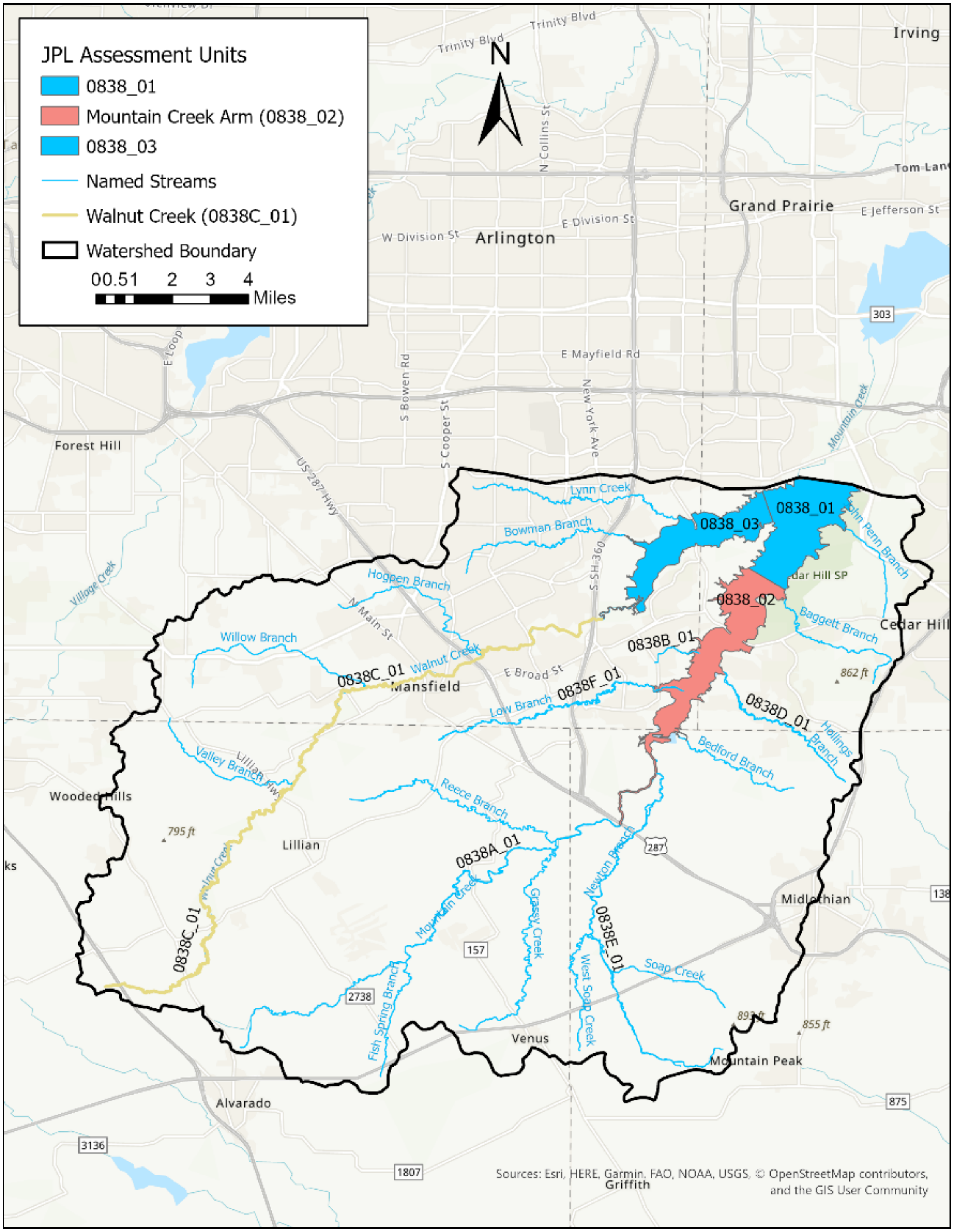
EPA Reference Criteria

The EPA Reference Criteria are regional values based on data from reservoirs and streams within specific ecoregion units and subunits (USEPA, 2000). It is worth noting that these Reference Criteria differ from the Texas Nutrient Screening Levels in that EPA developed the Reference Criteria using conditions that are indicative of minimally impacted (or in some cases, pristine) waterbodies, attainment of which would result in protection of all designated uses within those specific units and subunits. As such, Reference Criteria thresholds are much lower than those for state screening levels, and surpassing Reference Criteria thresholds may not necessarily indicate a concern, as is the case with the state thresholds (Table 2-4). Where state screening levels or national reference criteria were non-existent, other sources were used, for nitrite in particular (Mesner and Geiger, 2010).

2.1.3 Segment Impairments and Concerns

When a sufficient number of elevated water quality measurements cause the waterbody to surpass the water quality criteria (min, max, average, or geomean), the waterbody is considered impaired and may not be supportive of one or several of its designated uses. Although the most recent assessment period covered by the 2020 Texas Integrated Report did not identify concerns or impairments in JPL, the impetus to conduct water quality monitoring in JPL watershed was based on the TCEQ 2014 IR that did identify concerns and an impairment (TCEQ 2015b). This impairment was for elevated bacteria counts in Walnut Creek (0838C_01) (TCEQ 2015b).

If more than 20% of a waterbody's samples from the assessment period exceed a screening level, then on average, it will experience higher pollutant concentrations than 85% of the streams in Texas and thus is considered to have a concern for elevated nutrients. For the same 2014 assessment period, there was one assessment unit (AU) in the lake (Mountain Creek arm, Segment 0838_02) with a concern for nitrate (Figure 2-3) (TCEQ 2015b). No other concerns were identified in JPL or other tributaries in the watershed in the TCEQ 2014 IR or the current TCEQ 2020 IR. (TCEQ 2015b, 2020). A record of impairments and concerns in the watershed are listed in Table 2-5.



Basemap: ESRI World Street Map; Stream data source: NHD; AU source: TCEQ

Figure 2-3. Historically impaired segments and water quality concerns in the watershed.

Table 2-5. Record of impairments and concerns in the JPL watershed.

Texas Integrated Report	Joe Pool Lake-Mountain Creek Arm			Walnut Creek		
	AUs	Mean Exceed	Screening Level	AUs	Mean Exceed	Criteria
Recreation Impairment - *E.coli* (MPN/100 mL)						
2006		-		0838C_01	284.00	126
2008		-			284.00	
2010		-			256.63	
2012		-			285.01	
2014		-			195.60	
2016		-			126.62	
2018		-			94.75[c]	
General Concern - nitrate (mg/L)						
2006	0838_02	Concern[a]	0.37		-	
2008		-[a]			-	
2010		0.76			-	
2012		0.86			-	
2014		0.74			-	
2016		1.52[b]			-	

(a) parameter was assessed but means values were not reported in the assessment for this year.
(b) this geomean is composed of 3 carry-forward samples from the 2014 assessment, no new samples were included in this assessment.
(c) Walnut Creek *E.coli* value that supported the delisting in the 2018 Texas Integrated Report of Surface Water Quality

2.1.4 Geospatial Data Collection

Geospatial datasets from local, regional, state, and federal organizations were used for the different components of the project. These datasets were essential for selecting and locating monitoring sites. Moreover, geospatial data provided the foundation for determining the extent and severity of various pollutant sources and provided the opportunity to visually display the analysis results to stakeholders. A list of geospatial data sources utilized in this project are provided in Appendix A. Geospatial Data Sources Used for Watershed Analysis.

2.2 Statistical Analysis

Statistical analysis is important in the evaluation of model performance. The performance of LOADEST was evaluated using coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE), and the performance of SWAT was evaluated using R^2, NSE, Percent Bias (PBIAS), and the Kling-Gupta efficiency (KGE).

The R^2 describes the proportion of the variance in the observations explained by the model. The range of R^2 is from 0 to 1 where a higher value (1) gives less error variance and the values greater than 0.5 are considered acceptable range (Santhi et al., 2001, Van Liew et al., 2003). It only measures the deviation from the best fit line.

The value of R^2 is found by:

$$R^2 = \left(\frac{\sum_{i=1}^{N} (O_i - \bar{O}) \cdot (S_i - \bar{S})}{\sqrt{\sum_{i=1}^{N} (O_i - \bar{O})^2} \cdot \sqrt{\sum_{i=1}^{N} (S_i - \bar{S})^2}} \right)^2$$

Where O_i is the observed value, $\bar{O}$ is average of observed values, S_i is the simulated value and $\bar{S}$ is the average of simulated values and N is the total number of observations.

NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. The value of NSE ranges from -∞ to 1 where the value near 1 refers to a good fit of the model. The value for NSE is calculated by:

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{N} (O_i - S_i)^2}{\sum_{i=1}^{N} (O_i - \bar{O})^2}$$

Where O_i is the observed value, S_i is the simulated value, $\bar{O}$ is average of observed values, and N is the total number of observations.

PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Moriasi et al., 2007). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values of PBIAS indicate model underestimation bias, and negative values indicate model overestimation bias of total volume (Gupta et al., 1999). The PBIAS is calculated by:

$$\mathrm{PBIAS} = 100 \left(\frac{\sum_{i=1}^{N} (S_i - O_i)}{\sum_{i=1}^{N} O_i} \right)$$

Where O_i is the observed value, S_i is the simulated value and N is the total number of observations.

Similarly, KGE is the statistical tool that combines the correlation, bias, and coefficients of variation in a balanced way and has been widely used in evaluating hydrological models in recent years (Gupta et al., 2009). KGE is calculated by:

$$\mathrm{KGE} = 1 - \sqrt{(cc-1)^2 + \left(\frac{cd}{rd} - 1\right)^2 + \left(\frac{cm}{rm} - 1\right)^2}$$

Where *cc* is the Pearson coefficient, *cd* is standard deviation of forecast values, *rd* is standard deviation of observation values, *cm* is average of forecast values, and *rm* is the average of observed values.

2.3 SWAT

The SWAT model was developed for the JPL watershed to obtain flow data at each monitoring location. High quality flow data obtained from two USGS gaging stations, USGS 8049700 located at monitoring station 13621 (Walnut Creek at Matlock Road) and USGS 8049580 located at monitoring station 13622 (Mountain Creek at FM 157 north of Venus), was used for model calibration and validation.

SWAT Calibration

Model calibration is the process of adjusting the model parameters and forcing within the margins of the uncertainties (in model parameters and /or model forcing) to obtain a model representation of the processes of interest that satisfy pre-agreed criteria. This approach aims to improve the model by developing correction factors that can be applied to generate predicted values and improve model description. The reliability of the model depends on the model simulated results, and when the model results match with the observed values from streamflow measurement, then the users get greater confidence. To facilitate the evaluation of the model performance, statistical analysis was employed with the use of NSE, R^2, PBAIS, and KGE. For the calibration and uncertainty program for this project, the SWAT-CUP, a computer program for calibration of SWAT models, was used.

Daily calibration for streamflow was conducted from 1/1/2000 to 12/31/2018 at monitoring stations 13621 and 13622 of JPL watershed. The KGE was used as an objective function to optimize the set of parameter values during calibration as it is a reliable and widely used statistic for assessing the goodness of fit during SWAT calibration. The value of KGE ranges from -∞ to 1 where the value near 1 refers to a good fit of the model.

The SWAT model performance for streamflow during calibration was reasonable based on statistical analysis. Model simulations are considered satisfactory for streamflow if NSE and KGE values are greater than 0.50 and the absolute magnitude of the PBIAS value is less than 25% (Moriasi et al., 2007). The summary statistics obtained during the streamflow calibration at the outlet for the two monitoring stations USGS 8049700 (Monitoring stations 13621) and USGS 8049580 (Monitoring station 13622) in JPL watershed are presented in Table 2-6.

Table 2-6. Summary of statistics obtained during calibration of streamflow at the outlet of two monitoring stations in JPL watershed.

Statistic Name	USGS 8049700 (Monitoring stations 13621)	USGS 8049580 (Monitoring station 13622)
R^2	0.73	0.57
NSE	0.73	0.54
PBIAS	13.2	-4.2
KGE	0.71	0.74

Overall, all performance metrics showed significant results. The KGE matrix performed the best for both monitoring stations during calibration, therefore the corresponding best fit parameters from the KGE calibration were used in SWAT for final calibration of the model. Parameters with larger T statistic values indicate more influence on the simulated streamflow and P values below 0.05 indicate significance at the 95% threshold. The list of parameters including their range, significance statistics and fitted value used to calibrate the SWAT model are presented in Table 2-7.

Table 2-7. List of SWAT calibration parameters, their minimum, maximum, fitted value, and significance statistics found using KGE for JPL watershed.

Parameter Name	Fitted Value	Minimum Value	Maximum Value	T Statistic	P Value
R__CN2.mgt	-0.068	-0.1	0.1	-27.94	0.0
V__ALPHA_BF.gw	0.342	0	1	-0.43	0.7
A__GW_DELAY.gw	-3.188	-30	90	0.95	0.3
A__GWQMN.gw	165.625	-1000	1000	7.18	0.0
V__GW_REVAP.gw	0.094	0.02	0.1	2.39	0.0
A__RCHRG_DP.gw	0.043	-0.05	0.05	0.85	0.4
A__REVAPMN.gw	-377.344	-750	750	-1.35	0.2
V__ESCO.hru	0.721	0.5	0.8	-6.07	0.0
R__SOL_AWC(..).sol	0.002	0	0.05	1.69	0.1
V__CANMX.hru	7.328	0	10	0.22	0.8
V__SLSOIL.hru	68.203	0	150	0.61	0.5
V__LAT_TTIME.hru	7.634	0	14	-0.24	0.8
V__ALPHA_BF_D.gw	0.727	0	1	0.98	0.3
R__CH_S2.rte	-0.405	-0.5	0.5	1.59	0.1
V__CH_K2.rte	0.023	0	3	-0.82	0.4
V__OV_N.hru	0.039	0.01	0.1	1.12	0.3
V__CH_K1.sub	0.192	0	3	0.33	0.7
V__CH_N1.sub	0.028	0.01	0.1	0.27	0.8
V__CH_N2.rte	0.021	0.01	0.1	-0.24	0.8
V__SURLAG.bsn	7.613	0	24	1.24	0.2

R-indicates existing parameter value is multiplied by (1+fittedvalue), V- indicates existing parameter was replaced by the fitted value, and A-indicates existing parameter value is added by the fitted value.

The simulated flow data obtained from SWAT was used to develop LDCs at various locations within JPL watershed where USGS flow data were not available. In addition to the LDCs, SWAT provided information on watershed characteristics used in the prediction of possible spatiotemporal pollution loads and their sources.

2.4 LDC and FDC

LDCs are useful tools for illustrating the relationship between stream flow, pollutant concentration, and the resulting pollutant loads in watersheds. The pollutant loads during each monitoring event can be compared to the maximum allowable load at that flow rate. This data can then be used to calculate the reduction needed to meet the water quality goal for each pollutant. Although LDCs cannot be used to differentiate between specific sources (e.g., livestock, pets, OSSFs), they can be used to determine whether point sources or nonpoint sources are the primary concern by identifying whether exceedances occur within a specific flow regime. If exceedances are only observed during periods of high flow or mid-range flow conditions associated with storm events, then nonpoint sources are the likely contributor.

However, if allowable load exceedances are also present during dry conditions or periods of low flow, then it is likely that point sources are also contributing to the overall load, becoming more prominent as flows decrease (Figure 2-4). Both stakeholders and regulatory entities recognize that exceedances at the higher flows are usually attributed to flooding, and thus inherently unmanageable. Therefore, stakeholders agreed that reductions demonstrated in the mid-range flow regime would be most appropriate for representing the water quality reduction goal at each site.

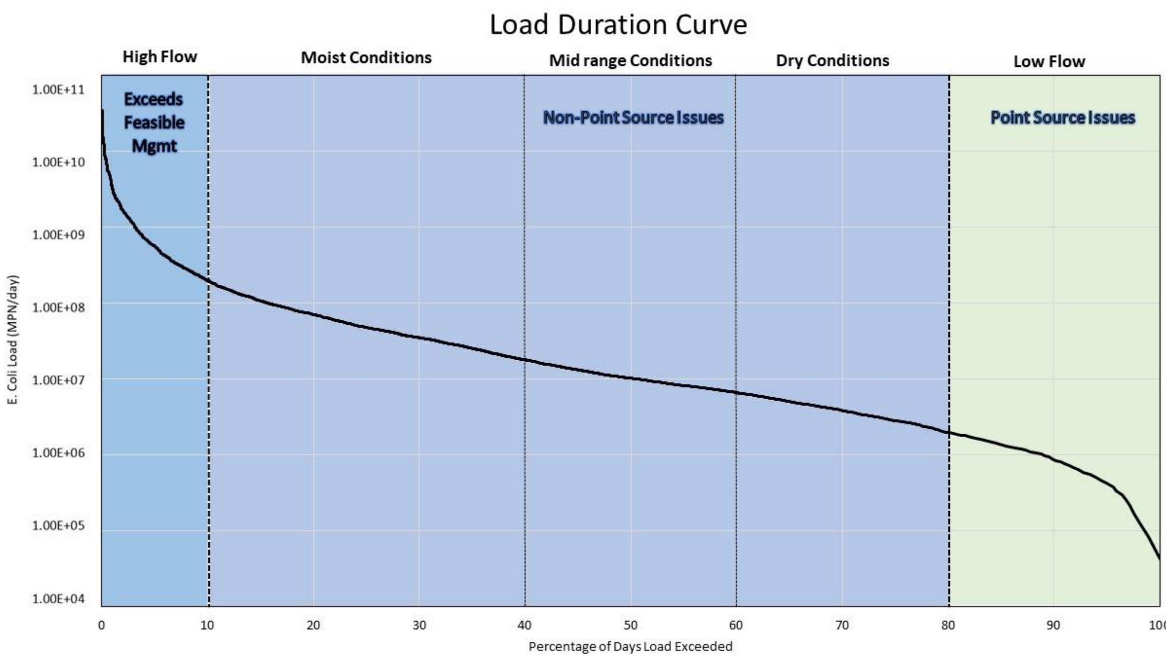
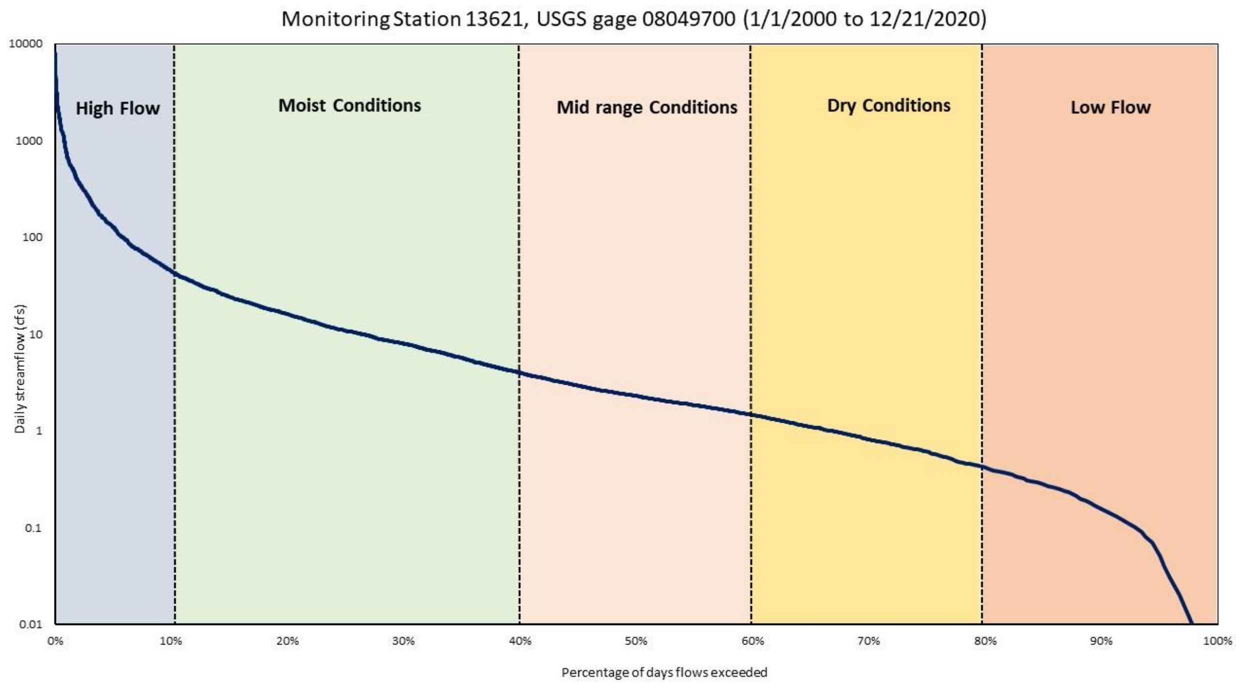


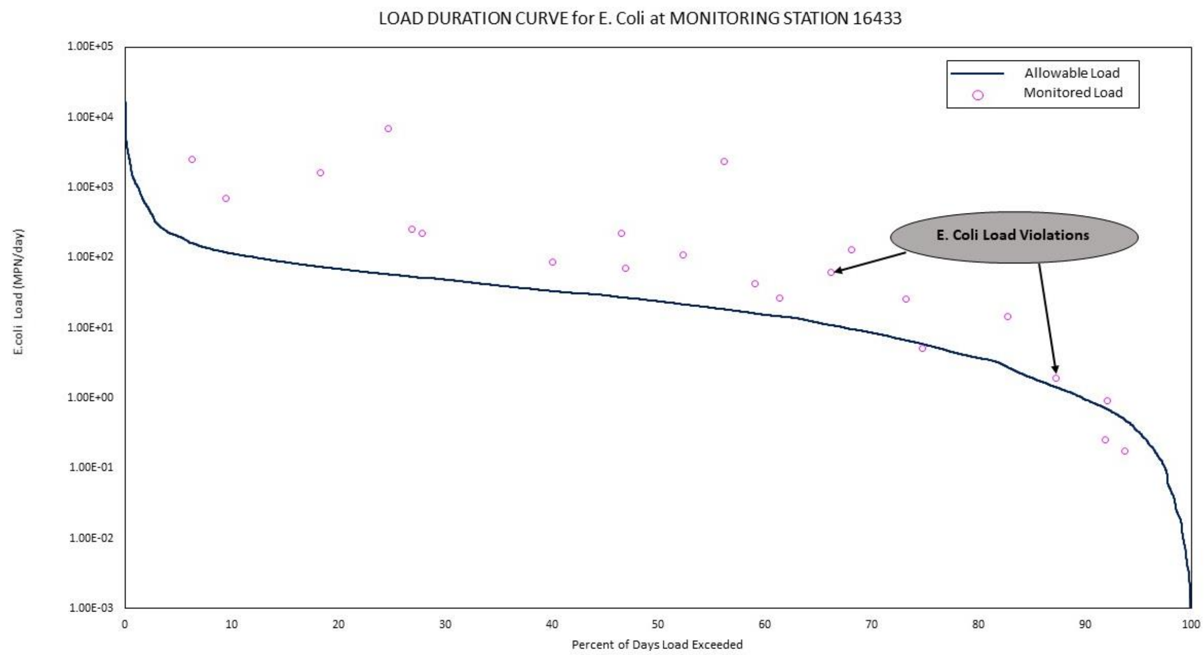
Figure 2-4. Flow categories and regions of likely pollutant sources along an example load duration curve.

LDCs allow for a visual interpretation of load exceedances in comparison to the allowable load at specific flow conditions. Using flow and *E.coli* data collected from a specific monitoring campaign, flow duration curves (FDCs) and LDCs can be built to further evaluate the contaminant sources. First, all flow values are aggregated and ranked from lowest to highest. This data is then graphically depicted to show the general flow regime, complete with the percentage of time that the waterbody is expected to be dry, as well as its response to storm flows (Figure 2-5).



Source: FDC for streamflow conditions at monitoring station 13621 on Walnut Creek, near Mansfield, TX
Figure 2-5. Flow duration curve example from JPL watershed (log scale Y-axis).

The FDC can then be used to develop a LDC for a specific pollutant of interest, given that there is pollutant concentration data that complements the flow data. Figure 2-6 depicts an example LDC based on the FDC shown in Figure 2-5. The first step in the process is to apply the pollutant's allowable limit concentration to all available flow values to produce the allowable load limit curve. In the case of bacteria, this value is 126 MPN/100 mL (blue line in Figure 2-6). Then, the baseline monitoring data values for *E.coli* in MPN/100 mL are multiplied by their associated flow values to get loads for each data point (pink squares in Figure 2-6). This can be developed further by performing regression analysis on the monitored data points, as depicted in Figure 2-7. Here, the allowable load limit is depicted in red, while the regression line for the data points is depicted in blue. Regression analysis can be completed using one of many techniques. In this case, a USGS program LOADEST is utilized. For each of the different flow regimes (High Flows, Moist Conditions, Mid-Range Conditions, Dry Conditions, and Low Flows), a load reduction estimate can be calculated. Achieving these reductions will become one of the primary targets for success once the WPP moves into the implementation stage.



Source: LDC for E.coli at monitoring station 16433 on Hollings branch, near Joe Pool Lake.
Figure 2-6. Load duration curve example from JPL watershed (log scale Y-axis).

However, it is worth noting that some of these reductions, specifically those within the “High Flows” range, may not be achievable due to feasibility of applying management measures to storm flows that fall within the extreme range. It is therefore customary to focus efforts on the load reductions identified at the lower flow conditions, where it becomes easier to separate potential point source contributors from nonpoint source contributors. In most cases, if a waterbody exhibits high pollutant loads on the extreme right of the graph where low flows are represented (Figure 2-4), it is highly likely that this may be attributable to a point source, such as a malfunctioning WWTF or leaking/failing wastewater infrastructure somewhere in the watershed. These types of contributions can typically be easily addressed and are worth investigating early on in the process. Conversely, if pollutant loads tend towards the middle of the graph, it is likely that they are attributed to stormwater runoff during periods of normal or moderate rainfall. While typically not as easily addressed as point sources, load reductions in these areas may also be targeted for watershed pollutant load reductions through BMP recommendations.

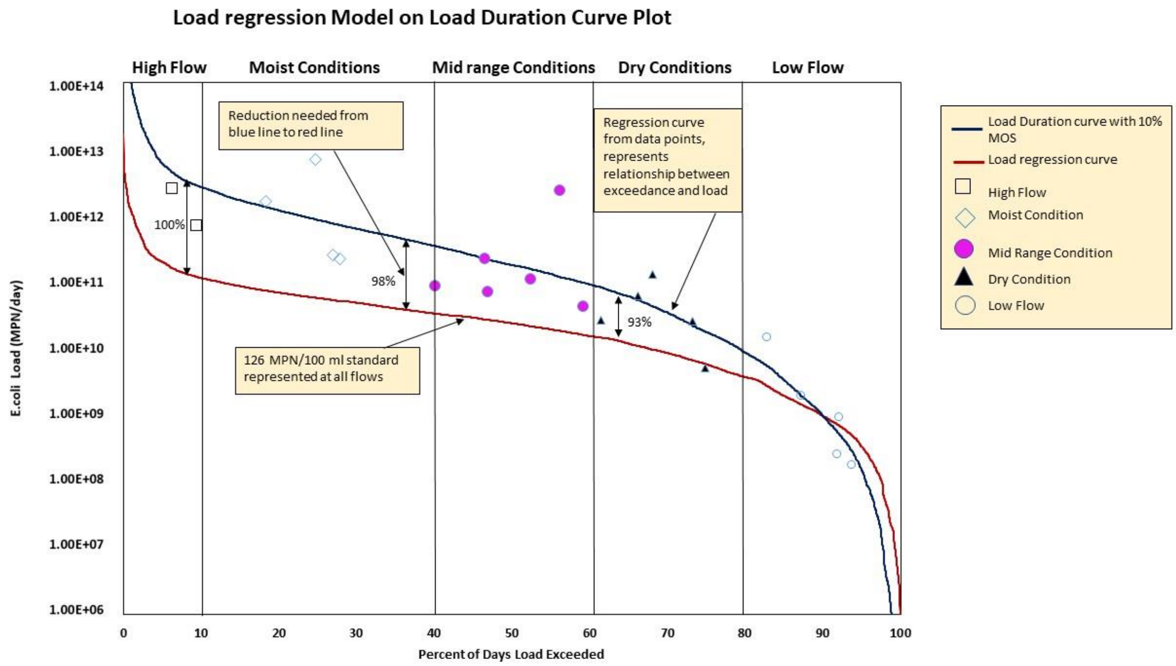


Figure 2-7. Load duration curve example for E.coli, with flow condition breakdowns and load reduction estimates.

A minimum of 12 paired stream flow-pollutant concentration data points are required to properly execute the LDC analysis tool. During the monitoring effort, nine paired samples were successfully collected from the 20 monitoring sites. LDCs were developed at each of the nine stations for five key constituents, *E.coli*, TP, OP, TKN, NO_X (NO_3 + NO_2) so that any trends between stations could be analyzed. Although the LDCs for all sites were instrumental in developing an understanding of pollutant load dynamics throughout the watershed, this project focused on only a few sites to determine several short-term and long-term water quality goals.

For planning purposes, site 22134 (Soap Creek upstream of Mountain Creek confluence), site 13621 (Walnut Creek at Matlock Rd), site 16434 (Mountain Creek at US 287), site 16433 (Hollings Branch at Tangle Ridge Rd), site 22135 (Low Branch at South Holland Rd) and site 22133 (Bowman Branch at South SH 360) were selected for establishing water quality goals for pollutant reductions. These sites represent distinct catchment or containment areas within the JPL watershed (Figure 2-2, Table 2-1).

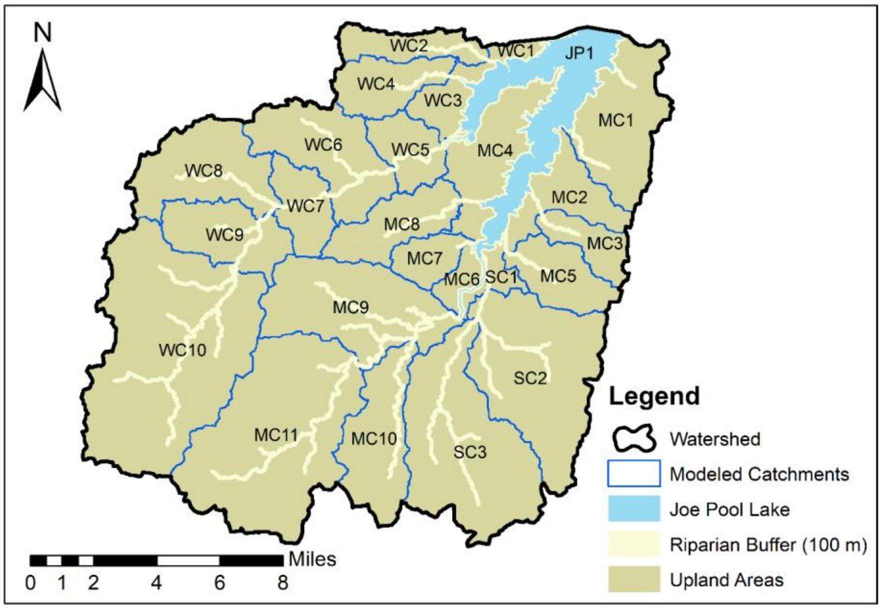
2.5 SELECT

Watershed prioritization and BMP recommendations were further refined with the use of the SELECT analysis, which distributes potential *E.coli* loads into 25 modeled catchments, or subwatersheds (Figure

2-8), based on likely *E.coli* sources as identified by watershed stakeholders. Using a combination of geographic information system (GIS) and spreadsheet tools, estimated populations of various warm-blooded animal species (humans, pets, livestock, wildlife) were distributed spatially throughout the watershed based on each population's applicability to different LULC characteristics. Once distributed, species-specific *E.coli* load production values published in scientific literature were applied to each population (Table 2-8), producing the *E.coli* loads that may eventually find their way to waterways (Figure 3-17, Figure 3-18, Figure 3-19). To account for the variety in the sizes of the subwatersheds, these loads were then normalized to a per-acre basis to ensure that contributions from larger subwatersheds did not overshadow those from several smaller ones. Finally, the separate, normalized sources are then aggregated to produce an overall normalized *E.coli* load for each subwatershed. It should be noted that SELECT was designed specifically for calculating loads from *E.coli* sources, and thus cannot be used to calculate loads from other pollutants of interest to stakeholders, despite their relative importance.

Proper distribution of populations is of paramount importance in the analysis, and stakeholders took care to ensure that distributions accurately reflected conditions experienced in watersheds existing along urban-rural fringes outside of major metropolitan areas like DFW. For example, it is unlikely that you would find a large cow/calf operation in the middle of a dense urban area, so no portion of the watershed's cattle population was distributed to urban land uses, instead they were placed in range and pasture lands. Conversely, while it is likely that the majority of the watershed's horse population will also be found in range and pasture land use classes, it is also likely that some portion may be found in low-density urban areas, on what are commonly known as small-acreage or "hobby" farms, typically 5 acres or less. Therefore, the stakeholder group elected to account for these "pocket populations" by distributing very small portions (5%) of applicable species populations to these low-density urban areas so that a more accurate characterization of the watershed conditions could be achieved.

Raw SELECT output is often seen as a "worst case scenario" for estimating *E.coli* loads, as the tool does not contain any built-in functionality that automatically adjusts for *E.coli* die-off, predation, soil entrainment, or other forms of mitigation between the time of deposition up to its introduction to a waterway. However, these processes can be partially accounted for by applying weights to the loads based on their distance to a waterway. For example, manure deposition within riparian buffer areas (<100-m (330-ft) from a stream), carry more weight than would deposition in an upland area further away (Figure 2-8). Use of this tactic will allow for further refinement of critical areas for BMP implementation.



Stream data source: NHD; watershed source: TCEQ, subwatershed source: TNRIS LiDAR 30m DEM
Figure 2-8. JPL subwatersheds and stream network for the use in SELECT analysis.

Table 2-8. E.coli loading factors for calculating E.coli loads from various sources.

Source	*E.coli* Loading Factor	Literature Source
Cattle	2.70E+9 MPN/AU-day	Metcalf and Eddy, 1991
Sheep/Goats	9.00E+9 MPN/AU-day	Metcalf and Eddy, 1991
Horses	2.10E+8 MPN/AU-day	ASAE, 1998
Deer	1.75E+8 MPN/AU-day	Teague et al., 2009
Feral Hogs	4.45E+9 MPN/AU-day	Metcalf and Eddy, 1991
Dogs/Cats	2.50E+9 MPN/AU-day	Horsley and Witten, 1996
Ducks	5.50E+9 MPN/AU-day	Metcalf and Eddy, 1991
Geese	2.45E+10 MPN/AU-day	LIRPB, 1978
OSSFs	1.33E+9 MPN/person-day	Teague et al., 2009
SSOs	1.89E+7 MPN/gal; daily volume varies based on reported release volumes (gal) from database	USEPA, 2001
WWTFs	4.78E+9 MPN/MGD; daily volume varies based on self-reported release volumes (MGD) from facility	Teague et al., 2009

2.5.1 General Approach

To further identify the extent of a certain source type's likely contribution to the bacteria load in a specific subwatershed, the SELECT analysis can be conducted for any number of potential bacteria source types, including urban/municipal runoff, agricultural runoff, failing septic systems, wildlife, and even invasive species.

The SELECT approach first uses spatial data for LULC data to determine where representatives from a particular contributing source might be located, and then uses watershed boundaries, topography, and stream network information to further determine suitability and range. Then, an estimated population density is applied to these suitable areas. Population density data can come in the form of census estimates for humans, literature values from published resource agency materials, or in some cases, anecdotal evidence from watershed stakeholders.

Finally, published literature values for *E.coli* production from these sources are applied to the estimated population so that a potential *E.coli* load can be calculated for each subwatershed in the analysis. This yields visual output that can be color-coded to show the severity of the load's potential contribution to the watershed, which can be used to pinpoint areas where management measures would provide the most cost-to-benefit ratio. Details about the process for calculating each source category's load estimate are provided below.

Two categories of pollutant sources known as point source and nonpoint source impacts the water quality in a watershed. Visible sources of pollution such as wastewater treatment facilities (WWTFs), and overflows from OSSFs are considered point sources whereas those that are not directly identifiable such as urban and agricultural runoff containing nutrients from excess fertilizers, pesticides crop residues, pathogens, livestock and pet waste, domestic waste etc. are the nonpoint source pollutants.
The sources of potential *E.coli* load in the JPL watershed assessed throughout this report consist of waste from pets, livestock, OSSFs, wildlife, and WWTFs. The distribution of these potential bacteria load sources JPL watershed is presented in Figure 2-9.

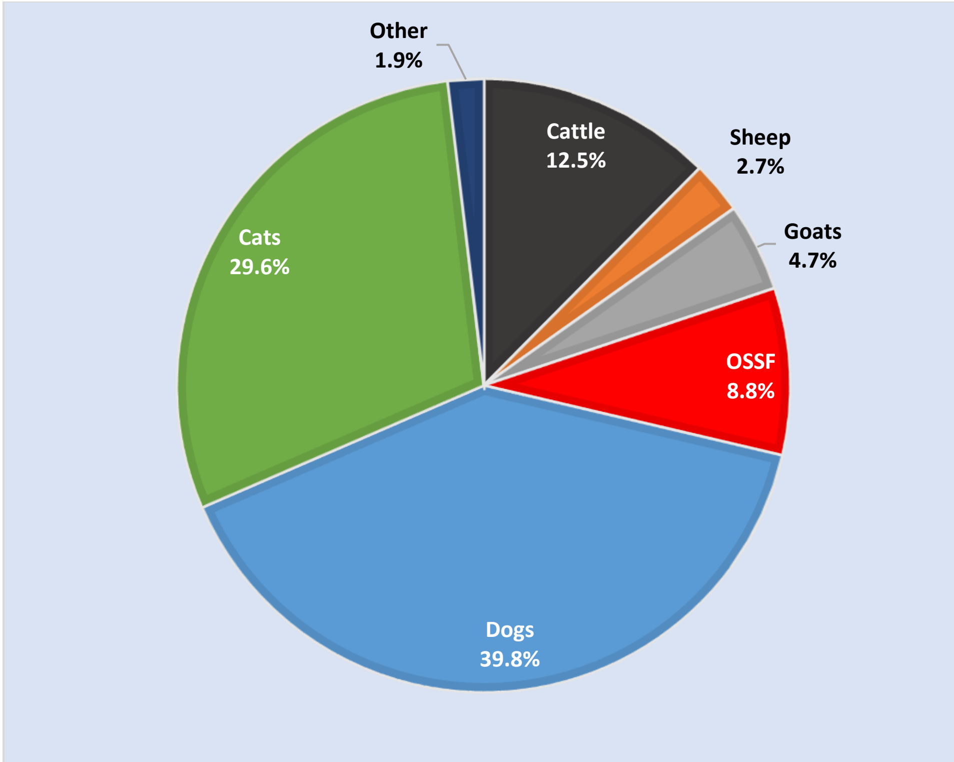


Figure 2-9. Potential Sources of E.coli loading in JPL watershed.

2.5.2 Point Source: WWTFs

There are six permitted and active WWTFs within the JPL watershed. Details about the six active WWTFs and any associated permit limit exceedances for water quality parameters are provided in Table 2-9. The WWTFs do not exceed the maximum allowable average daily discharge. WWTFs are not a significant source of *E.coli* for the JPL watershed as it contributes only about 0.002% of the load. The details of the permitted and active WWTFs locations and their permit limits are shown in Table 2-9.

The equation to calculate the *E.coli* (EC) for WWTFs is given as (Teague, 2009):

$$\mathrm{EC} = \text{Average flow (MGD)} \cdot \frac{\text{Reported } E.\,coli \text{ geomeanMPN}}{100\ \mathrm{mL}} \cdot \frac{10^6 \mathrm{gal}}{\mathrm{MG}} \cdot \frac{3785.41\ \mathrm{mL}}{\mathrm{gal}}$$

Total *E.coli* calculations for each subwatershed (in MPN/day) are normalized across the watershed by dividing by the sub-watershed's area (MPN/ac-day).

Table 2-9. Compliance history for active WWTFs in the JPL watershed.

NPDES Permit	Facility Name	Receiving Waterbody	Flow (daily average, MGD)		*E. coli* (daily average, MPN/100 mL)		Exceedances[4]			
			Permitted	Reported[1]	Permitted	Reported[2]	*E.coli*	Ammonia	BOD_5	TSS
TX0083437	Ash Grove Texas LP	Bedford Branch	0.3	0.1865	126	N/A	0	0	0	0
TX0083437	Ash Grove Texas LP	Bedford Branch	0.006	0.00138	126	1.19	0	0	0	12
TX0119229	Alvarado ISD	Unnamed Trib to King Branch to Walnut Creek	0.035	0.00139	126	4.596 [3]	0	0	1	1
TX0113573	Country Vista WWTP	Unnamed Trib to Valley Branch to Walnut Creek	0.042	0.0255	126	4.265[3]	0	0	3	8
TX0133388	Mansfield ISD	Unnamed Trib to Valley Branch to Walnut Creek	0.02	0.0116	126	2.888 [3]	0	0	14	16
TX0025011	Mountain Creek Regional WWTF	Unnamed Trib to Soap Creek	3	2.371	126	4.93	2	0	0	2
TX0118770	Walnut Creek MHP	Walnut Creek	0.0225	0.0139	126	66.93 [3]	2	0	26	33

(1) 4-year average based on daily measurements from USEPA data, 03/01/2017 - 06/01/2021.
(2) 4-year geomean based on daily measurements from USEPA data, 03/01/2017-06/01/2021.
(3) Reported quarterly rather than monthly.
(4) USEPA data, 03/01/2017-06/01/2021

2.5.3 Point Source: SSOs

Subwatershed Analysis

Sanitary sewer overflows (SSOs) can be a significant contributor of *E.coli* in urban watersheds if they occur near waterways. SSOs are not predictable and can occur when pipes are blocked, broken, or when deteriorating pipes and connections allow infiltration of stormwater or groundwater into the wastewater system. These inflow/infiltration (I/I) issues often result in combined stormwater/wastewater volumes that exceed the design capacity of the pipes, causing backups that will eventually find a relief point, often a manhole cover or other surface access. From this relief point, untreated sewage can potentially reach streams and lakes if not contained properly or in a timely manner. Older neighborhoods tend to be more prone to SSOs, as they tend to be serviced by older infrastructure that may be subject to the deterioration or design capacity issues. In addition, continued development over the years can outgrow the design capacity making these older systems more prone to SSOs. In general, SSOs are combined with pet waste nonpoint sources and used as surrogates for urban runoff when calculating pollutant loads from urban sources.

