Technical Report on Source Identification and Load Reduction Evaluation

for the

Village Creek-Lake Arlington Watershed Protection Plan

August 2018

Village Creek Lake Arlington WATERSHED PROTECTION

Trinity River Authority of Texas

On the cover:

Transition feature from channelized to natural channel conditions in an unnamed tributary east of Lake Arlington in Arlington, Texas.

Technical Report on Source Identification and Load Reduction Evaluation

for

The Village Creek-Lake Arlington Watershed Protection Plan

Funded by

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Investigating Entities

The Trinity River Authority of Texas
Tarleton State University, Texas Institute for Applied Environmental Research

Prepared by

Aaron Hoff, Trinity River Authority
Angela Kilpatrick, Trinity River Authority
Webster Mangham, Trinity River Authority
Larry Hauck, Texas Institute for Applied Environmental Research

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List of Acronyms

BMP	best management practice
BOD_5	5-day biological oxygen demand
CCN	Certificate of Convenience and Necessity
Chl-a	chlorophyll-a
DOQQ	Digital Orthogonal Quarter Quadrangle
DFW	Dallas-Fort Worth metropolitan area
DMR	Discharge Monitoring Report
E. coli	*Escherichia coli*
ECHO	Enforcement and Compliance History Online
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FDC	flow duration curve
geomean	geometric mean
GIS	geographic information system
I/I	infiltration/inflow
LDC	load duration curve
LULC	land use/land cover
MSL	mean sea level
NAIP	National Aerial Imagery Program
NHD	National Hydrography Dataset
NCTCOG	North Central Texas Council of Governments
NRCS	U.S. Department of Agriculture - Natural Resource Conservation Service
NWS	National Weather Service
OB	optical brightener
OP	orthophosphate
OSSF	on-site sewage facility
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SSO	sanitary sewer overflow
SUD	Special Utility District
SWCD	Soil & Water Conservation District
SWQM	Surface Water Quality Monitoring
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TKN	total Kjeldahl nitrogen
TNRIS	Texas Natural Resource Information System
TOP	Texas Orthoimagery Program
TP	total phosphorous
TPWD	Texas Parks and Wildlife Service
TRA	Trinity River Authority of Texas
TRWD	Tarrant Regional Water District
TSS	total suspended solids
TSSWCB	Texas State Soil & Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
USDOT	U.S. Department of Transportation
USGS	U.S. Geological Survey
VCLA	Village Creek-Lake Arlington Watershed

WPP	watershed protection plan
WWTF	wastewater treatment facility

1.0 Introduction

This technical report was prepared as part of an effort to restore water quality within Village Creek. There is also a further goal of protecting water quality in Lake Arlington, which utilizes the creek as its main tributary. These waterbodies and their shared watershed are located in Tarrant and Johnson Counties, in the southern extent of the Dallas/Fort Worth (DFW) Metroplex in North-central Texas (Figure 1-1). The data analysis, pollutant source identification, and pollutant load calculations explored in this report will serve to expand and enhance the knowledge of the stakeholder group as they make important management decisions to improve and protect water quality in the Village Creek-Lake Arlington (VCLA) watershed. This project will result in the development of a watershed protection plan (WPP) that integrates the results of these collected water quality data, Spatially Explicit Load Enrichment Calculation Tool (SELECT) calculations, and load duration curve (LDC) results with goals and strategies for water quality improvements. Specifics related to the data collection activities related to this project are provided in a separate report, titled, *Data Collection Report for the Village Creek-Lake Arlington Watershed Protection Plan* (TRA, 2017). Aspects of the SELECT and LDC analyses, along with other related pollutant source identification studies, will be covered in detail in this report.

1.1 Problem Statement

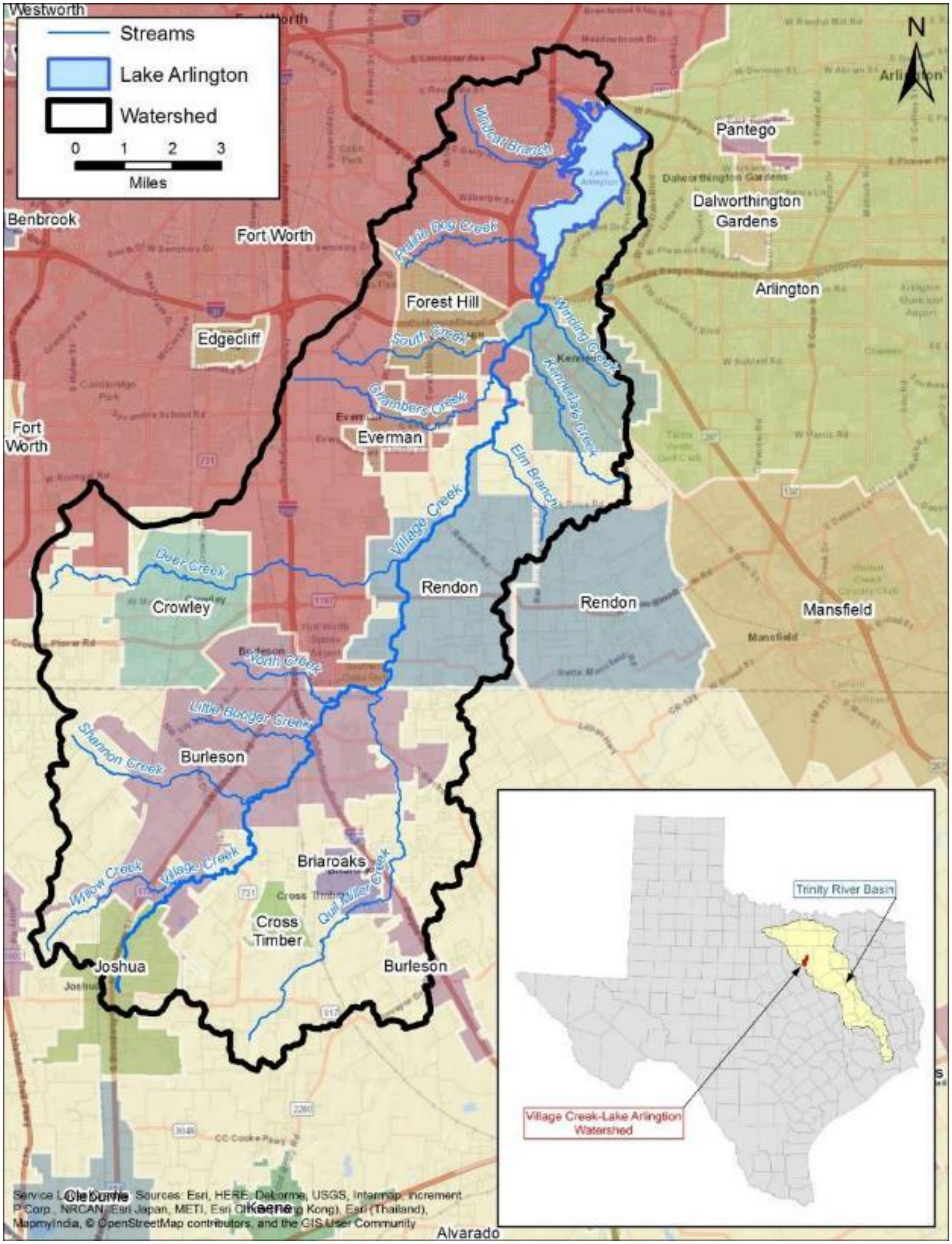
Village Creek was first listed for a recreational use impairment due to excessive levels of *Escherichia coli (E. coli)* bacteria in the 2010 *Texas Commission on Environmental Quality Integrated Report for Surface Water Quality* (TCEQ, 2015a). Successive reports published in 2012 and 2014 indicated that the creek is becoming progressively more impaired. Current data places Village Creek at a geometric mean (geomean) of 302 MPN/100 mL, more than double the state standard of 126 MPN/100 mL for water bodies designated for primary contact recreation (TCEQ, 2015b). While this impairment does not extend to Lake Arlington, the lake does exhibit levels of nitrate and chlorophyll-a (chl-a) that constitute general use concerns (TCEQ, 2015c). Chl-a is by far the longest-standing concern, first listed in 2006 with appearances in every biennial report since. The latest data from 2014 places three monitored assessment units within the lake at geometric means between 44.96 and 48.99 µg/L; each exceeding the screening level of 26.7 µg/L for lakes. Nitrate first appeared as a concern in 2012 and again in 2014, but only in an assessment unit separate from those experiencing elevated chlorophyll-a levels. In this unit, nitrate reached 0.47 mg/L in the 2014 report, exceeding the screening level of 0.37 mg/L for lakes.

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, LDC analysis based on collected data for multiple pollutants, and spatial analysis of potential *E. coli* sources using the SELECT analysis. Two other analyses for further characterization of sources were also conducted: optical brightener analysis for identification of potential human sewage contamination, and a photographic survey for documenting illegal dumping activity.

Data Analysis

Trends in water quality data from 11 sites collected from June 2016 to May 2017 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. Although routine sampling was a part of the sampling effort, flow-biased samples were also collected. 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, between stations during the same sampling event, with more intense analysis when unexpected data values or other events of interest were apparent.