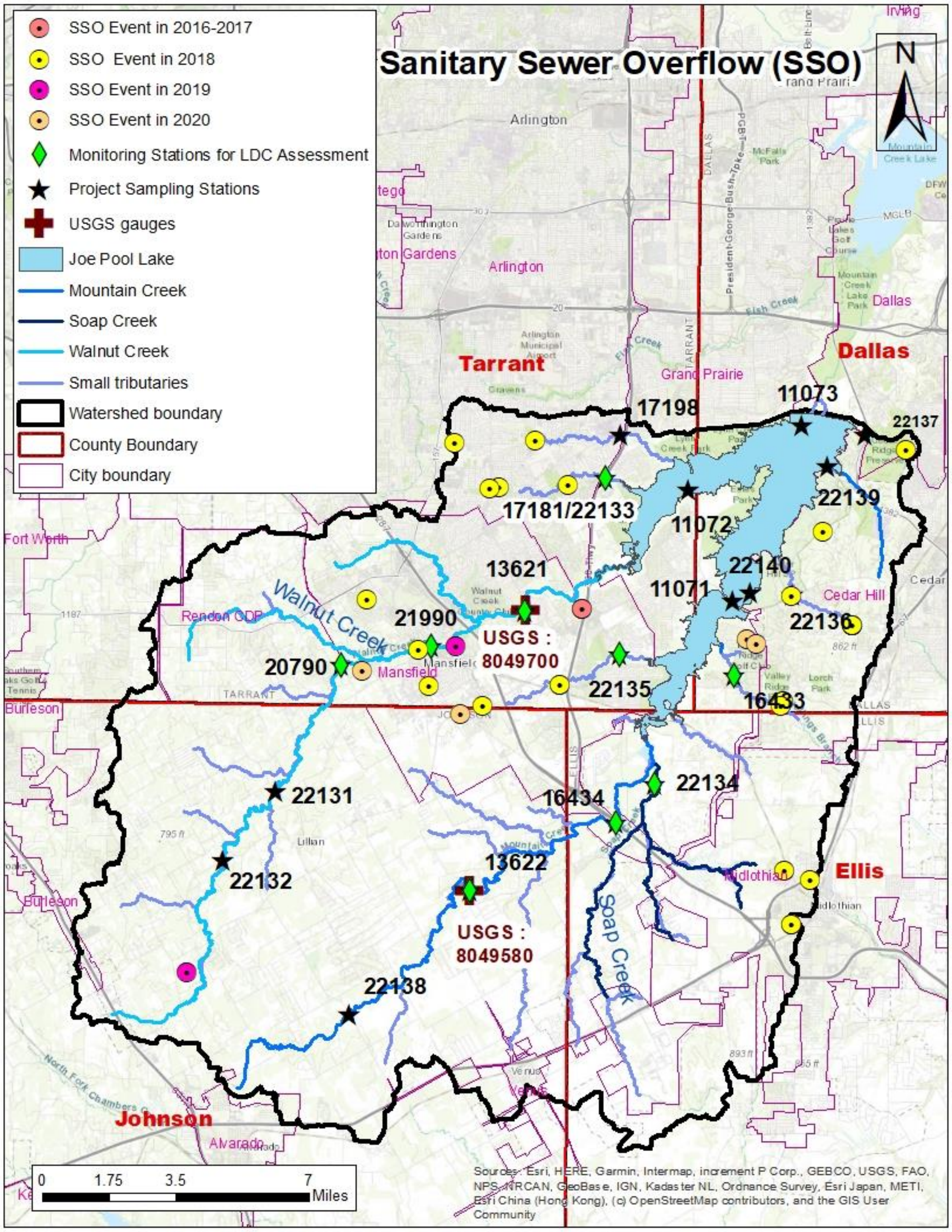
The compendium of past reports of SSO occurrences was used to illustrate locations, overflow amount, cause of SSOs, and potentially determine impacts of SSOs on the day of occurrence. NCTCOG acquired SSO data from TCEQ for the region for the period 2016-2020 across the 25 subwatersheds. For each subwatershed, the number of SSOs and the total gallons discharged were used. However, the amount of SSOs in the JPL watershed were too few to expand on in analysis and determine a daily discharge, as these are sporadic overflows. It is possible to calculate if there is a chronic overflow. BMPs for SSOs require infrastructure assessments and proper maintenance that are usually built into a Municipal Separate Sewer System (MS4) program.

Load Calculation

Although it was not possible to conduct load calculations for SSOs, the equation to calculate the EC for SSOs is provided below. EC is obtained from combined sewer overflow and septic equations in EPA's Protocol for Developing Pathogen TMDLs (USEPA, 2001), and given as:

$$\mathrm{EC} = \frac{\text{Avg discharge in gal}}{\text{day}} \cdot \frac{5 \cdot 10^{3}\ \text{MPN}}{\text{mL}} \cdot \frac{3785.41\ \text{mL}}{\text{gal}}$$

The *E.coli* load assigned to raw sewage is $5*10^3$ MPN/mL (USEPA, 2001). Total *E.coli* calculations for each subwatershed (in MPN/day) are then normalized across the watershed by dividing by the sub watershed's area (MPN/ac-day). According to the SSO data from NCTCOG spanning 2016-2020, there were thirty-nine incidents of overflow in the JPL watershed. The location, start and end date, cause, amount, and status of the overflow is presented in Table 2-10 and shown in Figure 2-10.



Basemap: ESRI World Street Map; Stream data source: NHD; station data
Figure 2-10. Location of Sanitary Sewer Overflows in the JPL watershed.

Table 2-10. Location, start and end date of overflow, cause of overflow, overflow amount, and status of the SSOs in JPL watershed.

Location	Latitude	Longitude	Start Date	End Date	Cause	Overflow amount (Gallon)	Status
CITY OF MANSFIELD	32.5813690	-97.0802680	3/30/2017	3/30/2017	EQUIPMENT FAILURE	10000	CLOSED
CITY OF CEDAR HILL	32.5855620	-97.0007370	9/8/2018	9/8/2018	POWER OUTAGE	810	CLOSED
CITY OF CEDAR HILL	32.5517220	-97.0041850	9/8/2018	9/8/2018	POWER OUTAGE	1080	CLOSED
CITY OF CEDAR HILL	32.5517270	-97.0042010	9/22/2018	9/22/2018	POWER OUTAGE	7200	CLOSED
CITY OF CEDAR HILL	32.6323580	-96.9571390	9/22/2018	9/22/2018	POWER OUTAGE	8400	CLOSED
CITY OF CEDAR HILL	32.5760090	-96.9776060	9/22/2018	9/22/2018	POWER OUTAGE	3600	CLOSED
CITY OF CEDAR HILL	32.5517270	-97.0041910	10/9/2018	10/9/2018	INFILTRATION AND INFLOW	6300	CLOSED
CITY OF CEDAR HILL	32.5760090	-96.9775870	10/9/2018	10/9/2018	POWER OUTAGE	32400	CLOSED
CITY OF CEDAR HILL	32.5502000	-97.0049160	10/13/2018	10/13/2018	INFILTRATION AND INFLOW	1200	CLOSED
CITY OF CEDAR HILL	32.5760090	-96.9776010	10/13/2018	10/13/2018	INFILTRATION AND INFLOW	3150	CLOSED
CITY OF CEDAR HILL	32.5760100	-96.9776050	10/17/2018	10/17/2018	INFILTRATION AND INFLOW	2700	CLOSED
CITY OF CEDAR HILL	32.5760080	-96.9776000	10/24/2018	10/25/2018	INFILTRATION AND INFLOW	900	CLOSED
CITY OF CEDAR HILL	32.5760110	-96.9776030	11/7/2018	11/7/2018	POWER OUTAGE	1560	CLOSED
CITY OF CEDAR HILL	32.5760110	-96.9776300	11/10/2018	11/10/2018	INFILTRATION AND INFLOW	600	CLOSED
CITY OF CEDAR HILL	32.5760110	-96.9776030	11/11/2018	11/11/2018	INFILTRATION AND INFLOW	450	CLOSED
CITY OF CEDAR HILL	32.6061270	-96.9886840	11/25/2018	11/25/2018	EQUIPMENT FAILURE	2700	CLOSED
CITY OF MIDLOTHIAN	32.4946380	-96.9935910	2/27/2018	2/27/2018	LINE BREAK	30000	CLOSED
CITY OF MIDLOTHIAN	32.4804430	-97.0006890	3/5/2018	3/5/2018	LINE BLOCKAGE (NON-GREASE)	335	CLOSED
CITY OF MIDLOTHIAN	32.4804430	-97.0006890	3/13/2018	3/13/2018	GREASE BLOCKAGE	225	CLOSED
MOUNTAIN CREEK REGIONAL WWTP	32.4976500	-97.0036650	10/16/2018	10/18/2018	INFILTRATION AND INFLOW	213750	CLOSED
JOHNSON COUNTY SUD WWTF	32.5683270	-97.1428000	9/22/2018	9/24/2018	LINE BLOCKAGE (NON-GREASE)	300	CLOSED
CITY OF KEMP	32.5571480	-97.0888060	10/9/2018	10/9/2018	LINE BLOCKAGE (NON-GREASE)	3600	CLOSED
CITY OF KEMP	32.5571480	-97.0888060	10/9/2018	10/9/2018	GREASE BLOCKAGE	3600	CLOSED
CITY OF ARLINGTON COLLECTION SYSTEM	32.6204190	-97.1118500	1/4/2018	1/4/2018	GREASE BLOCKAGE	285	CLOSED
CITY OF ARLINGTON COLLECTION SYSTEM	32.6343820	-97.1288510	1/21/2018	1/21/2018	GREASE BLOCKAGE	404	CLOSED
CITY OF MANSFIELD	32.5503790	-97.1182570	3/9/2018	3/9/2018	LINE BLOCKAGE (NON-GREASE)	17500	CLOSED
CITY OF MANSFIELD	32.5567650	-97.1384060	3/13/2018	3/13/2018	GREASE BLOCKAGE	5000	CLOSED
CITY OF ARLINGTON COLLECTION SYSTEM	32.6198620	-97.1155830	3/18/2018	3/18/2018	GREASE BLOCKAGE	680	CLOSED

CITY OF ARLINGTON COLLECTION SYSTEM	32.6352340	-97.0982490	5/21/2018	5/21/2018	GREASE BLOCKAGE	30	CLOSED
CITY OF ARLINGTON COLLECTION SYSTEM	32.6210100	-97.0856650	11/27/2018	11/27/2018	GREASE BLOCKAGE	225	CLOSED
CITY OF ARLINGTON COLLECTION SYSTEM	32.5844750	-97.1622950	12/31/2018	12/31/2018	HUMAN ERROR	860	CLOSED
WALNUT CREEK MHP	32.4651100	-97.2307300	5/32/2019	6/5/2019	INFILTRATION AND INFLOW	25000	CLOSED
CITY OF MANSFIELD	32.5695100	-97.1284550	7/8/2019	7/8/2019	LINE BREAK	10000	CLOSED
CITY OF MANSFIELD	32.5813660	-97.0802270	6/6/2019	6/6/2019	EQUIPMENT FAILURE	5760	CLOSED
CITY OF GRAND PRAIRIE	32.5716325	-97.0176299	8/4/2020	8/4/2020	LINE BREAK	520	CLOSED
CITY OF GRAND PRAIRIE	32.5703580	-97.0140819	8/7/2020	8/7/2020	GREASE BLOCKAGE	200	CLOSED
CITY OF MIDLOTHIAN	32.4976517	-97.0036628	2/12/2020	2/12/2020	INFILTRATION AND INFLOW	24000	CLOSED
CITY OF VENUS WWTP SITE B	32.5478720	-97.1266490	6/5/2020	6/5/2020	LINE BREAK	12000	CLOSED
CITY OF MANSFIELD	32.5617232	-97.1640219	12/23/2020	12/23/2020	LINE BLOCKAGE (NON-GREASE)	800	CLOSED

2.5.4 Nonpoint Source: Dogs & Cats

Households Analysis

The 2020 Traffic Survey Zones (TSZs) (NCTCOG, 2011) population and household estimates were obtained from the North Central Texas 2045 Demographic Forecast dataset provided by NCTCOG. The population projections were based on a combination of the Gravity Land Use Model (G-LUM) and the UPlan urban growth model with inputs derived from the 2000 and 2010 Census data.

For each subwatershed, if the TSZ was completely within the sub-watershed, its entire population was used. If the TSZ was partially in the sub-watershed, the population in the sub-watershed was estimated by multiplying the block group population to the proportion of its area in the sub-watershed. The area of JPL sub-watershed was removed from the TSZ shapefile before applying the population and household over the block group area to avoid applying population projections to the lake area.

Approximately 36.5% of U.S. households have dogs, with 30.4% owning cats, and it is estimated that there are 1.6 dogs per HH with dogs, an average of 0.614 dogs per household overall, 1.8 cats per HH with cats, and an average of 0.457 cats per household overall (AVMA, 2018).

Load Calculation

The equation to calculate the EC for dogs and separately for cats is given as:

$$\mathrm{EC} = \text{Number of households} * \frac{\text{fraction of pets}}{\text{household}} * 2.5 * 10^{9}\ \mathrm{MPN\ d^{-1}\ head^{-1}}$$

The EC loading of $2.5*10^9$ MPN/day-head comes from fecal coliform estimate of $5.0*10^9$ MPN/day-head (Horsley and Witten, 1996) with the 50% fecal coliform (FC) to *E.coli* "rule of thumb" conversion applied. A 90% contribution was assumed to reach waterways within the 330-ft (100-m) riparian buffers, with a presumed 50% contribution from upland areas. Total EC calculations for each subwatershed (in MPN/day) are then normalized across the watershed by dividing by the subwatersheds area (MPN/ac-day).

2.5.5 Nonpoint Source: Livestock, Deer, Horse & Feral Hogs

Estimating Population Density

Similar steps were taken when developing the EC loads for larger mammals, such as domestic livestock, deer, and feral hogs. First, land use categories were considered for their suitability as habitat for the species of interest. Total watershed acreage of land uses relevant to large mammal populations were calculated based on the NCLD 2016 database (Table 2-12). County-wide National Agricultural Statistics Service (NASS) population estimates were then extrapolated to the watershed using a percent-area basis (Table 2-13). Animal populations were originally based on proportioned NASS, Texas Parks and Wildlife Department (TPWD), or Texas A&M University (TAMU) data. These were then modified based on steering committee recommendations (Table 2-14). If a particular land use was only partially utilized as habitat by a species, population density adjustments were made to that land use category (Table 2-15). Population densities for each species were then calculated using the stakeholder-recommended populations and the land use-based density adjustments (Table 2-16, Table 2-17).

Load Calculation

The adjusted animal population densities were used to calculate the *E.coli* loads for various livestock, deer, and feral hogs with the equations as shown in Table 2-11 (Teague, 2009):

Table 2-11. Equations to calculate the E.coli loads for various livestock, deer, feral hogs, and avian.

Source	Calculation
Cattle	$EC = \#cattle * 2.7 * 10^9 MPN d^{-1} head^{-1}$
Horses	$EC = \#horses * 2.1 * 10^8 MPN d^{-1} head^{-1}$
Sheep and goats	$EC = \#sheep * 9 * 10^9 MPN d^{-1} head^{-1}$
Deer	$EC = \#deer * 1.75 * 10^8 MPN d^{-1} head^{-1}$
Feral Hogs	$EC = \#hogs * 4.45 * 10^9 MPN d^{-1} head^{-1}$
Ducks	$EC = \#ducks * 5.5 * 10^9 MPN d^{-1} head^{-1}$
Geese	$EC = \#geese * 2.45 * 10^{10} MPN d^{-1} head^{-1}$

Total *E.coli* calculations for each subwatershed (in MPN/day) are then normalized across the watershed by dividing by the subwatersheds area (MPN/ac-day).

Table 2-12. Total land cover acreages for relevant land uses in JPL watershed.

Land Cover	Acres
Grassland	45,670
Pasture/Hay	12,943
Deciduous Forest	19,622
Evergreen Forest	4,252
Mixed forest	370
Developed	35,965

Table 2-13. Percentage of area of different counties falling within the boundary of JPL Watershed from NLCD 2016.

County	Total Acres	Acres in Watershed	% of County	% of Watershed
Johnson	469,950	55,998	11.92%	39.13%
Ellis	609,282	30,550	5.01%	21.35%
Tarrant	577,376	38,508	6.67%	26.91%
Dallas	581,676	18,036	3.10%	12.61%
Total	2,238,284	143,091		100%

Table 2-14. Assumed populations of various large mammals in the watershed based on Steering Committee (SC) recommendations.

SC Recommendations		
Large Mammals	Number	Notes
Cattle	11,165	Original estimates based on USDA-NASS data
Equine	1,207	Original estimates based on USDA-NASS data, added 130 across low density urban land
Sheep	736	Original estimates based on USDA-NASS data
Goats	1,255	Original estimates based on USDA-NASS data
Deer	902	Original estimates based on TPWD annual median density estimate for DMU #20,21,22
Feral Hogs	593	Original estimates based on TAMU
Cats	28,698	Original estimates based on AVMA data
Dogs	38,558	Original estimates based on AVMA data

Table 2-15. Proposed population density adjustments based on % of each land use type used by each animal classification across watershed.

Density Adjustments	Grassland	Pasture/Hay	Shrub/Scrub	Low Density Urban
Cattle	1	1	1	
Equine	1	1	1	1
Sheep	1	1	1	
Goat	1	1	1	

Table 2-16. Estimated animal densities, animals/acre and acres/animal basis.

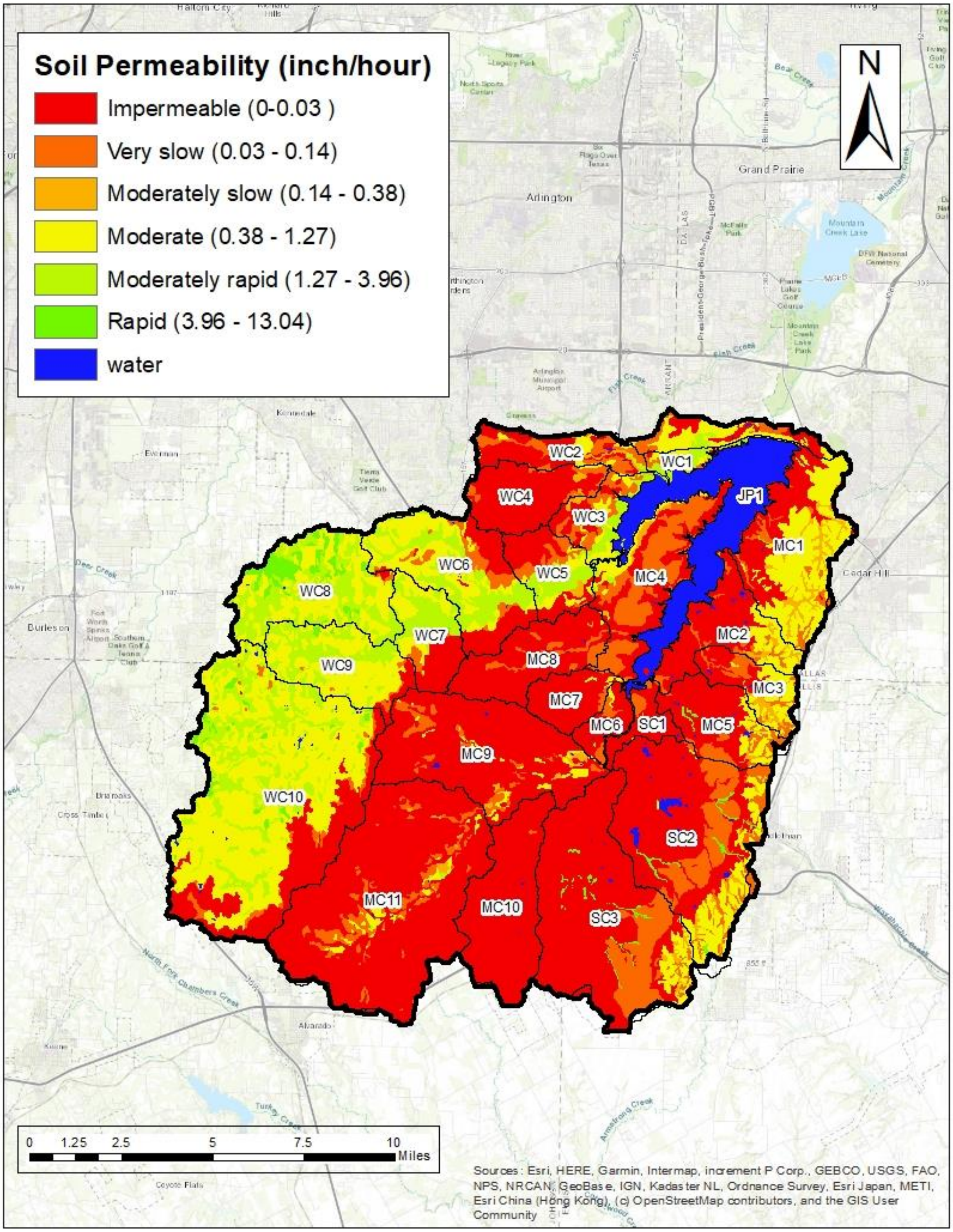
Species	animal/ac	ac/animal	Notes
Cattle	0.19	5.39	100% pasture, 100% grassland, 100% shrub/scrub
Equine	0.02	56.03	100% pasture, 100% grassland, 100% shrub/scrub
Equine	0.2	5	5% low density urban
Sheep	0.01	81.7	100% pasture, 100% grassland, 100% shrub/scrub
Goat	0.02	48	100% pasture, 100% grassland, 100% shrub/scrub
Deer	0.02	53.7	whole watershed except developed (all), open water
Feral Hogs	0.02	50.4	100 % riparian zones, 100 % forest land uses

Table 2-17. Acreages used in calculation of feral hog population (in green).

LULC Category	Acres	
	Riparian	**Upland**
Open Water	1,772	5,373
Developed, Open Space	550	10,708
Developed, Low Density	355	12,561
Developed, Med Density	158	9,256
Developed, High Density	41	2,335
Barren land (Rock/Sand/Clay)	10	698
Deciduous Forest	4,944	14,678
Evergreen Forest	86	4,166
Mixed Forest	52	318
Shrub/Scrub	149	1,530
Grassland/Herbaceous	3,030	42,640
Pasture/Hay	754	12,190
Cultivated Crops	180	13,988
Woody Wetlands	104	58
Emergent Herbaceous Wetlands	291	117
Total Suitable Acreage	10,704	19,162
Total Composite Acreage		29,866

2.5.6 Nonpoint Source: OSSFs

There are several unincorporated and rural areas in the watershed where OSSFs are used by residents for wastewater treatment. When not functioning properly, OSSFs can become sources of pollution for *E.coli*, nutrients, and solids, both in groundwater and surface water bodies. A variety of causes can be to blame for reduced performance or malfunctions, including improper design/installation, lack of maintenance, unsuitable soil types (Figure 2-11), age of the system, and proximity to other systems.



Basemap: ESRI World Street Map; Soil data: NRCS-SSURGO
Figure 2-11. Permeability of soils in the JPL watershed.

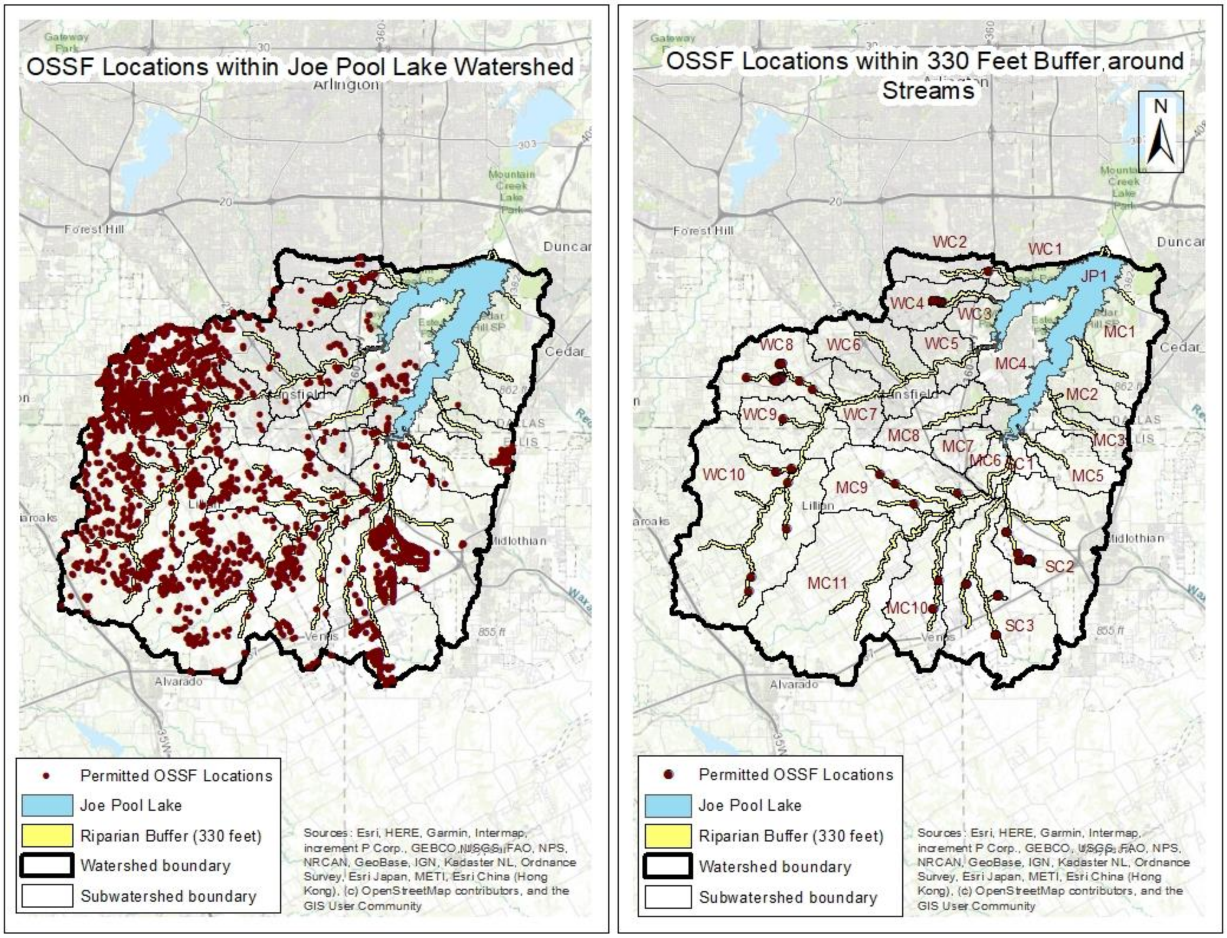
Methods

Since 1989, counties are responsible for maintaining records of permitted OSSFs, which must be inspected to ensure compliance with state regulations. Many of the known existing systems in the watershed installed prior to 1989 are not tied to a current permit, indicating that they have not been recently inspected, and thus have a much higher likelihood for failure. Since many of these systems were constructed before stricter permitting requirements were put in place, it is possible that many were either designed or installed improperly, especially in areas where soils are less suitable and unable to treat and absorb effluent loads. These "non-permitted" systems present a greater contamination risk to water quality. However, it is expected that even some permitted systems are currently in a state of failure, usually due to neglect or lack of homeowner knowledge regarding OSSF operation. Designated representatives (DRs) for counties in the watershed, as well as other stakeholders, agreed with statewide estimates of 50% failure rate for "non-permitted" and 12% for permitted systems used in several other WPP efforts in Texas (Reed et al., 2002).

Permitted OSSFs were pulled from Johnson, Ellis, and Tarrant counties, and from the cities of Grand Prairie and Arlington. Only the last 7 years of permits were available from Johnson County therefore the number of total permitted OSSFs could be higher across the JPL watershed in this county. Based on the available data for permitted OSSFs a total of 4,756 were located within the JPL watershed (Figure 2-12). No information was available for the actual number of "non-permitted" OSSFs across the JPL watershed. Stakeholders indicated there are about two "non-permitted" OSSFs present for every permitted OSSF across the watershed. Using this ratio, a total of 9,512 "non-permitted" OSSFs were designated for the SELECT analysis.

Stakeholders realized that while some element of upland-located OSSFs may be contributing, this riparian-focused approach would provide the most benefit while remaining economical. This decision was made due to the high costs associated with OSSF rehabilitation/replacement. Of the total 14,268 OSSFs estimated to exist in the watershed, only 4,756 have existing permits. If the scope is limited to those OSSFs inside the riparian buffer, 115 OSSFs (Figure 2-12) have associated permits and potentially 230 "non-permitted" OSSFs could be present. Proximity to other systems can also affect OSSF performance, particularly in areas where systems are densely spaced. In these situations, multiple failures are possible if one drain field exceeds its capacity and impacts adjacent fields, potentially resulting in drain field contaminants reaching waterbodies.

In the JPL watershed, OSSF's contribute 8.8% of the total *E.coli* load (Table 3-10). Failure rates of 50% for "non-permitted" systems and 12% for permitted systems were assumed to calculate the number of failing systems (Reed et al., 2001). The details for OSSFs, their failure rates, average person per household, and average *E.coli* load produced is presented in Table 2-18 for each subwatershed.



Basemap: ESRI World Street Map; OSSF data: Ellis, Johnson, and Tarrant County and the cities of Grand Prairie and Arlington
Figure 2-12. Permitted OSSFs across the JPL (left) and permitted OSSFs within the 330-ft riparian buffer (right).

Table 2-18. Permitted and "non-permitted" Onsite Sewage Facilities (OSSF), their failure rates, average person per household, and average E.coli Load produced by subwatershed.

Subwatershed	Number of Permitted OSSFs	Failure Rate	Number of "non-permitted" OSSF	Failure rate	Average persons per Household	Load (MPN/day)
JP1	0	0.12	0	0.5	0.00	1.46E+12
MC1	0	0.12	0	0.5	2.76	7.28E+12
MC2	1	0.12	2	0.5	2.88	4.28E+12
MC3	137	0.12	274	0.5	3.14	2.06E+12
MC4	85	0.12	170	0.5	3.37	1.61E+13
MC5	7	0.12	14	0.5	2.84	2.37E+12
MC6	4	0.12	8	0.5	2.95	4.49E+11
MC7	29	0.12	58	0.5	3.36	1.86E+12
MC8	9	0.12	18	0.5	3.16	8.34E+12
MC9	134	0.12	268	0.5	3.03	8.56E+12
MC10	105	0.12	210	0.5	3.05	4.21E+12
MC11	300	0.12	600	0.5	3.32	1.65E+13
SC1	24	0.12	48	0.5	3.04	8.14E+11
SC2	712	0.12	1,424	0.5	2.90	1.45E+13
SC3	714	0.12	1,428	0.5	2.97	1.02E+13
WC1	0	0.12	0	0.5	3.35	2.46E+12
WC2	17	0.12	34	0.5	3.44	1.88E+13
WC3	5	0.12	10	0.5	3.15	6.19E+12
WC4	116	0.12	232	0.5	3.48	2.17E+13
WC5	19	0.12	38	0.5	3.20	1.31E+13
WC6	144	0.12	288	0.5	2.89	2.80E+13
WC7	35	0.12	70	0.5	2.99	7.41E+12
WC8	1,111	0.12	2,222	0.5	3.10	1.50E+13
WC9	557	0.12	1,114	0.5	3.05	7.21E+12
WC10	491	0.12	982	0.5	2.86	2.32E+13
Total	4,756		9,512			2.42E+14

Load Calculation

The equation to calculate EC for OSSFs is:

$$EC = \#\text{failing systems} \cdot \frac{5 \cdot 10^3 \text{ MPN}}{\text{mL}} \cdot \frac{2.65 \cdot 10^5 \text{ mL}}{\text{person} \cdot \text{day}} \cdot \frac{\text{Avg \#persons}}{\text{household}}$$

The *E.coli* load assigned to OSSFs: $5*10^5$ MPN/100 mL, with the average per-person water use estimated at 70gal/person-day ($2.65*10^5$ mL) to be delivered to the OSSF (Teague, 2009).

3.0 Results and Discussion

3.1 Statistical Analysis

For Figure 3-1, investigators related flow to *E.coli*. Flow is represented by black horizontal bars. *E.coli* is represented by the vertical bars. The red dotted line represents the water quality criteria for *E.coli* (126 MPN/100 mL), which is technically only appropriate for geomean measurements, but is shown here simply for comparison. For all sites on Walnut Creek (upstream of station 13621), *E.coli* concentrations appeared to be closely related to precipitation events and thus higher flows, indicating that nonpoint sources and/or resuspension of existing instream colonies are likely to be the significant contributors of *E.coli*. Figure 3-1 provides an example of the flow-concentration relationship typical of these stations. Additional site summaries for *E.coli* and streamflow can be found in Appendix D. Site Summaries for *E.coli* and Streamflow.

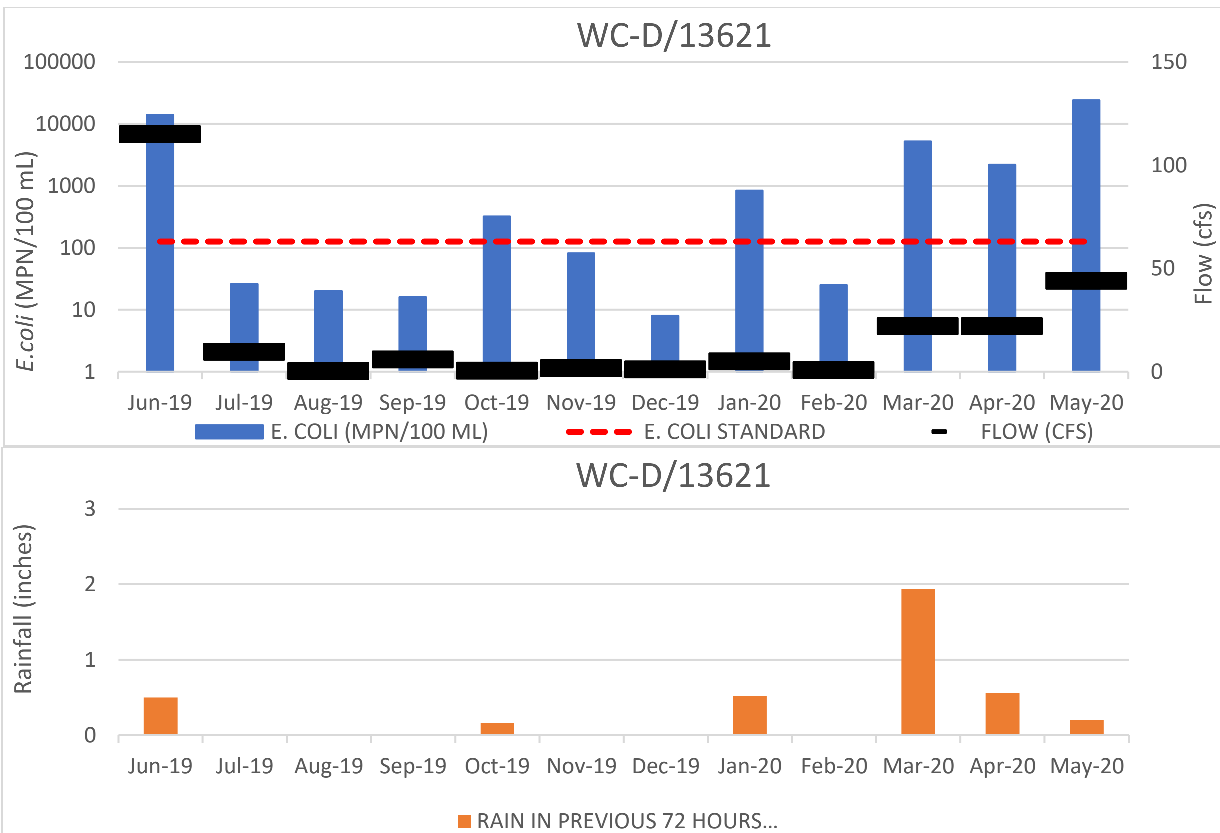
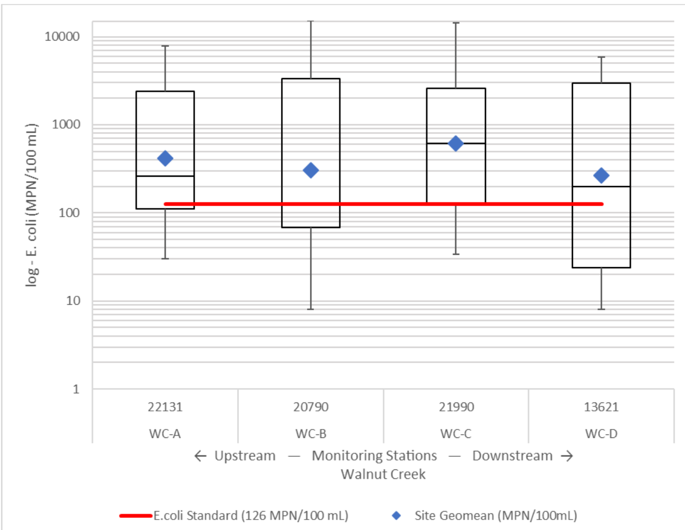


Figure 3-1. Hydrology and E.coli parameters, Walnut Creek at Matlock Road (13621).

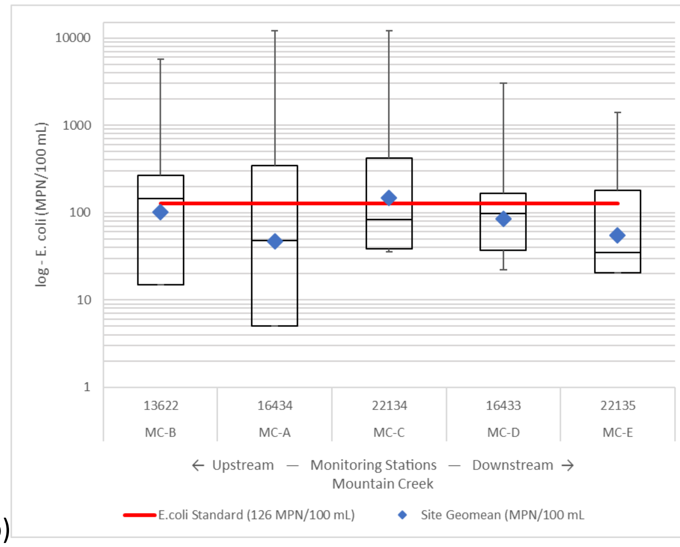
3.1.1 *E.coli*

The additional monitoring conducted in 2019-2020 indicates that contact recreational use is not supported in Walnut Creek due to elevated *E.coli* levels. Contact recreational use is supported in Mountain Creek albeit at one site, Soap Creek MC-C/22134. Contact recreational use is supported in JPL.

a)



b)



c)

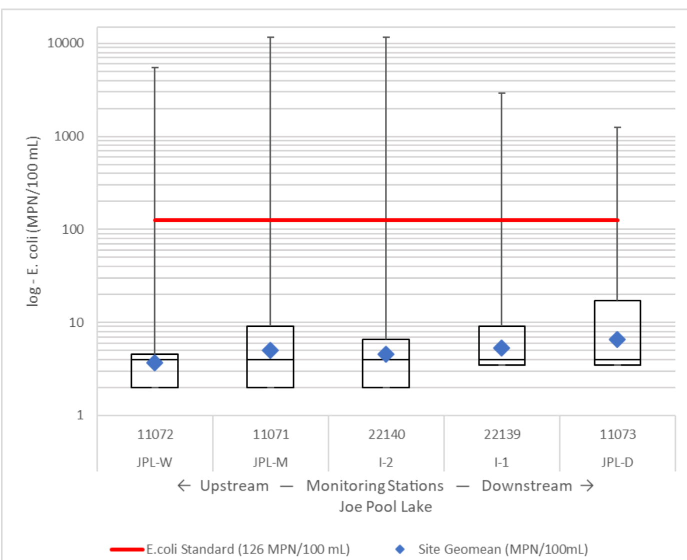


Figure 3-2. Boxplots and geomeans for E.coli samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that JPL and Mountain Creek stations maintained a geomean concentration below the water quality standard (126 MPN/100 mL) with the exception of Station 22134 (MC-C/Soap Creek) that had a geomean concentration of 147 MPN/100mL. All Walnut Creek stations exceeded the water quality standard with geomeans ranging from 268 MPN/100mL (WC-D/Walnut Creek at Matlock) to 614 MPN/100mL (WC-C/Walnut Creek at Katherine Rose Park).

3.1.2 Nutrients

Nitrate

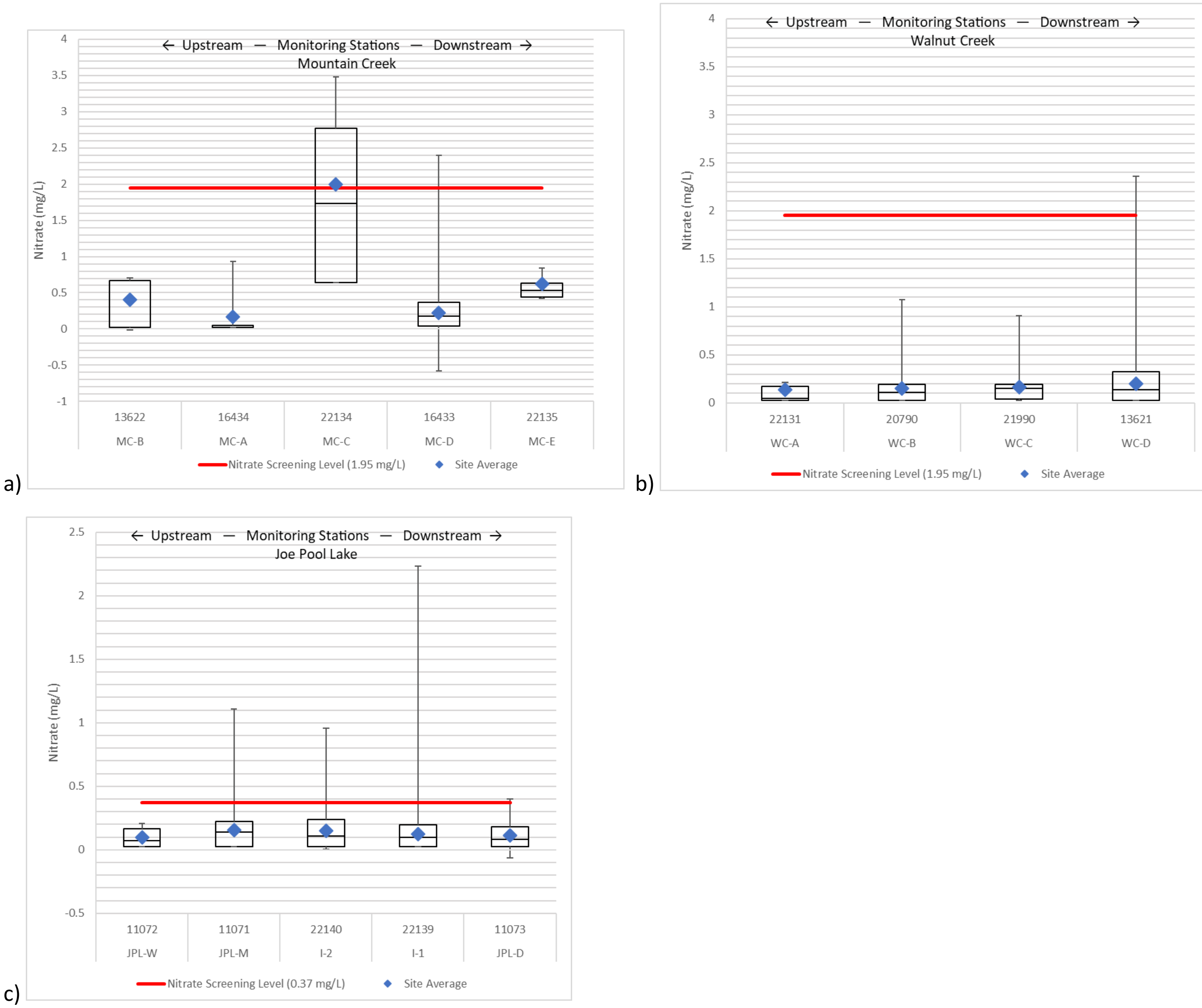


Figure 3-3. Boxplots and geomeans for Nitrate samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that JPL, Walnut Creek and Mountain Creek stations maintained an average concentration below the water quality screening level (1.95 mg/L streams and 0.37 mg/L lakes) with the exception of Station 22134 (MC-C/Soap Creek) that had an average concentration of 2.00 mg/L.

Total Kjedahl Nitrogen

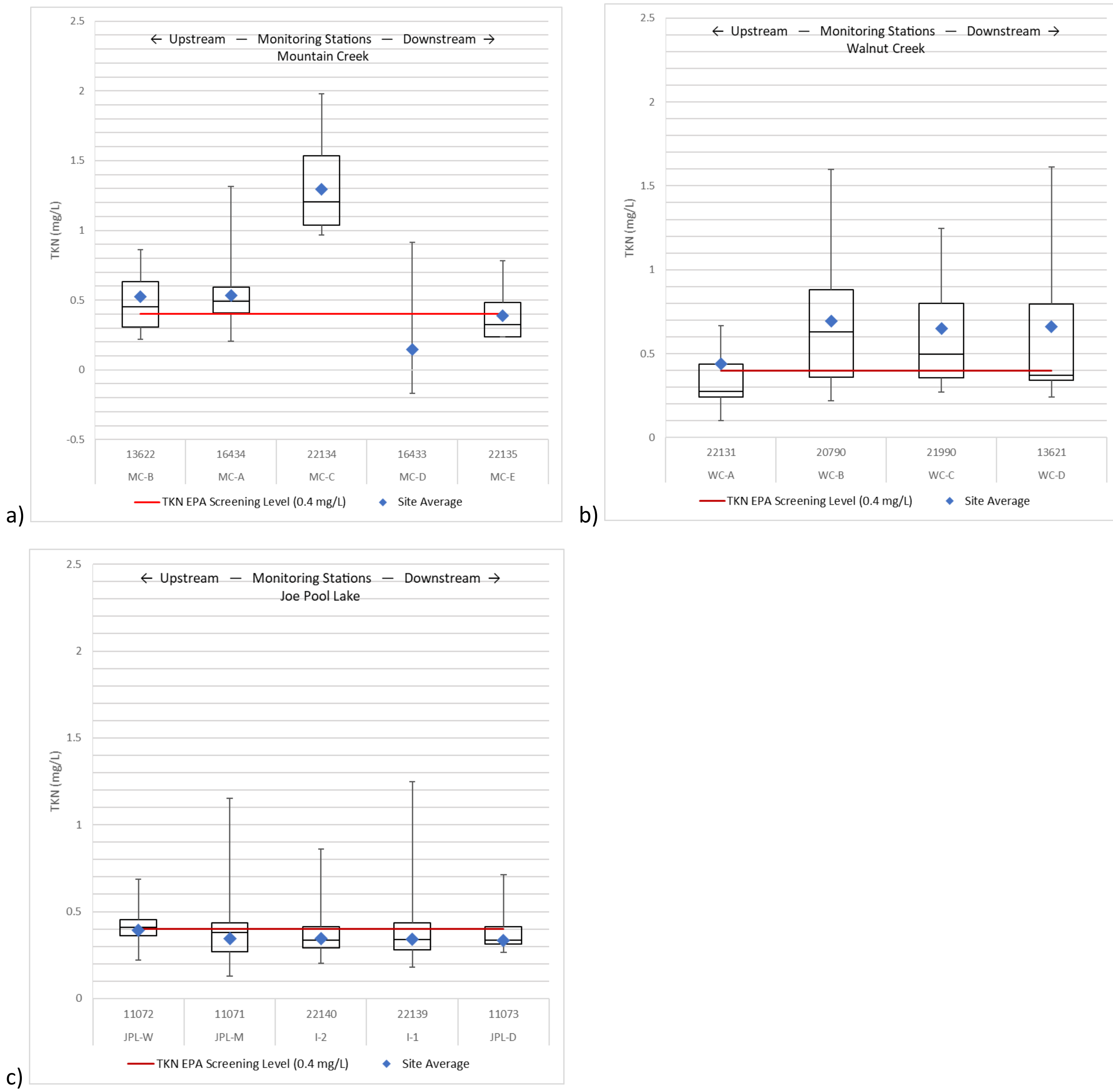
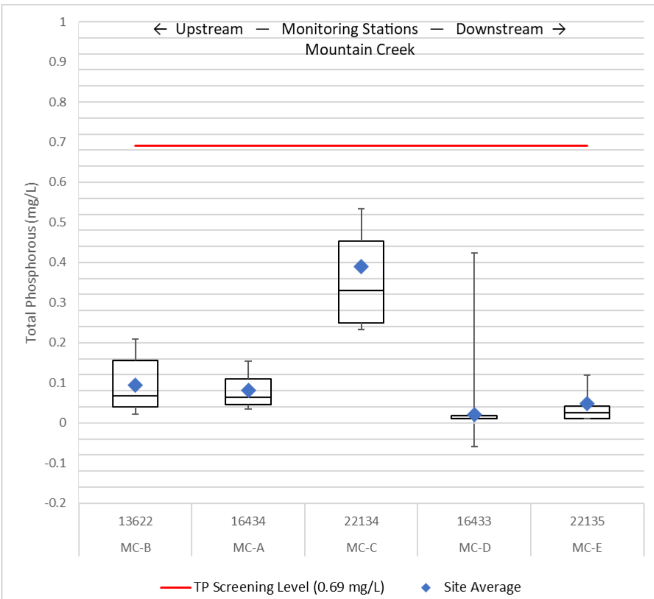


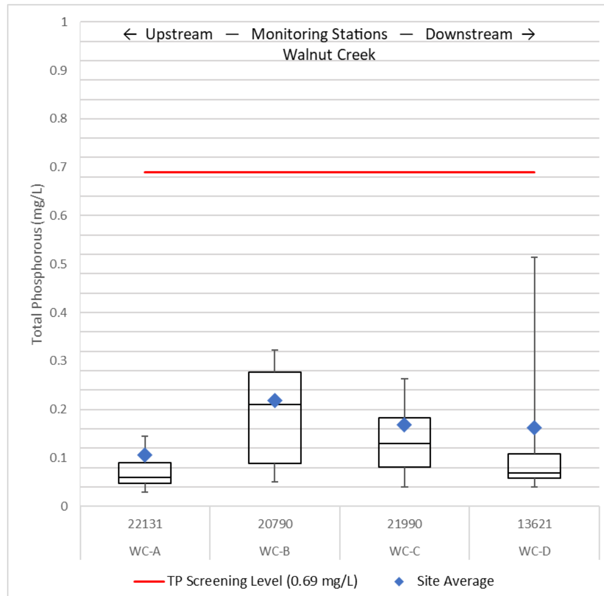
Figure 3-4. Boxplots and geomeans for TKN samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that all stations within Walnut Creek and majority of Mountain Creek stations exceeded the EPA reference water quality screening level (0.4 mg/L streams and 0.41 mg/L lakes) with the exception of Station 16433 (MC-D/Hollings Branch) that had an average concentration of 0.15 mg/L and Station 22135 (MC-E/Low Branch) that had an average concentration of

0.39 mg/L. Walnut Creek stations ranged from 0.44 mg/L to 0.69 mg/L. JPL stations did not exceed the EPA reference water quality screening level.

Total Phosphorus

a) 

b) 

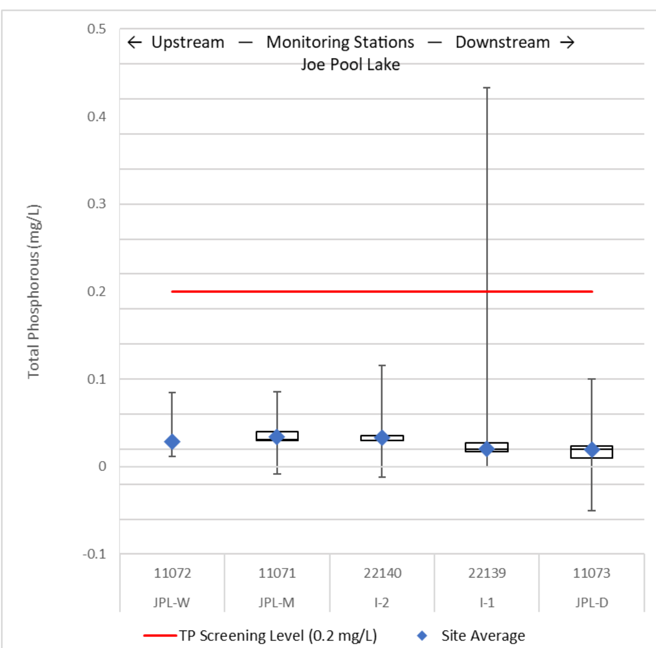
c) 

Figure 3-5. Boxplots and geomeans for TP samples collected June 2019 - April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that all stations within JPL Watershed maintained an average concentration below the water quality screening level (0.69 mg/L streams and 0.20 mg/L lakes).

Ortho-phosphate Phosphorus

OP is no longer used for TCEQ screening purposes as of the 2014 Texas Integrated report.

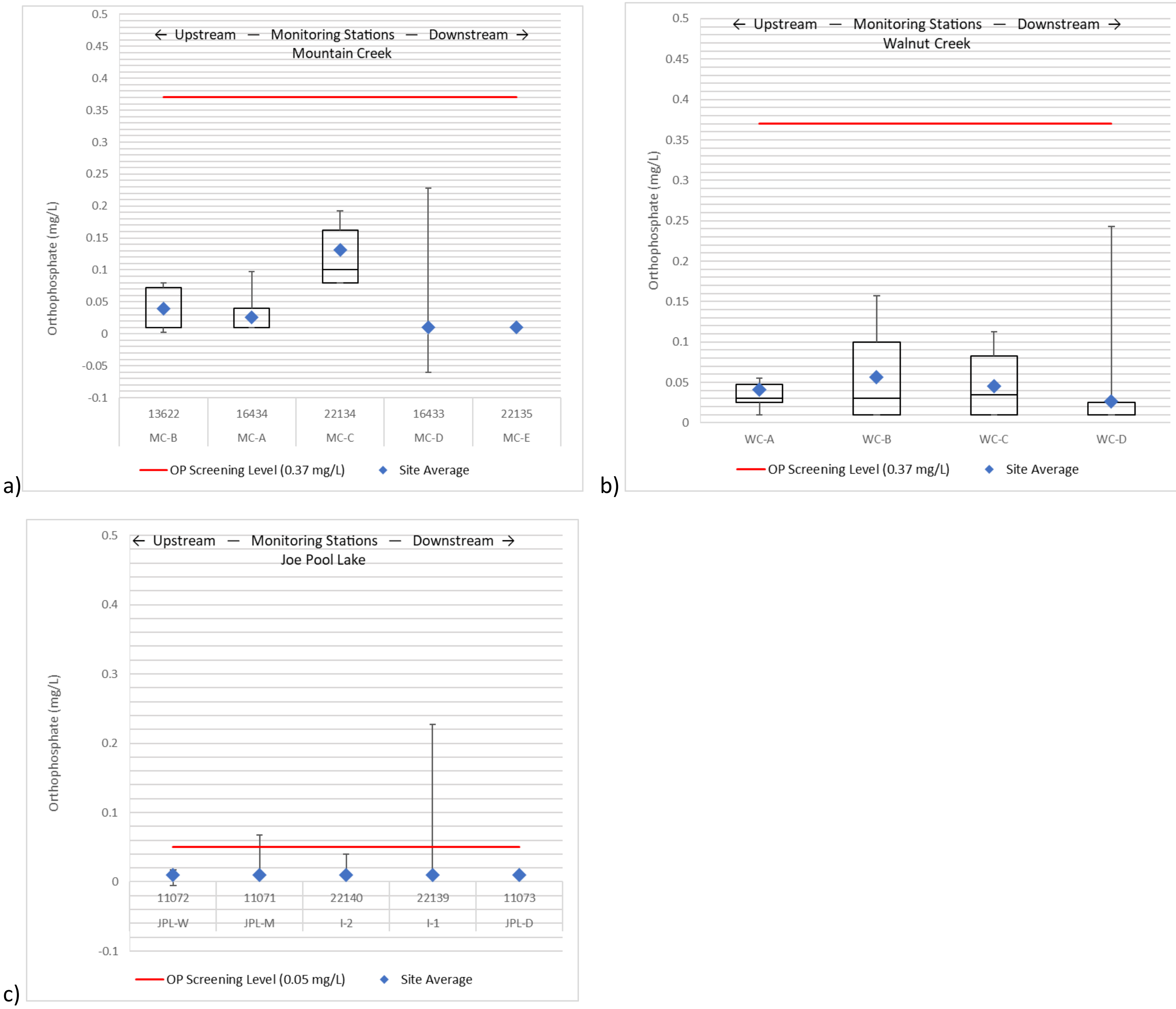


Figure 3-6. Boxplots and geomeans for OP samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that all stations within JPL Watershed maintained an average concentration below the water quality screening level (0.37 mg/L streams and 0.05 mg/L lakes).

Chlorophyll-a

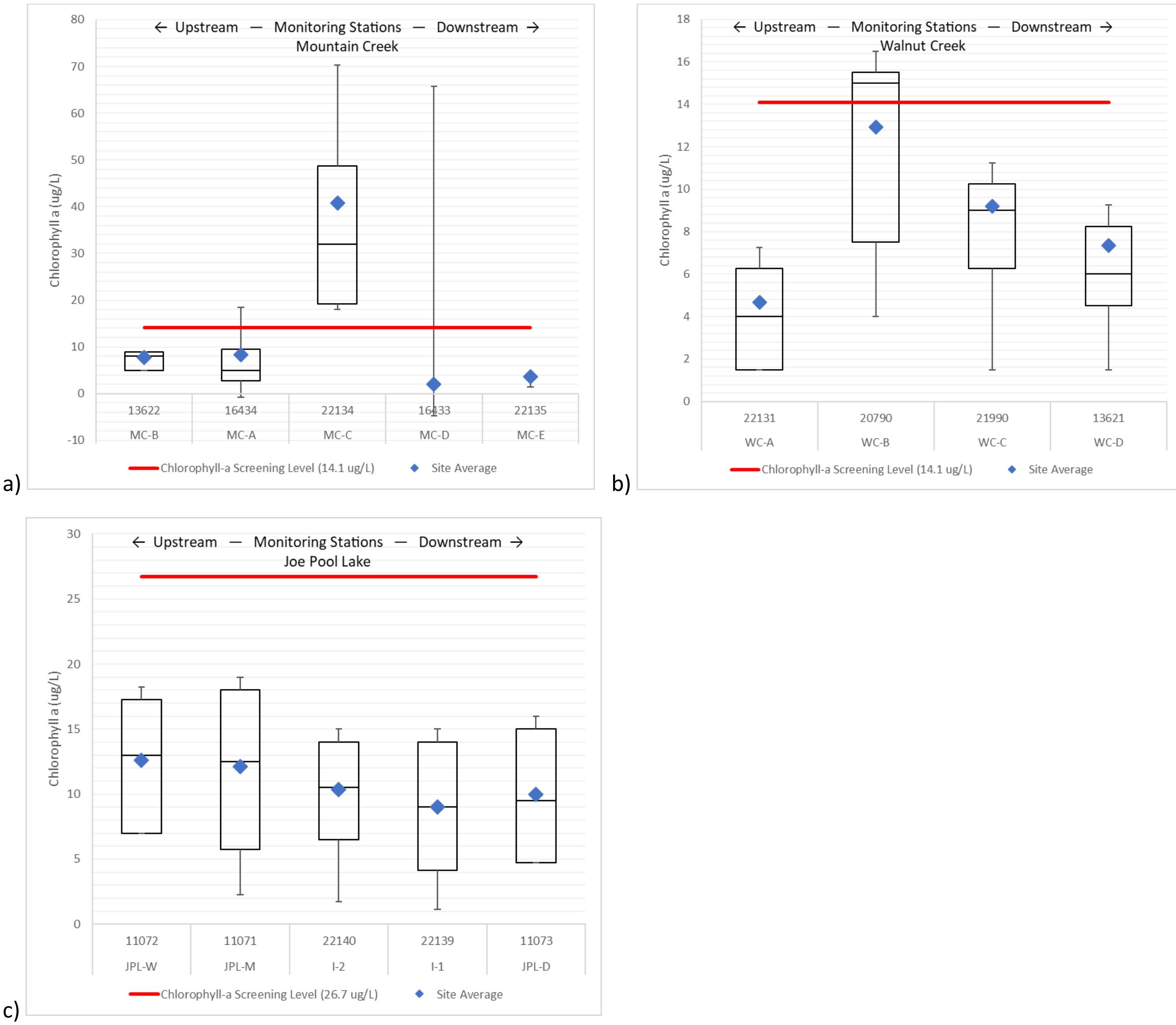


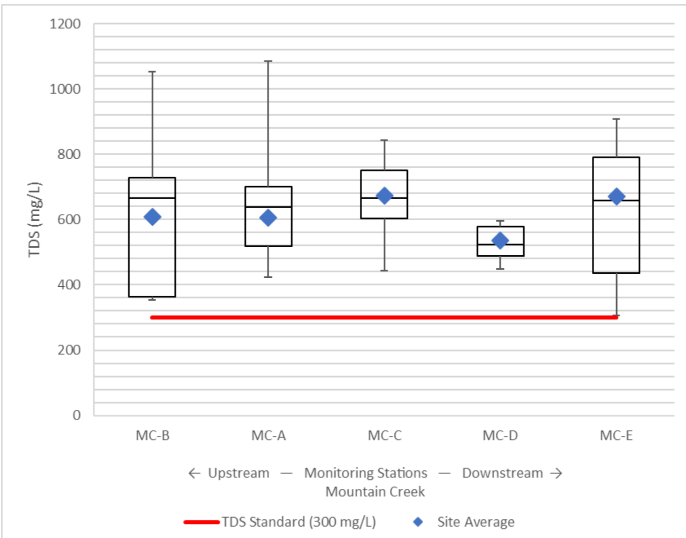
Figure 3-7. Boxplots and geomeans for Chlorophyll-a samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that the majority of stations within the JPL watershed do not exceed the water quality screening level (14.1 ug/L streams and 26.7 ug/L lakes) with the exception of Station 22134 (MC-C/Soap Creek) that had an average concentration of 40.83 ug/L.

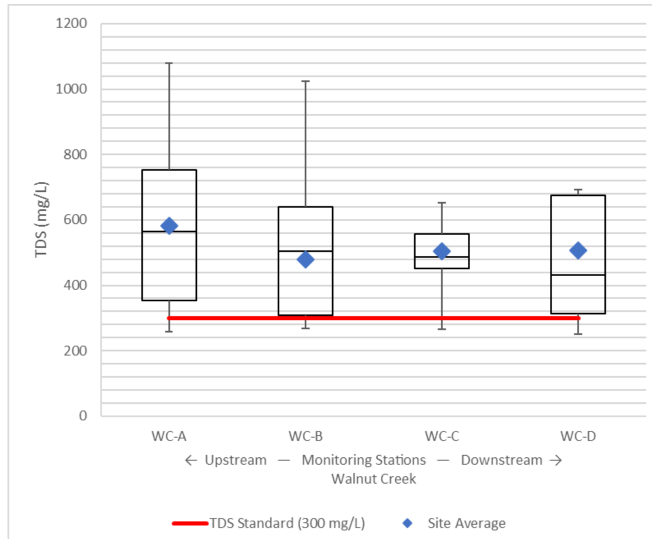
3.1.3 Solids

Total Dissolved Solids

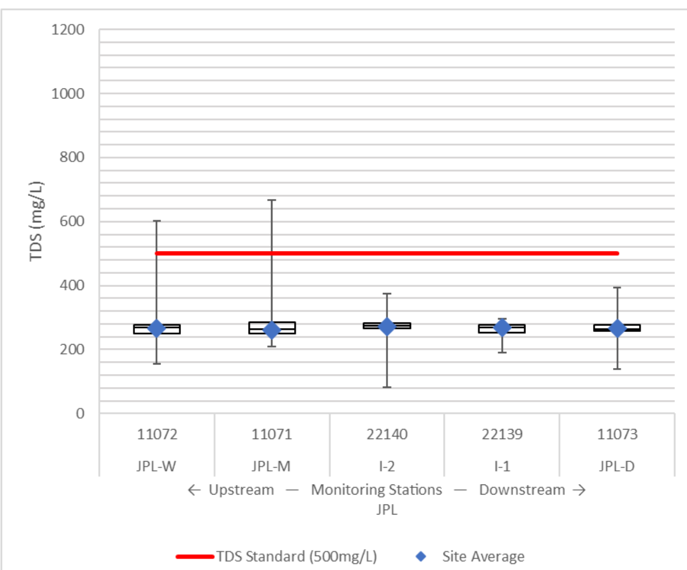
Most of the BMPs aimed at curbing TDS are applicable to reducing *E. coli* and nutrient inflows, so they can easily be grouped in with those contaminants for simplicity.



a)



b)



c)

Figure 3-8. Boxplots and geomeans for TDS samples collected June 2019-April 2020; a) Walnut Creek, b) Mountain Creek, c) JPL.

A boxplot analysis of all stations revealed that all stations within Walnut Creek and Mountain Creek exceeded the water quality standard (300 mg/L streams and 500 mg/L lakes). Mountain Creek average concentrations ranged from 535 mg/L to 674 mg/L. Walnut Creek average concentrations ranged from 480 mg/L to 583 mg/L. JPL stations did not exceed the water quality standard.

3.1.4 Correlation Analysis

The correlation coefficients for the combined dataset of all parameters indicate that significant associations exist between flow, *E. coli,* suspended solids, and nutrients (Table 3-1). This suggests that constituents like *E. coli,* suspended solids, and nutrients are being introduced to waterways via increase in flow which can stem from permitted or illicit discharges and nonpoint source runoff, and thus should be addressed primarily through management practices targeted to these events. Of note are correlations between a) flow vs. *E. coli* and b) flow vs. TSS and volatile suspended solids (VSS). Other notable correlations include a) TKN vs. TP, *E. coli,* and chl-a and b) nitrate vs. Chlorophyll-a and OP.

Table 3-1. Correlation Coefficients for data collected June 2019-April 2020.

	24 Hr rain	72 Hr rain	Flow (cfs)	Secchi Depth (m)	TSS (mg/L)	VSS (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	TKN (mg/L)	TP (mg/L)	Chlorophyll-a (ug/L)	OP (mg/L)
TSS (mg/L)			0.720									
VSS (mg/L)			0.703	-0.546	0.953							
Nitrate (mg/L)							0.671					
TKN (mg/L)			0.694	-0.653	0.718							
TP (mg/L)			0.741	-0.606	0.775	0.830			0.870			
E. coli (MPN/100mL)			0.541			0.596			0.597			
Chlorophyll-a (ug/L)						0.516	0.654	0.558	0.600	0.639		
OP (mg/L)							0.749	0.584	0.5007	0.621	0.613	
Days Since Precipitation	-0.507											
Turbidity (NTU)					0.830	0.677				0.551		
BGA RFU							0.592		0.514	0.571	0.878	0.541

notes: An arbitrary cut-off of +/- 0.5 was defined to indicate those correlations which may be significant.

3.2 LDC Analysis

3.2.1 Nutrients

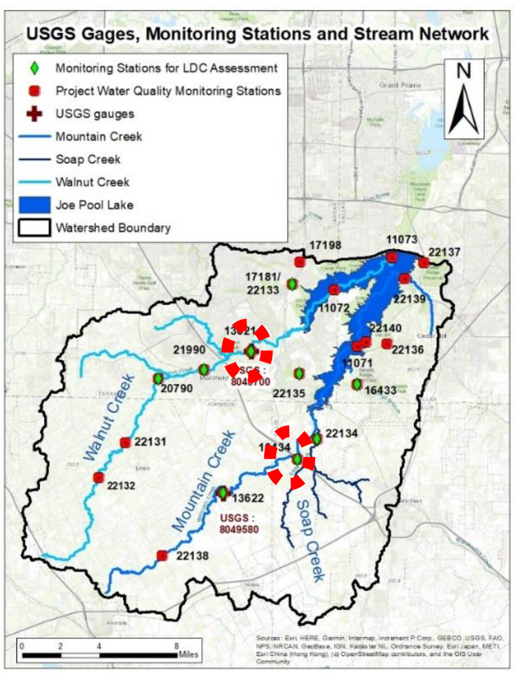
Nutrients are transient in a flowing system such as a creek or river, but once those nutrients are delivered to a dammed waterbody like a lake or reservoir, flow rates decrease significantly, and will likely even be difficult to accurately measure during reservoir releases at the dam. This increased residence time leads to accumulation of nutrients, sediment, and other solids. Nutrients will continue to accumulate in both the water column and bed sediments, until they are used by organisms, removed by human means (typically through dredging), or resuspended and flushed downstream over the dam. If excessive nutrients begin to accumulate in a lake, this reduces the growth limitations on algae, and algal blooms will often result. This phenomenon is commonly referred to as lake eutrophication. In many cases, eutrophication is a natural process in lakes, but can be intensified with the proliferation of urban environments. These environments and their associated increase in impervious surfaces decrease groundwater infiltration rates. This increases stormwater runoff and elevates the potential for pollutants (including excess nutrients) being delivered to waterways. In addition to the potentially harmful environmental effects, algal blooms may also cause taste and odor problems in municipal water taken from the lake and may impact recreational opportunities.

Phosphorus

TP and OP TCEQ screening level of concern is 0.69 mg/L and 0.37 mg/L, respectively. Based on historical and current data analysis, the geometric mean of calculated concentrations of TP and OP at five flow conditions (high flow, moist conditions, mid-range conditions, dry conditions, and low flow) at all monitoring stations were below the geometric means of respective allowable TCEQ concentrations, with two exceptions; monitoring station 22134 exceeded the allowable concentration for OP during dry and low flow conditions and monitoring station 16433 exceeded the allowable concentration for OP during high flow conditions. It should be noted that OP is no longer used as a TCEQ screening level as of the TCEQ 2014 IR (Appendix B. LDCs Results).

Nitrogen

The geomeans of NO_x for Soap Creek (monitoring station 22134) exceeded the TCEQ screening level of 1.95 mg/L at all 5 flow conditions. Walnut Creek Station at Matlock Road (monitoring station 13621) exceeded the screening level at high flow conditions. All other stations did not exceed the screening level. Figure 3-9 depicts the location of the stations that exceeded the screening level.



Basemap: ESRI World Street Map; Stream data source: NHD
Figure 3-9. NO_x exceedance at Station 13621 and Station 22134.

The Mountain Creek arm of JPL was listed for a screening level concern due to heightened levels of nitrate in the TCEQ 2014 IR. A water body is listed as a screening level concern for nitrate if the water quality sample exceeds 0.37 mg/L for lakes and 1.95 mg/L for streams. Based on historic and current data analysis, Mountain Creek monitoring station 16434, upstream of the Mountain Creek arm, did not exceed the allowable screening level. No load reductions are needed on the main stem of Mountain Creek (Figure 3-10).

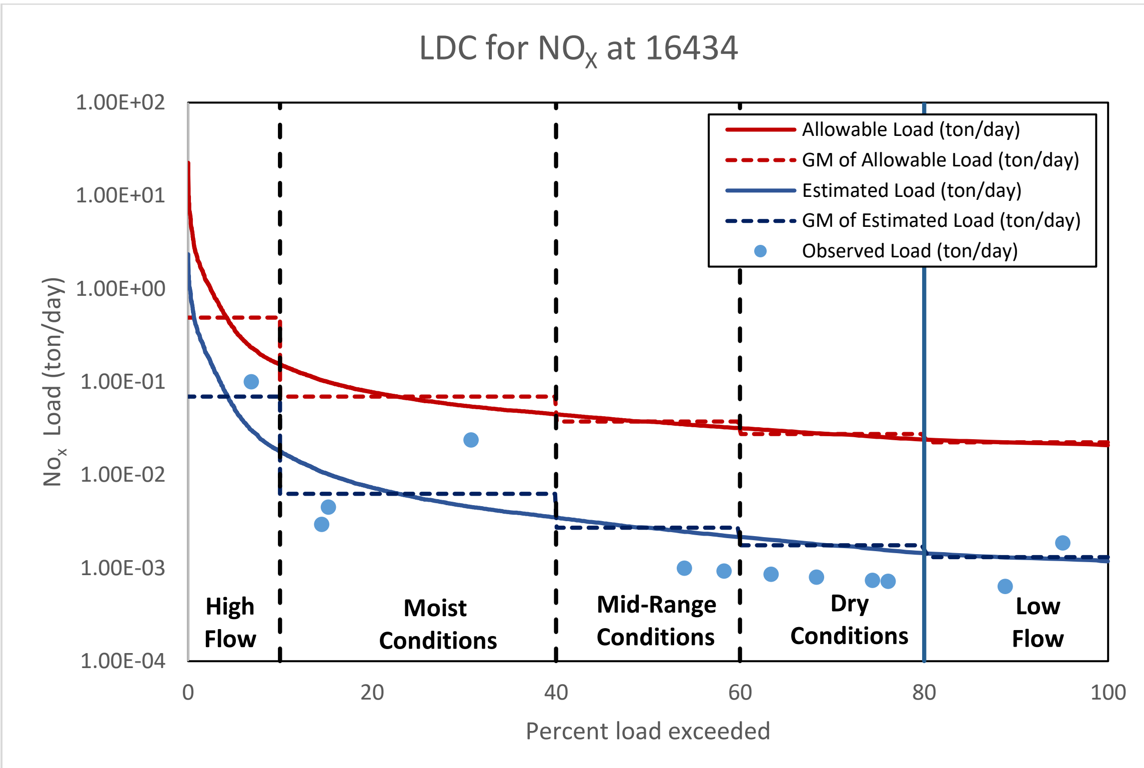


Figure 3-10. Load Duration Curve NO_X Station 16434 Mountain Creek at US 287.

However, downstream of station 16434, Soap Creek converges with Mountain Creek upstream of the confluence with JPL. The monitoring station 22134 on Soap Creek receives most of the runoff from forest and rangelands. The upstream portion of the monitoring station is covered by 9% of forest land, 14% urban, 26% agriculture and 45% of rangelands (Table 2-1). The majority is rangeland/pastureland and agriculture, but there is some urban land that can be contributing to the nonpoint source runoff of nutrients. Figure 3-11 displays the computation of load duration of NO_X in ton/day spanning high flows to low flows from 2013 to 2020. The LDC was compared to the maximum allowable load which accounts for a 10% MOS and the allowable load (TCEQ water quality standard) in order to determine the amount of reduction needed to meet the allowable load. The LDC depicted in Figure 3-11 exceeded the allowable NO_X level thus load reduction is required. The percentage of reduction of daily NO_x loading needed at site 22134 is between 40-56% for wetter flow conditions and 1% for low flow conditions. Table 3-2 provides the allowable and estimated geometric mean daily load along with annual reduction values needed at station 22134.

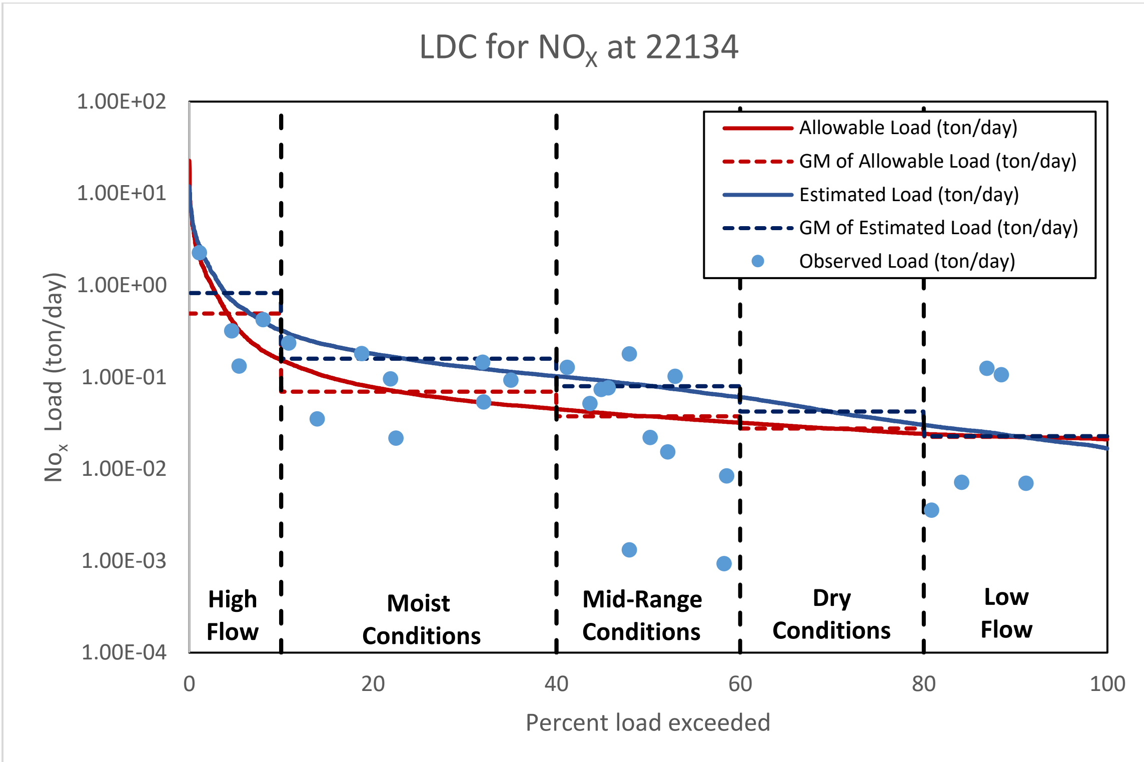


Figure 3-11. Load Duration Curve NO_X Site 22134 Soap Creek.

The NO_x loading at this monitoring station may be due to waste from livestock like cattle, sheep, goat, and horses from upstream rangelands (Table 2-1). Better management of livestock grazing in the surrounding area could be a viable way to reduce the amount of NO_x loading at this monitoring station.

Table 3-2. Average allowable loading, estimated loading, and load reduction of NO_X for monitoring station 22134.

Flow Condition at site 22134	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Load Reduction Needed	Annual Loading (ton/yr)	Annual Reduction Needed (ton/yr)
High Flow	0-10%	4.92E-01	8.25E-01	40%	3.01E+02	1.22E+02
Moist Conditions	10-40%	6.94E-02	1.58E-01	56%	5.77E+01	3.24E+01
Mid-Range Conditions	40-60%	3.75E-02	7.97E-02	53%	2.91E+01	1.54E+01
Dry Conditions	60-80%	2.76E-02	4.23E-02	35%	1.54E+01	5.35E+00
Low Flow	80-100%	2.24E-02	2.27E-02	1%	8.30E+00	1.08E-01

Results and Discussion

Similar to the Mountain Creek arm, NO_X reduction was needed at only one of the three monitoring stations along Walnut Creek. No reduction was needed for any flow conditions at station 20790 or station 21990. However further downstream at station 13621 reduction was needed. For high flow events, a 48% reduction in the daily load was needed which translates to an annual reduction of about 270 ton/yr (Table C - 1). All three of these monitoring stations are located adjacent to urban areas. Since the majority of excess NO_X stems from agricultural runoff the lack of NO_X along the Walnut Creek was expected. The exceedance at high flow for station 13621 can be attributed to occasional severe rain and could possibly be mitigated by enhancing or expanding urban buffers along the stream.

Of the nine monitoring stations where LDCs were analyzed, three stations were in the Mountain Creek subwatershed, three were in the Walnut Creek subwatershed, and three stations were located on smaller streams that flow directly into JPL. The stations along the smaller creeks do not require NO_X reduction. The summary of water quality standard exceedance for each of the monitoring stations is summarized in Table 3-3. An annual reduction of 15.4 ton/yr during mid-range conditions is needed at site 22134 (Soap Creek upstream of Mountain Creek confluence) (Appendix C. Geometric mean of Nutrient and Bacteria Load. The complete list of geometric means of allowable loading, estimated loading, and reduction of nutrient loading needed for NO_x at all monitoring stations are presented in Appendix C. Geometric mean of Nutrient and Bacteria Load and the corresponding LDCs are presented in Appendix B. LDCs Results.

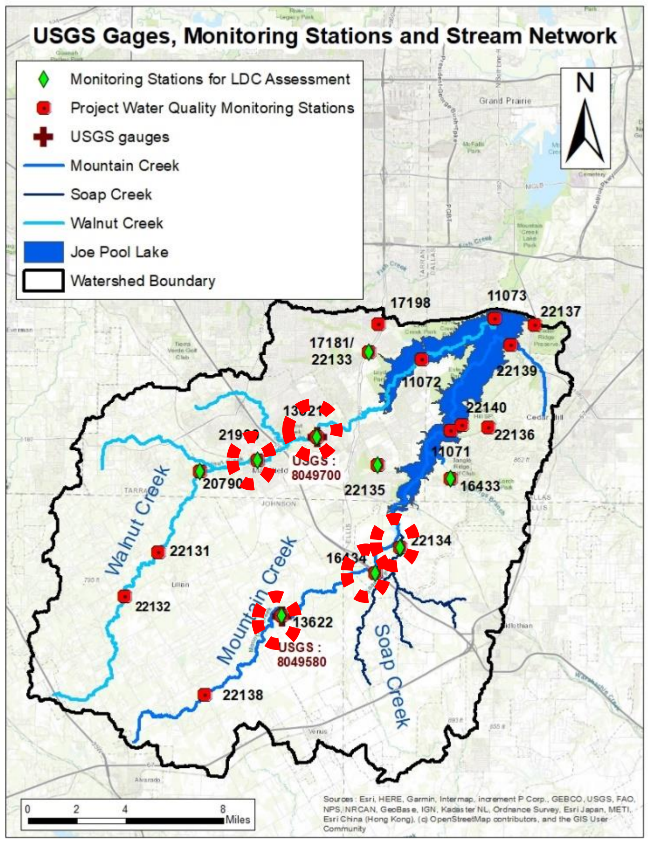
Table 3-3. Summary of water quality screening exceedance at different flow conditions for NO_X.

Monitoring Stations	Low Flow	Dry Conditions	Mid-Range Conditions	Moist Conditions	High Flow
16433	✓	✓	✓	✓	✓
22135	✓	✓	✓	✓	✓
22134	×	×	×	×	×
16434	✓	✓	✓	✓	✓
13622	✓	✓	✓	✓	✓
22133	✓	✓	✓	✓	✓
13621	✓	✓	✓	✓	×
21990	✓	✓	✓	✓	✓
20790	✓	✓	✓	✓	✓

Symbol × indicates exceedance and symbol ✓ indicates no exceedance

Total Kjedahl Nitrogen

In the case of TKN, no management trigger levels exist, although reference concentrations do (USEPA, 2000). The geomeans of TKN for five stations exceeded the EPA screening level of 0.4 mg/L at all flow conditions. All stations exceeded the screening level for mid-range conditions, moist conditions, and high flow, while 6 of the 9 exceeded the screening level at low flow. Figure 3-12 depicts the location of the stations that exceeded the screening level at all flow conditions.



Basemap: ESRI World Street Map; Stream data source: NHD
Figure 3-12. TKN exceedance for all flow conditions at five stations in the JPL watershed.

The screening level criteria of TKN was exceeded at all nine monitoring stations for at least one flow condition. The three stations located on the Mountain Creek arm exceeded the screening level criteria at all flow conditions resulting in larger reduction values further downstream. Station 22134, the furthest downstream station in the mountain creek watershed, resulted in reduction values of 74% for most of the flow conditions with high flow needing an annual reduction of about 105 ton/yr. Table 3-4 provides all screening criteria and load reduction values for station 22134. The LDC for station 22134 is shown in Figure 3-13 which shows almost all observed loadings exceed the allowable screening level criteria across all flow conditions.

A similar scenario was found on Walnut Creek; all three monitoring stations indicate TKN reduction is needed which was compounded downstream. The furthest station downstream, 13621, resulted in a load reduction of 69% for high flow conditions which is an annual reduction of about 130 ton/yr (Table C - 2). The stations located on the smaller streams also exceeded the screening level criteria but not for all flow conditions. Table 3-5 summaries the screening level criteria of TKN for all monitoring stations.

Table 3-4. Average allowable loading, estimated loading, and load reduction of TKN for monitoring station 22134.

Flow Condition at site 22134	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Load Reduction Needed	Annual Loading (ton/yr)	Annual Reduction Needed (ton/yr)
High Flow	0-10%	1.01E-01	3.88E-01	74%	1.42E+02	1.05E+02
Moist Conditions	10-40%	1.42E-02	5.44E-02	74%	1.99E+01	1.47E+01
Mid-Range Conditions	40-60%	7.69E-03	2.91E-02	74%	1.06E+01	7.82E+00
Dry Conditions	60-80%	5.66E-03	2.13E-02	73%	7.78E+00	5.71E+00
Low Flow	80-100%	4.60E-03	1.72E-02	73%	6.29E+00	4.61E+00

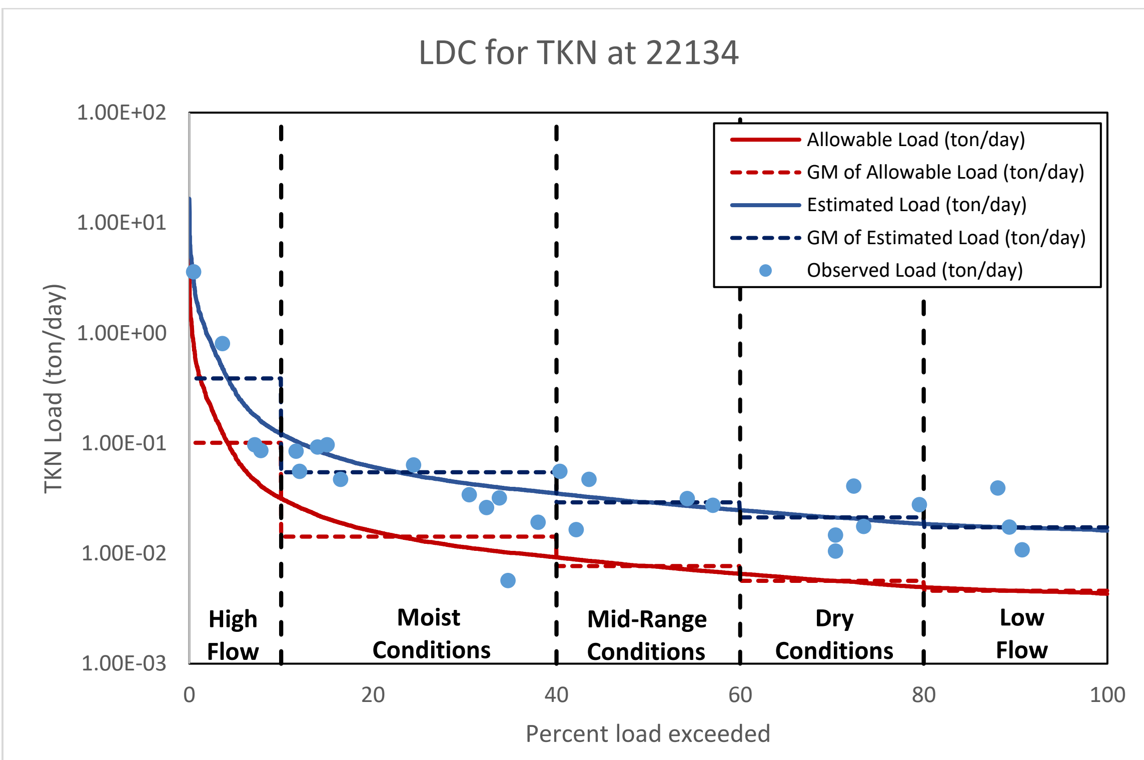


Figure 3-13. LDC for TKN at monitoring station 22134.

Results and Discussion

The TKN component of total nitrogen is the sum of organic nitrogen and ammonia which comes mainly from animal manure. The TKN loading exceedance at monitoring station 16433 during high flow conditions was high due to the runoff containing manure from feral hogs and deer from upstream forests (Table 2-1) while the high loading at stations 22134 and 13622 were caused by waste from livestock grazing on rangelands and pasturelands upstream of these monitoring stations (Table 2-1). Additionally, the TKN loading exceedance at low flow conditions may be due to OSSFs and WWTFs. Similarly, the high concentration of TKN at high flow conditions for the Walnut Creek monitoring stations (20790, 21990, and 13621) may be caused by the runoff received from the surrounding grasslands (Table 2-1) containing waste from livestock. TKN at low flow conditions at these monitoring stations may be related to SSO, OSSF, and WWTFs in the area.

Water quality screening level exceedance for TKN at each monitoring station is summarized Table 3-5. To ensure the water quality goals are achieved for TKN, an annual reduction of 7.82 ton/yr during mid-range conditions is needed at site 22134 (Soap Creek upstream of Mountain Creek confluence), an annual reduction of $6.16*10^{-1}$ ton/yr during mid-range conditions is needed at site 13621 (Walnut Creek at Matlock Rd), an annual reduction of 1.26 ton/yr during mid-range conditions is needed at site 16434 (Mountain Creek at US 287), an annual reduction of $1.63*10^{-1}$ ton/yr during mid-range conditions is needed at site 16433 (Hollings Branch at Tangle Ridge Rd), an annual reduction of $1.39*10^{-2}$ ton/yr during mid-range conditions is needed at site 22135 (Low Branch at South Holland Rd) and an annual reduction of $1.56*10^{-3}$ ton/yr during mid-range conditions is needed at site 22133 (Bowman Branch at South SH 360). The complete list of geometric means of allowable loading, estimated loading, and reduction of nutrient loading needed for TKN at all monitoring stations are presented in Appendix C. Geometric mean of Nutrient and Bacteria Load and the corresponding LDCs are presented in Appendix B. LDCs Results.

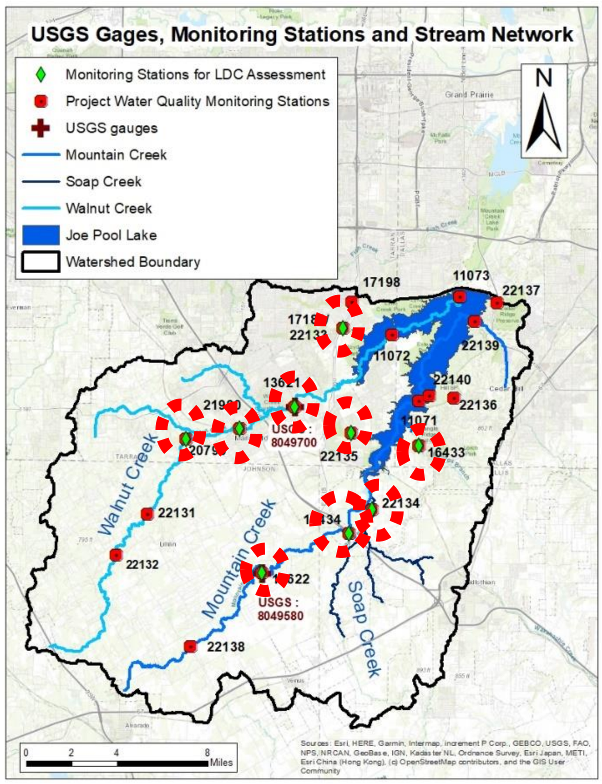
Table 3-5. Summary of EPA water quality screening level exceedance at different flow conditions for TKN.