Basemap: ESRI World Streetmap.

Figure 1-1. Location of Village Creek-Lake Arlington Watershed.

LDCs

The LDC 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 a pollutant load for each parameter of interest. 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 Texas Commission on Environmental Quality (TCEQ) and the Environmental Protection Agency (EPA) for determining the success of both total maximum daily load (TMDL) and WPP projects, so development of LDC analyses is beneficial for tracking progress on these projects.

SELECT

Once the pollutant loads and their associated load reductions have been calculated, the next step is relating the loads to pollutant sources throughout the watershed. SELECT is an analytical tool that uses LULC data to spatially distribute actual or estimated population data for humans and animals to estimate where pollutant loads originate, along with their relative volume. However, in the case of SELECT, only loads for *E. coli* can be estimated, so no other pollutant loads were analyzed with SELECT aside from bacteria.

Supplemental Analyses

Throughout the data collection process, field staff observed the general conditions in the watershed while on their travels, resulting in recommendations for additional analyses that could further differentiate sources for both *E. coli* contamination and illegal dumping activities in the watershed.

Optical brightener (OB) detection is an inexpensive, simple, and rapidly-deployable test for potential contamination by raw human sewage in waterways. Though typically used in municipal stormwater systems, it has been used in streams and creeks as a quick and inexpensive first step in locating contamination from suspect wastewater pipelines (Hanson, 2013). Cases like these are possible in the VCLA watershed, but the initial idea driving the study was to discern the potential for raw human sewage contamination from malfunctioning on-site sewage facilities (OSSFs), more commonly known as septic systems, in the more rural sections of the watershed.

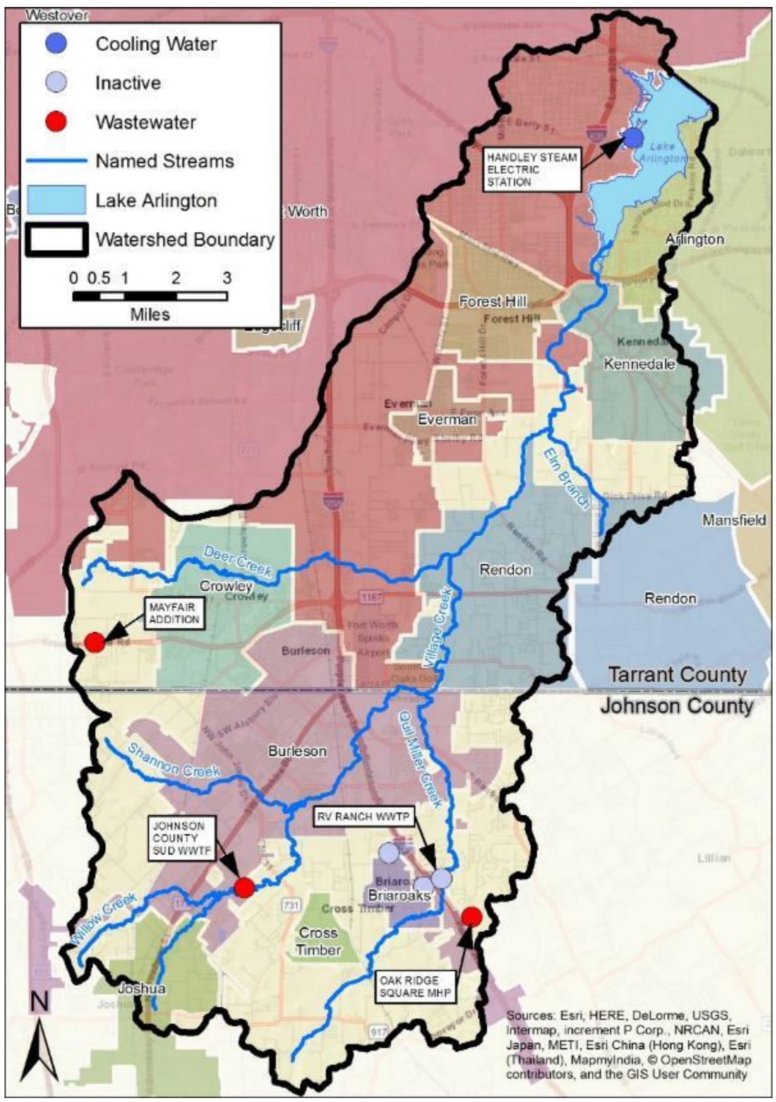
Illegal dumping surveys were initiated after field staff observed several instances of illegal dumping of household refuse, discarded furniture and household appliances, industrial refuse, hazardous chemicals, and medical waste. Photographs of impacted areas were aggregated into a spatial database, where a story map was used to visually relate photographic evidence to spatial locations. This database was created with the intention of updating it with new information and new sites as the study is allowed to expand to new sections of the watershed.

1.3 Study Area Description

The VCLA watershed extends approximately 28 river miles from its headwaters near the City of Joshua in Johnson County to the Lake Arlington dam in Tarrant County. Elevations in the watershed range from 1,065 ft above mean sea level (MSL) at Caddo Peak in the headwaters of Willow Creek west of Joshua in Johnson County, down to 550 ft above MSL at the normal conservation pool elevation of Lake Arlington. The watershed contains two TCEQ-designated segments, Lake Arlington (0828), and Village Creek (0828A). The entire drainage area behind the Lake Arlington dam consists of approximately 143 mi^2, or 91,402 ac. While Lake Arlington receives the majority of its natural flow from Village Creek, it will occasionally receive storm flows from other smaller tributaries along its perimeter. Wildcat Branch and Prairie Dog Creek are the largest tributaries on the west side of the lake, but both they and the majority of the other direct lake tributaries are largely ephemeral in nature, aside from a few smaller tributaries on the east side that drain housing subdivisions. These are typically ephemeral too, aside from the southernmost tributary where low, consistent baseflow is observed even during drought conditions. Village Creek is fed by several named tributaries, with Winding Creek, Kennedale Creek, and

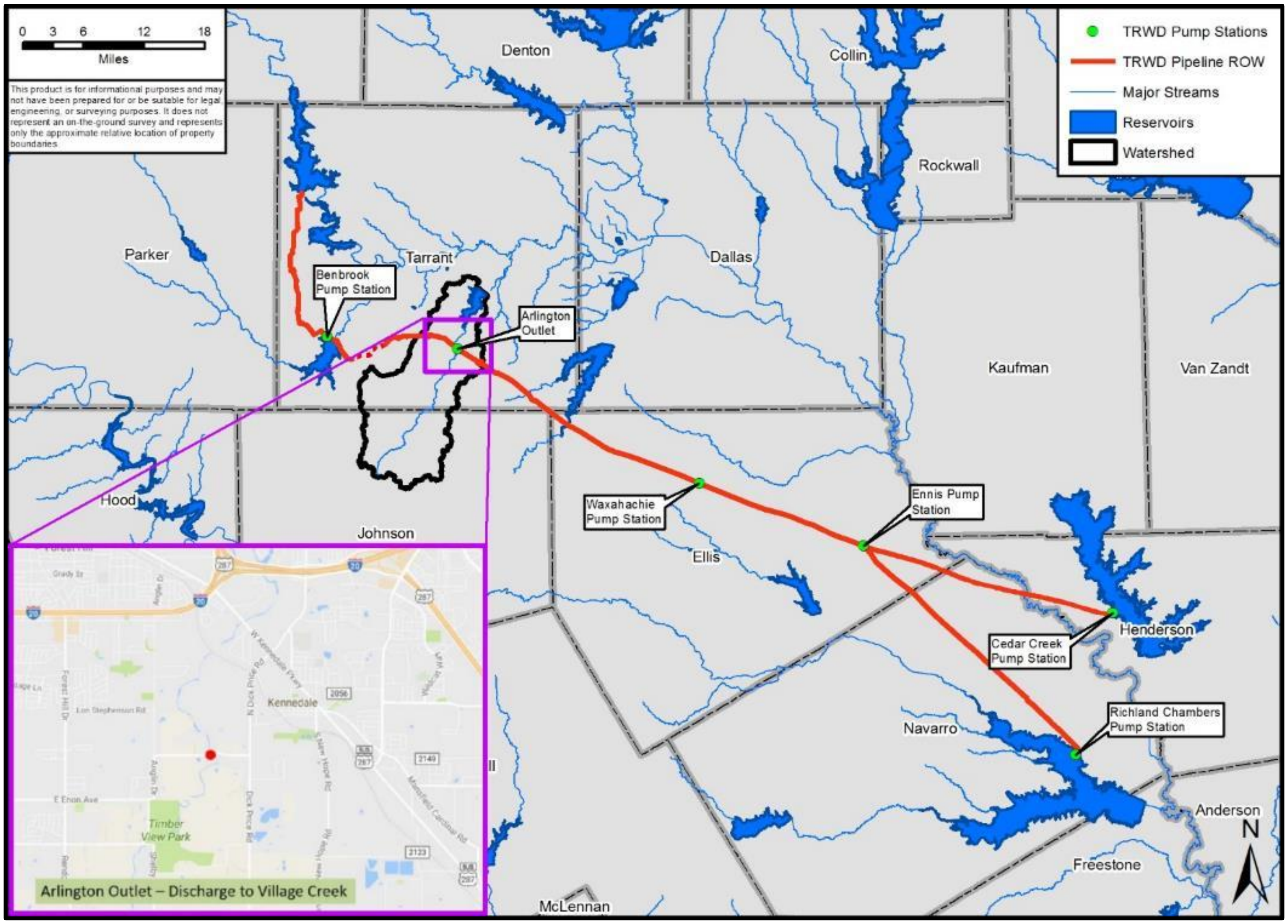
Elm Branch draining the area in the vicinity of Kennedale. Deer Creek drains Crowley and parts of northern Burleson, while Little Booger Creek, Shannon Creek, and Willow Creek drain the western portion of Burleson around IH-35. To the east, Quil Miller Creek drains a large rural area containing eastern Burleson, along with the towns of Briaroaks and Cross Timber. Spring flow in Village Creek is rare, but several seeps have been identified midway through the watershed that may constitute some small portion of baseflow as well. Groundwater comes from two major aquifer groups within the VCLA watershed, the Trinity group and the Woodbine group (Ashworth and Hopkins, 1995).

Natural flows are supplemented with effluent flows from three active wastewater treatment facilities (WWTFs) in the watershed (Figure 1-2). The significance of the WWTF locations in this watershed is that effectively all monitored reaches of the watershed may contain some portion of wastewater effluent constituting their baseflow throughout the year. Additional water piped in from two other reservoirs in East Texas, Richland-Chambers and Cedar Creek Reservoirs, supplements the natural flow and wastewater effluent from the tributaries. The outlet for this pipeline is situated just downstream of the Village Creek bridge on Everman-Kennedale Road, shown on the inset map (see 'Arlington Outlet') on Figure 1-3. When active, discharge from the outlet significantly alters flow conditions in the creek, significantly increasing both stage and velocity downstream, sometimes creating pooled conditions just above the outlet when discharge is particularly high.



Data source: TCEQ; Basemap: ESRI World Imagery.

Figure 1-2. Permitted discharges in the VCLA watershed.



Data Source: Tarrant Regional Water District. Area of interest (in purple) shows detail for the location of the Arlington Outlet.

Figure 1-3. Pipeline right-of-way for reservoir connectivity within the Trinity River Diversion Water Supply Project.

Soils in the vicinity of the lake are composed mainly of fine sandy loams, with silty clays near the transitional zone within Village Creek. In upland areas of the watershed, include Crosstell fine sandy loams, Sanger clays, Crosstell-Urban land complex, and Ponder clay loam. Several hydric soils occupy the bottom land areas of the watershed, with Frio silty clays, Pulexas fine sandy loam, and Hassee fine sandy loam being most common (USDA, 2015a, 2015b). The watershed is wholly situated within the Cross Timbers ecoregion. All of Lake Arlington is located in the Eastern Cross Timbers ecoregion (29b). Here, oaks are common overstory trees, along with hickory, redcedar, and various sumac species. Native grasses such as bluestem, Indiangrass, and dropseed are represented in the understory and prairie inclusions. The majority of Village Creek also falls within 29b, but the western portion of the watershed, including several smaller tributaries, is encompassed within the Grand Prairie ecoregion (29d). The upland area is dominated by tallgrass prairie species. In undisturbed areas, this includes bluestems, Indiangrass, gramas, and cupgrasses. In riparian bands, woody species such as elm, pecan, and hackberry are common (Griffith et al., 2007).

The upstream portions of the watershed have remained generally rural, with rangeland and pastureland being dominant (Table 1-1, Figure 1-4). Pockets of row-crop agriculture also exist, with undeveloped lots being more prominent further downstream as the watershed becomes more urbanized. The downstream portions of the watershed surrounding the lake are nearly fully developed, with only a few large, undeveloped tracts existing on the west shore. Major population centers include the city of Burleson and the communities of the southwest DFW Metroplex, which includes portions of Fort Worth and Arlington. These population centers compose the majority of the developed land in the area, shown in red on Figure 1-4 (a). Based on data collected by the North Central Texas Council of Governments (NCTCOG), the 2013 land use within the watershed is depicted in Figure

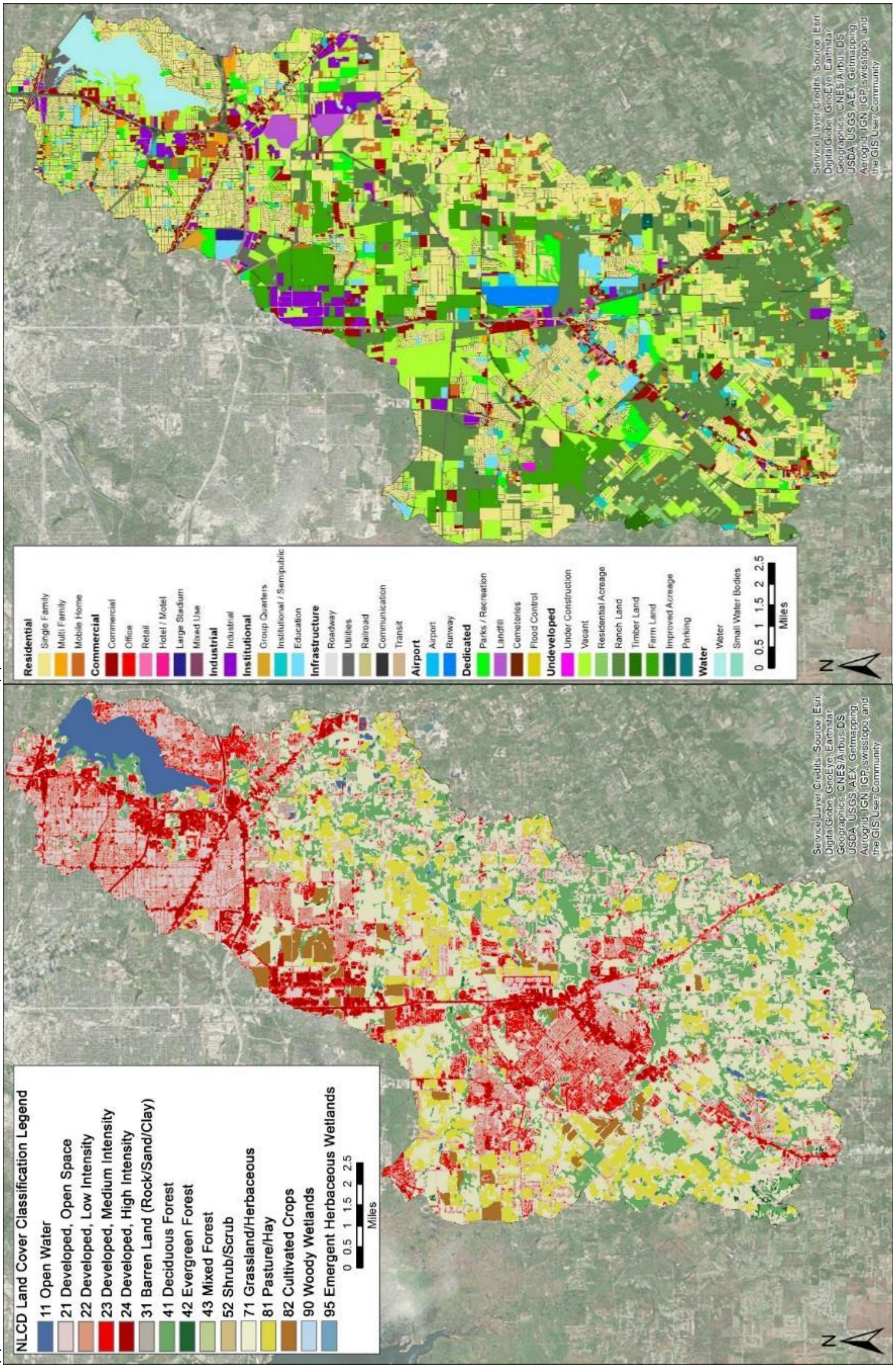
1-4 (b), which relates a use category (residential, industrial, undeveloped, etc.) to the land cover information. The urban centers previously mentioned are characterized by a high percentage of single-family homes and other low-intensity development, but a significant percentage of industrial complexes are shown to exist immediately south and west of the lake. Water quality concerns related to urban land use are present and common to the watershed, with numerous floatable trash snags/mats present near the lake and at flow obstructions within the tributaries, themselves. Significant amounts of submerged manmade materials are also commonly observed in the streambed, most commonly near bridges. These bridge crossings, particularly those in undeveloped locations in urban areas, are also popular locations for illegal dumping sites, several of which appear to have be used habitually for extended periods of time.

Table 1-1. Land use/land cover data summary for the watershed.

Class Name	Area (ac)	%
Open Water	2,321	2.5%
Developed, Open Space	13,427	14.7%
Developed, Low Intensity	14,108	15.4%
Developed, Med Intensity	6,839	7.5%
Developed, High Intensity	3,133	3.4%
Barren Land (Rock/Sand/Clay)	659	0.7%
Deciduous Forest	12,915	14.1%
Evergeen Forest	199	0.2%
Mixed Forest	186	0.2%
Grassland/Herbaceous	25,929	28.4%
Pasture/Hay	9,286	10.2%
Cultivated Crops	2,292	2.5%
Woody Wetlands	63	0.1%
Emergent Herbaceous Wetlands	56	0.1%
Total	**91,413**	**100.0%**

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/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.