Monitoring Stations	Low Flow	Dry Conditions	Mid-Range Conditions	Moist Conditions	High Flow
16433	×	×	×	×	×
22135	✓	×	×	×	×
22134	×	×	×	×	×
16434	×	×	×	×	×
13622	×	×	×	×	×
22133	×	✓	×	×	×
13621	×	×	×	×	×
21990	✓	×	×	×	×
20790	✓	✓	×	×	×

Symbol × indicates exceedance and symbol ✓ indicates no exceedance

3.2.2 *E.coli*

To evaluate the potential of *E.coli* concentrations exceeding the standard at each station, geometric means were used. The geometric means of *E.coli* concentration were found to exceed the standard of 126 MPN/100mL at all nine stations at all flow conditions (Table 3-9). This indicates that nonpoint source inputs and in-stream resuspension of *E.coli* from bed sediments are primarily responsible for the exceedances. However, point sources may also need to be addressed. Figure 3-14 depicts the location of the stations that exceeded the standard criteria of *E.coli* at all flow conditions.



Basemap: ESRI World Street Map; Stream data source: NHD
Figure 3-14. E.coli exceedances for all flow conditions at seven stations in the JPL watershed.

The *E.coli* historical data available for the stations inside the Lake could not be utilized for LDC analysis. Instead, they were used for the statistical analysis, comparing their minimum, maximum, and geometric mean values which are summarized for all available monitoring stations from 1998 to 2016 in Table 3-6.

Table 3-6. E.coli historical statistics from 1998-2016 across the JPL watershed.

Station	Count	Minimum value of *E.coli* (MPN/100mL)	Maximum value of *E.coli* (MPN/100mL)	Geometric Mean*(MPN/100mL)
11073	31	<1	79	3
11072	30	<1	649	3
22139	11	1	125	6
22136	22	2	2,599	40
22134	6	19	2,419	409
16433	26	4	4,839	194
13621	13	24	4,813	183
22133	31	6	41,100	144

The geometric mean of *E.coli* concentration was observed to be high compared to the geometric mean of allowable concentration (126 MPN/100 ml) at all flow conditions for both Mountain Creek and Walnut Creek tributaries in JPL watershed. The percentage of reduction required for *E.coli* for high flow conditions was observed to be around 100% for most of the monitoring stations while the reduction required for low flow conditions ranged from 33- 99%. The geometric mean of allowable loading, estimated loading, and required reduction percentage of *E.coli* loading for monitoring stations 13621 (Walnut Creek @ Matlock Rd) and 16434 (Mountain Creek @ FM 287) are presented in Table 3-7 and Table 3-8 respectively. The LDC for *E.coli* at monitoring stations 13621 and 16434 are presented in Figure 3-15 and Figure 3-16, respectively.

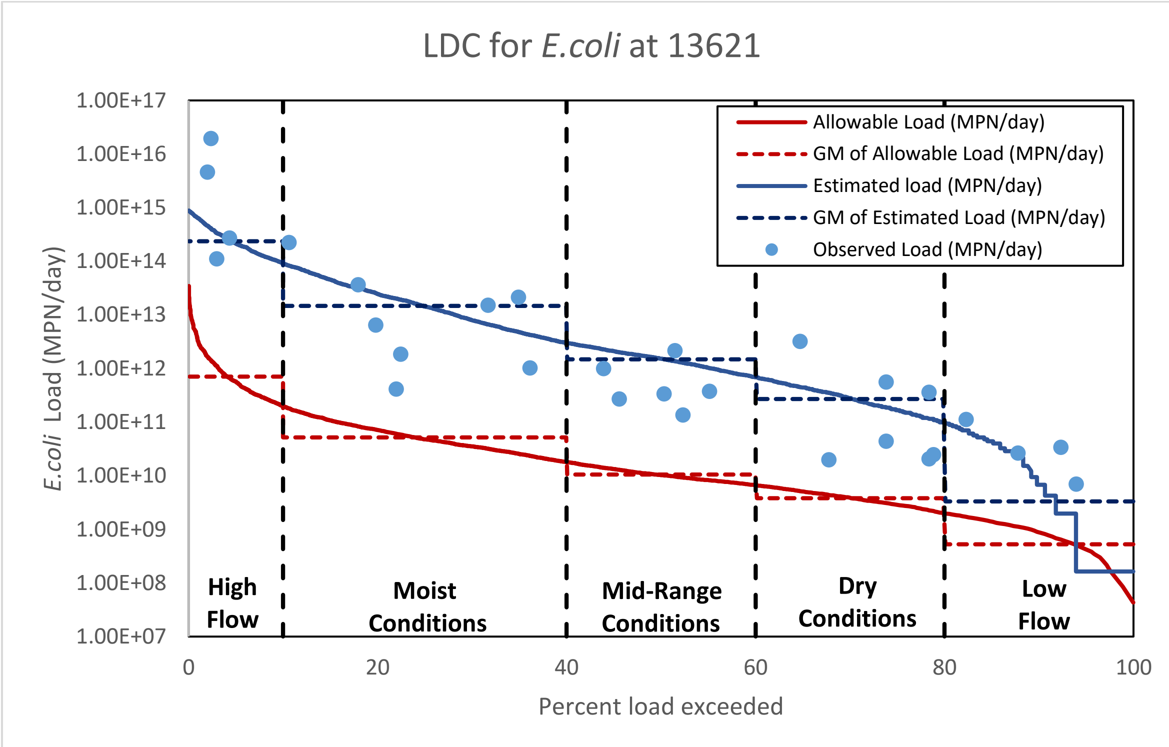


Figure 3-15. LDC for E.coli at monitoring station 13621.

Table 3-7. Average allowable loading, estimated loading, and load reduction of E.coli loading for monitoring station 13621.

Flow Condition at site 13621	% of Time Flow Exceeds	Allowable Loading (MPN/day)	Daily Loading (MPN/day)	% Daily Load Reduction Needed	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)
High Flow	0-10%	7.11E+11	2.37E+14	100%	8.64E+16	8.62E+16
Moist Conditions	10-40%	5.19E+10	1.48E+13	100%	5.40E+15	5.38E+15
Mid-Range Conditions	40-60%	1.05E+10	1.48E+12	99%	5.41E+14	5.37E+14
Dry Conditions	60-80%	3.80E+09	2.69E+11	99%	9.83E+13	9.69E+13
Low Flow	80-100%	5.25E+08	3.33E+09	84%	1.21E+12	1.02E+12

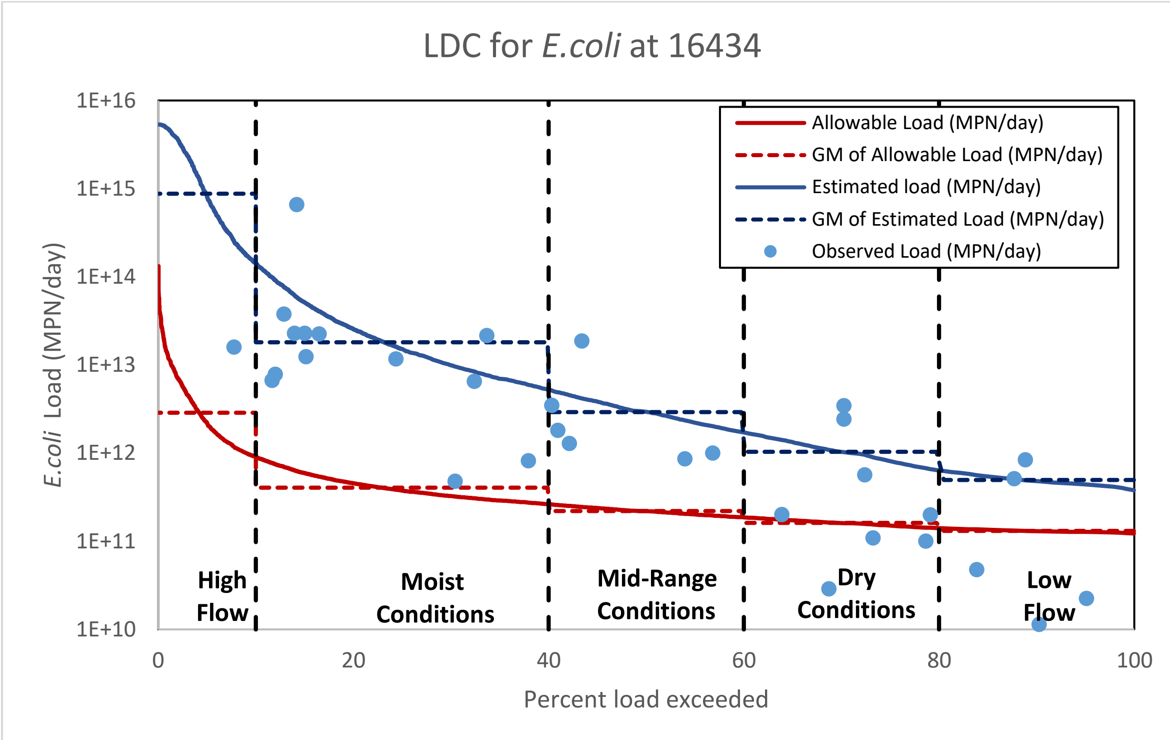


Figure 3-16. LDC for E.coli at monitoring station 16434.

Table 3-8. Average allowable loading, estimated loading, and load reduction of E.coli loading for monitoring station 16434.

Flow Condition at site 16434	% of Time Flow Exceeds	Allowable Loading (MPN/day)	Daily Loading (MPN/day)	% Daily Load Reduction Needed	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)
High Flow	0-10%	2.88E+12	8.79E+14	100%	3.21E+17	3.20E+17
Moist Conditions	10-40%	4.06E+11	1.81E+13	98%	6.61E+15	6.46E+15
Mid-Range Conditions	40-60%	2.19E+11	2.93E+12	93%	1.07E+15	9.88E+14
Dry Conditions	60-80%	1.61E+11	1.03E+12	84%	3.78E+14	3.19E+14
Low Flow	80-100%	1.32E+11	4.97E+11	74%	1.82E+14	1.33E+14

E.coli loading at all of the monitoring stations exceeded the *E.coli* water quality standard under all flow conditions. The monitoring stations 22134, 16434, and 13622 in Mountain Creek subwatershed receive the majority of their runoff from rangelands (Table 2-1). Similarly, monitoring stations 16321, 21990, and 20790 in Walnut Creek subwatershed receive runoff from rangelands and forests (Table 2-1). Stations 22135 and 22133 located on individual tributaries to JPL receive most of their runoff from urban land 41% and 64%, respectively, while station 16433 on the western side of JPL receives the largest amount of runoff from forests (49%, Table 2-1).

E.coli loading is high during high flow, moist conditions, and mid-range conditions which indicate runoff containing nonpoint sources such as pet waste from urban areas, livestock waste from rangeland/pasturelands, and wildlife waste from forested areas to be the source. *E.coli* loading also exceeded the water quality standard during dry and low flow conditions that also indicate nonpoint sources, but could include point sources such as OSSFs in rural areas. The *E.coli* load due to WWTF was negligible for the JPL watershed based on SELECT analysis and will be discuss in further detail in 3.3 SELECT Analysis. The summary of the water quality standard exceedances for each monitoring station for all flow conditions with the exception of low flow at site 16433 for *E.coli* is summarized in Table 3-9.

Table 3-9. Summary of TCEQ water quality standard exceedance at different flow conditions for E.coli.

Monitoring Stations	Low Flow	Dry Conditions	Mid-Range Conditions	Moist Conditions	High Flow
16433	✓	×	×	×	×
22135	×	×	×	×	×
22134	×	×	×	×	×
16434	×	×	×	×	×
13622	×	×	×	×	×
22133	×	×	×	×	×
13621	×	×	×	×	×
21990	×	×	×	×	×
20790	×	×	×	×	×

Symbol × indicates exceedance and symbol ✓ indicates no exceedance

To ensure the water quality goals are achieved, an annual reduction of $7.70*10^{14}$ MPN/yr during mid-range conditions is needed at site 22134 (Soap Creek upstream of Mountain Creek confluence), an annual reduction of $5.37*10^{14}$ MPN/yr during mid-range conditions is needed at site 13621 (Walnut Creek at Matlock Rd), an annual reduction of $9.88*10^{14}$ MPN/yr during mid-range conditions is needed at site 16434 (Mountain Creek at US 287), an annual reduction of $5.72*10^{13}$ MPN/yr during mid-range conditions is needed at site 16433 (Hollings Branch at Tangle Ridge Rd), an annual reduction of $4.8*10^{13}$ MPN/yr during mid-range conditions is needed at site 22135 (Low Branch at South Holland Rd) and an annual reduction of $1.60*10^{13}$ MPN/yr during mid-range conditions is needed at site 22133 (Bowman Branch at South SH 360). The Geometric mean of allowable loading, estimated loading, and required reduction of bacteria loading for all monitoring stations are presented in Appendix C. Geometric mean of Nutrient and Bacteria Load and LDCs for *E.coli* for all stations are presented in Appendix B. LDCs Results.

3.3 SELECT Analysis

The management targets generated by the LDCs can now be put into a source context through the application of SELECT's suite of analysis. *E.coli* loads were similar for all livestock species (cattle, sheep & goats, and horses), being generally more prevalent in the more rural areas in the southern region of the JPL watershed, with minimal impacts in the urban areas east and west of JPL. In particular, per-acre loads were most concentrated in subwatersheds MC9, MC11, WC10, and SC1 (Figure 3-17).

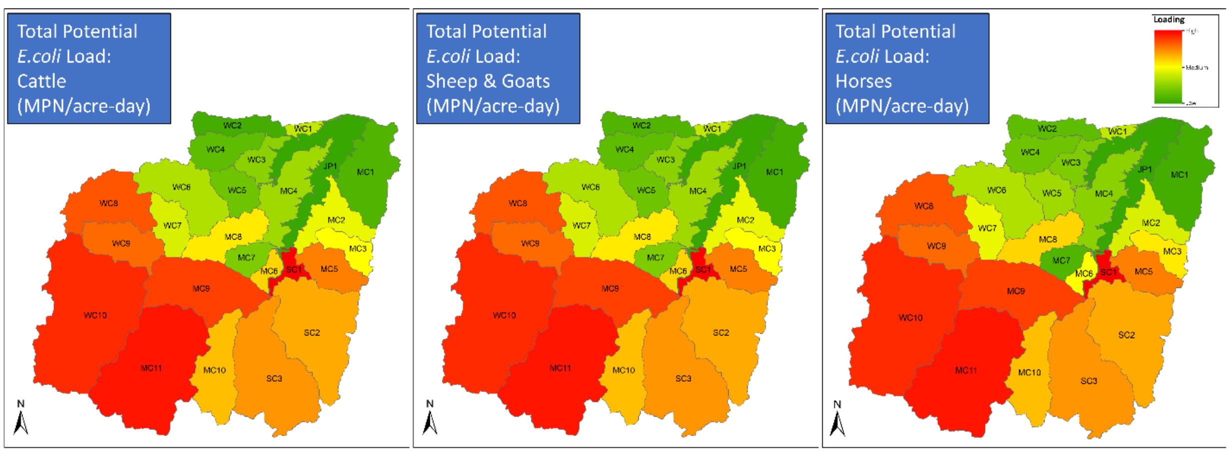


Figure 3-17. Relative severity of E.coli loads from cattle, sheep & goats, and horses, by subwatershed.

The largest impacts from deer *E.coli* loads were found in the western side of the watershed (WC8, WC9, and WC10) with moderate loads in the forested area in the northeast. The highest *E.coli* loads for feral hogs were exhibited in subwatersheds MC1 and WC1 located adjacent to northern JPL. Subwatersheds MC2 and MC3 located on the eastern side of JPL also had slightly higher loads. In contrast, *E.coli* loads from dogs and cats tended to be highest in urban dominated subwatersheds, with the highest loads encountered in subwatersheds WC2 and WC4. Slightly higher and moderate loads were found closer on the western rim of the lake (Figure 3-18).

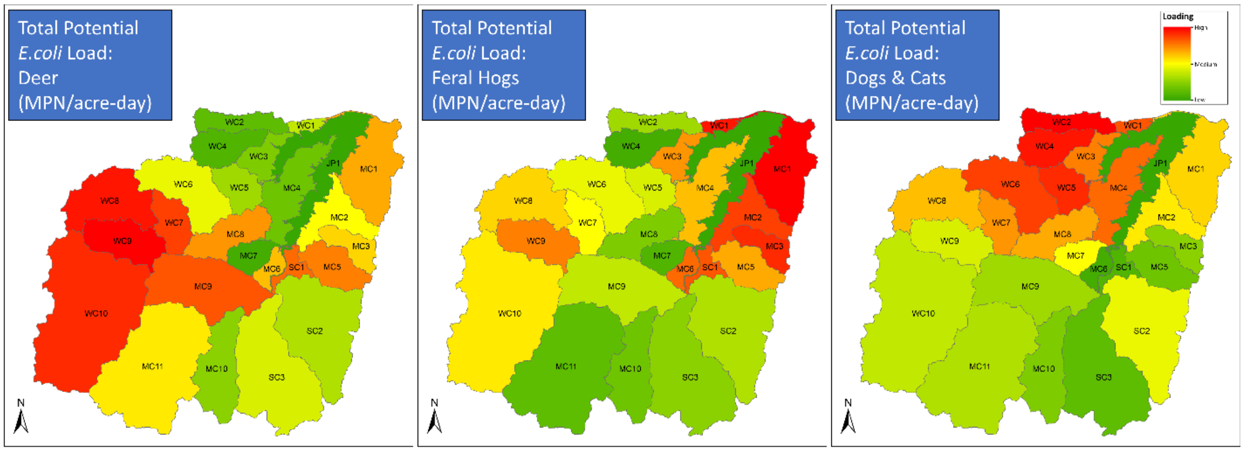


Figure 3-18. Relative severity of E.coli loads from deer, feral hogs, and dogs & cats, by subwatershed.

As expected, *E.coli* loads from OSSFs were most significant in the rural areas to the west, with highest loads coming from subwatersheds WC8,WC9, and MC3. For WWTFs, the three subwatersheds containing active facilities WC10, MC11, and SC2, were the only ones with measurable loads with the highest loads found in SC2 where Midlothian is located (Figure 3-19).

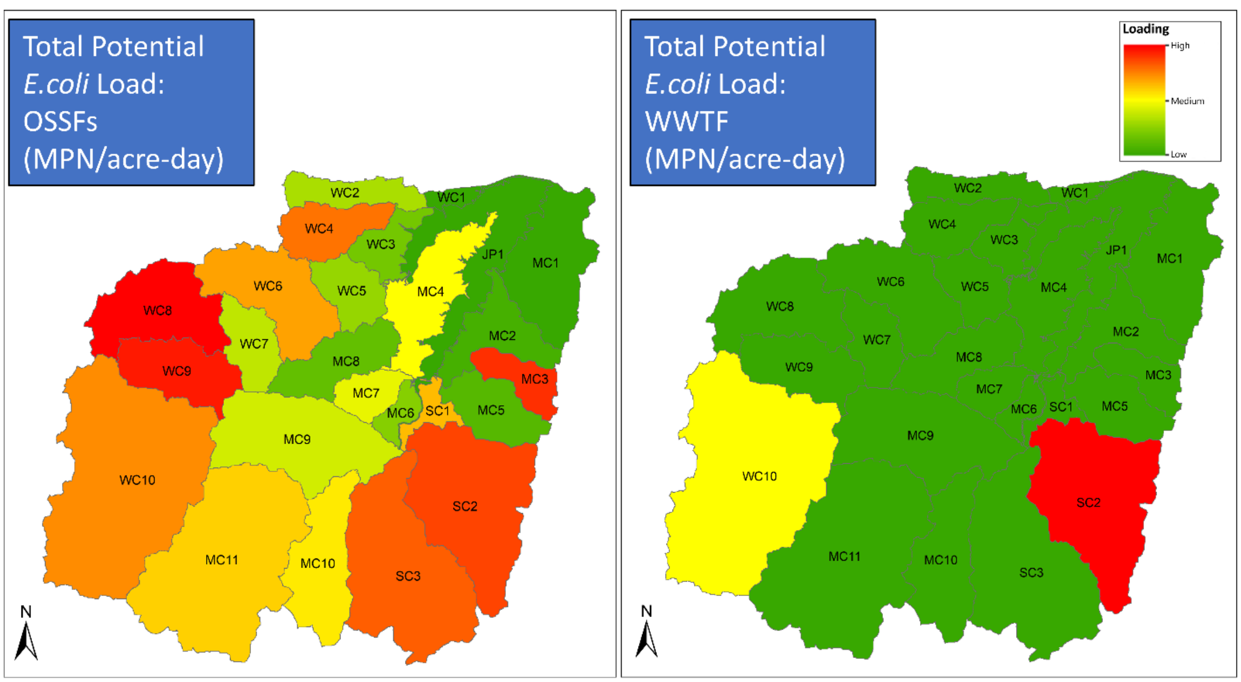


Figure 3-19. Relative severity of E.coli loads from human waste sources, by subwatershed.

As with any spatial analysis, aberrations can occur, and unexpected results should be discussed with stakeholders. For example, after the initial stakeholder meeting, it was requested that horses from "hobby farms" be included. To account for this, 5% of all low density urban land use (9% of the watershed) was used. This was the agreeable amount of viable land within low density urban area. The total low density land use is about 13,000 acres, therefore 650 acres (or 5% of the total) was used for this analysis. One horse was added for every 5 acres of viable land resulting in an increase of 130 horses across the watershed.

Overall, impacts from all combined *E.coli* sources appeared to be most prevalent in the smaller subwatersheds surrounding the lake (Figure 3-20). These watersheds are comprised of urban areas with the predominant *E.coli* loading attributed to pet waste. Although the western subwatersheds on Walnut Creek had high loadings from deer and livestock, the values of high loading were well below the 126 MPN/acre-day allowable loading and therefore did not have a large contribution to the total loading from all sources. OSSFs also supplied high to moderate loads in the south, and WWTFs contributed to the overall *E.coli* loading only in regions where they were located. Figure 3-21 provides a visual comparison of the minimum and maximum loading values for all evaluated *E.coli* sources for the watershed, while Table 3-10 provides an in-depth analysis of all evaluated sources in all 25 subwatersheds. Please note that Figure 3-21 uses units of MPN/acre-day for comparison between pollutant source classes, while Table 3-10 uses units of MPN/day to establish the scope of the reductions needed to meet water quality goals.

As noted previously, there exist several potential *E.coli* sources that could not be included reliably, but the stakeholders still recognize them as viable pollutant management opportunities. These excluded sources will also be considered in the overall management strategy and discussed within the WPP document for this project.

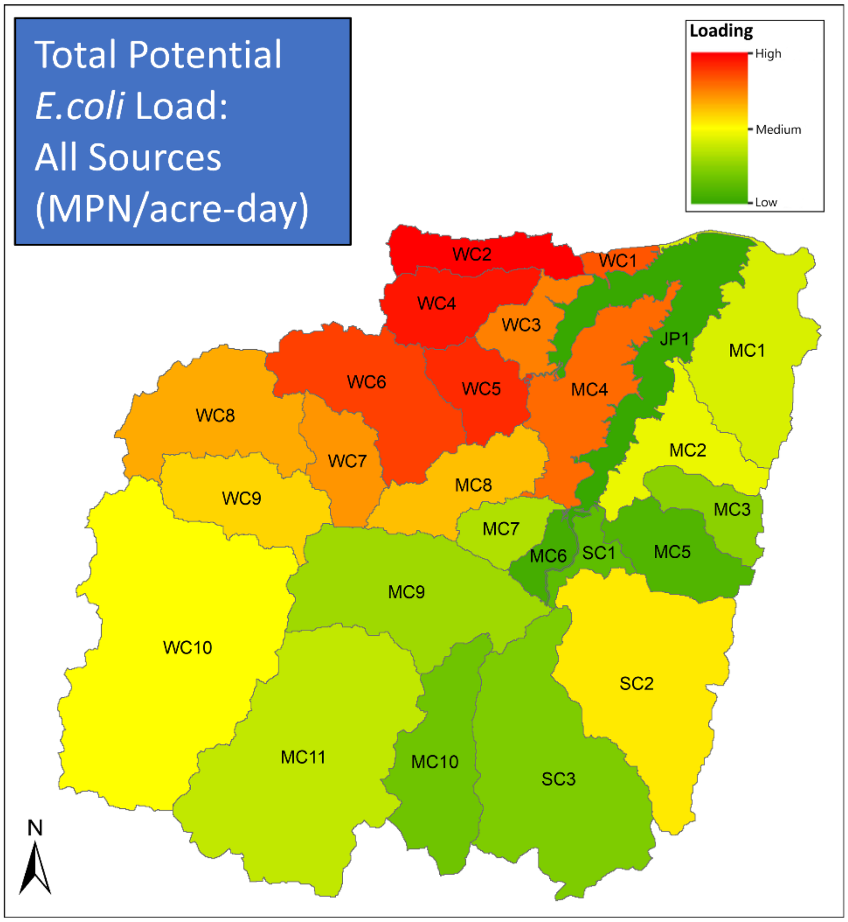


Figure 3-20. Relative severity of E.coli loads from all sources by subwatershed.

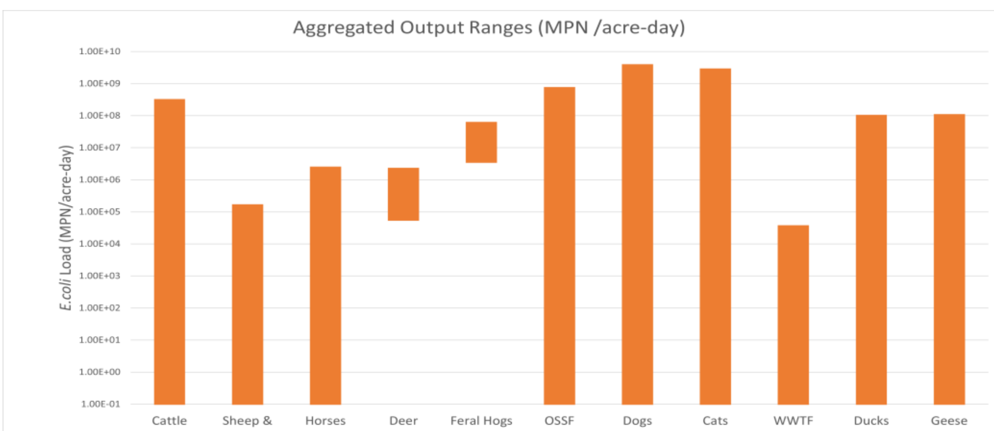


Figure 3-21 Daily potential E.coli load ranges by source categories. All values are area-normalized.

Table 3-10. Potential Load of E.coli (MPN/day) from point and nonpoint sources for subbasins in JPL watershed as predicted by SELECT analysis.

Sub-watershed	Cattle	Sheep	Goats	Horses	Deer	Feral Hogs	OSSF	Dogs	Cats	WWTF	Ducks	Geese	Total *E.coli*
JP1	-	-	-	-	3.50E+08	2.23E+10	-	-	-	-	7.04E+11	7.35E+11	**1.46E+12**
MC1	3.67E+11	8.1E+10	1.35E+11	3.99E+09	6.83E+09	4.54E+11	-	3.58E+12	2.66E+12	-	-	-	**7.28E+12**
MC2	6.18E+11	1.35E+11	2.34E+11	5.46E+09	3.50E+09	1.51E+11	3.79E+09	1.79E+12	1.34E+12	-	-	-	**4.28E+12**
MC3	3.78E+11	8.1E+10	1.44E+11	3.57E+09	2.10E+09	8.90E+10	6.31E+11	4.20E+11	3.13E+11	-	-	-	**2.06E+12**
MC4	5.15E+11	1.17E+11	1.89E+11	5.88E+09	2.80E+09	1.25E+11	4.21E+11	8.45E+12	6.29E+12	-	-	-	**1.61E+13**
MC5	9.47E+11	2.07E+11	3.51E+11	7.35E+09	3.50E+09	8.46E+10	2.99E+10	4.23E+11	3.15E+11	-	-	-	**2.37E+12**
MC6	2.21E+11	4.5E+10	8.1E+10	1.68E+09	1.05E+09	3.12E+10	1.55E+10	3.00E+10	2.25E+10	-	-	-	**4.49E+11**
MC7	1.64E+11	3.6E+10	6.3E+10	1.47E+09	7.00E+08	1.34E+10	1.42E+11	8.28E+11	6.15E+11	-	-	-	**1.86E+12**
MC8	7.31E+11	1.62E+11	2.7E+11	6.93E+09	4.03E+09	4.01E+10	4.16E+10	4.06E+12	3.03E+12	-	-	-	**8.34E+12**
MC9	2.68E+12	5.94E+11	1.008E+12	2.1E+10	1.12E+10	1.20E+11	5.97E+11	2.02E+12	1.51E+12	-	-	-	**8.56E+12**
MC10	1.35E+12	2.97E+11	5.04E+11	1.09E+10	4.03E+09	4.90E+10	4.73E+11	8.70E+11	6.48E+11	-	-	-	**4.21E+12**
MC11	4.90E+12	1.08E+12	1.836E+12	3.86E+10	1.49E+10	1.29E+11	1.47E+12	4.06E+12	3.02E+12	-	-	-	**1.65E+13**
SC1	3.78E+11	8.1E+10	1.44E+11	2.94E+09	1.40E+09	3.56E+10	1.08E+11	3.50E+10	2.75E+10	-	-	-	**8.14E+11**
SC2	2.84E+12	6.3E+11	1.071E+12	2.33E+10	9.10E+09	1.51E+11	3.04E+12	3.84E+12	2.86E+12	4.39E+08	-	-	**1.45E+13**
SC3	3.15E+12	6.93E+11	1.188E+12	2.49E+10	9.80E+09	1.34E+11	3.12E+12	1.07E+12	7.95E+11	-	-	-	**1.02E+13**
WC1	8.91E+10	1.8E+10	3.6E+10	8.4E+08	5.25E+08	3.56E+10	-	1.31E+12	9.70E+11	-	-	-	**2.46E+12**
WC2	1.35E+11	2.7E+10	5.4E+10	2.52E+09	1.23E+09	3.12E+10	8.61E+10	1.06E+13	7.86E+12	-	-	-	**1.88E+13**
WC3	1.94E+11	4.5E+10	7.2E+10	2.31E+09	1.40E+09	5.79E+10	2.49E+10	3.32E+12	2.47E+12	-	-	-	**6.19E+12**
WC4	1.86E+11	4.5E+10	7.2E+10	3.36E+09	1.40E+09	2.23E+10	5.96E+11	1.19E+13	8.86E+12	-	-	-	**2.17E+13**
WC5	1.83E+11	3.6E+10	7.2E+10	3.15E+09	2.10E+09	4.01E+10	8.84E+10	7.25E+12	5.40E+12	-	-	-	**1.31E+13**
WC6	6.31E+11	1.35E+11	2.34E+11	8.19E+09	5.78E+09	9.35E+10	6.12E+11	1.50E+13	1.12E+13	-	-	-	**2.80E+13**
WC7	4.15E+11	9E+10	1.53E+11	4.2E+09	3.85E+09	4.90E+10	1.53E+11	3.75E+12	2.79E+12	-	-	-	**7.41E+12**
WC8	1.77E+12	3.87E+11	6.66E+11	1.407E+10	1.42E+10	1.42E+11	5.07E+12	4.00E+12	2.98E+12	-	-	-	**1.50E+13**
WC9	1.22E+12	2.7E+11	4.59E+11	9.66E+09	1.07E+10	1.20E+11	2.50E+12	1.50E+12	1.12E+12	-	-	-	**7.21E+12**
WC10	6.04E+12	1.33E+12	2.259E+12	4.70E+10	4.15E+10	4.18E+11	2.07E+12	6.30E+12	4.69E+12	4.06E+07	-	-	**2.32E+13**
Total	**3.01E+13**	**6.62E+12**	**1.13E+13**	**2.53E+11**	**1.58E+11**	**2.64E+12**	**2.13E+13**	**9.64E+13**	**7.17E+13**	**4.79E+08**	**7.04E+11**	**7.35E+11**	**2.42E+14**

4.0 Conclusions

The geomeans of OP and TP at all five flow conditions for all the nine stations were below the TCEQ screening criteria for concentrations of 0.37 mg/l and 0.69 mg/l, respectively with two exceptions for OP at site 16433 high flow conditions and site 22134 at dry and low flow conditions. The geomeans of NO_X for one station exceeded the screening criteria of 1.95 mg/l at all flow conditions and one station exceeded the screening criteria at only high flow conditions. The geomeans of TKN for six stations exceeded the screening criteria of 0.4 mg/l at all five flow conditions, one station exceeded the screening criteria at dry and low flow conditions, one station exceeded the screening criteria at low flow only, and one station exceeded the screening criteria at dry conditions only. The geomeans of *E.coli* for all nine stations exceeded the TCEQ water quality standard of 126 MPN/100 ml at all five flow conditions with one exception during low flow conditions at site 16433.

The analysis showed that geometric means of estimated concentration of NO_x at monitoring stations 22134 and 13621 were above permissible geometric mean at high flow conditions. Since the NO_x loading dissipated relatively quickly after the storm event, it showed that nonpoint source runoff was the dominant source of nutrient loading. Since nutrients usually come from agricultural runoff, the majority of the stations do not have much concern as the proportion of agricultural land in the watershed is limited at about 10%. The higher concentration of NO_x was due to the grazing activity of domestic livestock like cattle, sheep, goat, and horses at the rangelands and pastures from which the runoff is received. The NO_x concentration at this monitoring station can be reduced with BMPs targeted towards grazing livestock . The monitoring station 13621 located near grasslands and forests has high NO_x loading during high flow condition from nonpoint source runoff that contains livestock and wildlife waste.

The geometric mean of estimated TKN Load was observed to be very high compared to the geometric mean of allowable TKN load based on EPAs screening level at high flow condition for the monitoring stations 22134, 16434, and 13622. Since the TKN component of total nitrogen is the sum of organic nitrogen and ammonia, it comes mainly from the animal manure; so, the runoff from rangelands and pasturelands used for grazing livestock are the main source of TKN loading at these stations. The geometric mean of observed TKN concentration at high flow condition for monitoring stations 22135 and 22133, which receives runoff from urban areas, and the monitoring station 16433 receiving most of the runoff from forests were also high compared to geometric mean of allowable TKN concentration. The high concentration of TKN at high flow condition for these stations are due to runoff containing pet waste from the surrounding urban areas and wildlife waste from forests, respectively. Additionally, the high concentration of TKN at low flow conditions were due to SSO, OSSF, and WWTFs in the area.

The geometric mean of *E.coli* concentration was very high compared to the geometric mean of the allowable concentration at all flow conditions for both Mountain Creek and Walnut Creek tributaries in JPL watershed. From the LDC analysis, the *E.coli* load is very high during high flow conditions for all of the monitoring stations. The sources may be related to the runoff containing pet waste from urban areas, livestock waste from rangeland and pasturelands, and wildlife from the forests. The *E.coli* load remained higher than the allowable load in mid-range and low flow conditions possibly due to point sources such as OSSF in rural areas. The *E.coli* load due to WWTF was negligible for the JPL watershed based on the SELECT analysis. SELECT analysis found the average potential *E.coli* load was significant due to waste from pets. Dog waste contributed around 40% of *E.coli* load and cat waste contributed 30% of the *E.coli* load. The contribution from pets was higher in the northern region of JPL where the majority of the urban centers are located. Moreover, the range of *E.coli* load by point sources shows that the loadings are high only during large storm events with runoff from the upland area. However, the median value of potential *E.coli* load from all the sources are well below the average which suggests the main source of *E.coli* are the nonpoint sources rather than point sources. The dominant source of *E.coli* from the SELECT analysis across the subwatersheds were in accordance with exceedance of the *E.coli* load for monitoring stations located within subwatershed.

Based on these analyses, nonpoint source pollution is the main driver of water quality impairments in the Joe Pool Lake tributaries. It is clear that there are several significant sources of *E. coli*, nutrients, and other contaminants distributed throughout the watershed, and that focusing on one particular land use or location will not provide a viable solution. In many cases, wildlife tend to be the primary contributor of *E. coli* in Texas watersheds. Stakeholders have few management options in these cases, and stakeholders in the JPL watershed even expressed interest in avoiding management of wildlife contributions altogether, instead preferring to account for wildlife *E. coli* loads as background or baseline contributions. However, due to the significant amount of urbanized area in the JPL watershed, several sources that are inherently more manageable outranked wildlife sources. For this reason, *E. coli* contributions from dogs and cats are likely the primary source of pollution in the watershed, followed closely by agricultural livestock. These sources prove to be advantageous for *E. coli* management in the watershed, as several well-known and proven management strategies exist for both source categories, whether it be for *E. coli* or nutrients. Additional BMPs put in place for several of the other source categories will provide additional flexibility for achieving an annual reduction of 7.82 ton/yr TKN, $1.54*10^{1}$ ton/yr NO_x and $7.70*10^{14}$ MPN/yr *E.coli* during mid-range conditions at site 22134 (Soap Creek upstream of Mountain Creek confluence), an annual reduction of $6.16*10^{-1}$ ton/yr TKN and $5.37*10^{14}$ MPN/yr *E.coli* during mid-range conditions at site 13621 (Walnut Creek at Matlock Rd), an annual reduction of 1.26 ton/yr TKN and $9.88*10^{14}$ MPN/yr *E.coli* during mid-range conditions at site 16434 (Mountain Creek at US 287), an annual reduction of $1.63*10^{-1}$ ton/yr TKN and $5.72*10^{13}$ *E.coli* during mid-range conditions at site 16433 (Hollings Branch at Tangle Ridge Rd), an annual reduction of $1.39*10^{-2}$ ton/yr TKN and $4.8*10^{13}$ MPN/yr *E.coli* during mid-range conditions at site 22135 (Low Branch at South Holland Rd) and an annual reduction of $1.56*10^{-3}$ ton/yr TKN and $1.60*10^{13}$ MPN/yr *E.coli* during mid-range conditions at site 22133 (Bowman Branch at South SH 360) (Appendix C. Geometric mean of Nutrient and Bacteria Load).

It is expected that some form of routine monitoring regime resembling that which was used to characterize the watershed will continue into the future. That prospect, if supported by both funding availability and stakeholder willingness, will supply researchers and decision-makers in the watershed with the data and knowledge required to continue application of one or several of the analyses detailed in this report to track progress for the improvement and protection of water quality in the JPL watershed.

Appropriate BMPs must be implemented to reduce TKN, NOx, and *E.coli* concentrations where estimated concentrations exceeded the screening criteria or the water quality standard concentration. In urban regions management of pet waste and in rangelands management of grazing activities can be helpful to reduce both the nutrient and bacteria load. BMPs for SSO events would consist of proper maintenance and prevention measures as the impacts from such events are difficult to simulate or predict.

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Appendix A. Geospatial Data Sources Used for Watershed Analysis

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Digital Elevation Mode (30 m)	USGS 3D EP	2019	Mosaic and clip raster files to watershed mask, process to develop stream network.	Watershed delineation in Arc SWAT
Land Use and Land Cover (LULC)	USGS NLCD	2016	Merge with CDL LULC to form LULC map for modelling	HRU delineation land management input to SWAT (NLCD LULC provides land use data for range, forest, water, urban, wetland, etc)
Land use and Land Cover (LULC)	USDA-NASS-CDL	2017, 2018, 2019	Merged with NLCD LULC to form resulting LULC map for modeling	HRU delineation- CDL LULC provides detailed crop wise land use category for agricultural lands
Soil Database	NRCS-SSURGO	2019	Clip SSURGO soil polygon to watershed boundary	HRU delineation and land management input to SWAT
Wastewater Treatment Plants (WWTPs)	NPDES	2020	Clip points to watershed boundary	Point source input- ArcSWAT and *E.coli* load calculation
Wastewater Treatment Facilities (WWTFs)	TCEQ	2019	Clip to watershed boundary, verify operational state	Point source input- ArcSWAT and *E.coli* load calculation
Weather data (precipitation, Maximum and minimum temperature, relative humidity, solar radiation, and wind speed)	NWS, NOAA	2000-2020	Extraction of weather data in the SWAT input format	Application in ArcSWAT
Aerial imagery	NAIP, TOP	2016, 1996	Mosaic and clip raster files to watershed	Determine ground conditions of watershed
Topographic maps (1.24,000 scale)	USGS	1996	Isolate DOQQs situated inside/tangent to watershed boundary	Characterize watershed, reference for hydrologic features
Detailed streets and highways	ESRI	2016	None	Public outreach component, orient map viewers to watershed extents
City boundaries	TCEQ	2014	Clip features to watershed boundary	Public outreach component
County boundaries	TCEQ	2014	Clip features to watershed boundary	Public outreach component
Joe Pool Lake watershed	NHD	2009	Aggregate of HUC 12 subwatersheds above Joe Pool Lake outlet	Clipping boundary for isolating other data sources
Census data	U.S. Census Bureau	2010	Distribute population density characteristics appropriately to watershed	Determine population characteristics, base data for several *E.coli* loading components
911 address structures points	NCTCOG	2015	Clip source points to watershed boundary	Determine location, density of structures

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
SWQM stations	TRA, TCEQ	Varies (1981-2020)	Relate to surface water quality data sampling results	Document locations of surface water quality monitoring stations
County Soils Maps	NRCS (SSURGO)	2014	Identify areas that may prove problematic for modeling and/or pollutant transport	Characterize watershed, watershed delineation
General Soils Maps	NRCS (STATSGO)	1997	Identify areas that may prove problematic for modeling and/or pollutant transport	Characterize watershed, watershed delineation
LULC field verification points	TRA	2016-2017	Compare to NLCD database	Determine accuracy of NLCD data
SWCD boundaries	TSSWCB	2014	Isolate Dalworth/Johnson SWCDs	Public outreach strategy
List of steering committee member locations	TRA	2020	Gather geographic information at stakeholder meetings, personal communication, email	Determine distribution of committee member locations to ensure adequate watershed representation
RUAA sampling locations	TCEQ	2011 (Walnut Creek)	Generalize sampling location results to applicable extents within watershed	Determine extent of recreational use in watershed for bacteria standards applicability
Shape files for existing lakes and reservoirs	NHD	2009	Ground truth feature margins for accuracy	Watershed delineation
Shape files for streams	NHD	2009	Clip NHD features to watershed boundary	Watershed delineation
Named streams	NHD	2009	Generalize NHD data for streams, isolate named streams to new layer	Public outreach – use for general information maps
TCEQ stream segments	TCEQ	2016	Clip features to watershed boundary	Watershed delineation
TCEQ assessment units	TCEQ	2016	Clip features to watershed boundary	Watershed delineation
Aquifers – major and minor	TWDB	2006	None	Public outreach component
New TCEQ surface water quality monitoring stations	TRA/TCEQ	Created through JPL project	Identify new/existing station locations at strategic points along stream path	Watershed delineation
Floodplain data	National Flood Hazard Layer – FEMA	2015	Compare and adjust LULC maps as appropriate	Used to update LULC maps as necessary, public outreach component
Public water system wells & surface water intakes	TCEQ	2016	Append well constituent tables to spatial network of wells	Determine if wells may be subject to pollution from nearby sources
Bridge locations	National Bridge Inventory (USDOT)	2012	Append bridge location data to well information tables, apply to watershed	Component of approximating *E.coli* loading rate from avian sources
Municipal solid waste sites/landfills	TCEQ	2007	Verify activity & history of sites clipped to watershed	Potential pollutant point source identification

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Solid waste sites/landfills/ illegal dump site field verification	TRA	Created through JPL project	Compare MSW/L database points, add points for illegal dump sites found in watershed	Determine accuracy of municipal solid waste sites/landfills data, identify other dump site point sources
Water control structures database	NRCS/TRA	Created through JPL project	Comparison and integration of TRA and NRCS records	Identify and verify significant impoundments in watershed
Oil & natural gas wells	RRC of Texas	Varies	Clip database to watershed boundary	Locate and determine density of oil/natural gas wells for potential pollutant point source identification
Permitted industrial /hazardous waste sites	TCEQ	n/a	Clip database to watershed boundary – **none in watershed**	Locate sites for potential pollutant point source identification
Cattle – population density	USGS National Agricultural Statistics Service	2017	Clip database to watershed boundary	*E.coli* load calculation
Sheep – population density	USGS National Agricultural Statistics Service	2017	Clip database to watershed boundary	*E.coli* load calculation
Goats – population density	USGS National Agricultural Statistics Service	2017	Clip database to watershed boundary	*E.coli* load calculation
Horses – population density	USGS National Agricultural Statistics Service	2017	Clip database to watershed boundary	*E.coli* load calculation
Deer – population density	TPWD deer density studies (Lockwood 2006 and Cain 2020)	2007, 2020	Clip database to watershed boundary	*E.coli* load calculation
Waterfowl (Ducks and Geese) – population density	Stakeholder input, using other WPP data as benchmarks, TPWD eBird Survey	Created through JPL project, 2010-2020	Bias to riparian buffers, other areas of interest identified by stakeholders	*E.coli* load calculation
Feral Hogs – population density	Stakeholder input, using peer-reviewed literature and other WPP data as benchmarks	Created through JPL project	Bias to riparian buffers, other areas of interest identified by stakeholders	*E.coli* load calculation
Certificates of Convenience and Necessity (CCNs)	Public Utility Commission of Texas	2014	Clip to watershed, verify extents	*E.coli* load calculation
OSSFs	NCTCOG-level 911 address points	2017	CCNs - City boundaries with WWTF but no available CCN = total households w/OSSFs	*E.coli* load calculation

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Dog Population	Census Bureau and stakeholder input	2010	Census data, households *0.614 = dogs	*E.coli* load calculation

Appendix B. LDCs Results

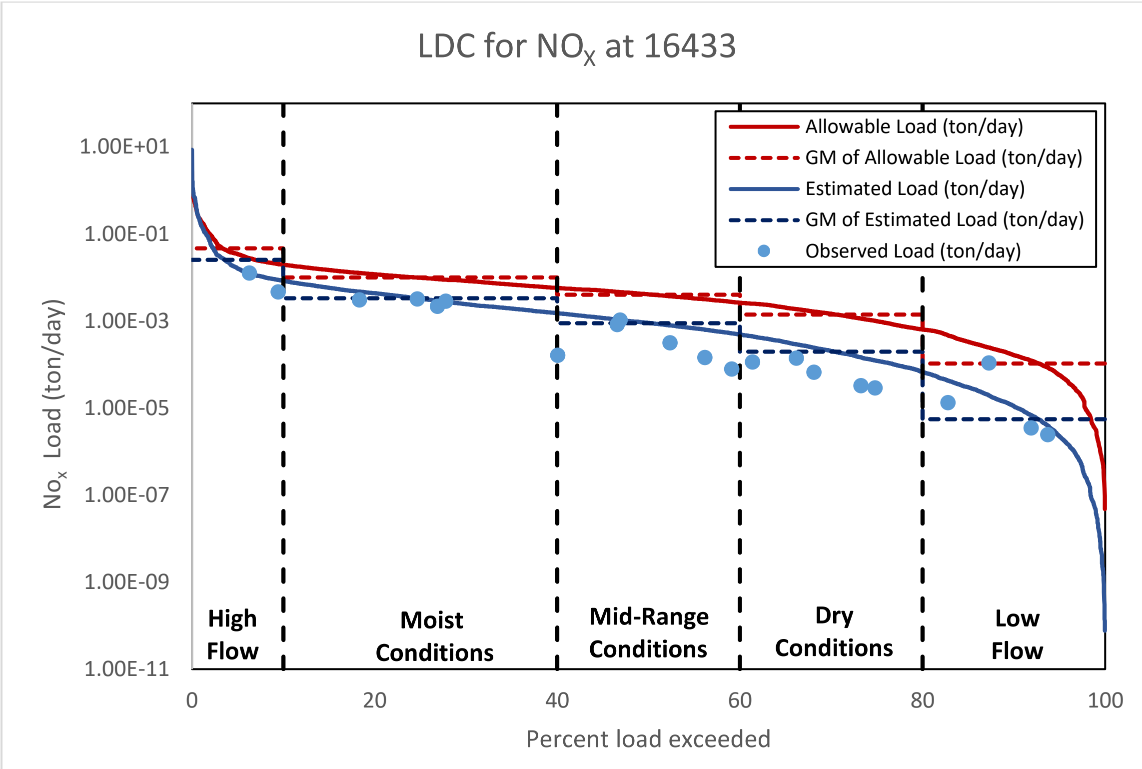

Figure B - 1. LDC for NO_x at monitoring station 16433.