Data source: Multi-Resolution Land Characteristics Consortium; Basemap: ESRI World Imagery.

Data source: NCTCOG; Basemap: ESRI World Imagery.

Figure 1-4. 2012 NLCD land cover classes (a) and 2013 NCTCOG land use classifications (b) in the watershed.

2.0 Methods

2.1 Data Collection Activities

The data to be analyzed in this report includes both routinely-collected and flow-targeted water quality sampling for several parameters, including *E. coli*, nitrite, nitrate, total Kjeldahl nitrogen (TKN), total phosphorus (TP), and orthophosphate phosphorus (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, 2017).

Monitoring sites were selected to encompass different LULC conditions and flow regimes (Figure 2-1). One site characterizes residential and industrial developments on the west side of Lake Arlington (10793), with another characterizing residential developments on the east side (10798). Seven sites are located on the main tributary to the lake, Village Creek. Two of these sites characterize industrial and manufacturing land uses and are under influence of the lake, especially when water levels are at or near the conservation pool elevation (10780 and 10781). Further upstream, two sites are located on either side of the Tarrant Regional Water District (TRWD) outfall (21762 and 13671), which brings in water from two east Texas lakes and significantly changes water quality when active. Another station (10786) is located at the site of a U.S. Geological Survey (USGS) gage, at the approximate midpoint of the watershed. Two additional stations are located further upstream and characterize suburban-rural mosaic land uses (10785 and 21763). Two upstream tributaries were also monitored: Deer Creek (10805) and Quil Miller Creek (21759), representing similar suburban-rural mosaic LULC conditions.

2.1.1 Texas Surface Water Quality Standards

Site-specific numeric water quality criteria, based on the Texas Surface Water Quality Standards (TSWQS) for Lake Arlington (Segment 0828) and Village Creek (Segment 0828A), as defined in Texas Administrative Code (TAC), Title 30, Chapter 307 (TCEQ, 2014), are presented in Table 2-1, along with designated use associated with each criteria parameter. 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, 2015d).

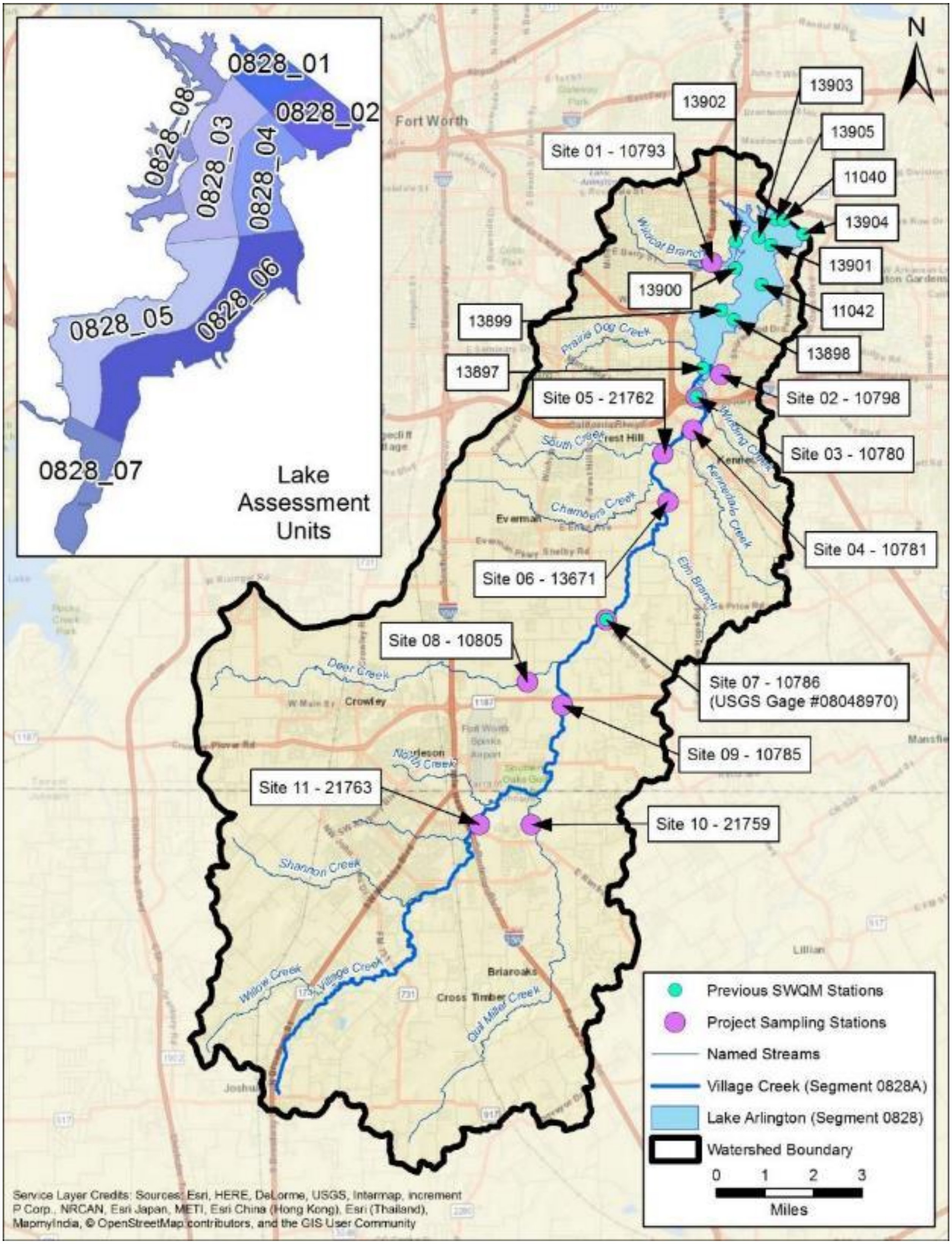
2.1.2 Nutrient Screening Levels and Reference Criteria

TCEQ Screening Levels

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 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 2-2). The Texas Nutrient Screening Levels are based on statistical analyses of Surface Water Quality Monitoring (SWQM) data (TCEQ, 2015d).

EPA Reference Criteria and Other Sources

The EPA Reference Criteria are regional values based on data from reservoirs and streams within specific ecoregion units and subunits (USEPA, 2000a, 2000b). 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 2-2). Where state screening levels or national reference criteria were non-existent, other sources were used, for nitrite in particular (Mesner and Geiger, 2010).



Basemap: ESRI World Street Map.

Figure 2-1. Assessment Units, segments, and monitoring stations in the watershed.

Table 2-1. Designated uses and site-specific water quality criteria for segments in the watershed.

Parameter	Criteria	Screening Level 0828	Screening Level 0828A	Corresponding Designated Use
DO (mg/L)	Grab minimum	3.0	2.0	Aquatic Life
DO (mg/L)	24-hr average	5.0	3.0	
DO (mg/L)	24-hr minimum	3.0	2.0	
E. coli (#/100ml)	Geomean	126	126	Contact Recreation
Chloride (mg/L)	Average	100	100	General
Sulfate (mg/L)		100	-	
TDS (mg/L)		300	300	
pH range		6.5-9.0	6.5-9.0	
Water temp (°F; °C)		95; 35	95; 35	

2.1.3 Segment Impairments and Concerns

For the assessment period covered by the *2014 Texas Integrated Report*, Village Creek was the only impairment in the watershed, specifically for bacteria (Table 2-3).For the same 2014 assessment period, there were three AUs in the lake with screening level concerns for chl-a and one with a concern for nitrate. No screening level concerns were identified in Village Creek, and no use concerns were identified anywhere in the watershed. Historically, *E. coli* geomeans have been on the rise since Village Creek was first listed in 2010. Since then, the mean exceedance has more than doubled from 141.54 MPN/100 mL to 302.07 MPN/100 mL in the latest Integrated Report (2014). Exceedances for chl-a also occurred on the 2010 Integrated Report, but further increases have been much less pronounced than those of *E. coli.*

Table 2-2. Nutrient Screening Levels and Reference Criteria.

Parameter		Lake/ Reservoir	Stream	Source
TKN	(mg/L)	0.41	0.4	EPA Reference Criteria[a]
Nitrite	(mg/L)	0.02	0.02	Other Sources[b]
Nitrate	(mg/L)	0.37	1.95	TCEQ Screening Levels
TP	(mg/L)	0.20	0.69	TCEQ Screening Levels
OP	(mg/L)	0.05	0.37	TCEQ Screening Levels[c]
Chl-a[d]	(µg/L)	26.7	14.1	TCEQ Screening Levels

(a) For Level III Ecoregion 29 waterbodies, upper 25th percentile of data from all seasons.

(b) 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.

(c) OP is no longer used for TCEQ screening purposes, as of the 2014 Texas Integrated Report.

(d) Chlorophyll-a, as measured by Spectrophotometric method with acid correction.

Table 2-3. Records of impairments and concerns in the watershed.

Texas Integrated Report	Village Creek			Lake Arlington		
	AUs	Mean Exceed	Criteria	AUs	Mean Exceed	Screening Level
Recreation Impairment - *E. coli* (MPN/100 mL)						
2010	0828A_01	141.54	126		-	
2012		182.07			-	
2014		302.07			-	
General Concern - nitrate (mg/L)						
2012		-		0828_07	0.52	0.37
2014		-		0828_07	0.47	
General Concern - chl-a (µg/L)						
2006		-		0828_02	N/A	26.7
		-		0828_05	N/A	
		-		0828_06	N/A	
2008		-		0828_02	N/A	26.7
		-		0828_05	N/A	
		-		0828_06	N/A	
2010		-		0828_02	41.94	26.7
		-		0828_05	43.85	
		-		0828_06	43.98	
2012		-		0828_02	44.28	26.7
		-		0828_05	46.33	
		-		0828_06	45.77	
2014		-		0828_02	44.96	26.7
		-		0828_05	48.99	
		-		0828_06	47.04	

2.1.4 Geospatial Data Collection

In addition to the water quality sampling efforts described above, a variety of existing geospatial datasets from local, regional, state, and Federal organizations were also used to support the project's many components. These datasets were vital for informing the water quality monitoring site selection process, provided the basis for geospatially determining the extent and severity of various pollutant sources, and provided investigators with the means to visually display the analysis results to stakeholders. A list of geospatial data sources utilized in this project are provided in Appendix A.

2.2 Statistical Analysis

Exploration of both temporal and spatial trends are of equal importance with respect to water quality analyses. In-depth temporal analyses normally require multiple years of data collection, significantly more than what was collected for this project. However, useful comparisons can still be made over this short period by incorporating precipitation and flow data to gauge the impacts of stormwater flows on *E. coli* loading. These analyses focused on the correlation of flow, *E. coli* measurements, and OB test results to rainfall events that occurred within a 72-hour window of a monitoring event. Results indicating correlation between rainfall, elevated flow, and elevated *E. coli* provide evidence that stormwater is the most likely pollutant source. If this relationship breaks down, then it may be an indication that point source pollution, non-stormwater flows, or other phenomena are prominent influences.

To illustrate trends that exist spatially between stations, box-and-whisker plots were generated for the parameters of interest. Box plot results were compared to the data geomeans for each parameter, along with the parameter's associated water quality criteria or screening value. Using these box plots, differences in variance can be compared between upstream and downstream stations, or at known confluence points to determine if certain tributaries are significant contributors of a pollutant.

2.3 LDCs

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 particular 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 moist 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 2-2). 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 conditions flow regime would be most appropriate for representing the water quality reduction goal at each site.

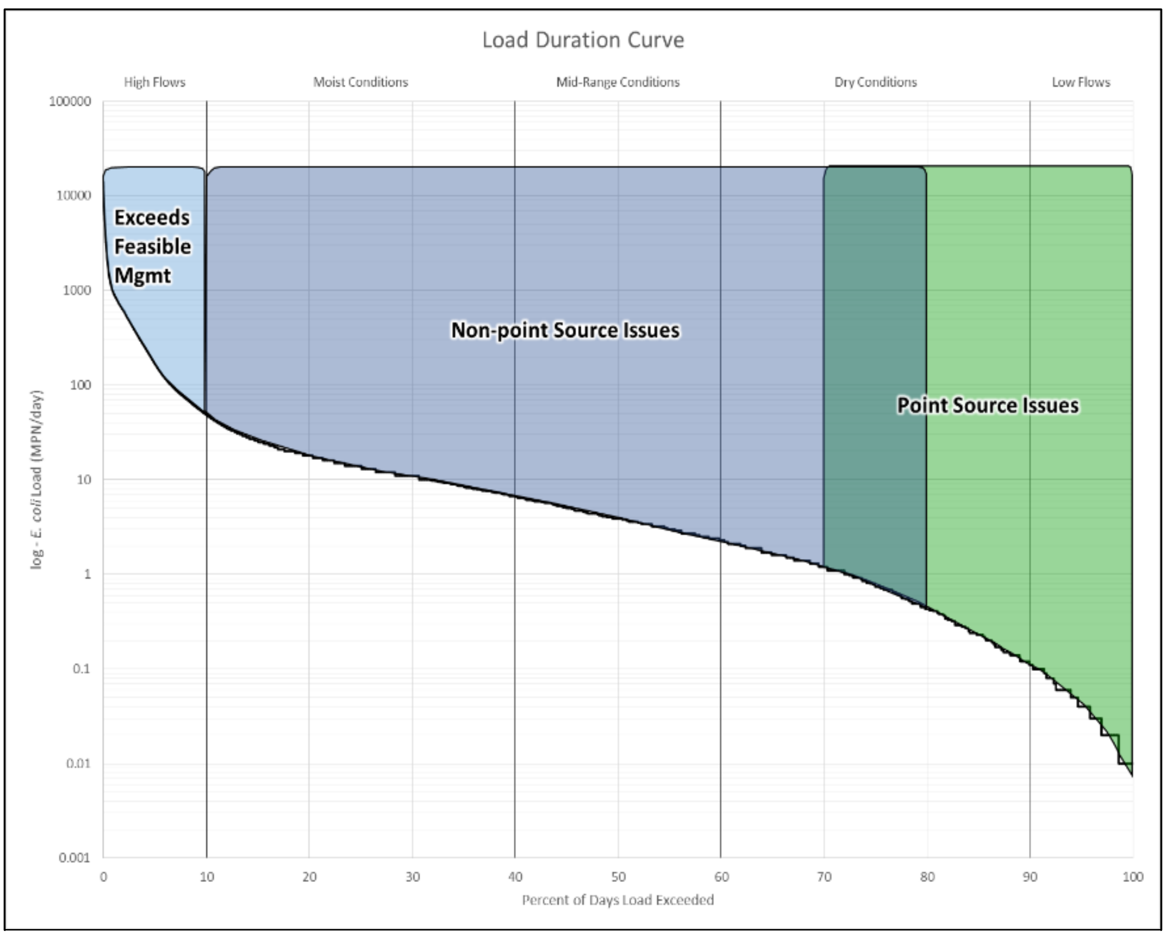
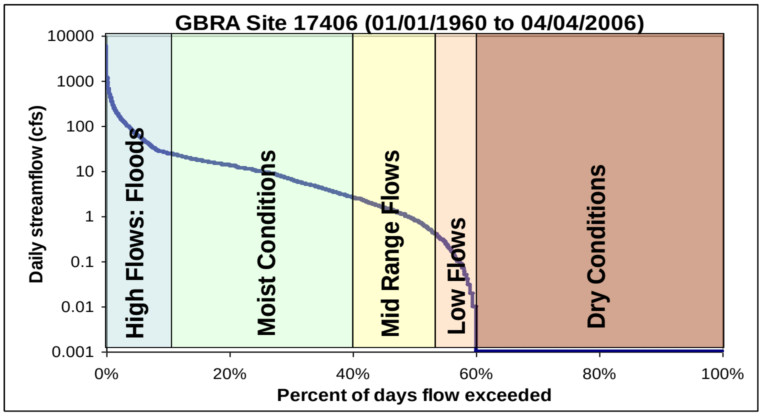


Figure 2-2. Flow categories and regions of likely pollutant sources along an example load duration curve.

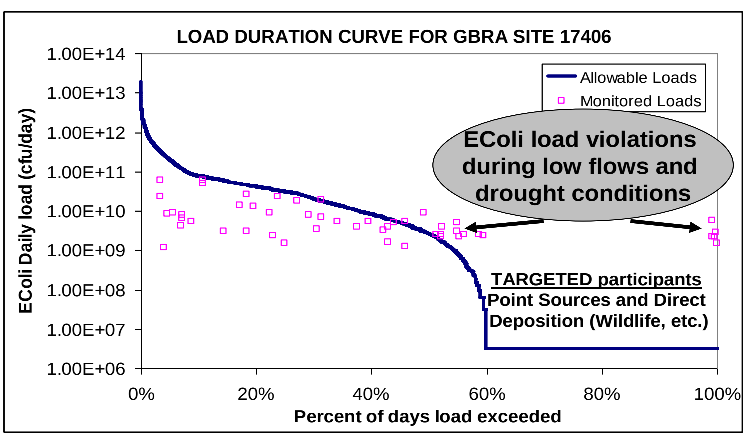
LDCs allow for a visual interpretation of load exceedances in comparison to the allowable load at specific flow conditions. Using flow and *E. coli* data collected from a specific monitoring campaign, flow duration curves (FDCs) and LDCs can be built to further evaluate the contaminant sources. First, 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 2-3).



Source: FDC for streamflow conditions at GBRA monitoring station 17406 on Plum Creek, near Uhland, TX.

Figure 2-3. Flow duration curve example from Plum Creek 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 2-4 depicts an example LDC based on the FDC shown in Figure 2-3. 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 2-4). Then, the baseline monitoring data values for *E. coli* (also in MPN/100 mL) are also multiplied by their associated flow values to get loads for each data point (pink squares in Figure 2-4). This can be developed further by performing regression analysis on the monitored data points, as depicted in Figure 2-5. 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 known as Load Estimator (LOADEST) is utilized. For each of the different flow regimes (High Flows, Moist Conditions, Mid-range Flows, etc.), a load reduction estimate can be calculated. Achieving these reductions will become the one of the primary targets for success once the WPP moves into the implementation stage.