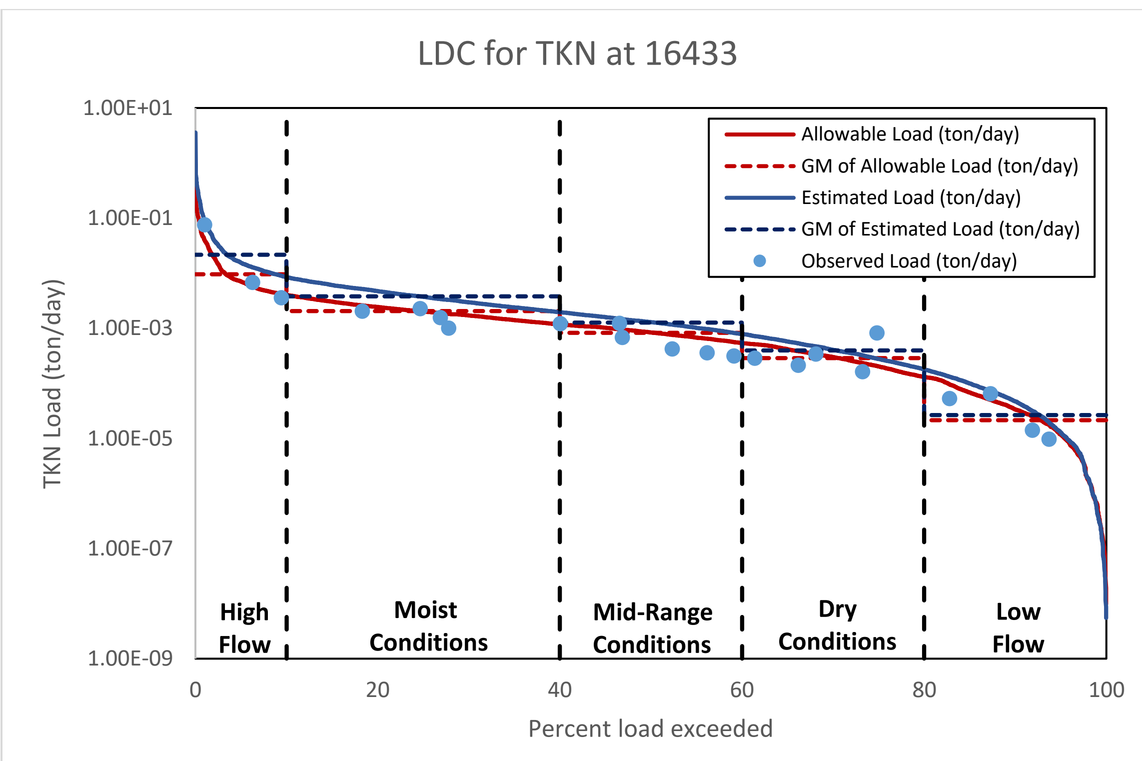

Figure B - 2. LDC for TKN at monitoring station 16433.

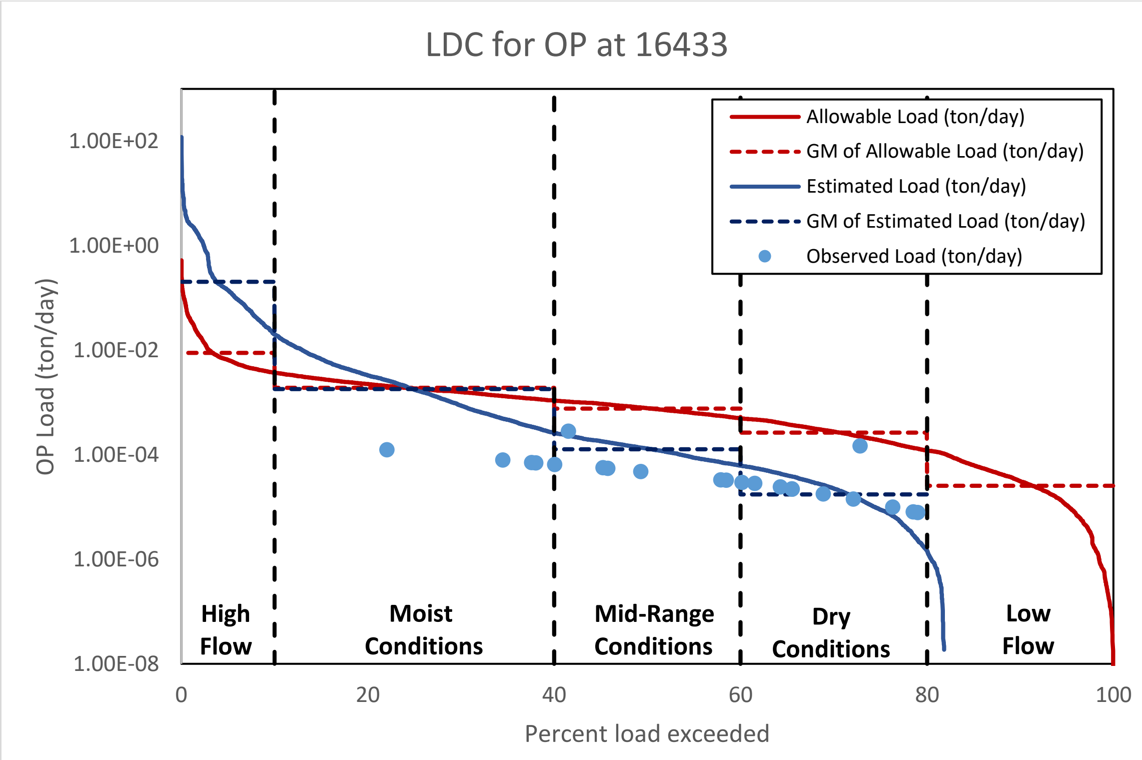

Figure B - 3. LDC for OP at monitoring station 16433.

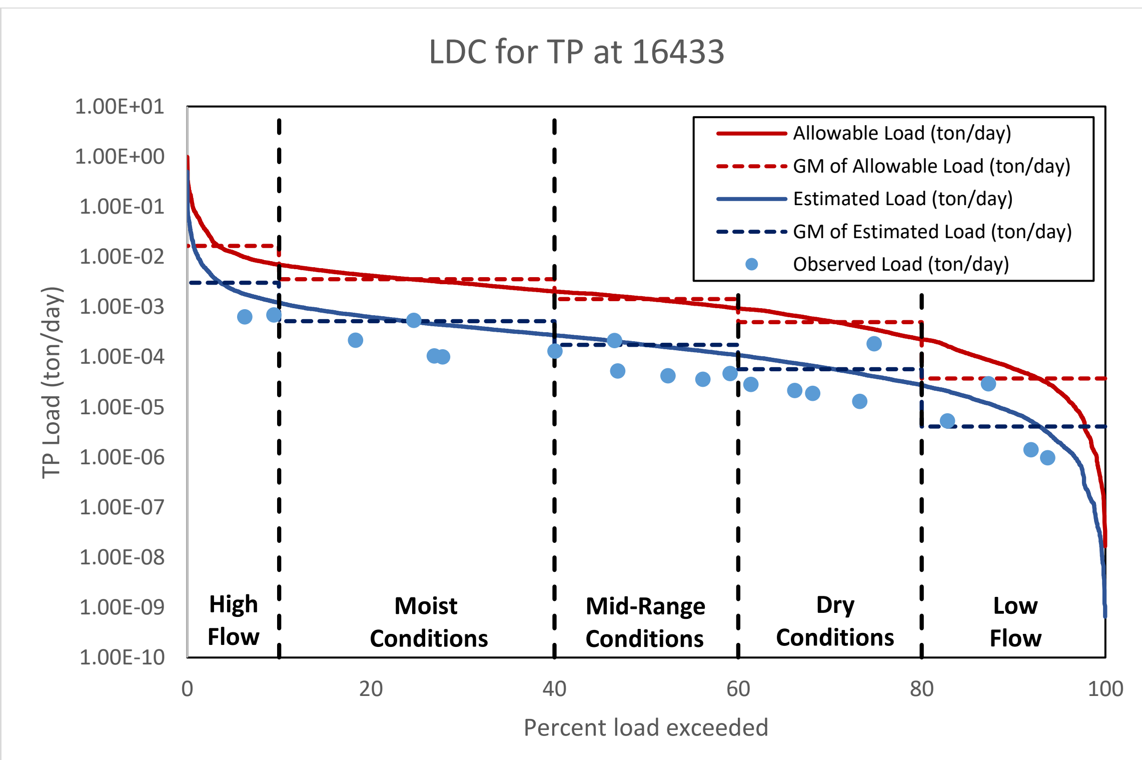

Figure B - 4. LDC for TP at monitoring station 16433.

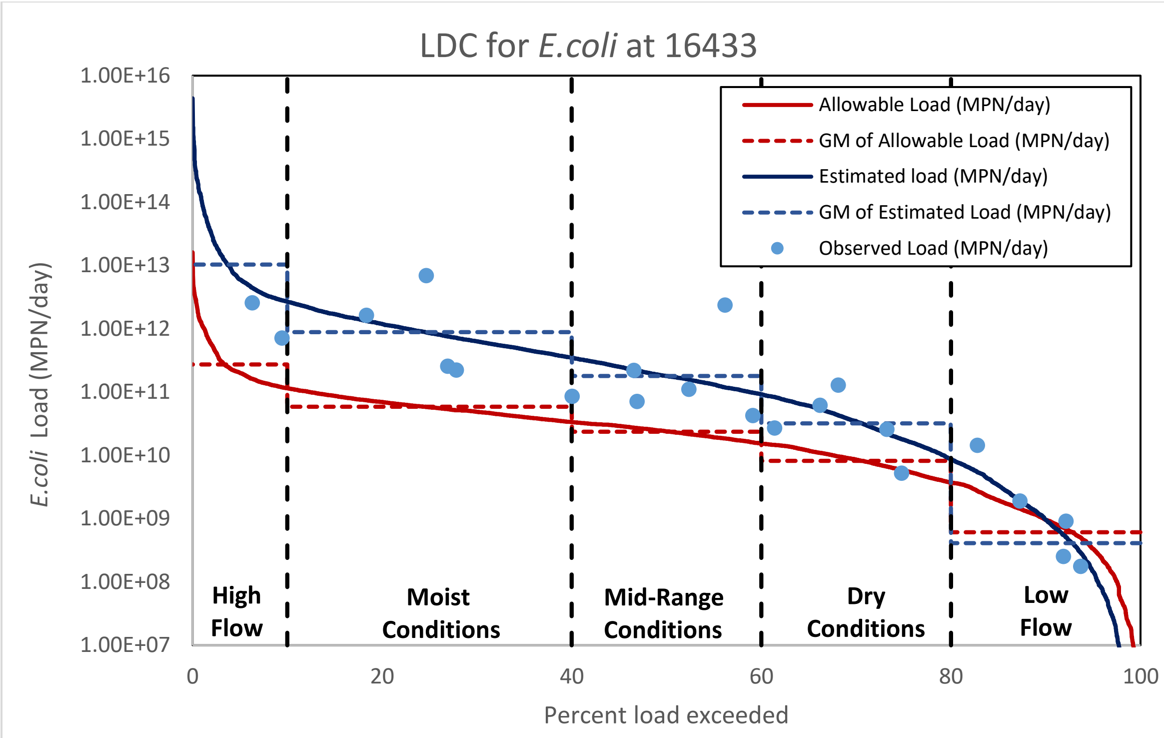

Figure B - 5. LDC for E.coli at monitoring station 16433.

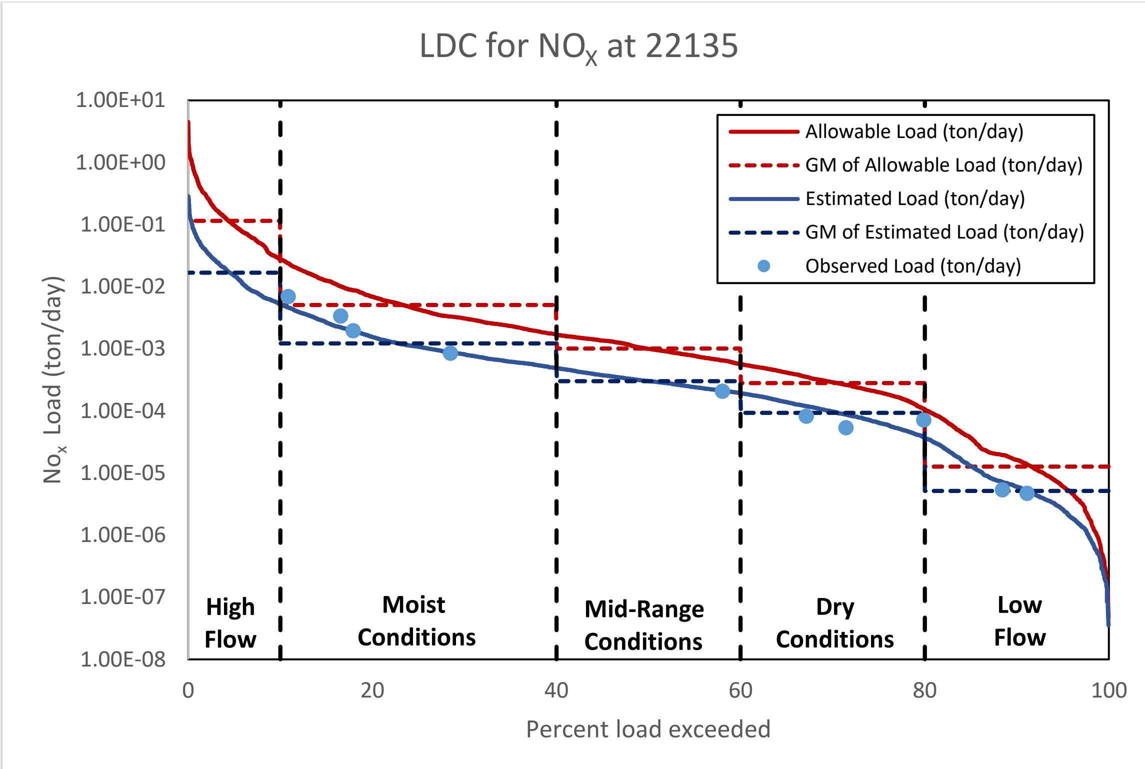

Figure B - 6. LDC for NO_x at monitoring station 22135.

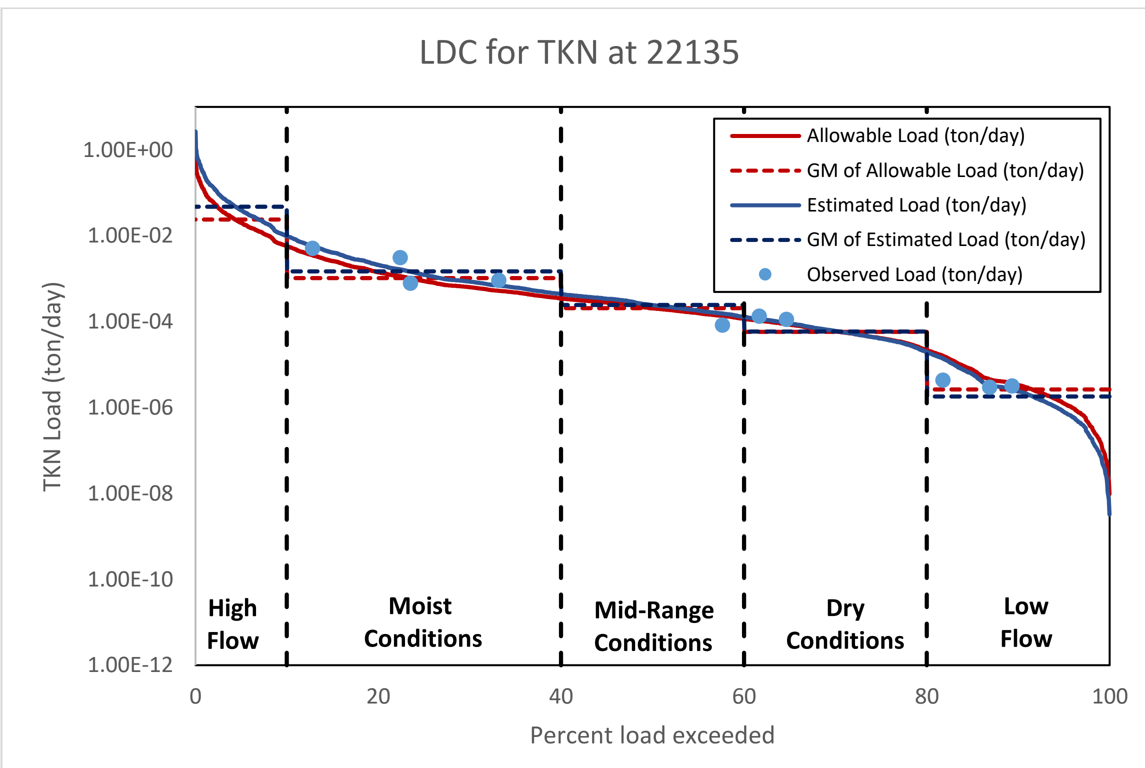

Figure B - 7. LDC for TKN at monitoring station 22135.

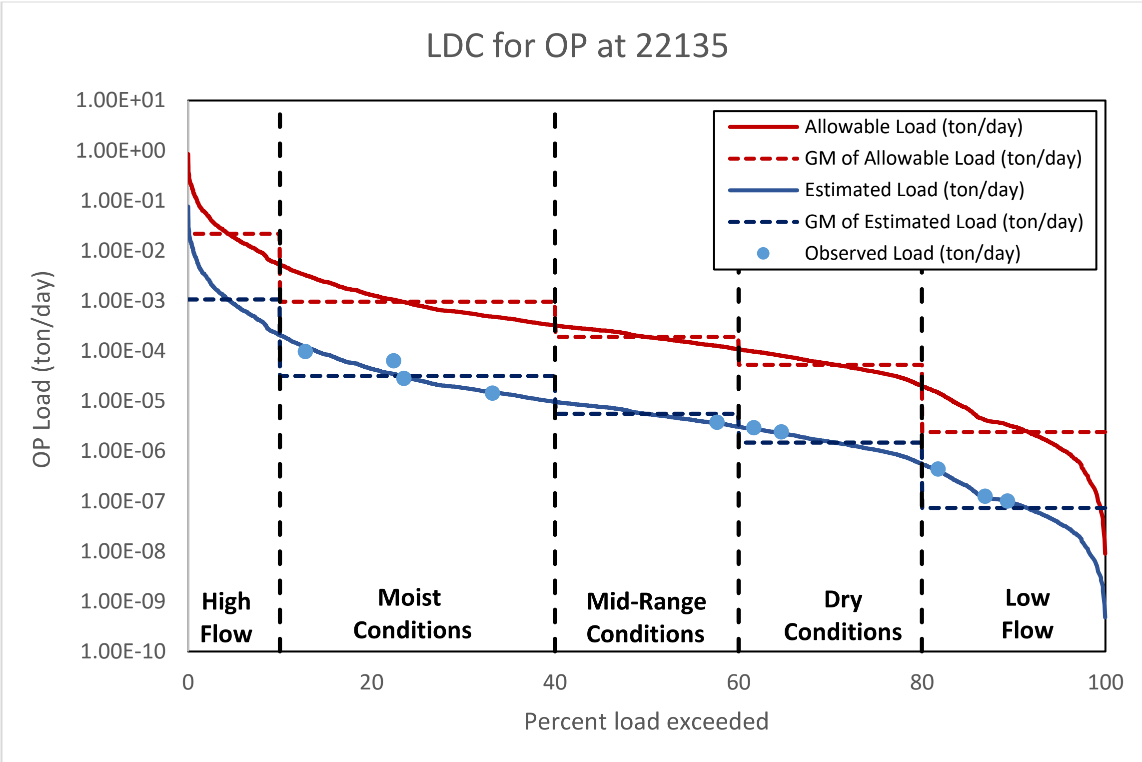

Figure B - 8. LDC for OP at monitoring station 22135.

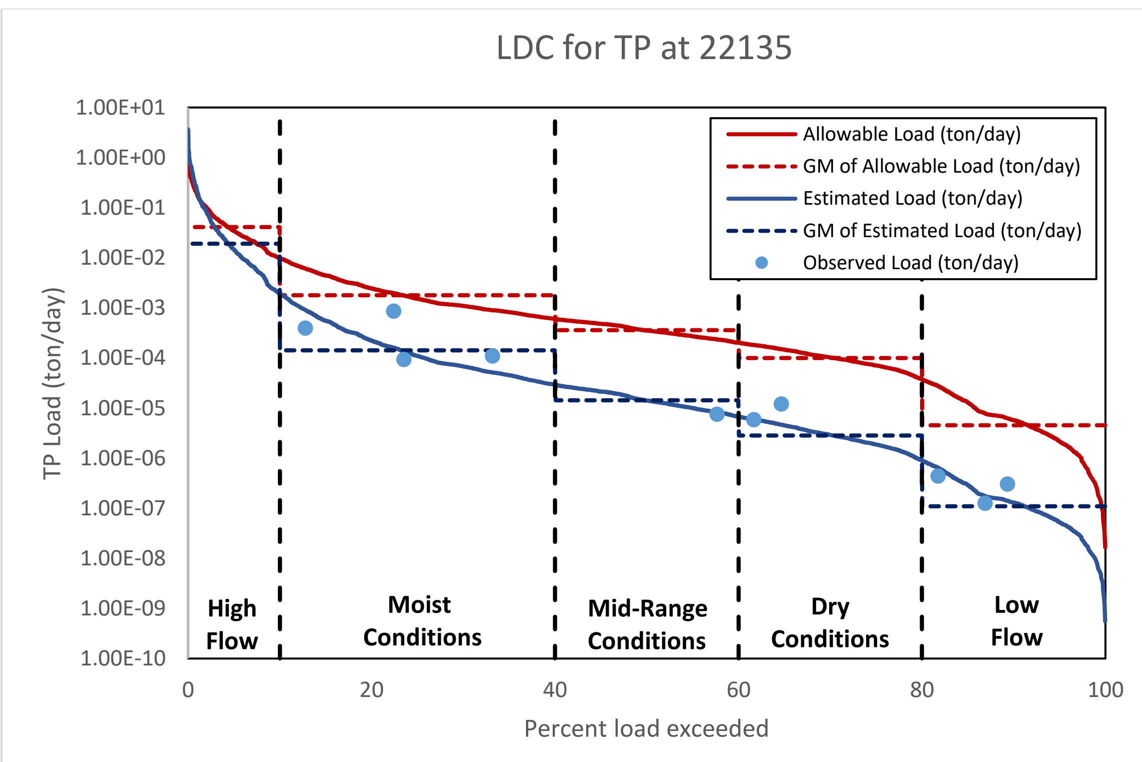

Figure B - 9. LDC for TP at monitoring station 22135.

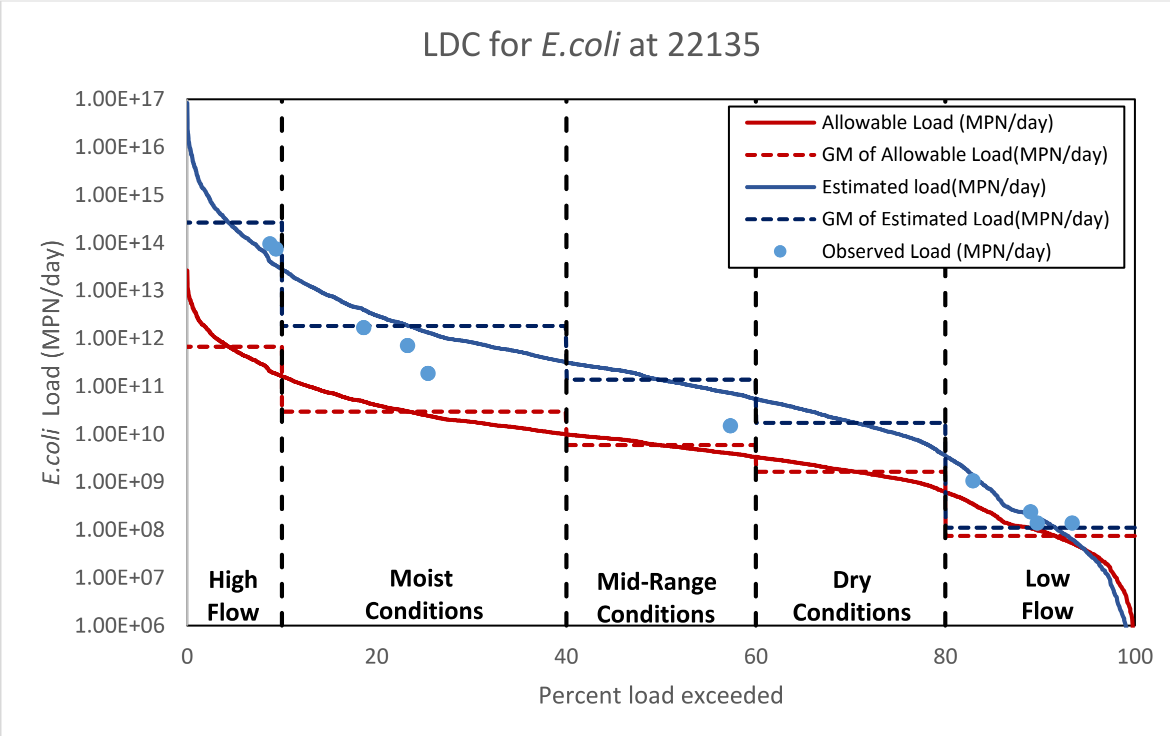

Figure B - 10. LDC for E.coli at monitoring station 22135.

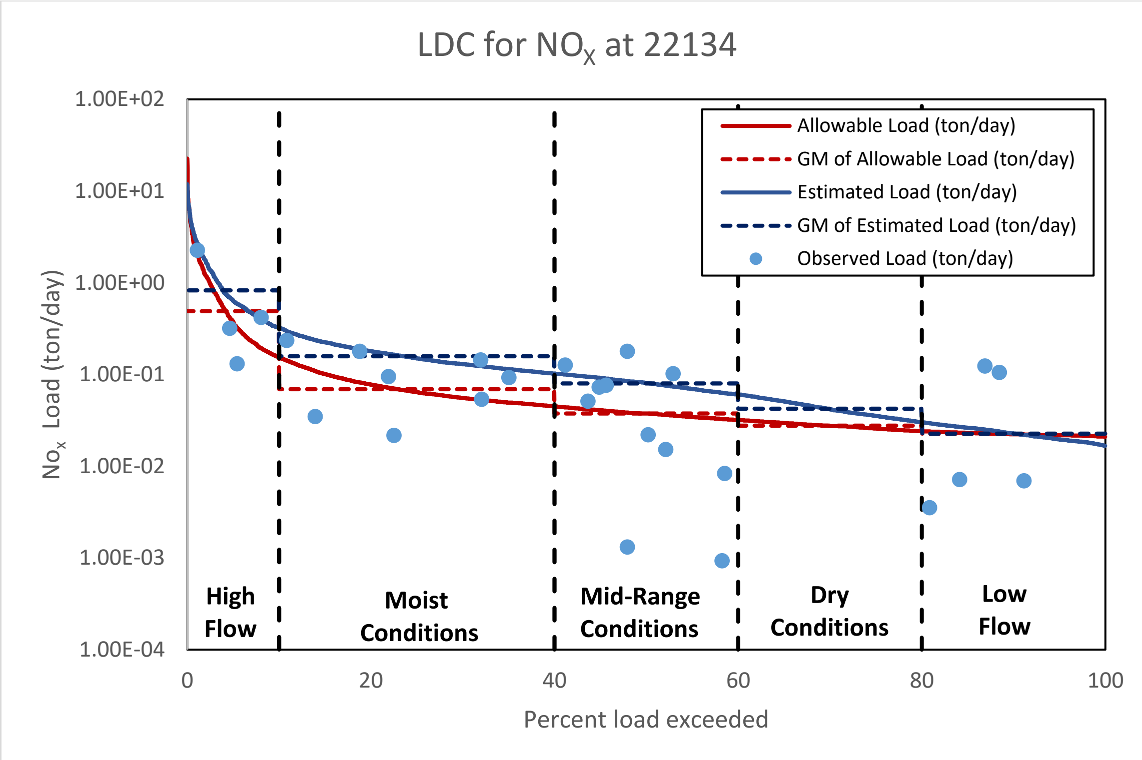

Figure B - 11. LDC for NO_x at monitoring station 22134.

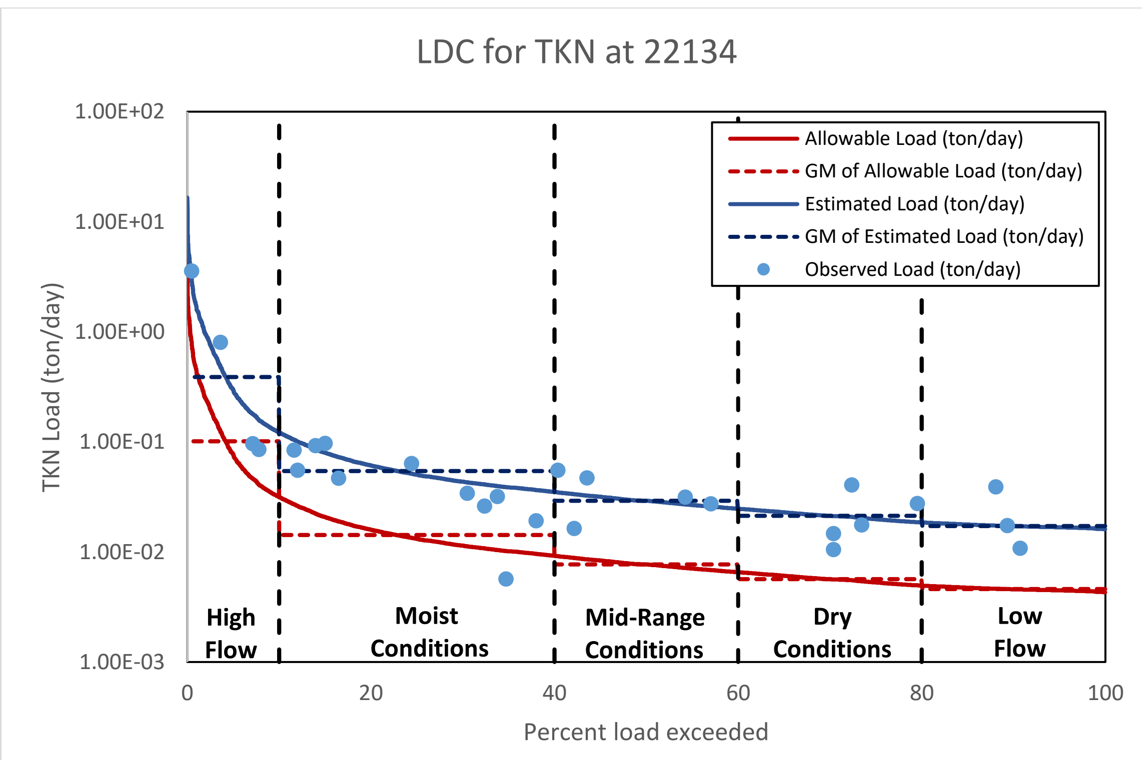

Figure B - 12. LDC for TKN at monitoring station 22134.

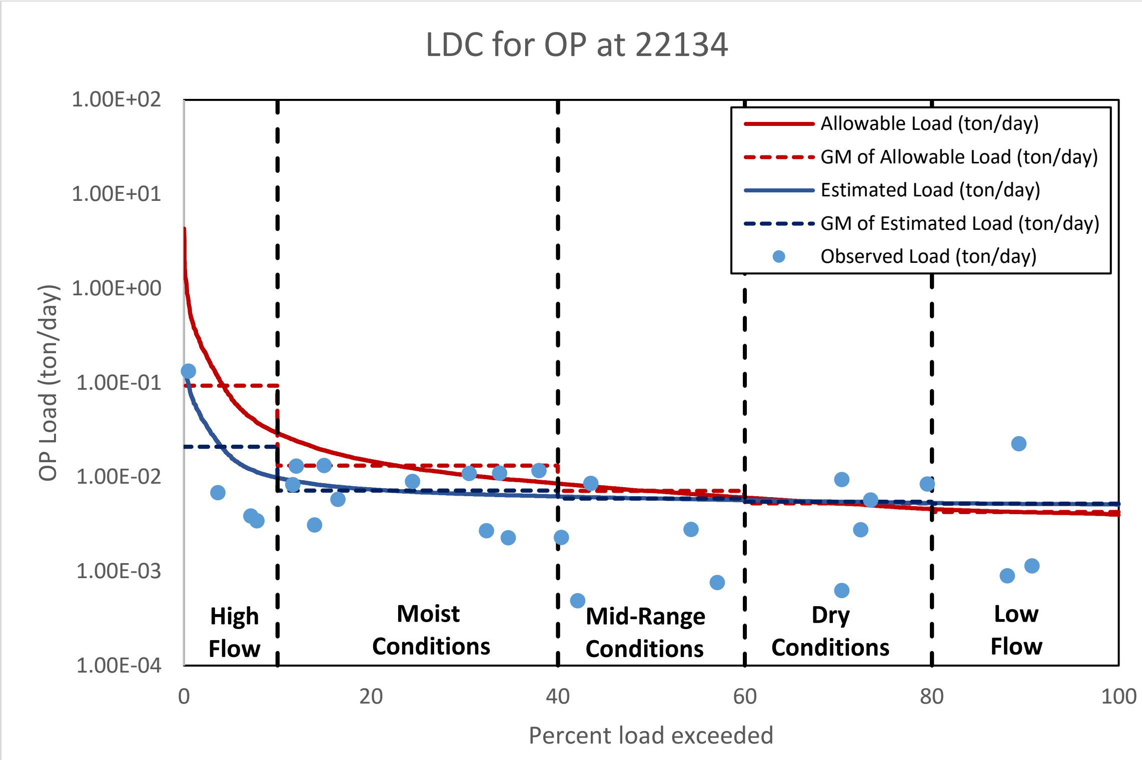

Figure B - 13. LDC for OP at monitoring station 22134.

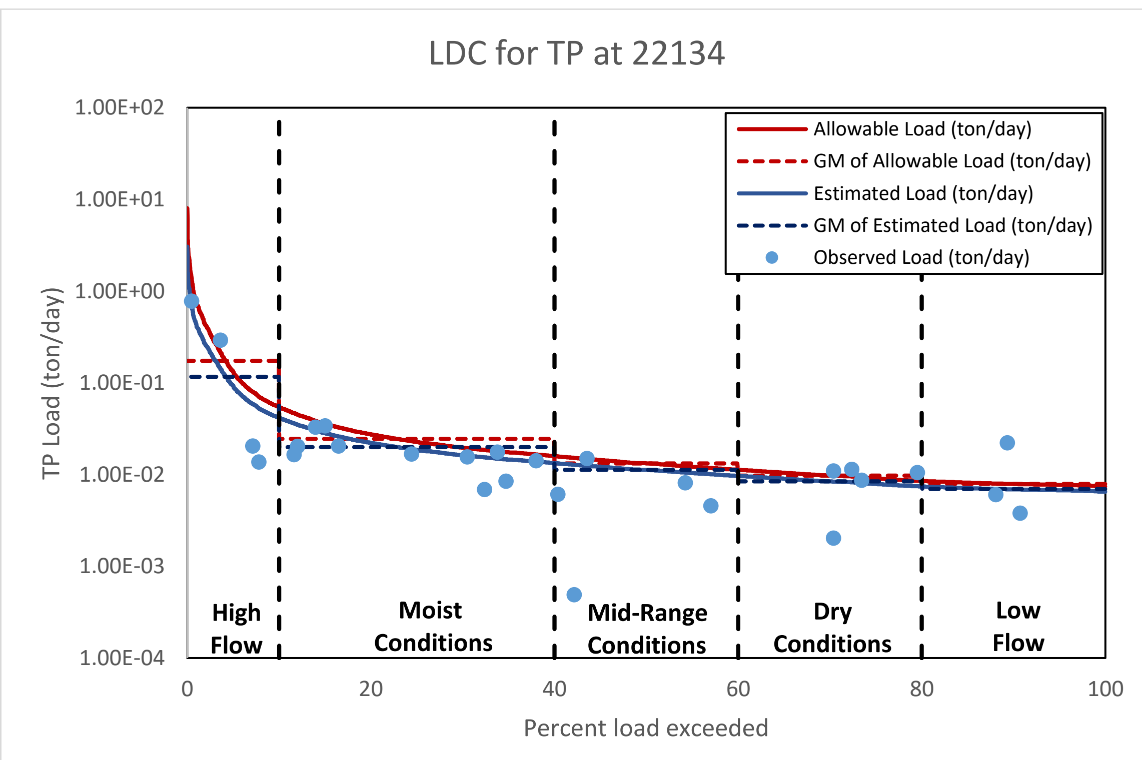

Figure B - 14. LDC for TP at monitoring station 22134.

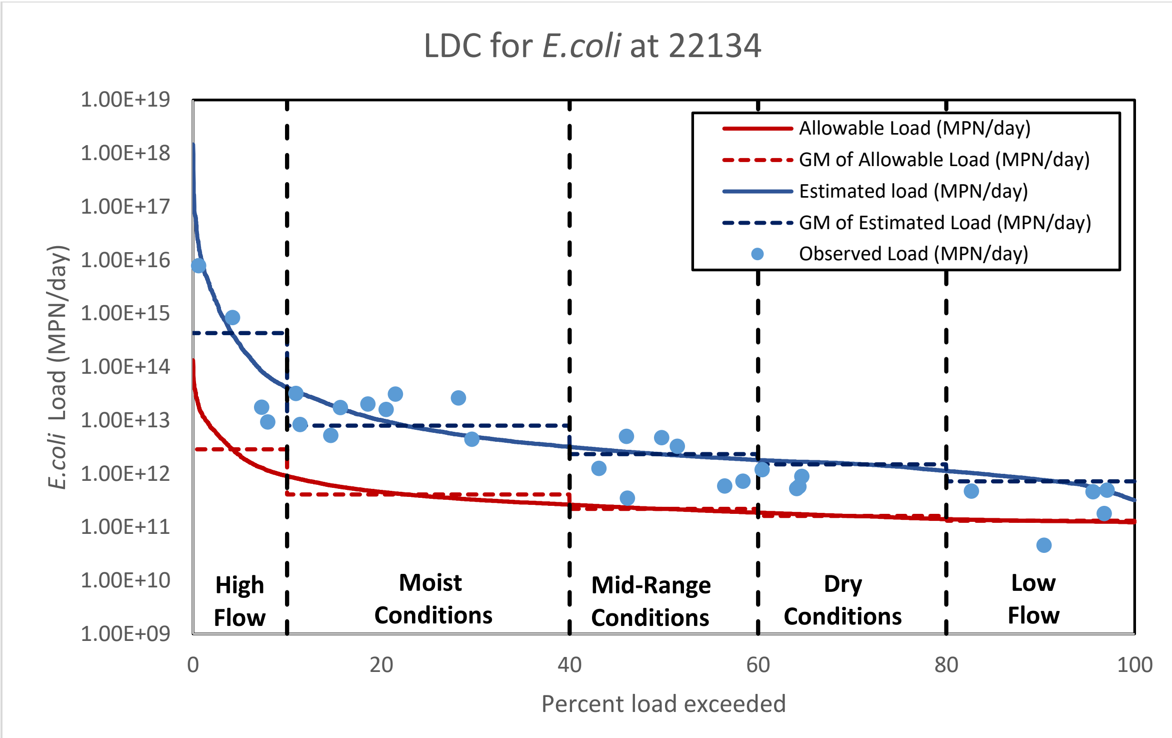

Figure B - 15. LDC for E.coli at monitoring station 22134.