Source: Load Duration Curve for E. coli at GBRA monitoring station 17406 on Plum Creek, near Uhland, TX.

Figure 2-4. Load duration curve example from Plum Creek 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 2-2), 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.

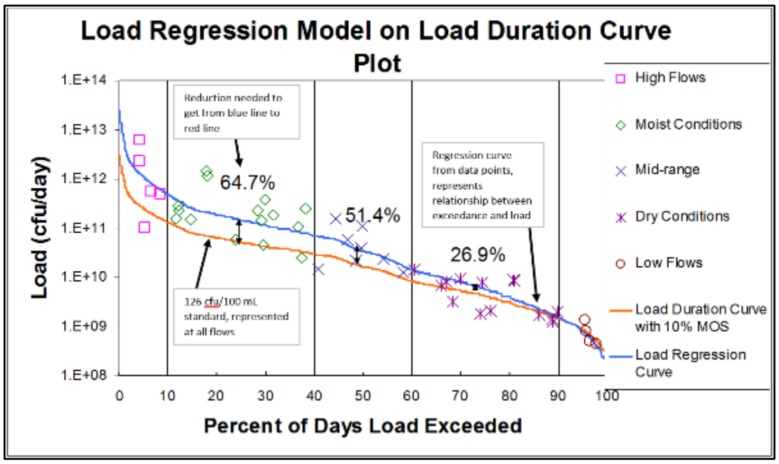


Figure 2-5. Load duration curve example for E. coli, with flow condition breakdowns and load reduction estimates (log scale Y-axis).

A minimum of 12 paired stream flow-pollutant concentration data points are required to properly execute the LDC analysis tool. During the monitoring effort, 12 paired samples were successfully collected for all sites except 10793, which experienced several periods of no flow during the monitoring effort. LDCs were developed at each of the 11 stations for 5 key constituents, *E. coli*, total dissolved solids (TDS), nitrate, TP, and chl-a, 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, we focused on two sites to determine several short-term and long-term water quality goals.

Site 10781

For planning purposes, site 10781 (Village Creek at US-287 BUS) was chosen as the benchmark for establishing water quality goals for pollutant reductions. While it is expected that lake influence (backwater conditions from the lake filling) may ultimately be present at site 10781, it was still considered the site that most accurately represented the entire watershed for several reasons:

- Lake influence is not as prominent and flow was consistently obtainable (advantage over site 10780);
- Site is convenient to access, with shoulder protected by concrete barriers (advantage over site 10780);
- Ongoing access is very likely due to the site's location in a bridge right-of-way (advantage over site 21762);
- Supplemental inputs from TRWD outfall releases captured in flow calculations (advantage over site 10786); and
- Site represents several Village Creek tributaries downstream of the TRWD outfall that often completely mask water quality improvements observed when releases are active (advantage over sites 13671, 21762);

Keeping in mind that protection of water quality in the lake is just as important to stakeholders as restoring water quality in Village Creek, using site 10781 as the benchmark for planning purposes is expected to provide valuable nutrient loading data as well as that for *E. coli*.

Site 10798

It is suspected that the unnamed tributary monitored at site 10798 may be impacted by point sources to a much greater extent than the rest of the watershed. For this reason, this tributary was analyzed with additional short-term goals in mind when compared to the long-term water quality goals identified for the whole watershed. LDC analysis for this site will help to further identify the source type (point vs. nonpoint) by comparing the required load reductions between the various flow categories.

2.4 SELECT analysis

Watershed prioritization and BMP recommendations were further refined with the use of the SELECT analysis, which distributes potential *E. coli* loads into 55 modeled catchments, or subwatersheds (Figure 2-6), 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 land use/land cover characteristics. Once distributed, species-specific *E. coli* load production values published in scientific literature were applied to each population (Table 2-4), producing the *E. coli* loads that may eventually find their way to waterways (Figure 3-10, Figure 3-11, Figure 3-12). 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. Please note 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 being placed in rangeland and pasture classes. Conversely, while it is likely that the majority of the watershed's horse population will also be found in range/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 from a stream), carry more weight than would deposition in an upland area further away (Figure 2-6). Use of this tactic will allow for further refinement of critical areas for BMP implementation.

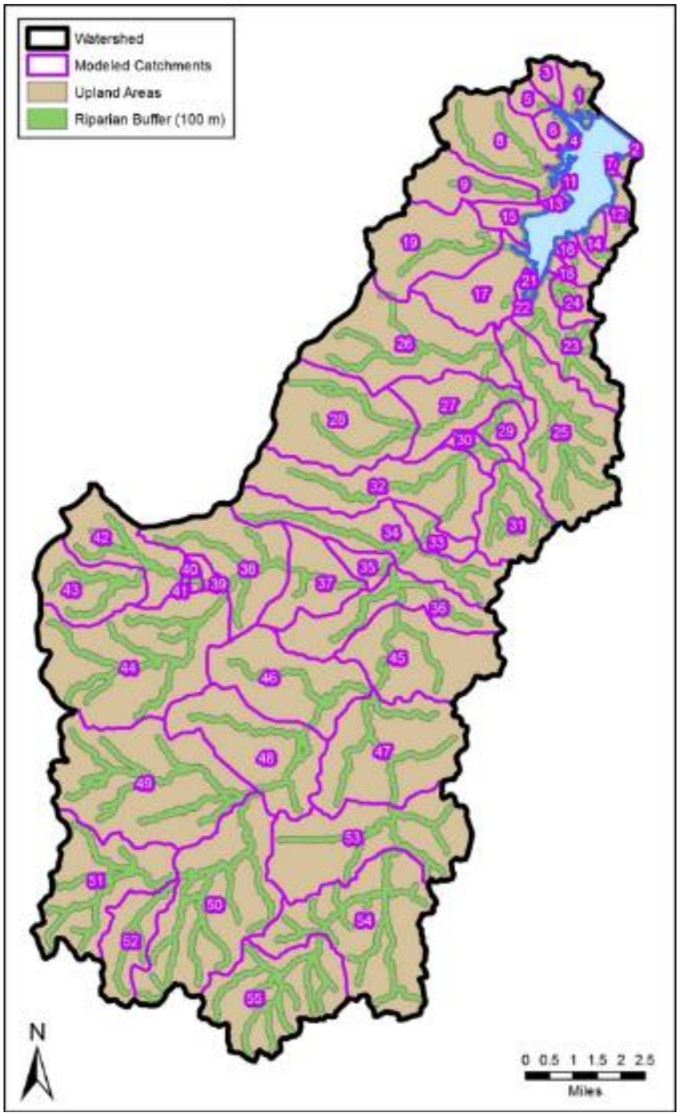


Figure 2-6. Subwatersheds and riparian buffer zones in the watershed for use in the SELECT analysis.

2.4.1 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. For this project, instead of the standard SELECT program, an equivalent employing the use of data entered by hand and calculated in Excel spreadsheets to drive visual output in ArcGIS was used.

The manual SELECT approach described above first uses spatial data for land use and/or land cover 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.

Table 2-4. *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
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

2.4.2 Point Source: WWTFs

Details about the three active WWTFs and any associated permit limit exceedances for water quality parameters are provided in Table 2-5. Of these facilities, only one is a municipal discharger, the Johnson County Special Utility District (SUD), with a permitted average daily discharge of 0.7 million gallons per day (MGD). The other two facilities are smaller plants that treat wastewater from a housing subdivision and a mobile home park. Both maintain a permitted average daily discharge of < 0.1 MGD. Over a three-year period, permit exceedances for *E. coli*, total suspended solids (TSS), 5-day biological oxygen demand (BOD_5), and ammonia were reported for these three facilities (Table 2-5).

Table 2-5. Compliance history for active WWTFs in the Village Creek-Lake Arlington watershed.

		Flow (daily average, MGD)		*E. coli* (daily average, cfu/100 mL)		Violations and Reporting Frequency (Monthly)				
Facility Name	Receiving Waterbody	Permitted	Reported(1)	Permitted	Reported(2)	Late/ Missing	*E.coli*	Ammonia	BOD_5	TSS
Johnson County Special Utility District WWTP	Village Creek	0.7	0.41	126	1.26	5	0	1	0	0
Mayfair WWTP	Unnamed trib of Deer Creek	0.0963	0.0405	126	7.75	8	1(3)	3	3	3
Oak Ridge Square MHP WWTP	Quil Miller Creek	0.0195	0.0143	126	3.70	11	0(3)	0	0	2

(1) 3-year average based on daily measurements from USEPA data, 1/31/2014 - 12/31/2016 .

(2) 3-year geomean based on daily measurements from USEPA data, 1/31/2014 - 12/31/2016 .

(3) Reported quarterly rather than monthly.

Three years of outfall data (calendar years 2014 through 2016) was obtained from the Discharge Monitoring Report (DMR) database via EPA's Enforcement and Compliance History Online (ECHO) website. Data was collected for all three active WWTFs currently treating human sewage in the watershed (Table 2-5). In cases where the reported flow was zero, it is customary to assume that 60% of the permitted flow was discharged and considered for calculations; however no recorded occurrences of this have been found at present for the facilities or timeframe of interest. Therefore, the treated effluent flow associated with each WWTF was assumed to be their self-reported flow.

The equation to calculate the *E. coli* (EC) for WWTFs is (Teague, 2007):

$$EC = Avg\ self\ reported\ flow\ (MGD) \cdot \frac{126\ cfu}{100\ mL} \cdot \frac{10^6 gal}{MG} \cdot \frac{3785.41\ mL}{gal}$$

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

2.4.3 Point Source: SSOs

Subwatershed Analysis

Sanitary sewer overflows (SSOs) can be a significant contributor of *E. coli* in urban watershed if they occur near waterways. SSOs occur when pipes are blocked, broken, or when deteriorating pipes and connections allow infiltration of stormwater or groundwater into the wastewater system. These 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. For this reason, proximity of the SSO site to a waterbody must be accounted for when analyzing potential impacts. For this project, 90% of the *E. coli* contributions from riparian areas are assumed to reach the stream. For upland areas outside of the riparian buffer, only 50% of the contributions are assumed to reach waterbodies. Values similar to these are used in other WPPs throughout the state.

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 mentioned previously (Figure 2-7). For the purposes of this project, SSOs, when combined with pet waste nonpoint sources, will be used as surrogates for urban runoff when calculating pollutant loads from urban sources.

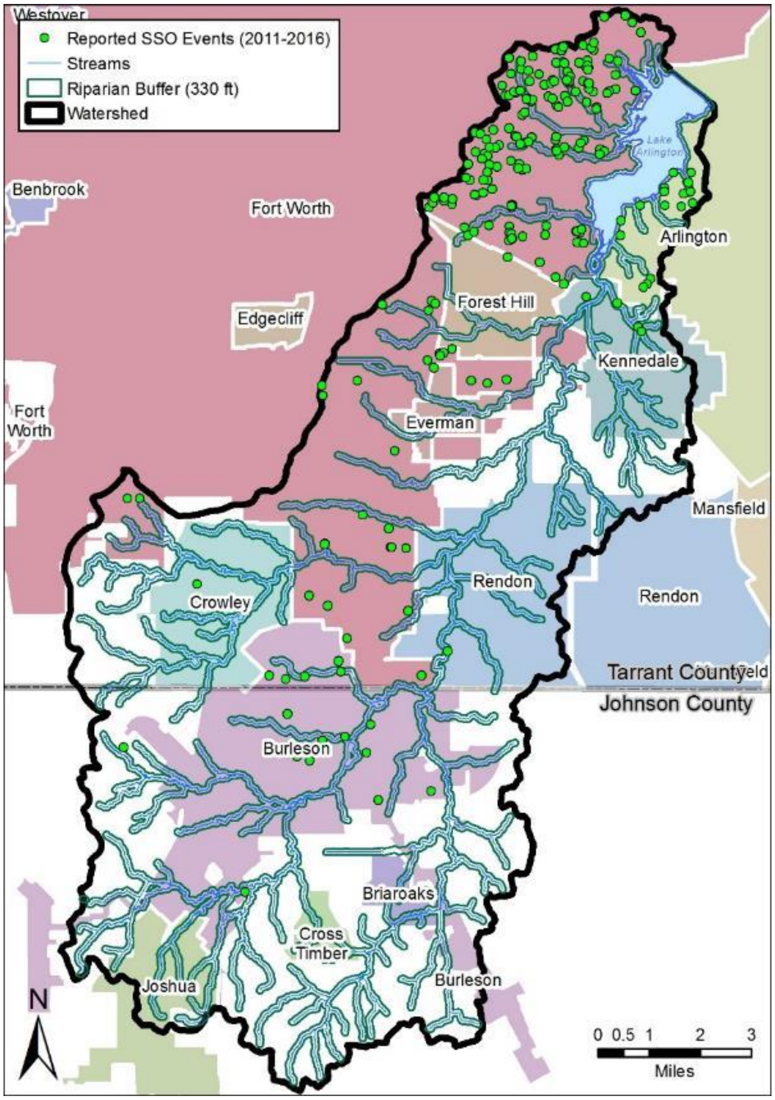
The compendium of past reports of SSO occurrences was used to calculate the average daily instance of an SSO occurring, which will be used as a surrogate for any one subwatershed's likelihood to encounter an SSO. NCTCOG acquired SSO data from TCEQ for the region for the period 2011-2016. Spreadsheets containing geospatial data for these events were digitized and then clipped to the 55 subwatersheds. These datasets were further subdivided between 330-ft (100-m) riparian buffer and upland zones in each subwatershed. This was done so that a weighted approach to waterbody contamination could be employed, with riparian buffer zones receiving higher weighting for pollutant influence due to their proximity to waterbodies. For each subwatershed, the number of SSOs and the total gallons discharged for both zones were retrieved. Total discharge was then divided by the number of days in the 2011-2016 period (2192) to get average daily discharge for each subwatershed's riparian and upland zone.

Load Calculation

The equation to calculate the EC for SSOs is borrowed from combined sewer overflow and septic equations in EPA's Protocol for Developing Pathogen TMDLs (USEPA, 2001) is:

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

The *E. coli* Load assigned to raw sewage is $5*10^5$ cfu/100 mL or $5*10^3$ cfu/mL (USEPA, 2001). It is assumed that 90% of overflow reached waterbodies within 330-ft (100-m) riparian buffer, but that this contribution is reduced to 50% from upland areas. Total *E. coli* calculations for each subwatershed (in cfu/day) are then normalized across the watershed by dividing by the subwatershed's area (cfu/ac-day).



SSO data source: NCTCOG

Figure 2-7. Reported SSO events in the watershed, 2011-2016.

2.4.4 Nonpoint Source: Dogs & Cats

Households Analysis

The calculations for populations of domestic dogs and outdoor cats were based on the number of households (HHs) in the watershed, separated into groups of HHs that are within and outside of the riparian buffer zone. The U.S. Census Bureau's 2015 "Cartographic Boundary Shapefiles - Block Groups" shapefile was used to delineate block groups (BGs) in the watershed (USCB, 2015a). This shapefile was populated with data from the 2015 American Community Survey (ACS) estimates for number of HHs in each census BG (USCB, 2015b) using a join operation to spatially distribute the ACS HH estimates to their BG. BGs were then clipped to the watershed boundary and an average HH/acre was calculated for each BG. BGs that overlapped with a subwatershed were included in the average HH/acre estimate for each subwatershed. This averaged value was applied to each subwatershed's acreage estimate to calculate the number of HH/subwatershed, separated into both its upland and riparian zones.

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 (AVMA, 2012). Stakeholders elected to also consider cat density as 1.6 cats per HH, a tactic intended to provide coverage for feral cats, barn cats, and house cats that defecate outdoors. These estimates were applied to the household numbers to estimate the number of pets in each subwatershed's upland and riparian zone.

Load Calculation

The equation to calculate the *E. coli* (EC) for dogs and separately for cats is:

$$EC = \#households\ w/pets * \frac{1.6\ pets}{household} * 2.5 * 10^9\ cfu\ d^{-1}\ head^{-1}$$

The EC loading of $2.5*10^9$ cfu/day-head (one head = one animal unit) comes from fecal coliform estimate of $5.0*10^9$ cfu/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 in 330-ft (100-m) riparian buffers, with a presumed 50% contribution from uplands. Total *EC* calculations for each subwatershed (in cfu/day) are then normalized across the watershed by dividing by the subwatershed's area (cfu/ac-day).

2.4.5 Nonpoint Source: Livestock, Deer, & 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 calculated based on the NCLD 2011 database (Table 2-6). County-wide NASS population estimates were then extrapolated to the watershed using a percent-area basis (Table 2-7). Animal populations that were originally based on proportioned National Agricultural Statistics Service (NASS), Texas Parks and Wildlife Department (TPWD), or Texas A&M University (TAMU) data. These were then modified based on steering committee recommendations (Table 2-8). 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 2-9). Population densities for each species were then calculated using the stakeholder-recommended populations and the land use-based density adjustments (Table 2-10, Table 2-11).

Load Calculation

The adjusted animal population densities were then used to calculate the *E. coli* for various livestock, deer, and feral hogs with the following equations (Teague, 2007):

Source	Calculation
Cattle	$EC = \#cattle \cdot 2.7 \cdot 10^9 cfu\ d^{-1}\ head^{-1}$
Horses	$EC = \#horses \cdot 2.1 \cdot 10^8 cfu\ d^{-1}\ head^{-1}$
Sheep and goats	$EC = \#sheep \cdot 9 \cdot 10^9 cfu\ d^{-1}\ head^{-1}$
Deer	$EC = \#deer \cdot 1.75 \cdot 10^8 cfu\ d^{-1}\ head^{-1}$
Feral hogs	$EC = \#hogs \cdot 4.45 \cdot 10^9 cfu\ d^{-1}\ head^{-1}$

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

Table 2-6. Total land cover acreages for relevant land uses in VCLA watershed.