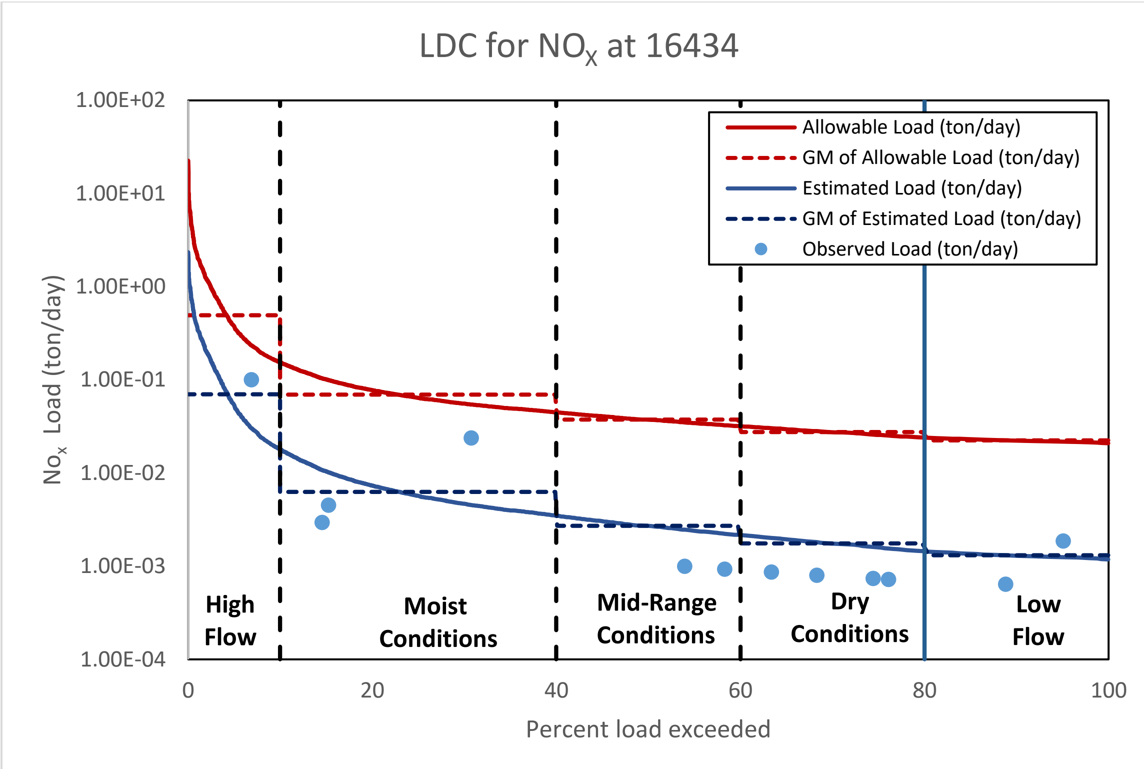

Figure B - 16. LDC for NO_x at monitoring station 16434.

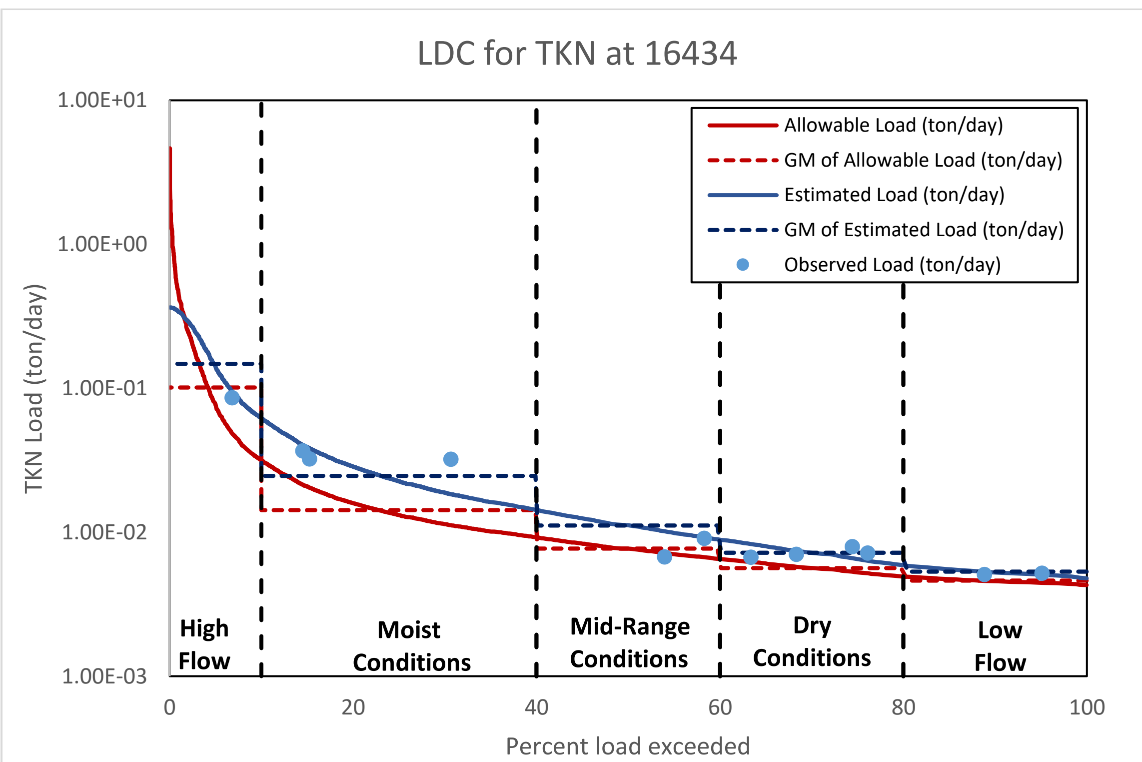

Figure B - 17. LDC for TKN at monitoring station 16434.

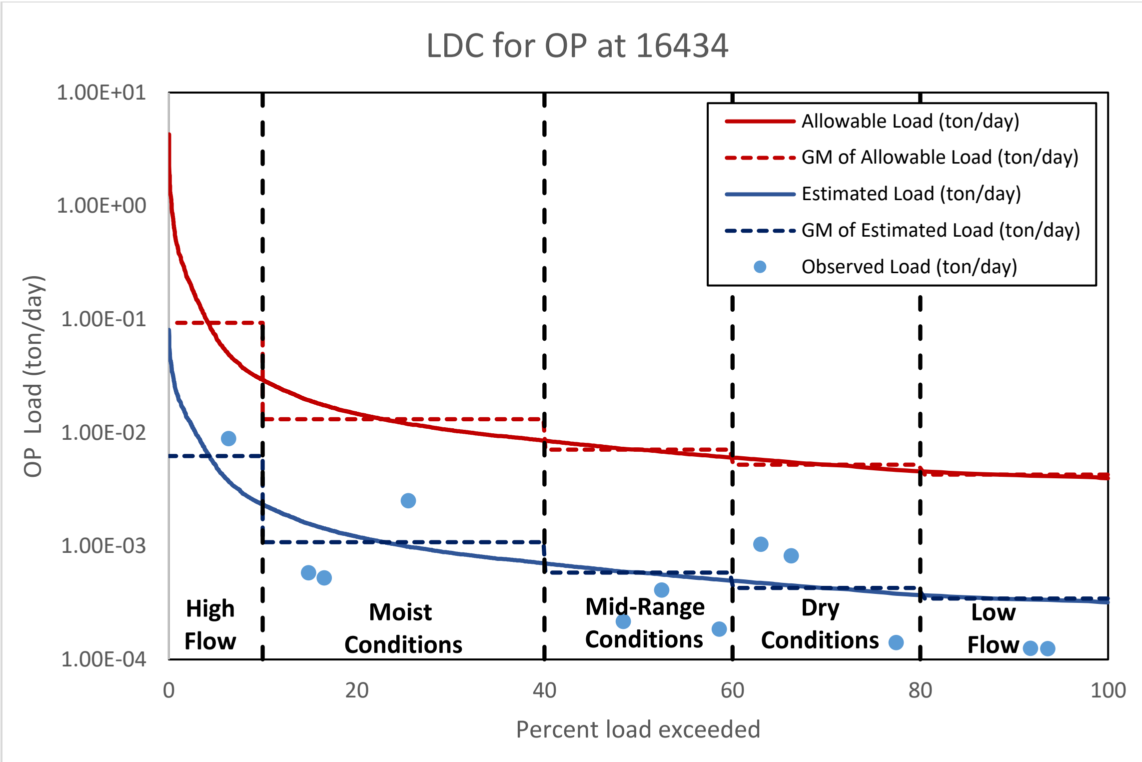

Figure B - 18. LDC for OP at monitoring station 16434.

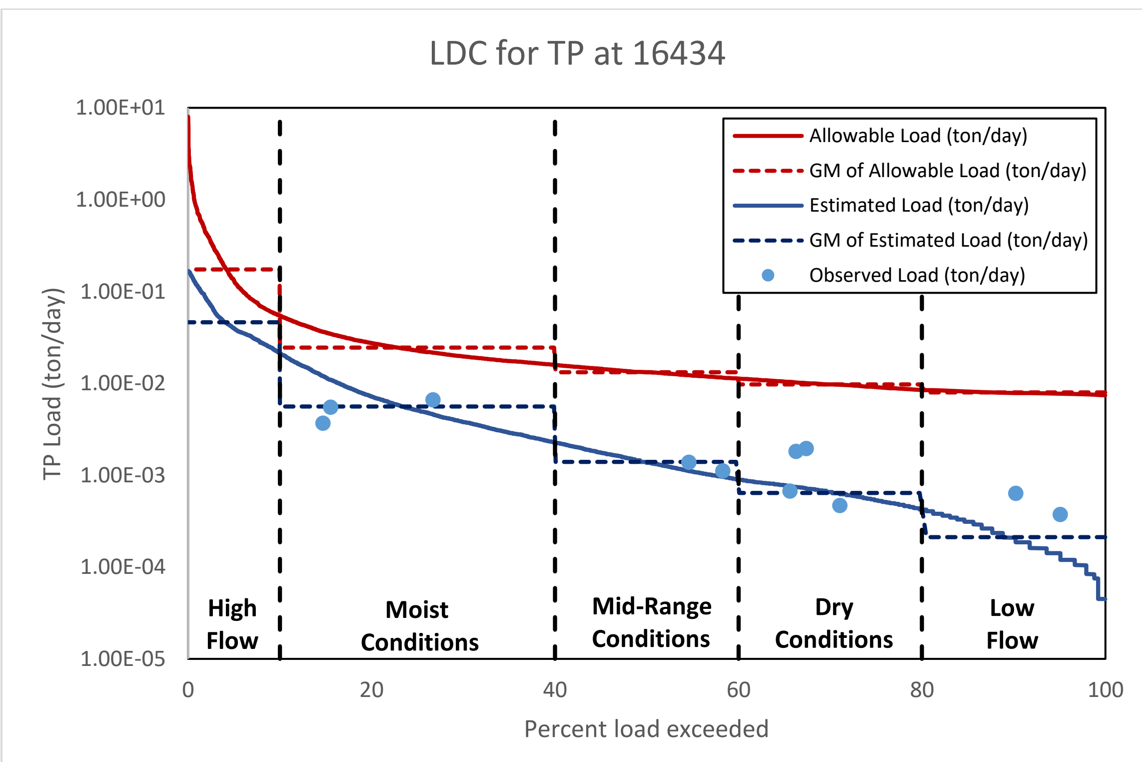

Figure B - 19. LDC for TP at monitoring station 16434.

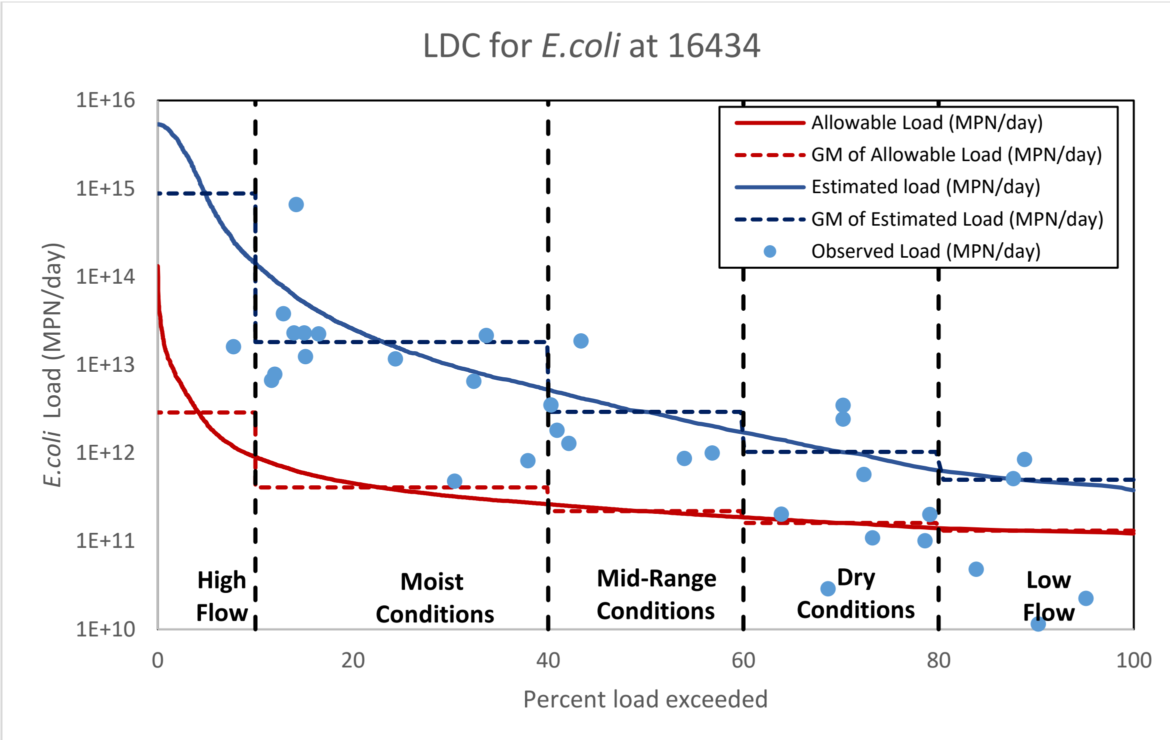

Figure B - 20. LDC for E.coli at monitoring station 16434.

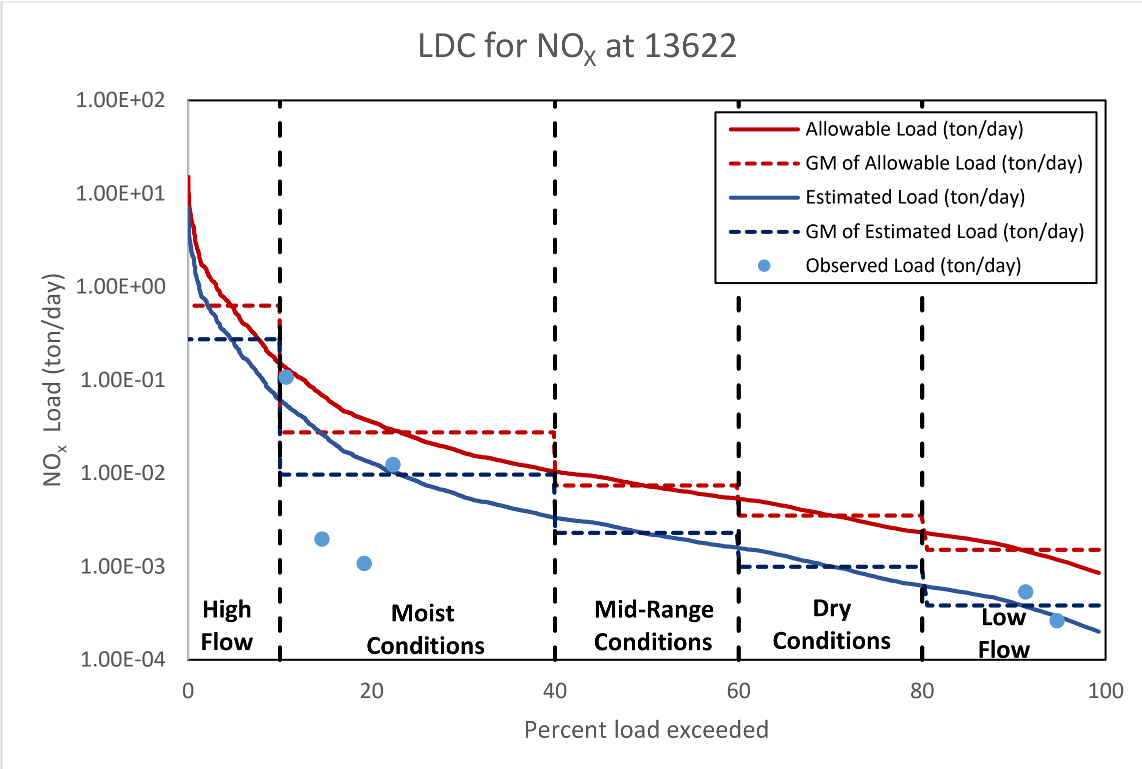

Figure B - 21. LDC for NO_x at monitoring station 13622.

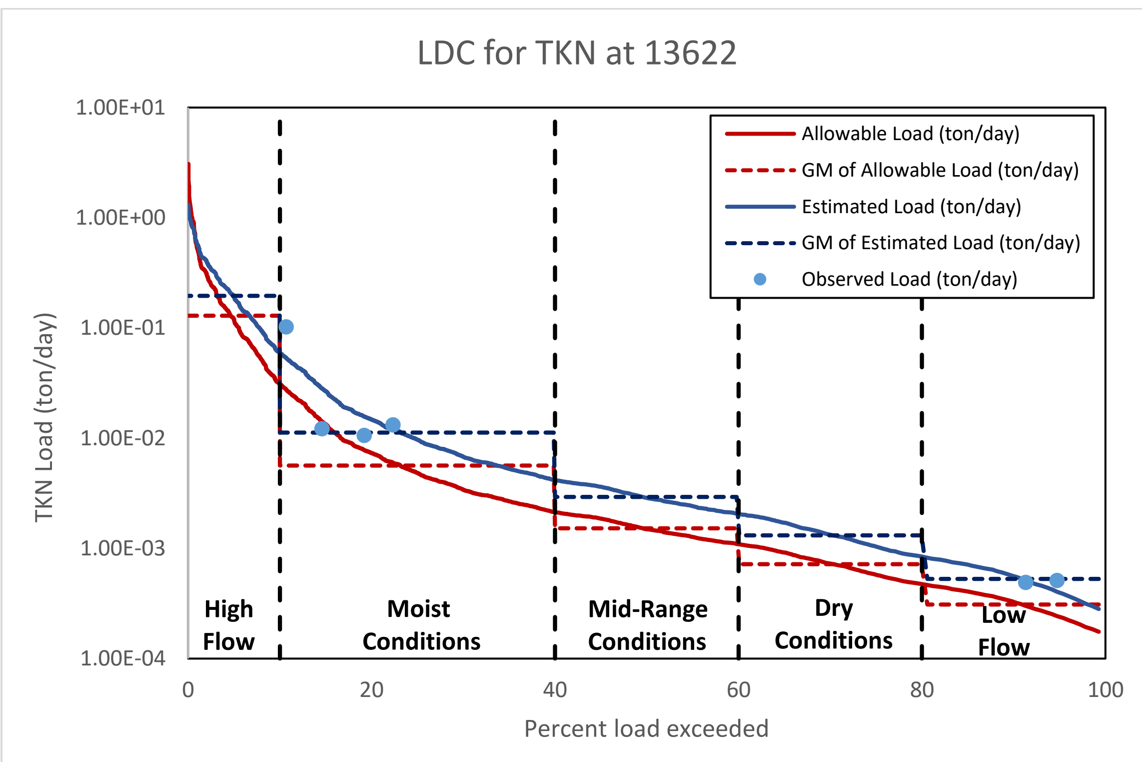

Figure B - 22. LDC for TKN at monitoring station 13622.

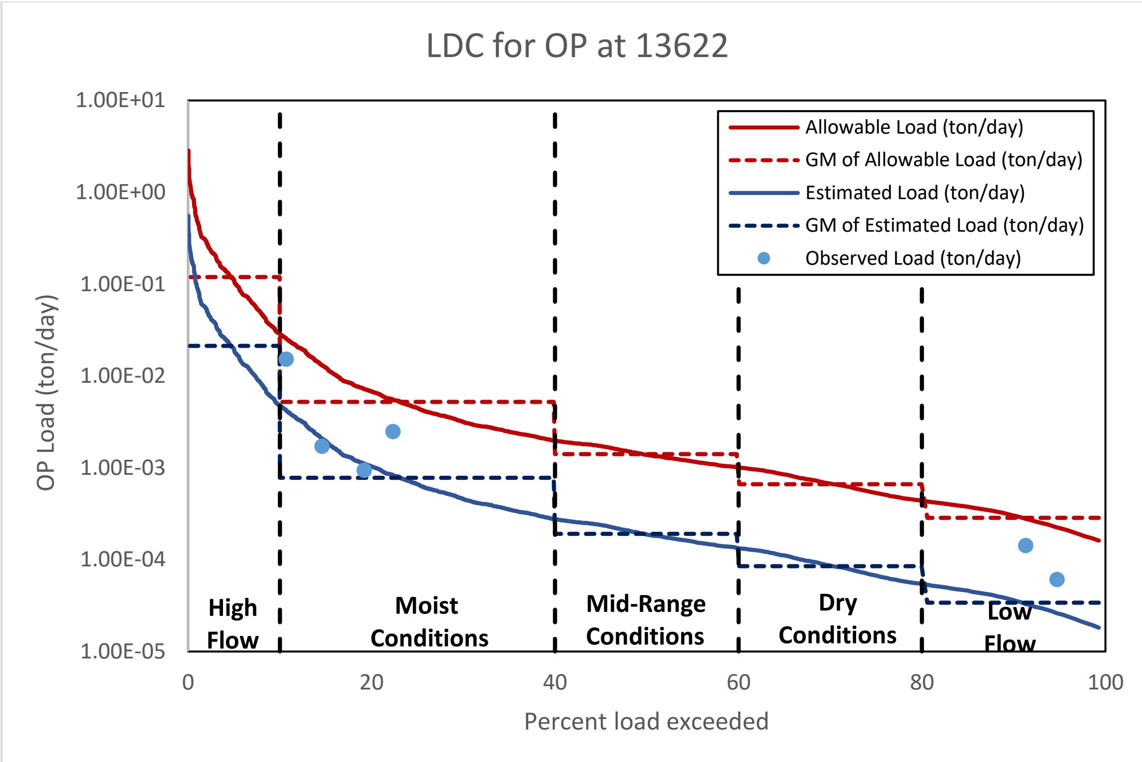

Figure B - 23. LDC for OP at monitoring station 13622.

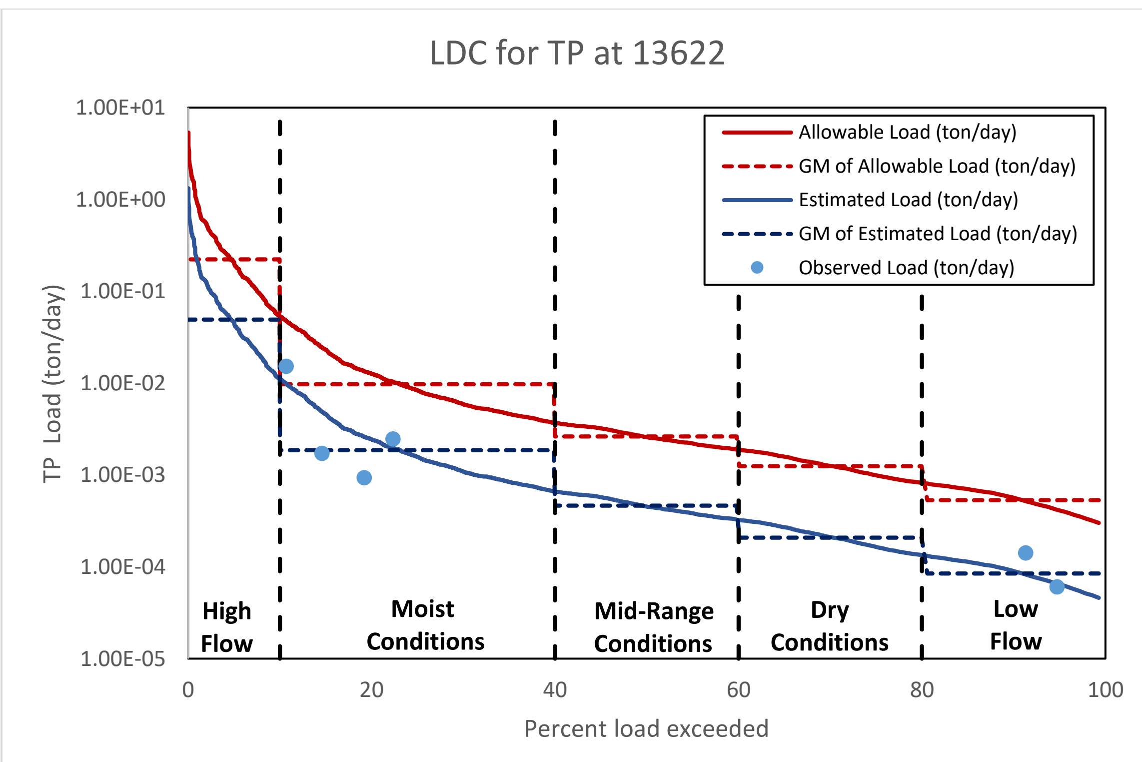

Figure B - 24. LDC for TP at monitoring station 13622.

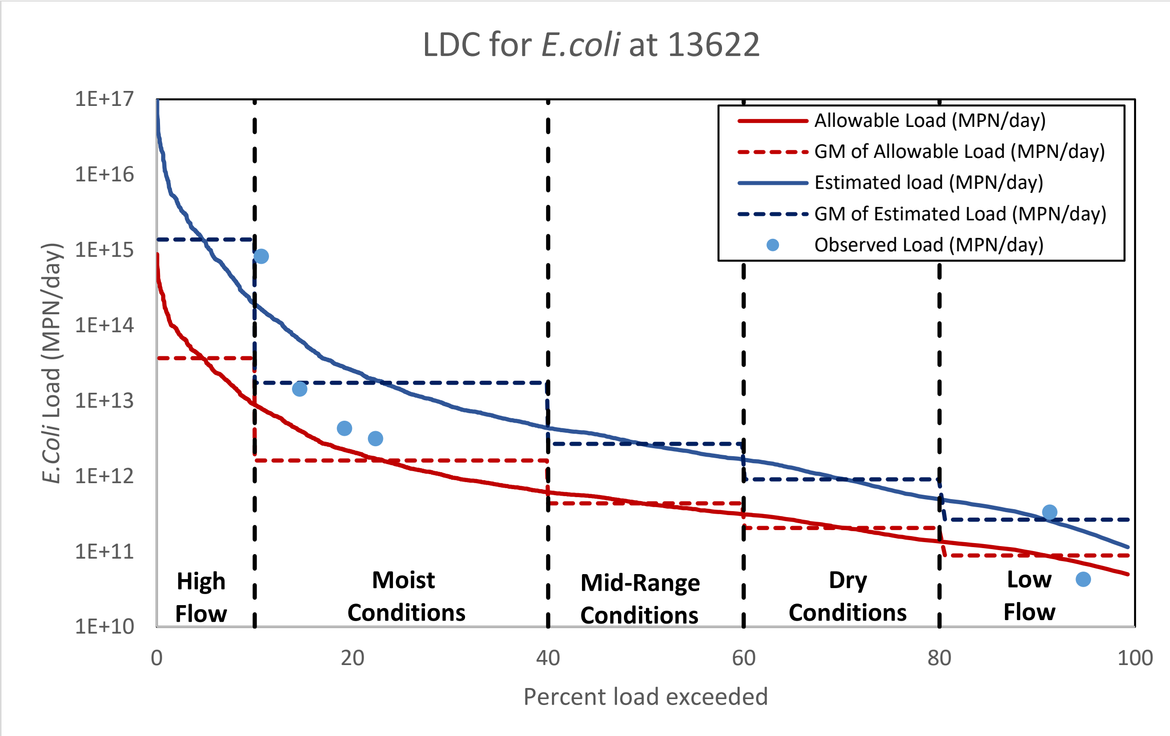

Figure B - 25. LDC for E.coli at monitoring station 13622.

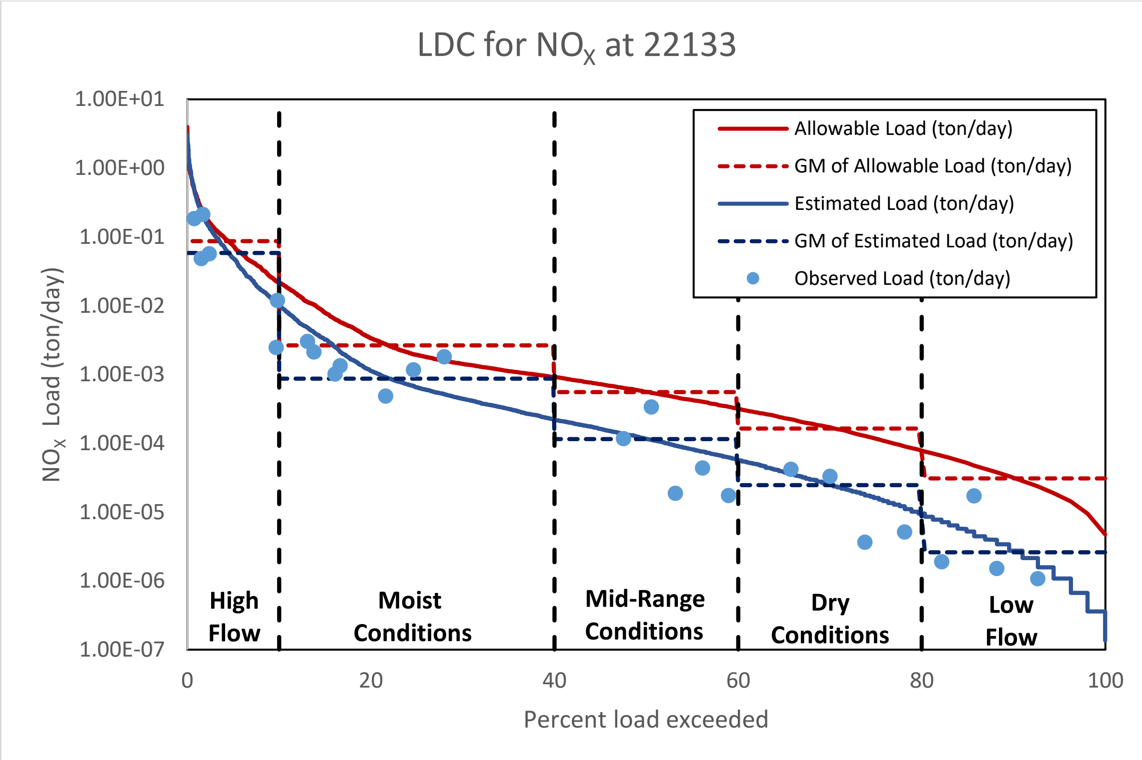

Figure B - 26. LDC for NO_x at monitoring station 22133.

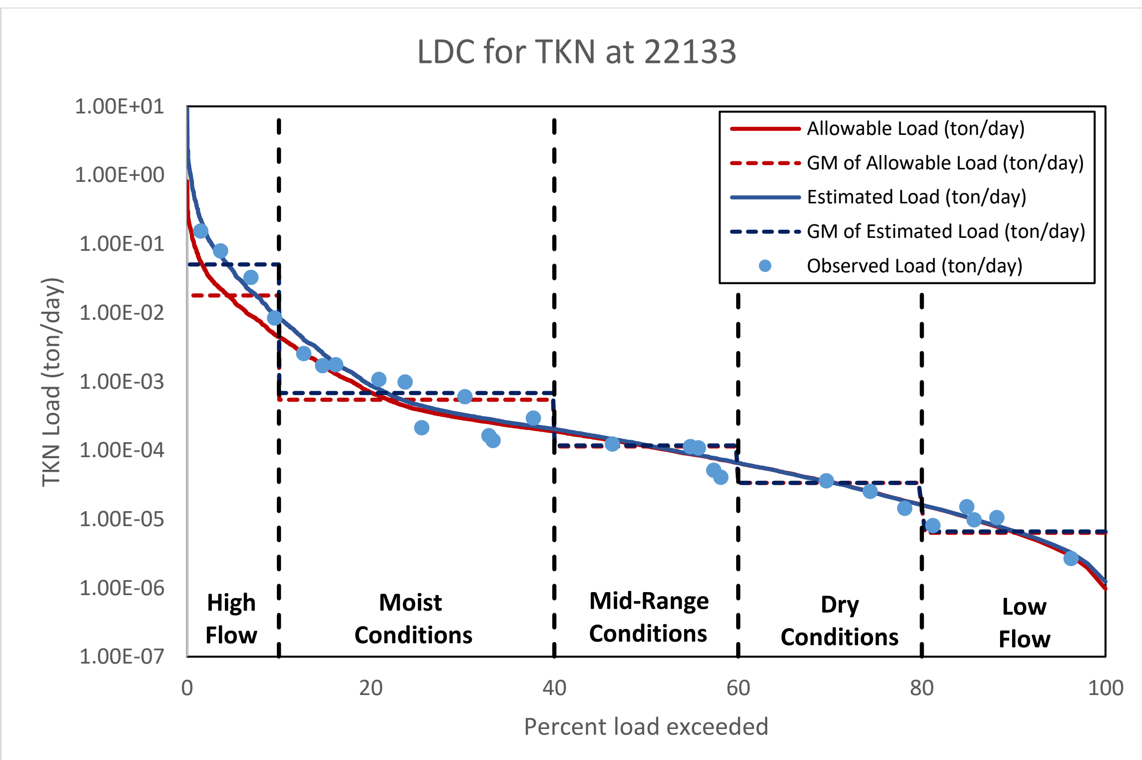

Figure B - 27. LDC for TKN at monitoring station 22133.

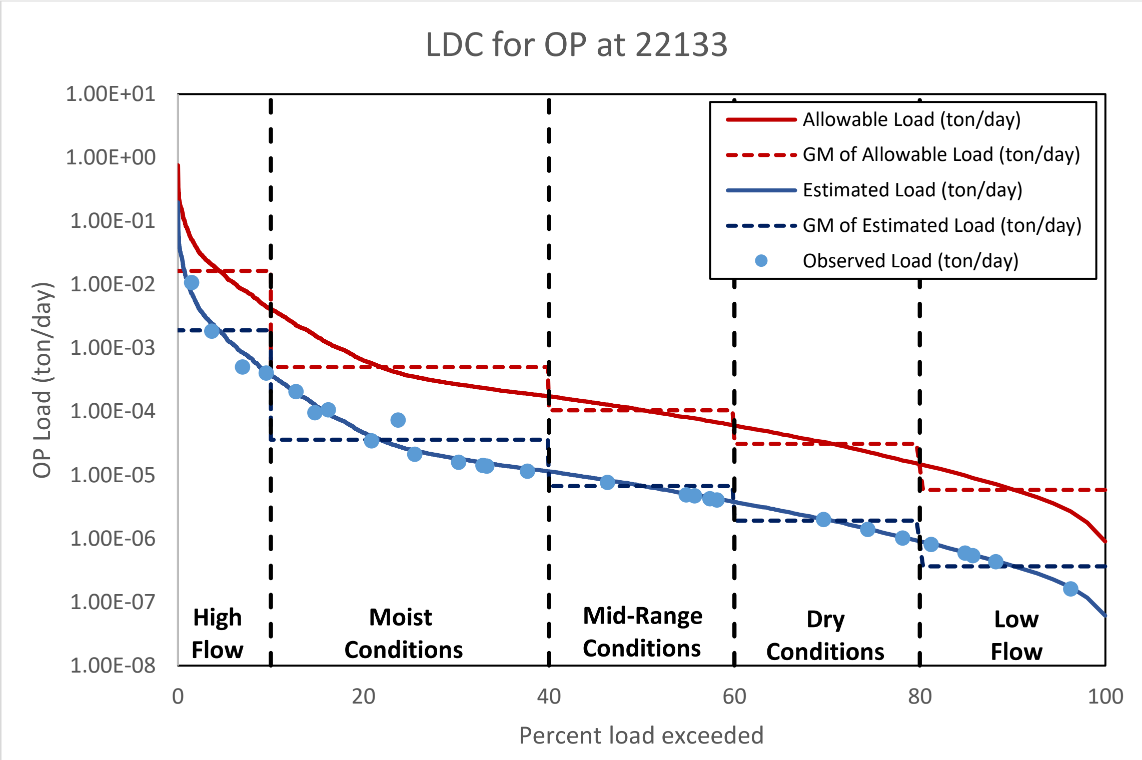

Figure B - 28. LDC for OP at monitoring station 22133.

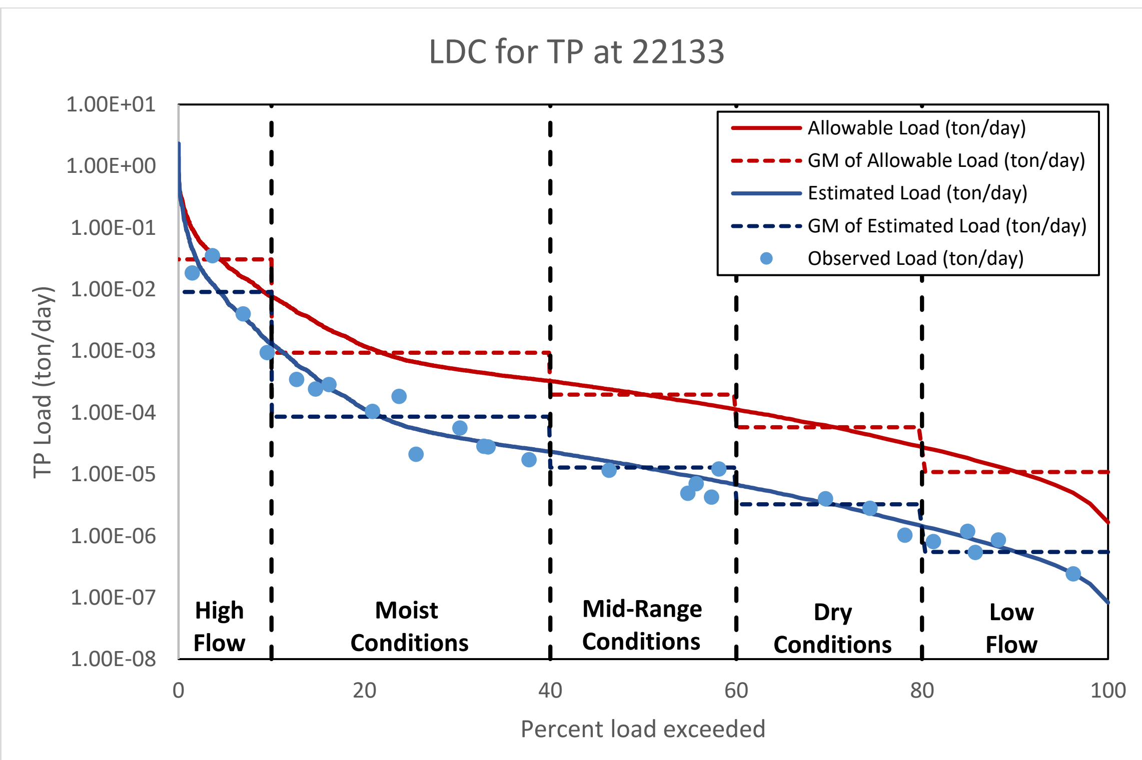

Figure B - 29. LDC for TP at monitoring station 22133.

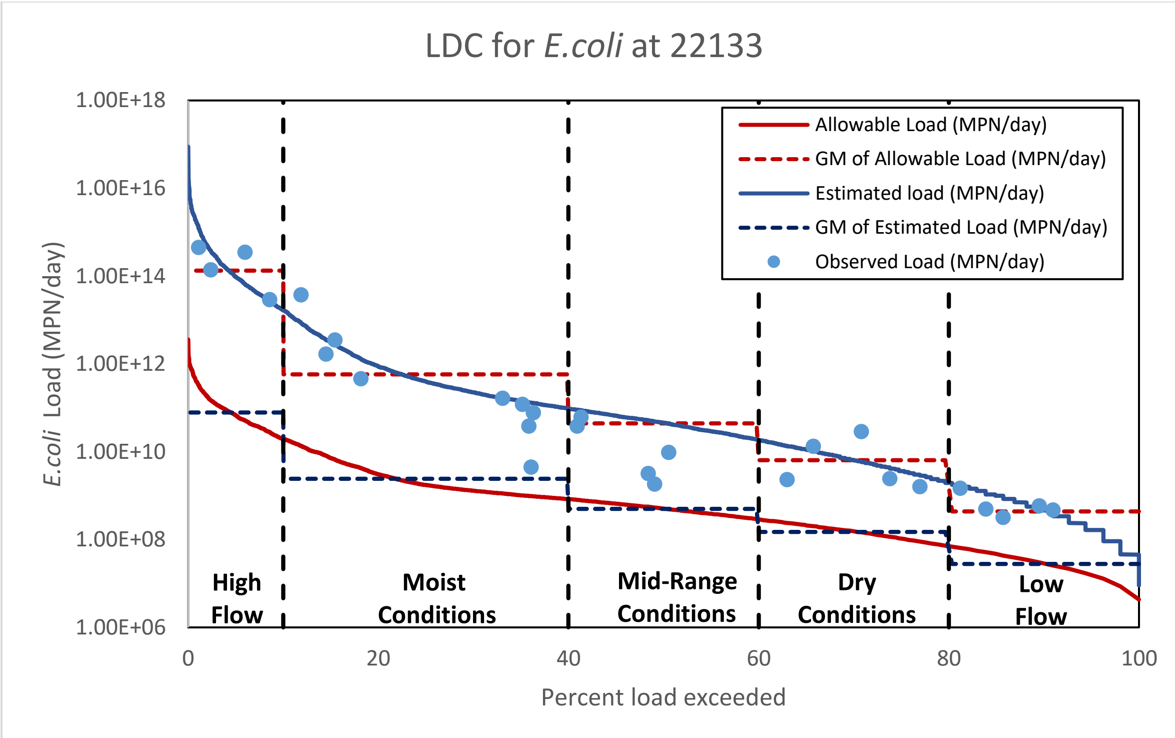

Figure B - 30. LDC for E.coli at monitoring station 22133.

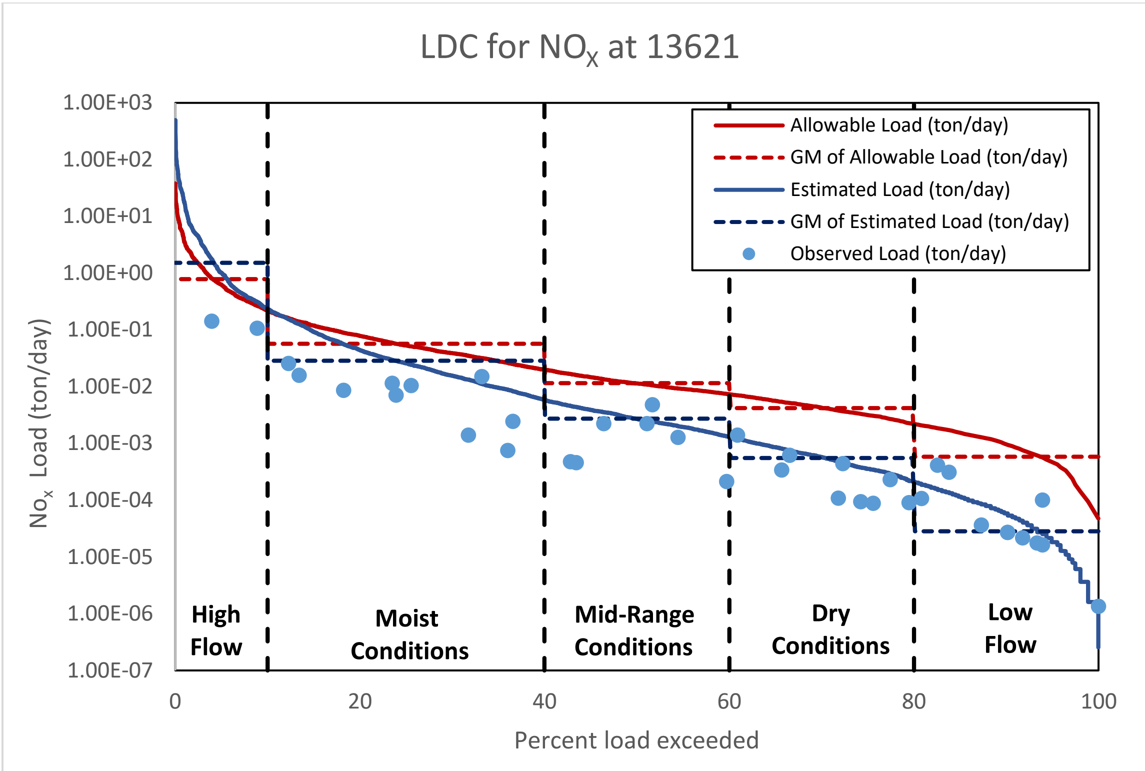

Figure B - 31. LDC for NO_x at monitoring station 13621.

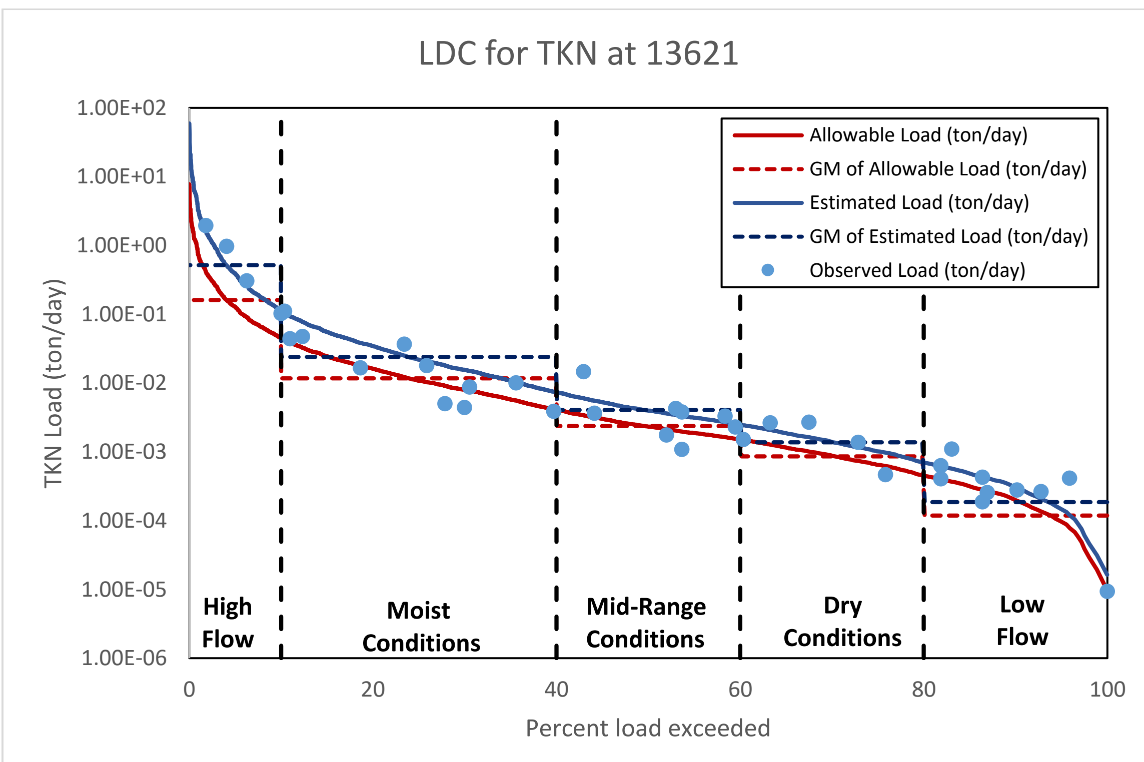

Figure B - 32. LDC for TKN at monitoring station 13621.

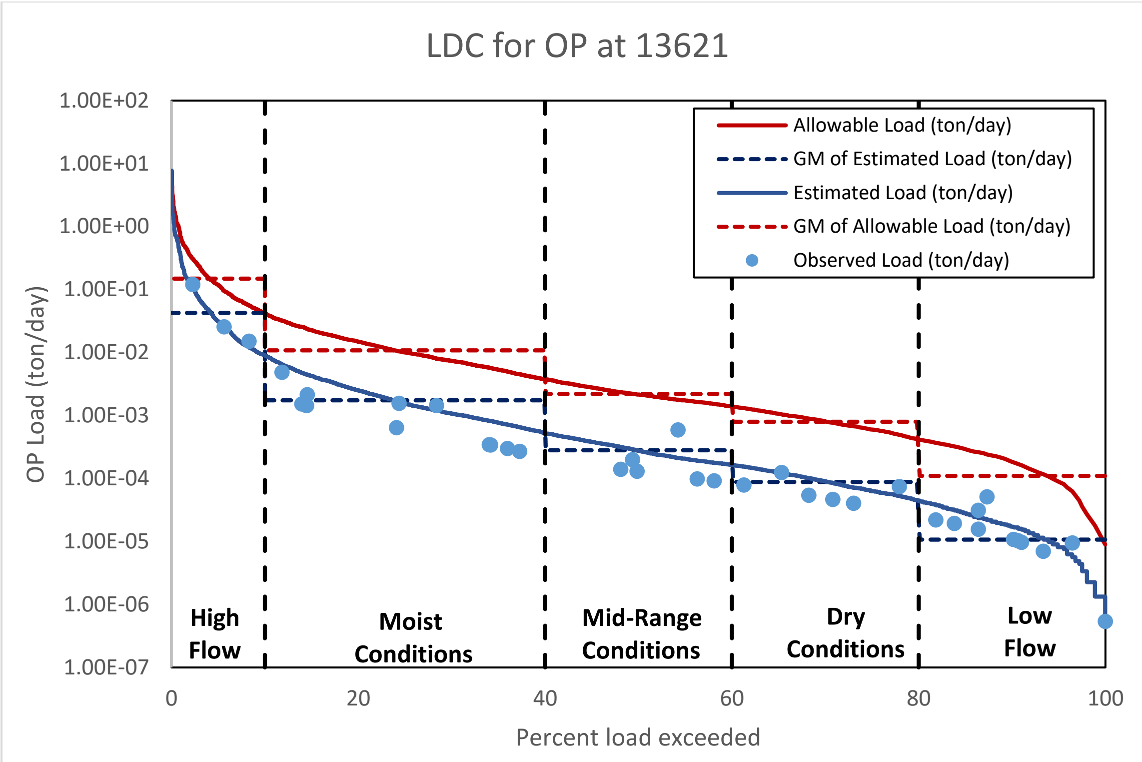

Figure B - 33. LDC for OP at monitoring station 13621.

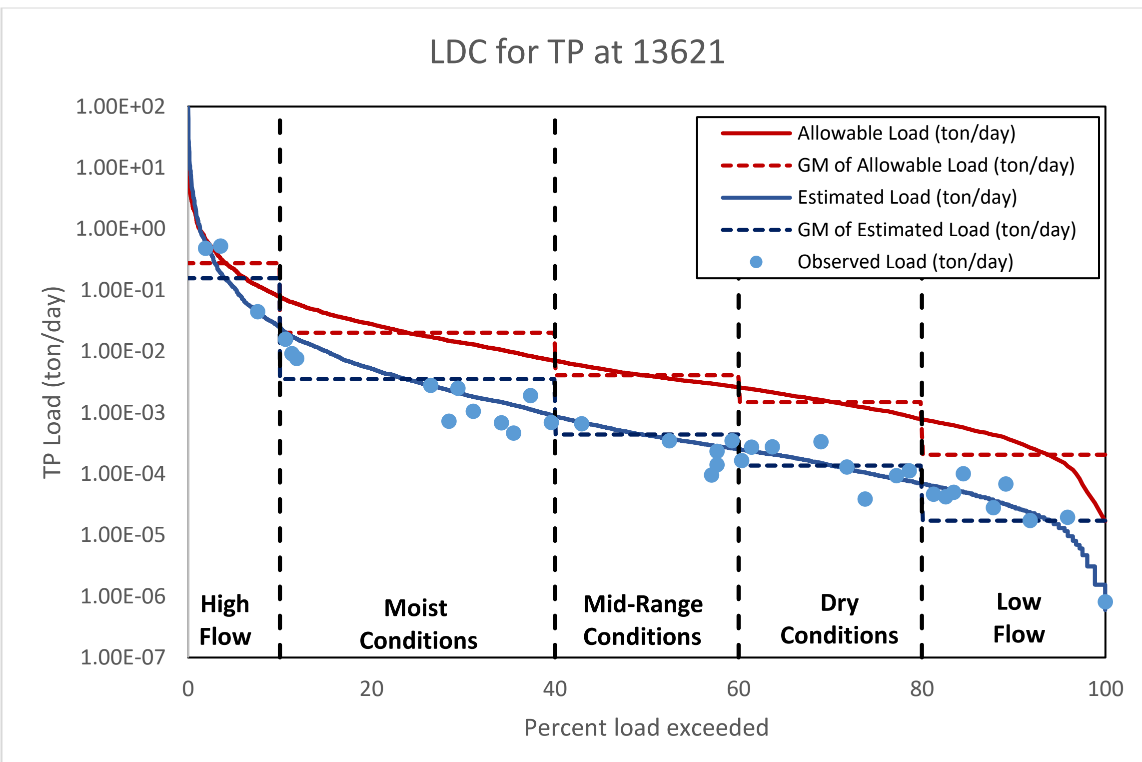

Figure B - 34. LDC for TP at monitoring station 13621.

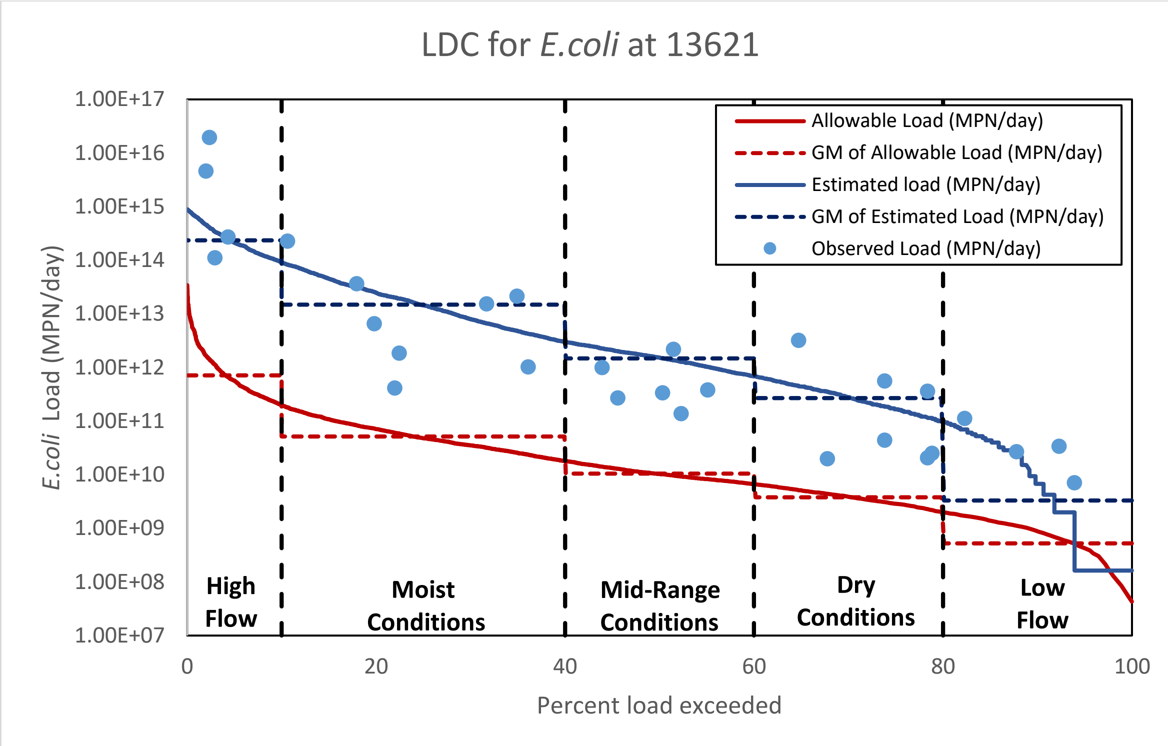

Figure B - 35. LDC for E.coli at monitoring station 13621.

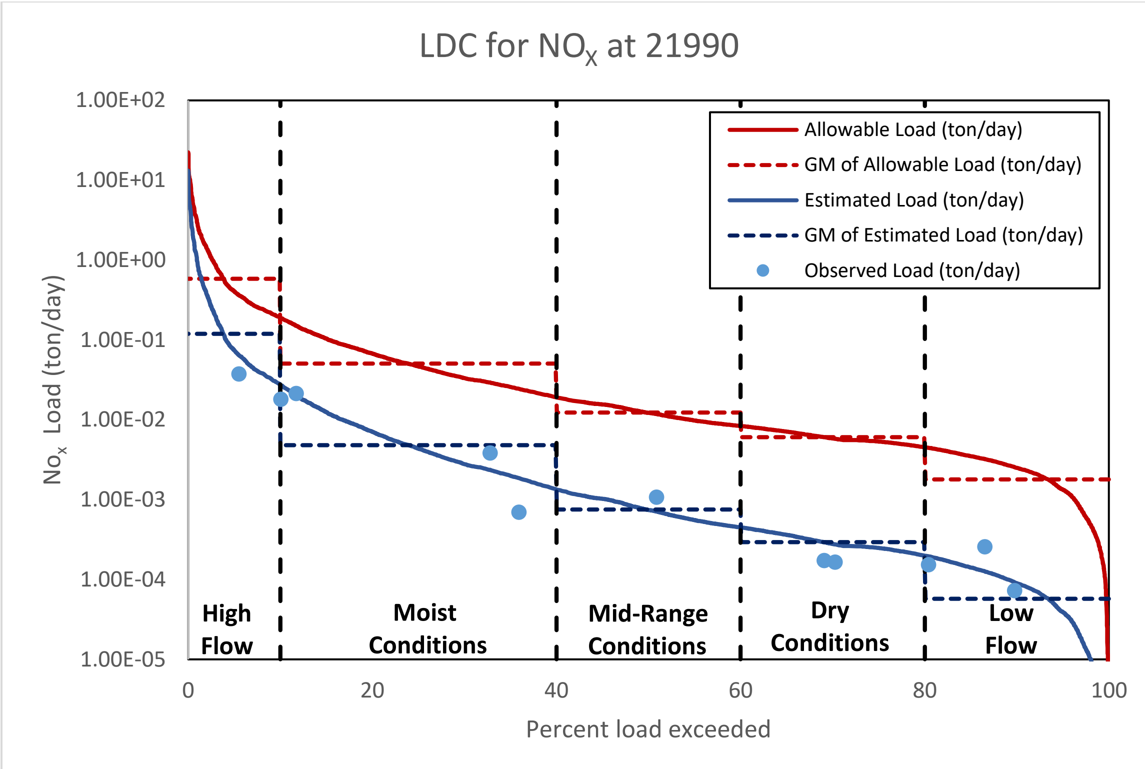

Figure B - 36. LDC for NO_x at monitoring station 21990.

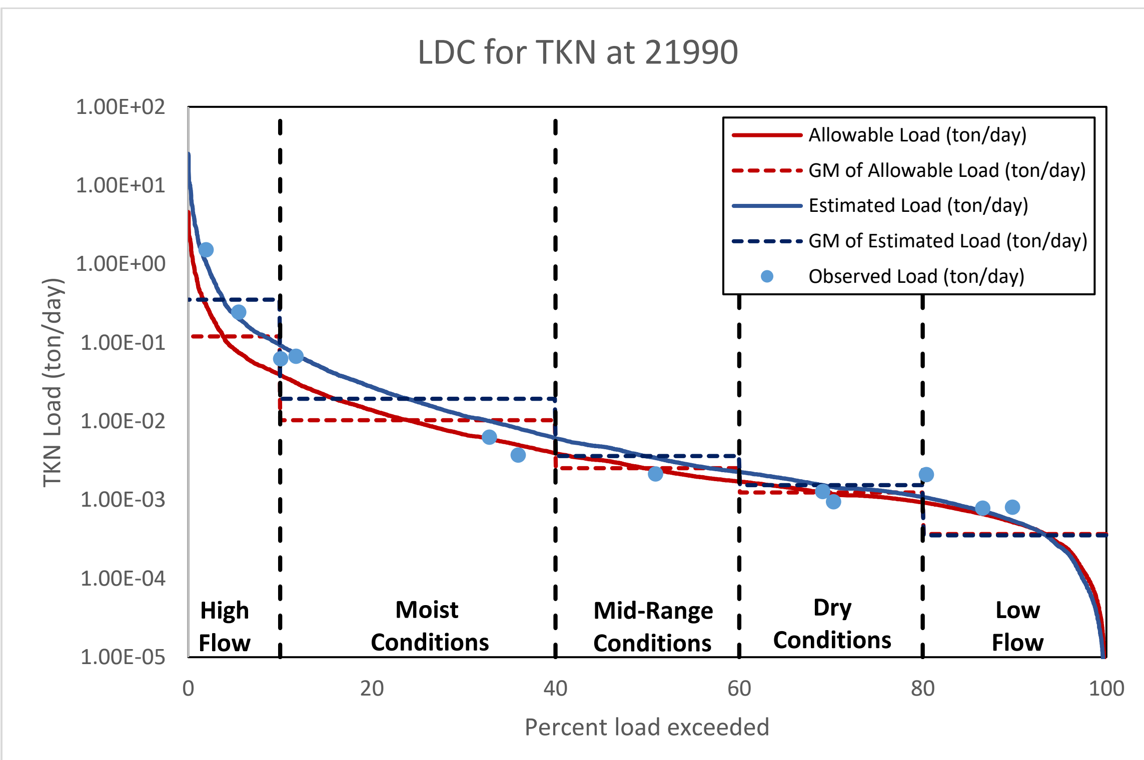

Figure B - 37. LDC for TKN at monitoring station 21990.

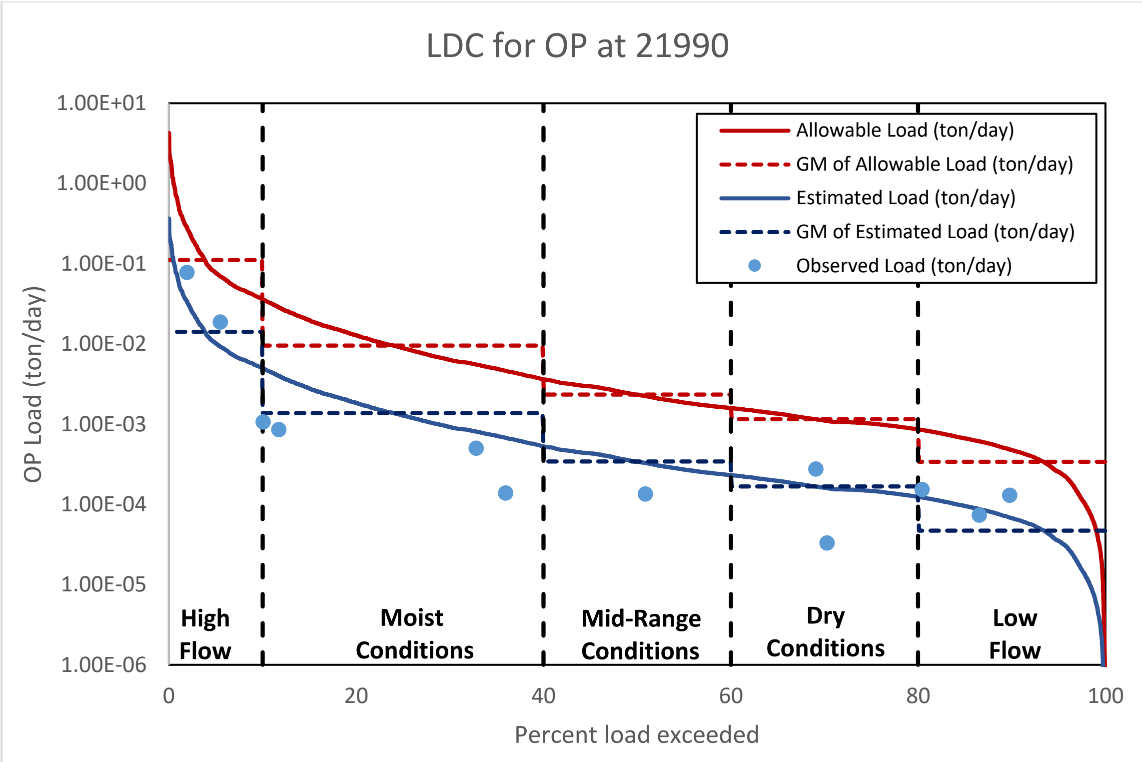

Figure B - 38. LDC for OP at monitoring station 21990.

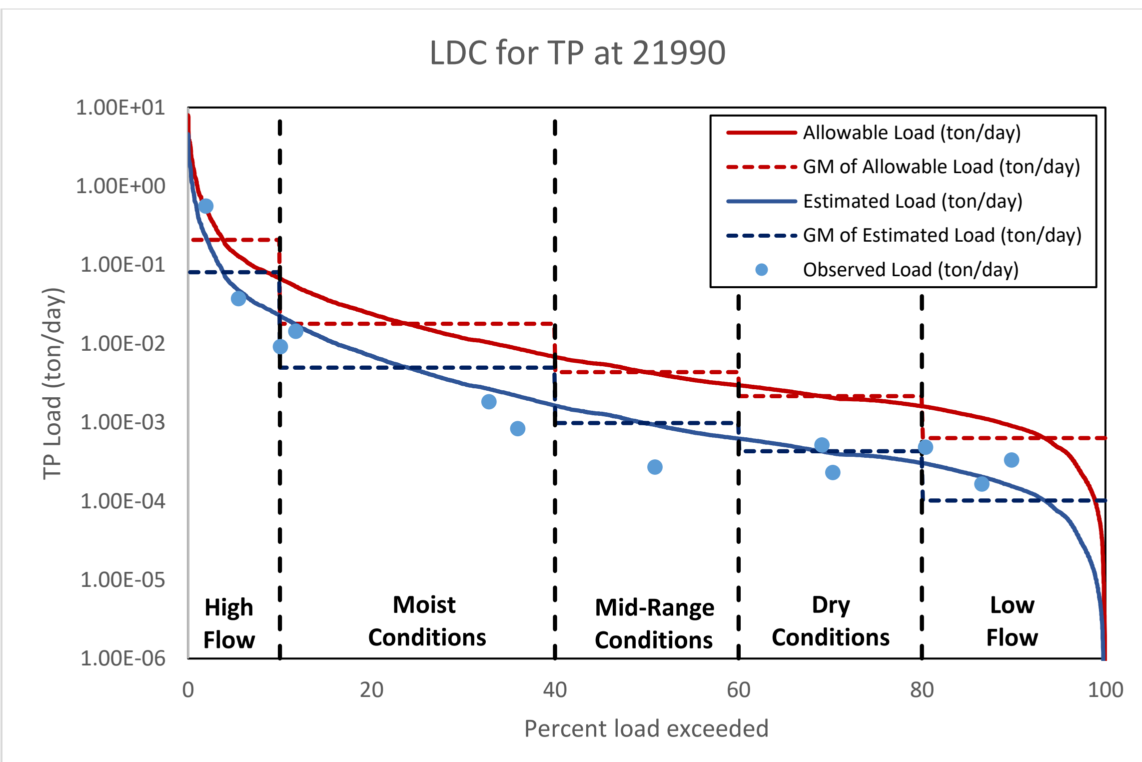

Figure B - 39. LDC for TP at monitoring station 21990.

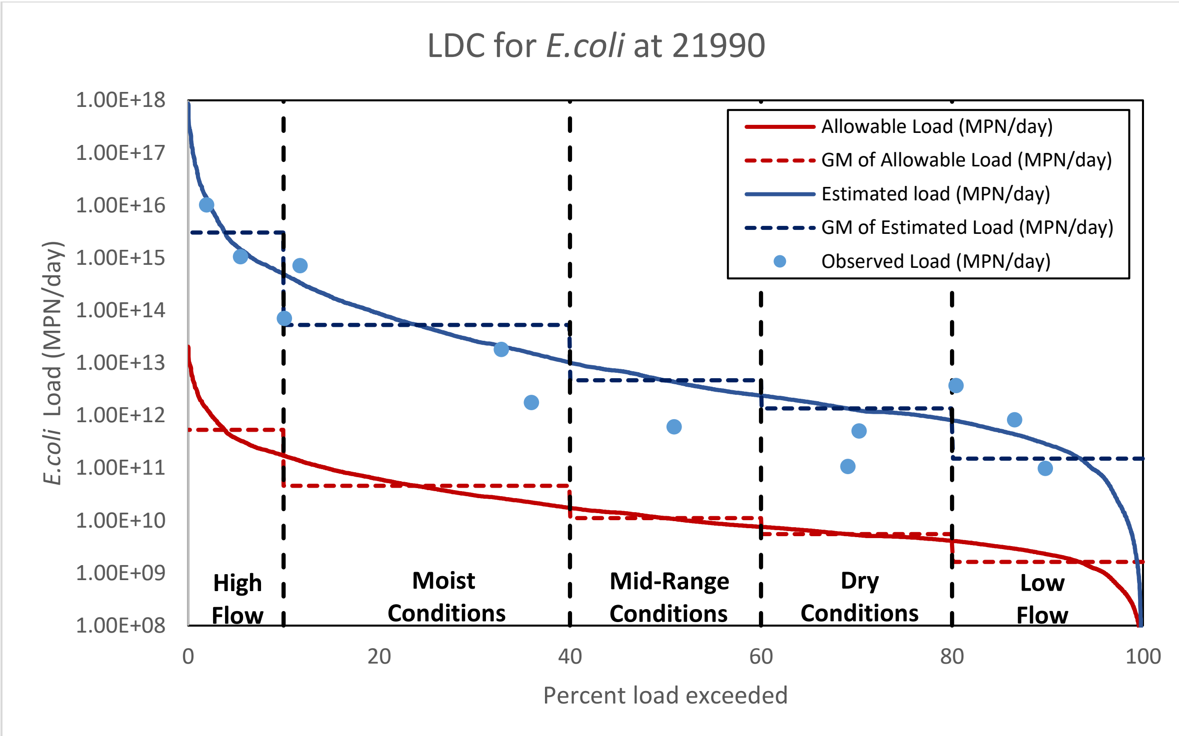

Figure B - 40. LDC for E.coli at monitoring station 21990.

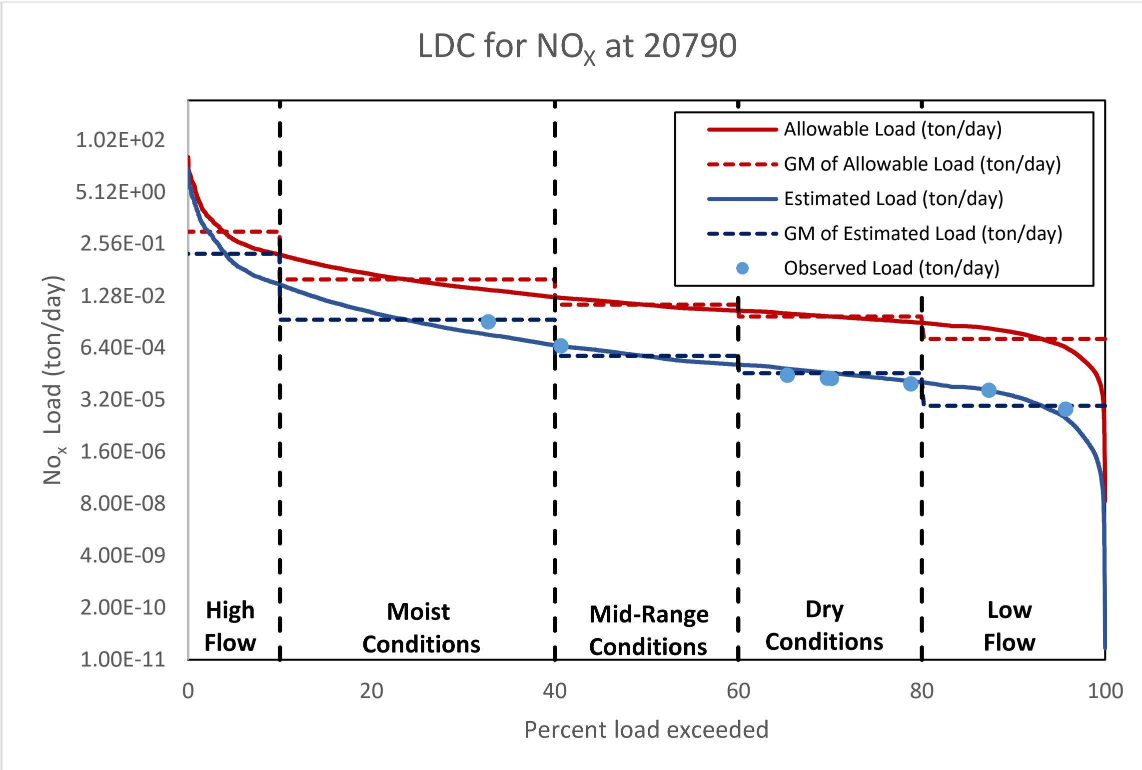

Figure B - 41. LDC for NO_x at monitoring station 20790.

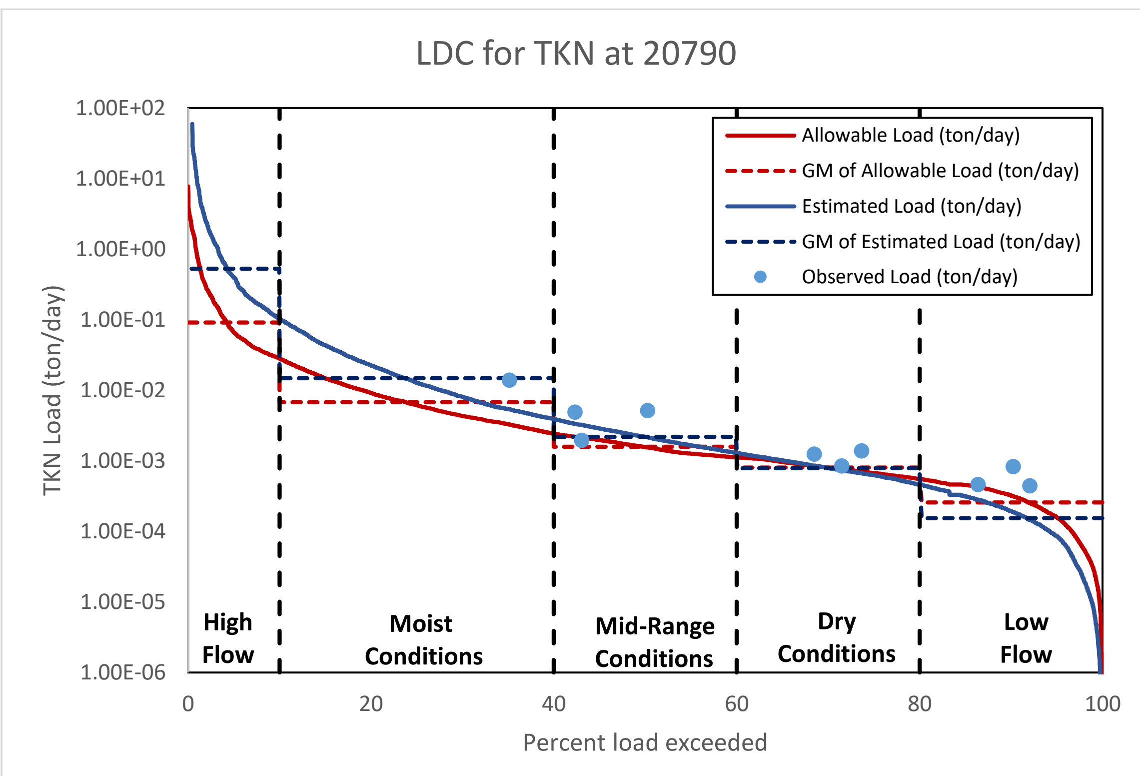

Figure B - 42. LDC for TKN at monitoring station 20790.

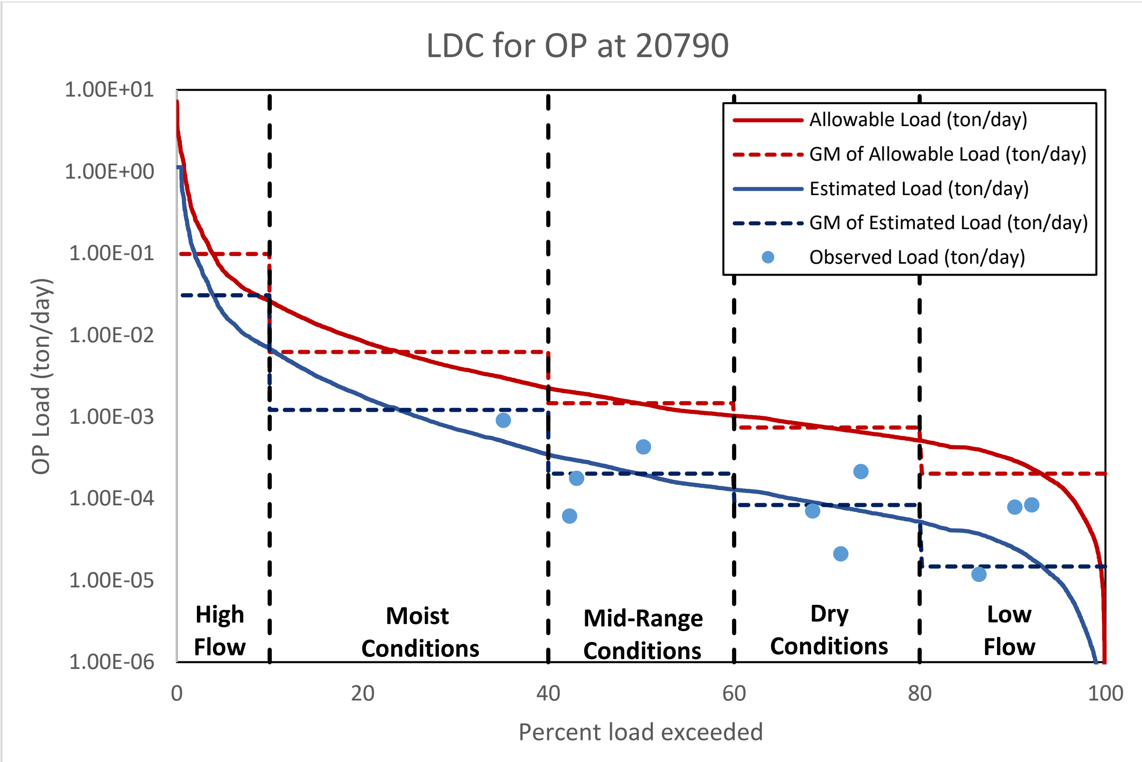

Figure B - 43. LDC for OP at monitoring station 20790.

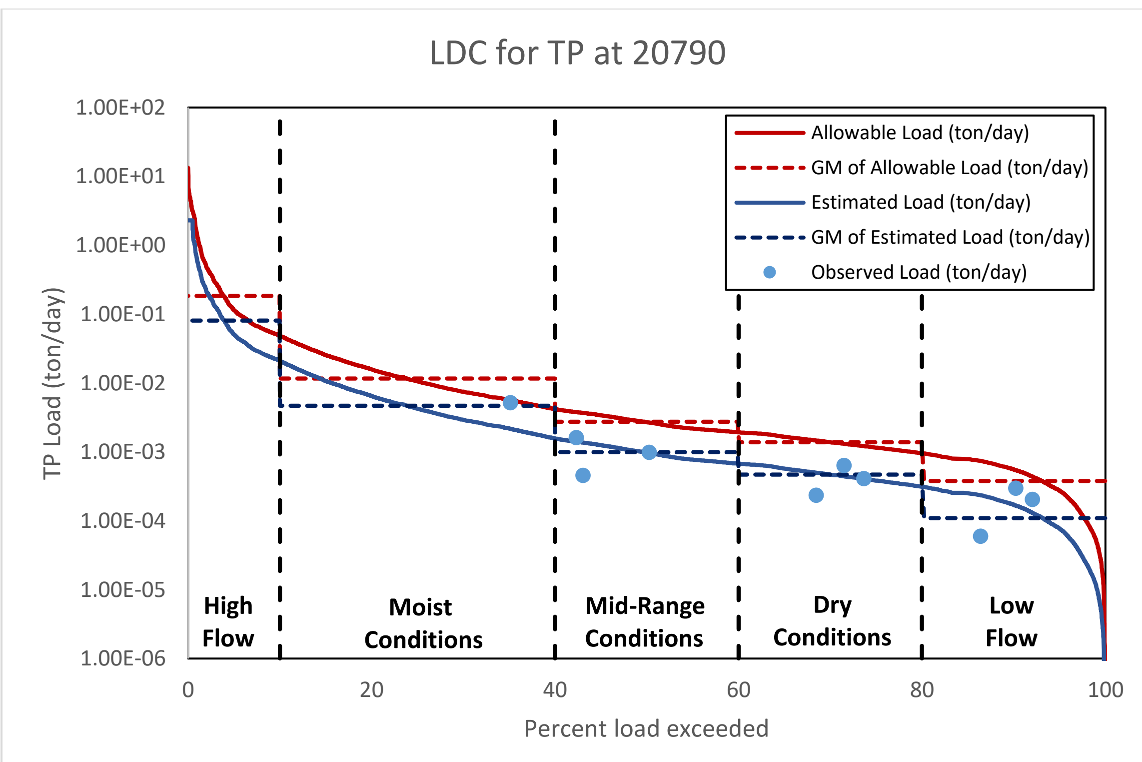

Figure B - 44. LDC for TP at monitoring station 20790.

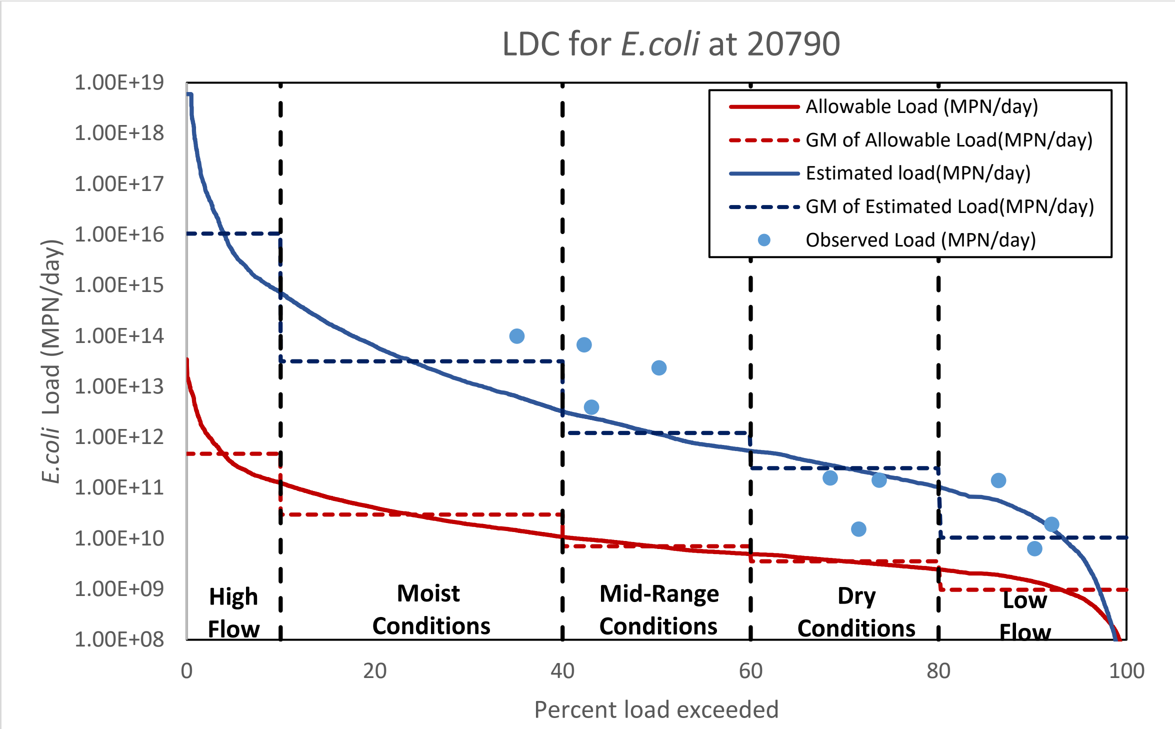

Figure B - 45. LDC for E.coli at monitoring station 20790.

Appendix C. Geometric mean of Nutrient and Bacteria Load

Table C - 1. Geometric mean of Allowable and Estimated Nitrate and Nitrite ($NO_3 + NO_2$) Load at each monitoring station across the JPL at different flow conditions.

Station Number	Flow Condition	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Reduction Needed	Annual Loading (ton/yr)	Annual reduction needed (ton/yr)
16433	High Flow	0-10%	4.92E-01	6.98E-02	-	2.55E+01	-
	Moist Conditions	10-40%	6.93E-02	6.28E-03	-	2.29E+00	-
	Mid-Range Conditions	40-60%	3.74E-02	2.71E-03	-	9.88E-01	-
	Dry Conditions	60-80%	2.75E-02	1.75E-03	-	6.40E-01	-
	Low Flow	80-100%	2.25E-02	1.31E-03	-	4.78E-01	-
22135	High Flow	0-10%	1.15E-01	1.68E-02	-	6.12E+00	-
	Moist Conditions	10-40%	5.06E-03	1.23E-03	-	4.48E-01	-
	Mid-Range Conditions	40-60%	1.01E-03	3.03E-04	-	1.10E-01	-
	Dry Conditions	60-80%	2.80E-04	9.35E-05	-	3.41E-02	-
	Low Flow	80-100%	1.28E-05	5.12E-06	-	1.87E-03	-
22134	High Flow	0-10%	4.92E-01	8.25E-01	40%	3.01E+02	1.22E+02
	Moist Conditions	10-40%	6.94E-02	1.58E-01	56%	5.77E+01	3.24E+01
	Mid-Range Conditions	40-60%	3.75E-02	7.97E-02	53%	2.91E+01	1.54E+01
	Dry Conditions	60-80%	2.76E-02	4.23E-02	35%	1.54E+01	5.35E+00
	Low Flow	80-100%	2.24E-02	2.27E-02	1%	8.30E+00	1.08E-01
16434	High Flow	0-10%	4.92E-01	6.98E-02	-	2.55E+01	-
	Moist Conditions	10-40%	6.93E-02	6.28E-03	-	2.29E+00	-
	Mid-Range Conditions	40-60%	3.74E-02	2.71E-03	-	9.88E-01	-
	Dry Conditions	60-80%	2.75E-02	1.75E-03	-	6.40E-01	-
	Low Flow	80-100%	2.25E-02	1.31E-03	-	4.78E-01	-
13622	High Flow	0-10%	6.30E-01	2.74E-01	-	1.00E+02	-
	Moist Conditions	10-40%	2.76E-02	9.70E-03	-	3.54E+00	-
	Mid-Range Conditions	40-60%	7.43E-03	2.29E-03	-	8.37E-01	-
	Dry Conditions	60-80%	3.51E-03	9.92E-04	-	3.62E-01	-
	Low Flow	80-100%	1.51E-03	3.82E-04	-	1.40E-01	-
22133	High Flow	0-10%	8.68E-02	5.81E-02	-	2.12E+01	-
	Moist Conditions	10-40%	2.65E-03	8.74E-04	-	3.19E-01	-
	Mid-Range Conditions	40-60%	5.54E-04	1.15E-04	-	4.21E-02	-
	Dry Conditions	60-80%	1.64E-04	2.45E-05	-	8.96E-03	-
	Low Flow	80-100%	3.07E-05	2.62E-06	-	9.55E-04	-
13621	High Flow	0-10%	7.84E-01	1.51E+00	48%	5.51E+02	2.65E+02
	Moist Conditions	10-40%	5.69E-02	2.87E-02	-	1.05E+01	-
	Mid-Range Conditions	40-60%	1.16E-02	2.73E-03	-	9.96E-01	-
	Dry Conditions	60-80%	4.19E-03	5.51E-04	-	2.01E-01	-
	Low Flow	80-100%	5.79E-04	2.82E-05	-	1.03E-02	-
21990	High Flow	0-10%	5.86E-01	1.19E-01	-	4.35E+01	-
	Moist Conditions	10-40%	5.04E-02	4.82E-03	-	1.76E+00	-
	Mid-Range Conditions	40-60%	1.23E-02	7.51E-04	-	2.74E-01	-
	Dry Conditions	60-80%	6.08E-03	2.94E-04	-	1.07E-01	-
	Low Flow	80-100%	1.79E-03	5.76E-05	-	2.10E-02	-
20790	High Flow	0-10%	5.18E-01	1.45E-01	-	5.28E+01	-
	Moist Conditions	10-40%	3.29E-02	3.21E-03	-	1.17E+00	-
	Mid-Range Conditions	40-60%	7.72E-03	4.01E-04	-	1.46E-01	-
	Dry Conditions	60-80%	3.89E-03	1.49E-04	-	5.45E-02	-
	Low Flow	80-100%	1.07E-03	2.27E-05	-	8.28E-03	-

Table C - 2. Geometric mean of Allowable and Estimated TKN Load at each monitoring station across the JPL watershed at different flow conditions.

Station Number	Flow Condition	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Reduction Needed	Annual Loading (ton/yr)	Annual reduction needed (ton/yr)
16433	High Flow	0-10%	9.61E-03	2.18E-02	56%	7.94E+00	4.44E+00
	Moist Conditions	10-40%	2.06E-03	3.81E-03	46%	1.39E+00	6.38E-01
	Mid-Range Conditions	40-60%	8.26E-04	1.27E-03	35%	4.64E-01	1.63E-01
	Dry Conditions	60-80%	2.87E-04	3.97E-04	28%	1.45E-01	4.02E-02
	Low Flow	80-100%	2.15E-05	2.66E-05	19%	9.69E-03	1.86E-03
22135	High Flow	0-10%	2.37E-02	4.75E-02	50%	1.73E+01	8.69E+00
	Moist Conditions	10-40%	1.04E-03	1.48E-03	30%	5.40E-01	1.61E-01
	Mid-Range Conditions	40-60%	2.07E-04	2.45E-04	16%	8.94E-02	1.39E-02
	Dry Conditions	60-80%	5.75E-05	5.85E-05	2%	2.14E-02	3.80E-04
	Low Flow	80-100%	2.62E-06	1.82E-06	-	6.63E-04	-
22134	High Flow	0-10%	1.01E-01	3.88E-01	74%	1.42E+02	1.05E+02
	Moist Conditions	10-40%	1.42E-02	5.44E-02	74%	1.99E+01	1.47E+01
	Mid-Range Conditions	40-60%	7.69E-03	2.91E-02	74%	1.06E+01	7.82E+00
	Dry Conditions	60-80%	5.66E-03	2.13E-02	73%	7.78E+00	5.71E+00
	Low Flow	80-100%	4.60E-03	1.72E-02	73%	6.29E+00	4.61E+00
16434	High Flow	0-10%	1.01E-01	1.48E-01	32%	5.39E+01	1.71E+01
	Moist Conditions	10-40%	1.42E-02	2.46E-02	42%	8.98E+00	3.79E+00
	Mid-Range Conditions	40-60%	7.68E-03	1.11E-02	31%	4.07E+00	1.26E+00
	Dry Conditions	60-80%	5.65E-03	7.20E-03	22%	2.63E+00	5.68E-01
	Low Flow	80-100%	4.61E-03	5.33E-03	14%	1.94E+00	2.63E-01
13622	High Flow	0-10%	1.29E-01	1.96E-01	34%	7.16E+01	2.44E+01
	Moist Conditions	10-40%	5.65E-03	1.12E-02	50%	4.10E+00	2.04E+00
	Mid-Range Conditions	40-60%	1.52E-03	2.92E-03	48%	1.07E+00	5.11E-01
	Dry Conditions	60-80%	7.20E-04	1.32E-03	45%	4.80E-01	2.18E-01
	Low Flow	80-100%	3.09E-04	5.27E-04	41%	1.92E-01	7.95E-02
22133	High Flow	0-10%	1.78E-02	5.05E-02	65%	1.84E+01	1.19E+01
	Moist Conditions	10-40%	5.45E-04	6.81E-04	20%	2.49E-01	5.00E-02
	Mid-Range Conditions	40-60%	1.14E-04	1.18E-04	4%	4.31E-02	1.56E-03
	Dry Conditions	60-80%	3.37E-05	3.35E-05	-	1.22E-02	-
	Low Flow	80-100%	6.30E-06	6.63E-06	5%	2.42E-03	1.21E-04
13621	High Flow	0-10%	1.61E-01	5.17E-01	69%	1.89E+02	1.30E+02
	Moist Conditions	10-40%	1.17E-02	2.39E-02	51%	8.73E+00	4.48E+00
	Mid-Range Conditions	40-60%	2.37E-03	4.06E-03	42%	1.48E+00	6.16E-01
	Dry Conditions	60-80%	8.59E-04	1.37E-03	37%	5.00E-01	1.87E-01
	Low Flow	80-100%	1.19E-04	1.85E-04	36%	6.74E-02	2.40E-02
21990	High Flow	0-10%	1.20E-01	3.52E-01	66%	1.29E+02	8.47E+01
	Moist Conditions	10-40%	1.03E-02	1.93E-02	46%	7.05E+00	3.27E+00
	Mid-Range Conditions	40-60%	2.53E-03	3.60E-03	30%	1.32E+00	3.93E-01
	Dry Conditions	60-80%	1.25E-03	1.55E-03	19%	5.64E-01	1.09E-01
	Low Flow	80-100%	3.68E-04	3.56E-04	-	1.30E-01	-
20790	High Flow	0-10%	9.08E-02	5.25E-01	83%	1.92E+02	1.59E+02
	Moist Conditions	10-40%	6.75E-03	1.48E-02	54%	5.40E+00	2.93E+00
	Mid-Range Conditions	40-60%	1.58E-03	2.19E-03	28%	7.99E-01	2.21E-01
	Dry Conditions	60-80%	7.99E-04	7.85E-04	-	2.87E-01	-
	Low Flow	80-100%	2.58E-04	1.54E-04	-	5.62E-02	-

Table C - 3. Geometric mean of Allowable and Estimated Ortho-phosphate phosphorus (OP) Load at each monitoring station across the JPL Watershed at different flow conditions.

Station Number	Flow Condition	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Reduction Needed	Annual Loading (ton/yr)	Annual reduction needed (ton/yr)
16433	High Flow	0-10%	8.89E-03	2.03E-01	96%	7.42E+01	7.10E+01
	Moist Conditions	10-40%	1.91E-03	1.81E-03	-	6.59E-01	-
	Mid-Range Conditions	40-60%	7.64E-04	1.28E-04	-	4.67E-02	-
	Dry Conditions	60-80%	2.65E-04	1.75E-05	-	6.40E-03	-
	Low Flow	80-100%	2.54E-05	-	-	-	-
22135	High Flow	0-10%	2.19E-02	1.06E-03	-	3.88E-01	-
	Moist Conditions	10-40%	9.60E-04	3.16E-05	-	1.15E-02	-
	Mid-Range Conditions	40-60%	1.91E-04	5.57E-06	-	2.03E-03	-
	Dry Conditions	60-80%	5.32E-05	1.48E-06	-	5.42E-04	-
	Low Flow	80-100%	2.42E-06	7.36E-08	-	2.69E-05	-
22134	High Flow	0-10%	9.33E-02	2.10E-02	-	7.66E+00	-
	Moist Conditions	10-40%	1.32E-02	7.17E-03	-	2.62E+00	-
	Mid-Range Conditions	40-60%	7.11E-03	5.93E-03	-	2.16E+00	-
	Dry Conditions	60-80%	5.24E-03	5.48E-03	4%	2.00E+00	8.85E-02
	Low Flow	80-100%	4.26E-03	5.20E-03	18%	1.90E+00	3.44E-01
16434	High Flow	0-10%	9.34E-02	6.22E-03	-	2.27E+00	-
	Moist Conditions	10-40%	1.32E-02	1.08E-03	-	3.95E-01	-
	Mid-Range Conditions	40-60%	7.10E-03	5.86E-04	-	2.14E-01	-
	Dry Conditions	60-80%	5.22E-03	4.26E-04	-	1.55E-01	-
	Low Flow	80-100%	4.26E-03	3.44E-04	-	1.26E-01	-
13622	High Flow	0-10%	1.19E-01	2.12E-02	-	7.73E+00	-
	Moist Conditions	10-40%	5.23E-03	7.82E-04	-	2.85E-01	-
	Mid-Range Conditions	40-60%	1.41E-03	1.92E-04	-	7.00E-02	-
	Dry Conditions	60-80%	6.66E-04	8.53E-05	-	3.11E-02	-
	Low Flow	80-100%	2.86E-04	3.40E-05	-	1.24E-02	-
22133	High Flow	0-10%	1.65E-02	1.90E-03	-	6.92E-01	-
	Moist Conditions	10-40%	5.04E-04	3.62E-05	-	1.32E-02	-
	Mid-Range Conditions	40-60%	1.05E-04	6.73E-06	-	2.46E-03	-
	Dry Conditions	60-80%	3.12E-05	1.93E-06	-	7.03E-04	-
	Low Flow	80-100%	5.82E-06	3.65E-07	-	1.33E-04	-
13621	High Flow	0-10%	1.49E-01	4.28E-02	-	1.56E+01	-
	Moist Conditions	10-40%	1.08E-02	1.75E-03	-	6.38E-01	-
	Mid-Range Conditions	40-60%	2.19E-03	2.81E-04	-	1.03E-01	-
	Dry Conditions	60-80%	7.94E-04	8.85E-05	-	3.23E-02	-
	Low Flow	80-100%	1.10E-04	1.07E-05	-	3.91E-03	-
21990	High Flow	0-10%	1.11E-01	1.42E-02	-	5.17E+00	-
	Moist Conditions	10-40%	9.56E-03	1.38E-03	-	5.02E-01	-
	Mid-Range Conditions	40-60%	2.34E-03	3.42E-04	-	1.25E-01	-
	Dry Conditions	60-80%	1.15E-03	1.67E-04	-	6.11E-02	-
	Low Flow	80-100%	3.40E-04	4.70E-05	-	1.72E-02	-
20790	High Flow	0-10%	9.82E-02	3.06E-02	-	1.12E+01	-
	Moist Conditions	10-40%	6.24E-03	1.22E-03	-	4.46E-01	-
	Mid-Range Conditions	40-60%	1.46E-03	2.01E-04	-	7.35E-02	-
	Dry Conditions	60-80%	7.39E-04	8.36E-05	-	3.05E-02	-
	Low Flow	80-100%	2.03E-04	1.48E-05	-	5.41E-03	-

Table C - 4. Geometric mean of Allowable and Estimated Total Phosphorous (TP) Load at each monitoring station across the JPL Watershed at different flow conditions.

Station Number	Flow Condition	% of Time Flow Exceeds	Allowable Loading (ton/day)	Daily Loading (ton/day)	% Daily Reduction Needed	Annual Loading (ton/yr)	Annual reduction needed (ton/yr)
16433	High Flow	0-10%	1.74E-01	4.64E-02	-	1.69E+01	-
	Moist Conditions	10-40%	2.45E-02	5.62E-03	-	2.05E+00	-
	Mid-Range Conditions	40-60%	1.32E-02	1.40E-03	-	5.11E-01	-
	Dry Conditions	60-80%	9.74E-03	6.39E-04	-	2.33E-01	-
	Low Flow	80-100%	7.95E-03	2.11E-04	-	7.71E-02	-
22135	High Flow	0-10%	4.09E-02	1.90E-02	-	6.95E+00	-
	Moist Conditions	10-40%	1.79E-03	1.43E-04	-	5.22E-02	-
	Mid-Range Conditions	40-60%	3.57E-04	1.44E-05	-	5.24E-03	-
	Dry Conditions	60-80%	9.92E-05	2.82E-06	-	1.03E-03	-
	Low Flow	80-100%	4.51E-06	1.09E-07	-	3.98E-05	-
22134	High Flow	0-10%	1.74E-01	1.17E-01	-	4.27E+01	-
	Moist Conditions	10-40%	2.46E-02	2.00E-02	-	7.29E+00	-
	Mid-Range Conditions	40-60%	1.33E-02	1.13E-02	-	4.11E+00	-
	Dry Conditions	60-80%	9.77E-03	8.44E-03	-	3.08E+00	-
	Low Flow	80-100%	7.94E-03	6.94E-03	-	2.53E+00	-
16434	High Flow	0-10%	1.74E-01	4.64E-02	-	1.69E+01	-
	Moist Conditions	10-40%	2.45E-02	5.62E-03	-	2.05E+00	-
	Mid-Range Conditions	40-60%	1.32E-02	1.40E-03	-	5.11E-01	-
	Dry Conditions	60-80%	9.74E-03	6.39E-04	-	2.33E-01	-
	Low Flow	80-100%	7.95E-03	2.11E-04	-	7.71E-02	-
13622	High Flow	0-10%	2.23E-01	4.94E-02	-	1.80E+01	-
	Moist Conditions	10-40%	9.75E-03	1.85E-03	-	6.76E-01	-
	Mid-Range Conditions	40-60%	2.63E-03	4.63E-04	-	1.69E-01	-
	Dry Conditions	60-80%	1.24E-03	2.09E-04	-	7.61E-02	-
	Low Flow	80-100%	5.33E-04	8.47E-05	-	3.09E-02	-
22133	High Flow	0-10%	3.07E-02	9.09E-03	-	3.32E+00	-
	Moist Conditions	10-40%	9.39E-04	8.65E-05	-	3.16E-02	-
	Mid-Range Conditions	40-60%	1.96E-04	1.28E-05	-	4.68E-03	-
	Dry Conditions	60-80%	5.82E-05	3.25E-06	-	1.19E-03	-
	Low Flow	80-100%	1.09E-05	5.46E-07	-	1.99E-04	-
13621	High Flow	0-10%	2.77E-01	1.57E-01	-	5.73E+01	-
	Moist Conditions	10-40%	2.01E-02	3.52E-03	-	1.28E+00	-
	Mid-Range Conditions	40-60%	4.09E-03	4.41E-04	-	1.61E-01	-
	Dry Conditions	60-80%	1.48E-03	1.36E-04	-	4.96E-02	-
	Low Flow	80-100%	2.05E-04	1.71E-05	-	6.25E-03	-
21990	High Flow	0-10%	2.07E-01	8.06E-02	-	2.94E+01	-
	Moist Conditions	10-40%	1.78E-02	4.97E-03	-	1.81E+00	-
	Mid-Range Conditions	40-60%	4.36E-03	9.78E-04	-	3.57E-01	-
	Dry Conditions	60-80%	2.15E-03	4.29E-04	-	1.57E-01	-
	Low Flow	80-100%	6.34E-04	1.02E-04	-	3.71E-02	-
20790	High Flow	0-10%	9.82E-02	3.06E-02	-	1.12E+01	-
	Moist Conditions	10-40%	6.24E-03	1.22E-03	-	4.46E-01	-
	Mid-Range Conditions	40-60%	1.46E-03	2.01E-04	-	7.35E-02	-
	Dry Conditions	60-80%	7.39E-04	8.36E-05	-	3.05E-02	-
	Low Flow	80-100%	2.03E-04	1.48E-05	-	5.41E-03	-

Table C - 5. Geometric mean of Allowable and Estimated E.coli Load at each monitoring station across the JPL Watershed at different flow conditions in MPN/day.

Station Number	Flow Condition	% of Time Flow Exceeds	Allowable Loading (MPN/day)	Daily Loading (MPN/day)	% Daily Reduction Needed	Annual Loading (MPN/yr)	Annual reduction needed (MPN/yr)
16433	High Flow	0-10%	2.74E+11	1.04E+13	97%	3.79E+15	3.69E+15
	Moist Conditions	10-40%	5.88E+10	8.88E+11	93%	3.24E+14	3.02E+14
	Mid-Range Conditions	40-60%	2.36E+10	1.80E+11	87%	6.58E+13	5.72E+13
	Dry Conditions	60-80%	8.19E+9	3.22E+10	75%	1.17E+13	8.77E+12
	Low Flow	80-100%	6.14E+08	4.09E+08	-	1.49E+11	-
22135	High Flow	0-10%	6.77E+11	2.66E+14	100%	9.72E+16	9.70E+16
	Moist Conditions	10-40%	2.97E+10	1.84E+12	98%	6.71E+14	6.60E+14
	Mid-Range Conditions	40-60%	5.91E+09	1.37E+11	96%	5.02E+13	4.80E+13
	Dry Conditions	60-80%	1.64E+09	1.73E+10	91%	6.33E+12	5.73E+12
	Low Flow	80-100%	7.48E+07	1.11E+08	33%	4.05E+10	1.32E+10
22134	High Flow	0-10%	2.88E+12	4.29E+14	99%	1.57E+17	1.55E+17
	Moist Conditions	10-40%	4.07E+11	7.93E+12	95%	2.90E+15	2.75E+15
	Mid-Range Conditions	40-60%	2.20E+11	2.33E+12	91%	8.50E+14	7.70E+14
	Dry Conditions	60-80%	1.62E+11	1.49E+12	89%	5.45E+14	4.86E+14
	Low Flow	80-100%	1.31E+11	7.20E+11	82%	2.63E+14	2.15E+14
16434	High Flow	0-10%	2.88E+12	8.79E+14	100%	3.21E+17	3.20E+17
	Moist Conditions	10-40%	4.06E+11	1.81E+13	98%	6.61E+15	6.46E+15
	Mid-Range Conditions	40-60%	2.19E+11	2.93E+12	93%	1.07E+15	9.88E+14
	Dry Conditions	60-80%	1.61E+11	1.03E+12	84%	3.78E+14	3.19E+14
	Low Flow	80-100%	1.32E+11	4.97E+11	74%	1.82E+14	1.33E+14
13622	High Flow	0-10%	3.69E+13	1.38E+15	97%	5.04E+17	4.90E+17
	Moist Conditions	10-40%	1.61E+12	1.74E+13	91%	6.35E+15	5.76E+15
	Mid-Range Conditions	40-60%	4.35E+11	2.67E+12	84%	9.76E+14	8.17E+14
	Dry Conditions	60-80%	2.06E+11	9.04E+11	77%	3.30E+14	2.55E+14
	Low Flow	80-100%	8.83E+10	2.64E+11	67%	9.63E+13	6.40E+13
22133	High Flow	0-10%	7.87E+10	1.33E+14	100%	4.84E+16	4.84E+16
	Moist Conditions	10-40%	2.41E+09	5.81E+11	100%	2.12E+14	2.11E+14
	Mid-Range Conditions	40-60%	5.03E+08	4.42E+10	99%	1.61E+13	1.60E+13
	Dry Conditions	60-80%	1.49E+08	6.36E+09	98%	2.32E+12	2.27E+12
	Low Flow	80-100%	2.78E+07	4.40E+08	94%	1.61E+11	1.50E+11
13621	High Flow	0-10%	7.11E+11	2.37E+14	100%	8.64E+16	8.62E+16
	Moist Conditions	10-40%	5.19E+10	1.48E+13	100%	5.40E+15	5.38E+15
	Mid-Range Conditions	40-60%	1.05E+10	1.48E+12	99%	5.41E+14	5.37E+14
	Dry Conditions	60-80%	3.80E+09	2.69E+11	99%	9.83E+13	9.69E+13
	Low Flow	80-100%	5.25E+08	3.33E+09	84%	1.21E+12	1.02E+12
21990	High Flow	0-10%	5.31E+11	3.04E+15	100%	1.11E+18	1.11E+18
	Moist Conditions	10-40%	4.57E+10	5.29E+13	100%	1.93E+16	1.93E+16
	Mid-Range Conditions	40-60%	1.12E+10	4.71E+12	100%	1.72E+15	1.72E+15
	Dry Conditions	60-80%	5.51E+09	1.36E+12	100%	4.97E+14	4.95E+14
	Low Flow	80-100%	1.63E+09	1.51E+11	99%	5.53E+13	5.47E+13
20790	High Flow	0-10%	4.70E+11	1.05E+16	100%	3.84E+18	3.84E+18
	Moist Conditions	10-40%	2.98E+10	3.17E+13	100%	1.16E+16	1.16E+16
	Mid-Range Conditions	40-60%	7.00E+09	1.21E+12	99%	4.41E+14	4.38E+14
	Dry Conditions	60-80%	3.53E+09	2.44E+11	99%	8.91E+13	8.78E+13
	Low Flow	80-100%	9.69E+08	1.04E+10	91%	3.80E+12	3.44E+12

Appendix D. Site Summaries for *E.coli* and Streamflow

Figure D - 1 through Figure D - 8 correlate flow and *E. coli* measurements to rainfall events. Flow is represented by black horizontal bars and *E. coli* is represented by the horizontal bars. The red dotted line represents the water quality criteria for *E. coli* (126 MPN/100 mL), which is technically only appropriate for geomean measurements, but is shown here for a rough comparison.

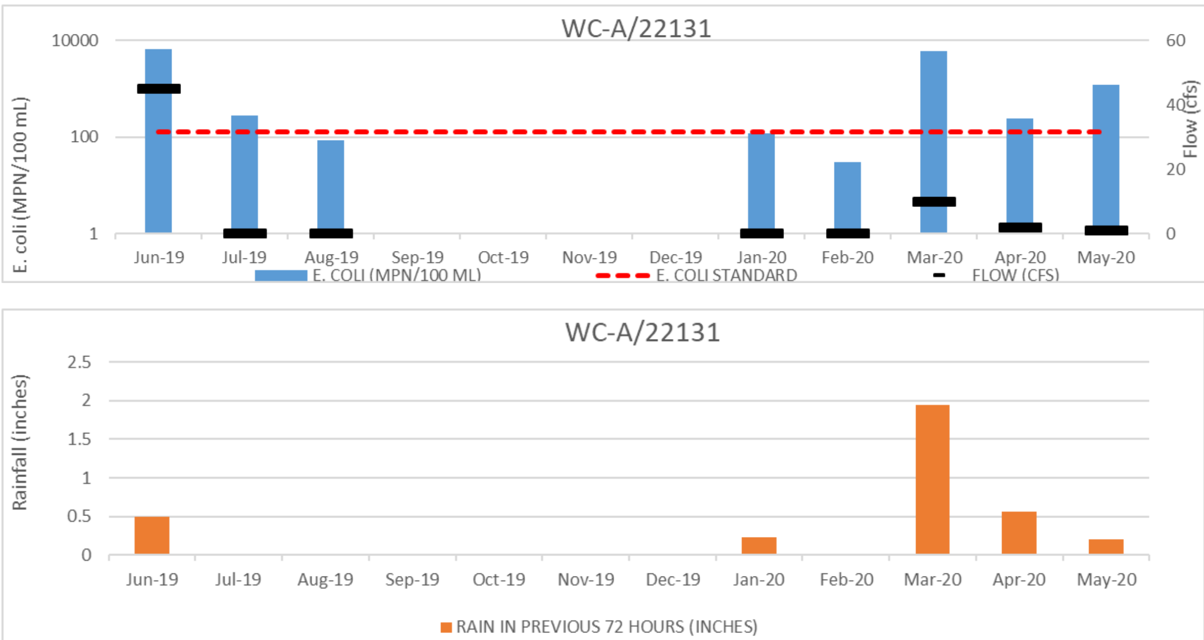

Figure D - 1. Hydrology and E.coli parameters, Walnut Creek @ FM 2738 (22131).

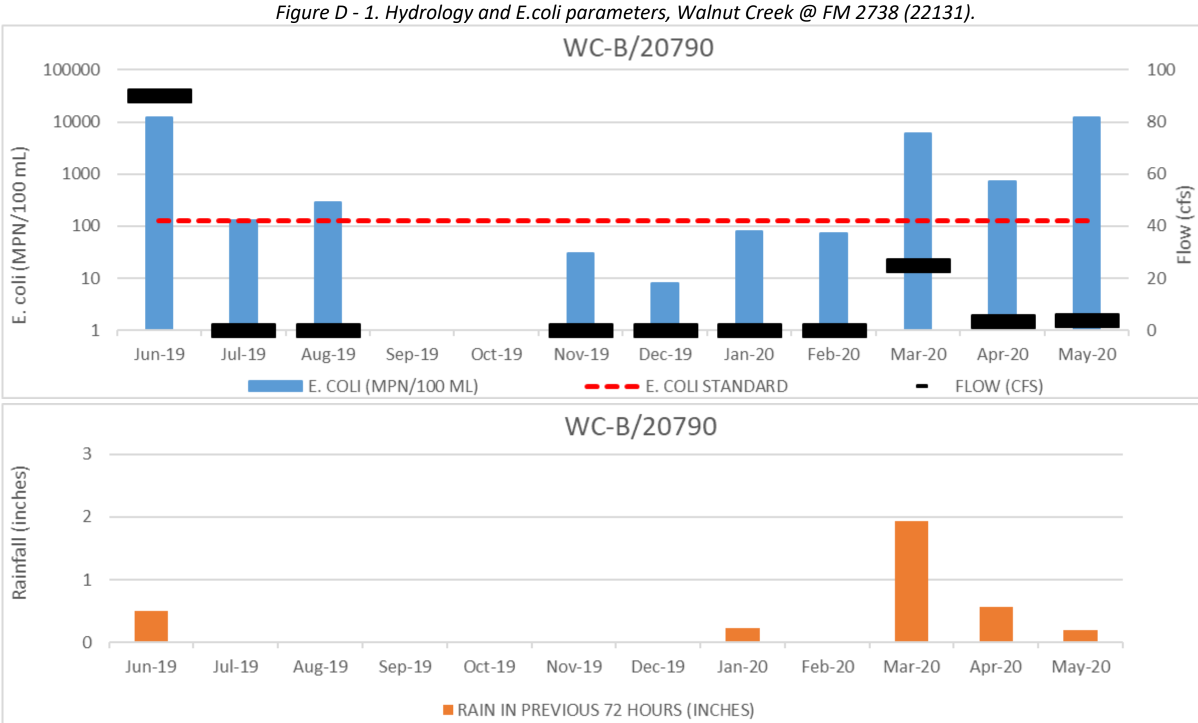

Figure D - 2. Hydrology and E.coli parameters, Walnut Creek @ Retta Road (20790).

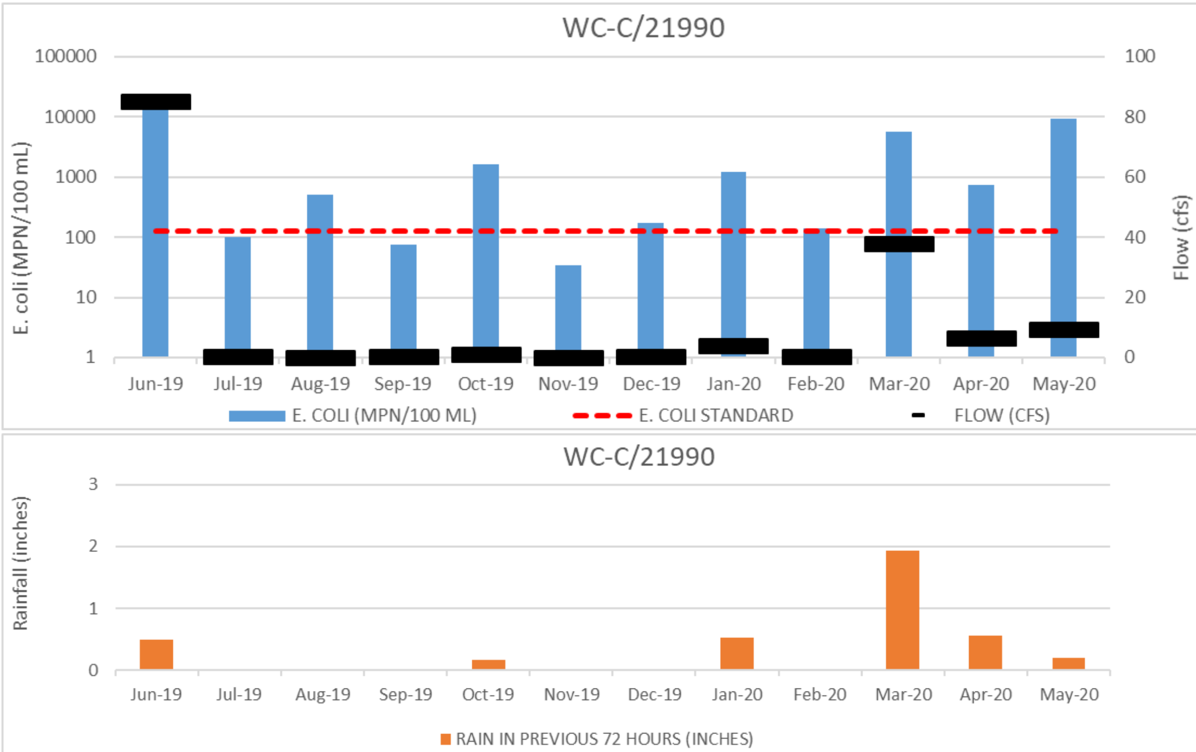

Figure D - 3. Hydrology and E.coli parameters, Walnut Creek @ Katherine Rose Park(21990).

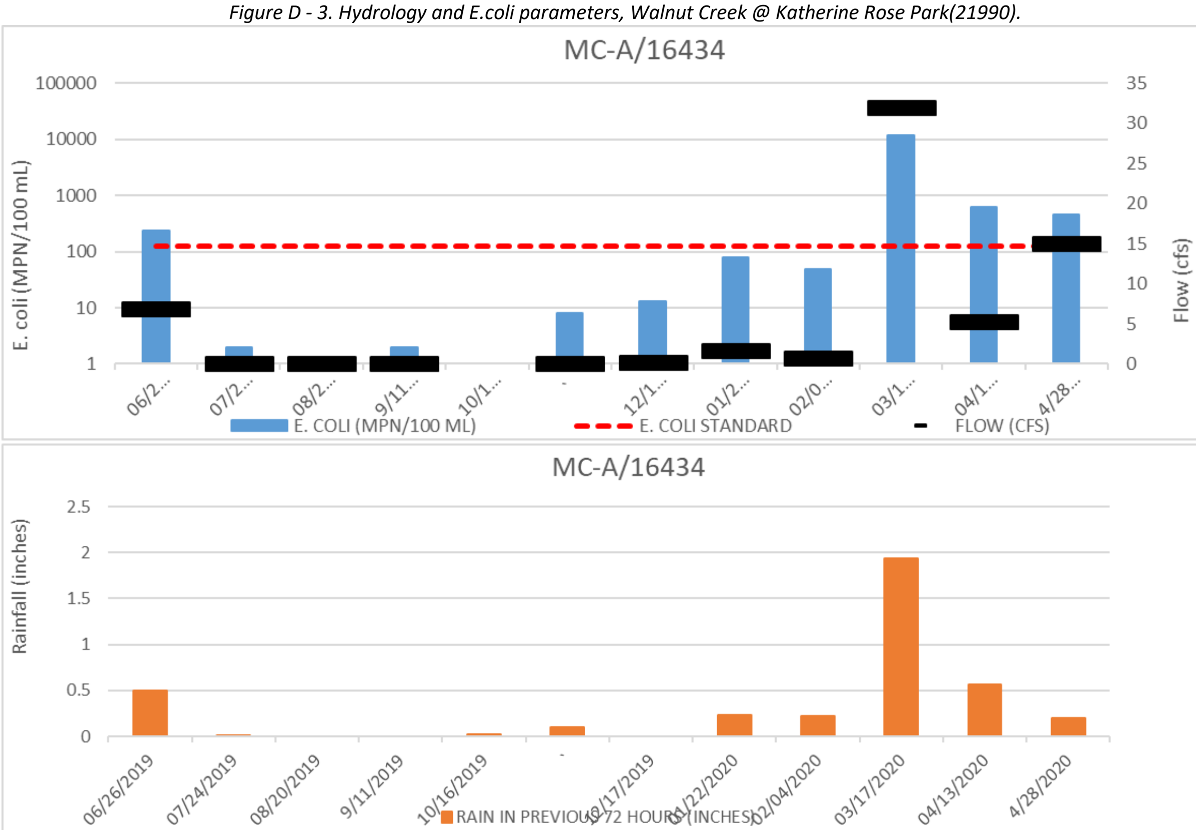

Figure D - 4. Hydrology and E.coli Parameters, Mountain Creek @ US 287 (16434).

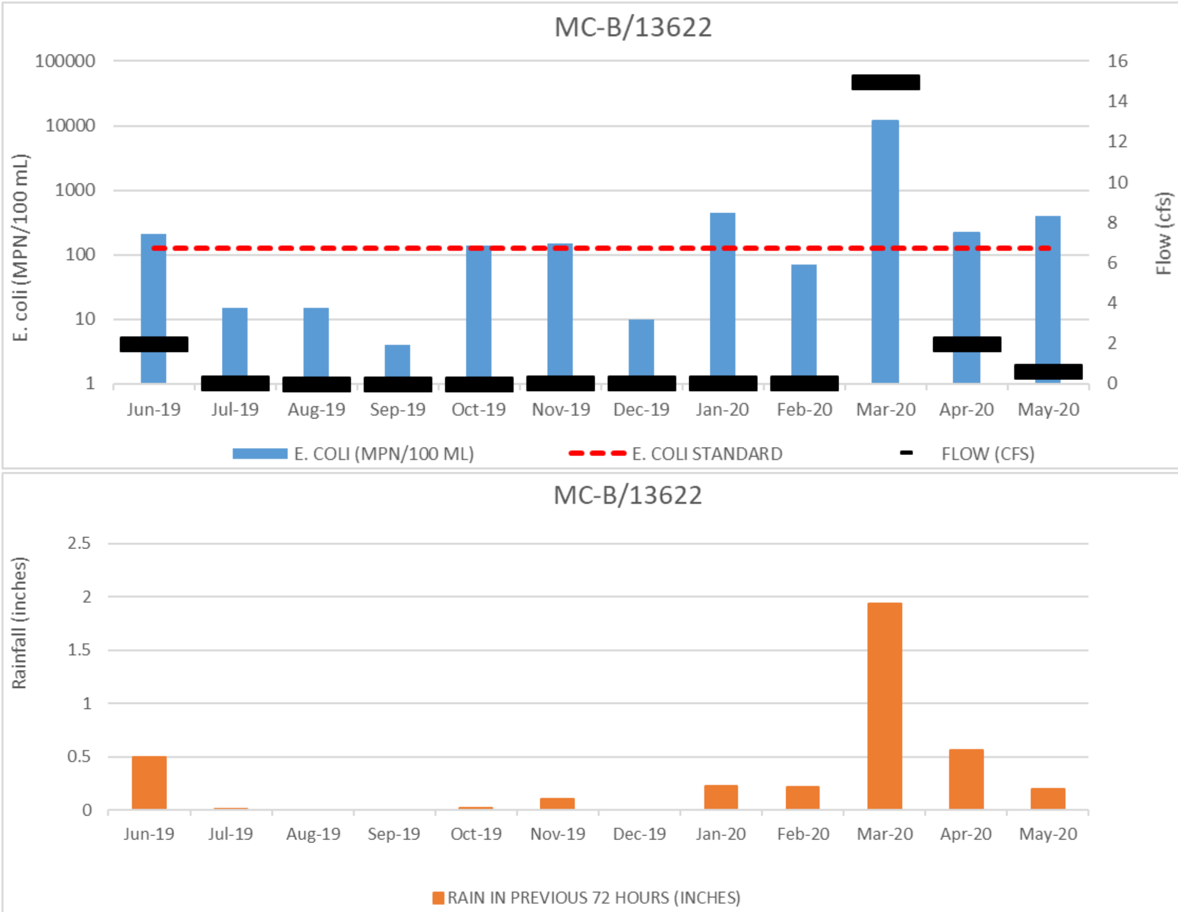

Figure D - 5. Hydrology and E.coli Parameters, Mountain Creek @ FM 157 (13622).

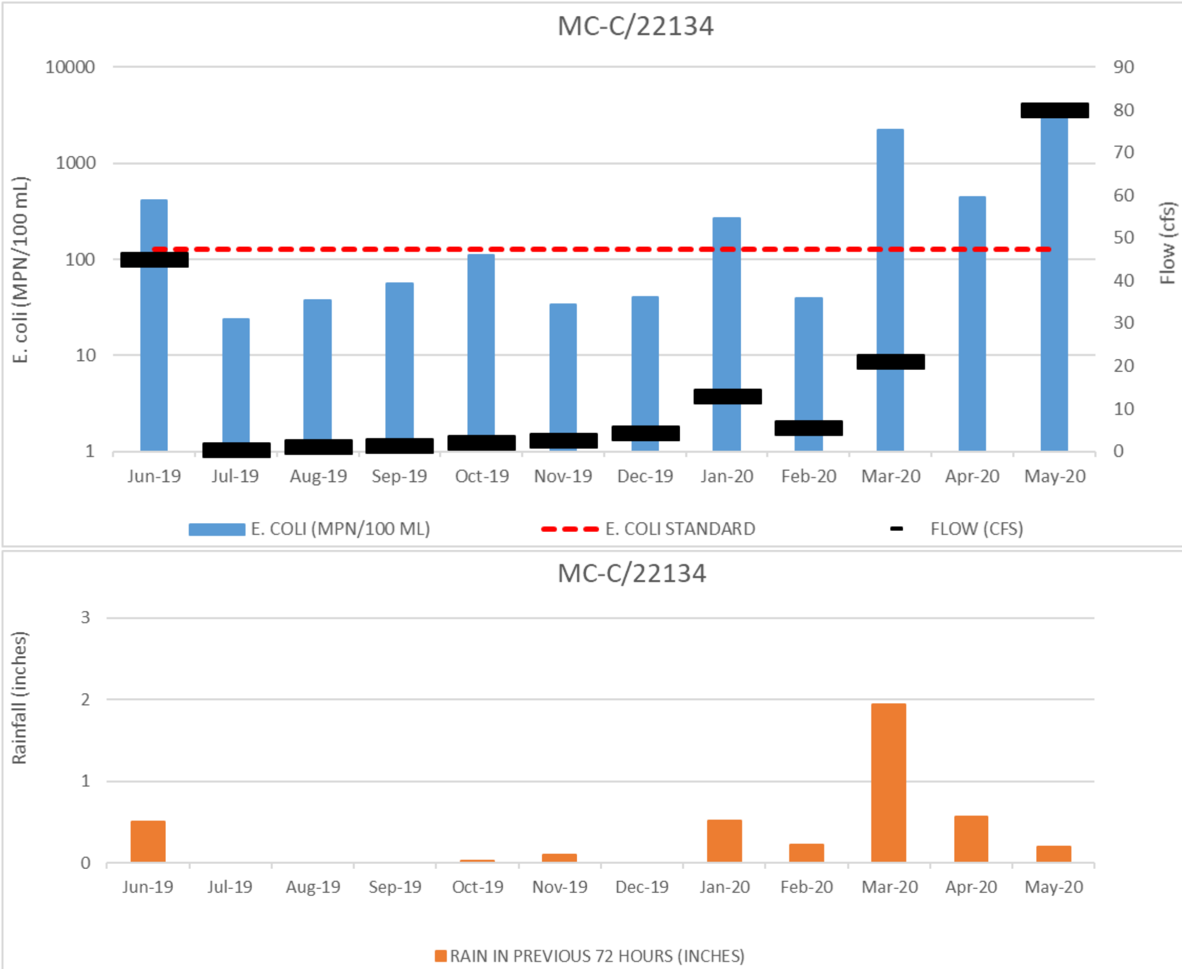

Figure D - 6. Hydrology and E.coli parameters, Soap Creek 1.1 km upstream of Mountain Creek (22134).

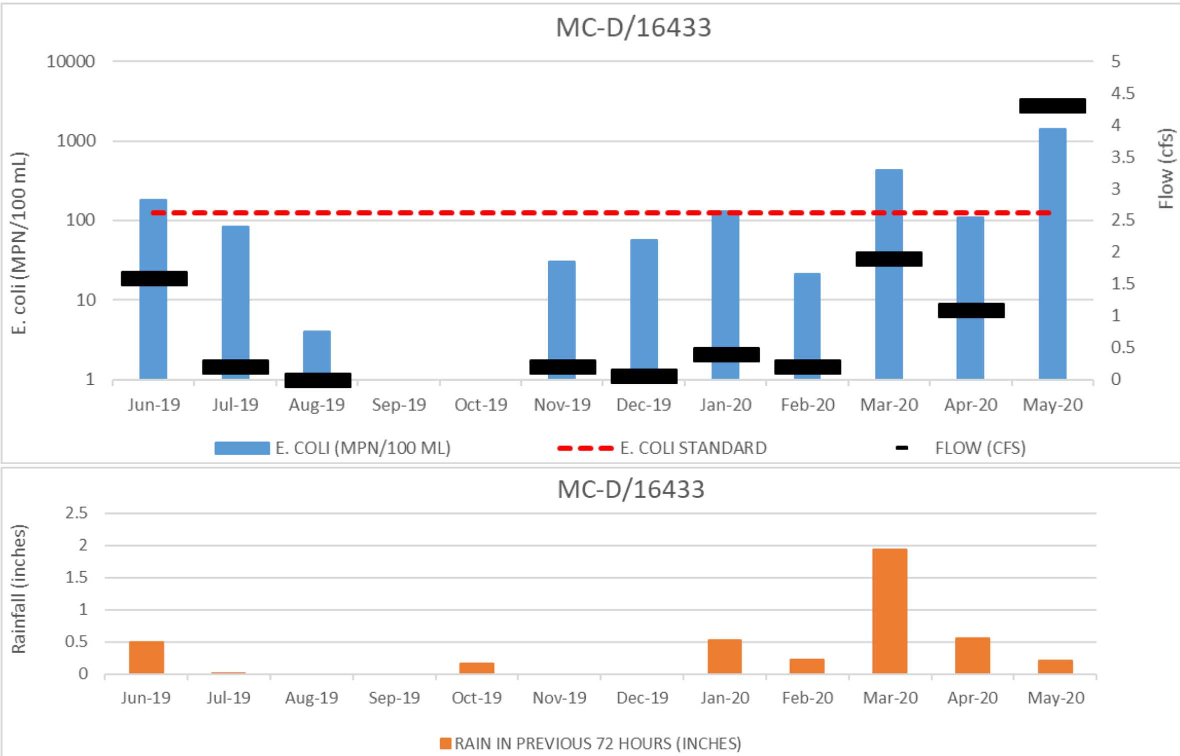

Figure D - 7. Hydrology and E.coli parameters, Hollings Branch @ Tangle Ridge Road (16433).

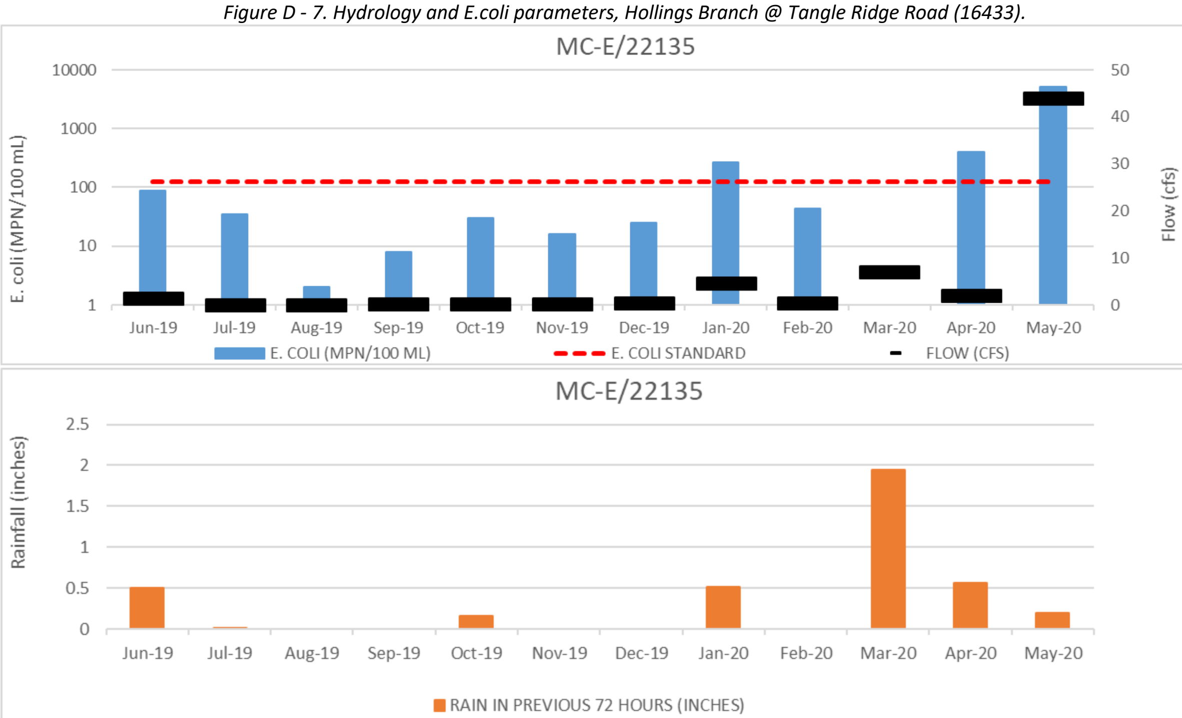

Figure D - 8. Hydrology and E.coli parameters, Low Branch @ South Holland Rd (22135).