Land Cover 2011*	Acres
Grassland	25929
Pasture/Hay	9286
Decidous Forest	12915
Evergreen Forest	199
Mixed Forest	186
Developed, Low	14108

*acreage in watershed, per NLCD database, 2011

Table 2-7. County acreage and % of county in each watershed.

County	Total Acres	Acres in Watershed	% of County	% of Watershed
Johnson	469,645	35,505	7.56%	38.84%
Tarrant	575,125	55,897	9.72%	61.16%
Total	1,044,770	91,403		100%

Table 2-8. Assumed populations of various large mammals in the watershed based on Steering Committee (SC) recommendations.

SC Recommendations		
# in Watershed	Number	Notes
Cattle*	6488	Original estimate based on USDA-NASS data
Equine**	2500	increased from NASS estimates to account for "hobby farms" and small acreage landowners who may not receive NASS survey
Sheep & Goats	2500	increased from NASS estimates to account for "hobby farms" and small acreage landowners who may not receive NASS survey
Deer	n/a	use TPWD median density of 53.7 ac/animal for Resource Management Unit (RMU) #22
Feral Hogs	1000	doubled from TAMU estimates to reflect about 2 hogs for every 1 deer

* includes beef, dairy

**includes horses, ponies, mules, donkeys, burros

Table 2-9. Proposed population density adjustments based on % of each land use type used by each animal classification across watershed.

Density Adjustments	Grassland	Pasture /Hay	Developed, Low Intensity
Cattle	1	1	
Equine	1	0.9	0.05
Sheep&Goat	1	0.9	0.05
Deer			

Table 2-10. Estimated animal densities, animals/acre and acres/animal basis.

Species	animal/ac	ac/animal	Notes
Cattle	0.18	5.43	100% pasture, 100% grassland
Equine	0.07	14.00	100% grassland, 90% pasture, 5% low intensity developed*
Sheep&Goat	0.07	14.00	100% grassland, 90% pasture, 5% low intensity developed*
Deer	0.02	53.70	whole watershed except developed (all), open water**
Feral Hogs	0.04	26.62	100% riparian zones, 100% forest land uses

* 5% low intensity development included at NRCS' and stakeholder's recommendation to account for "hobby farms" and small acreage landowners who may not receive NASS survey

** per TPWD's density analysis criteria and application

Table 2-11. Acreages used in calculation of feral hog population (in green).

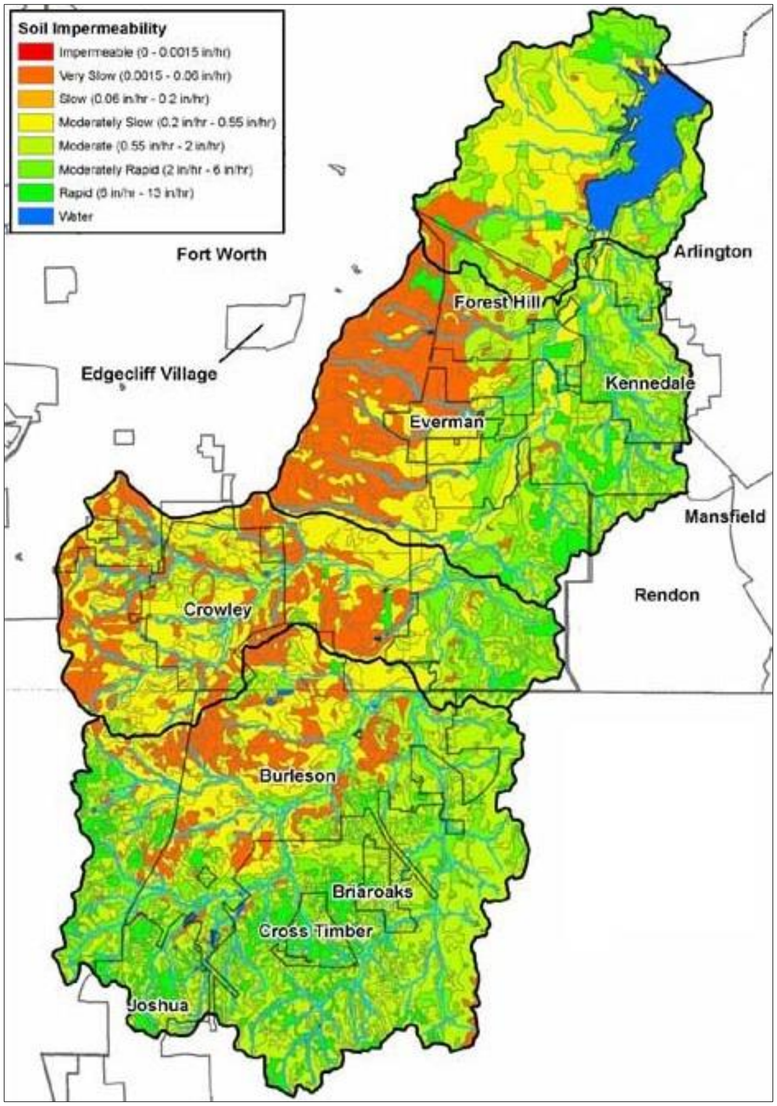
Land Use/Land Cover Category	Acres	
	Riparian	Upland
Open Water	260.4	170.6
Developed, Open Space	2191.3	11194.5
Developed, Low Intensity	1809.2	12268.4
Developed, Med Intensity	786.6	6032.0
Developed, High Intensity	280.9	2849.8
Barren Land (Rock/Sand/Clay)	146.8	511.7
Deciduous Forest	4731.7	8162.8
Evergeen Forest	92.5	107.0
Mixed Forest	27.1	159.0
Grassland/Herbaceous	6017.1	19897.4
Pasture/Hay	1807.0	7467.4
Cultivated Crops	228.6	2057.8
Woody Wetlands	42.0	18.2
Emergent Herbaceous Wetlands	33.6	15.8
Total Suitable Acreage	**18194.34**	**8428.765**
Total Composite Acreage	**26623**	

2.4.6 Nonpoint Source: OSSFs

There are several unincorporated and rural areas in the watershed where on-site sewage facilities (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 2-8), age of the system, and proximity to other systems.

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, and are weighted accordingly for analysis. 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 failure rates for non-permitted (50% failure) and permitted (12% failure) systems used in several other WPP efforts in Texas (RS&Y, 2002).

Proximity to a waterbody is also a major factor in contamination. Stakeholders, on the advice of technical advisory staff, agreed that OSSFs within a 330-ft (100-m) distance of a waterbody would be expected to have the greatest impact (Figure 2-9). For this reason, stakeholders chose to focus management efforts specifically on those OSSFs within the buffer for this project, agreeing to a 90% contribution weight from OSSFs within the riparian buffer, and entirely excluding OSSFs in the upland areas (effective 0% contribution weight).



Adapted from Lake Arlington Master PLan (Malcolm Pirnie and Arcadis U.S., 2011).

Figure 2-8. Permeability of soils in the watershed.

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 10,687 OSSFs estimated to exist in the watershed, only 3,454 have existing permits. If the scope is limited to those OSSFs inside the riparian buffer, 457 OSSFs have associated permits and 1,826 are non-permitted. 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.

By far the most complex analysis undertaken through SELECT, this component utilized data from a multitude of sources to develop datasets in two counties before they could be combined for the total load analysis. While it is known that there are many permitted OSSFs in both Tarrant and Johnson County, a review of aerial imagery, known addresses, and known municipal sewer infrastructure locations indicate that roughly only 1/3 of all OSSFs in the watershed are associated with active permits. Both subsets of OSSFs were explored in the SELECT analysis.

Tarrant County

For *permitted* OSSFs in Tarrant County, NCTCOG was able to provide geospatial datasets for sites in Arlington, Grand Prairie, and for the general Tarrant County area, for systems installed both pre- and post-2000. There is some overlap into Johnson County and beyond; these point locations were verified with an address locator analysis to ensure accuracy. This analysis was extended to other points inside the watershed that were suspected of being misplaced, including those in road centerlines and clustered at interstections. These errors are typically the result of new road construction where addresses are not yet recognized by the address locator being used.

For *non-permitted* OSSFs, 9-1-1 addresses are typically used to map all potential OSSFs in the county. However, neither Tarrant County nor the city of Burleson are participants in NCTCOG's regional 9-1-1 system. Instead, they use their own system. 9-1-1 address information was obtained from Burleson, but the County was unwilling to share their data, citing privacy issues. As an alternative, property parcel information was acquired from the Tarrant County Tax Assessor's website. These tax parcel polygons were converted to centerpoints to approximate addresses. Analysts then removed points that fell within municipal sewer certificates of convenience and necessity (CCNs), acquired from Public Utility Commission's website. Several cities were willing to provide sewer infrastructure shapefiles, allowing for additional addeses to be removed outside of CCN boundaries. Aerial imagery was used for additional quality assurance, to remove address points on parcels with no buildings (and therefore no obvious OSSFs), such open lots. To ensure thorough analysis, analysts used a numbered 3000 x 3000-ft "fishnet" grid to track progress. Analysts removed points that overlapped with points from the "Permitted OSSFs" layer generated above, using address data to verify and the fishnet grid to ensure complete coverage of the watershed. Ultimately, if there was any uncertainty as to whether or not a point overlap was a match, both points were retained.

Johnson County

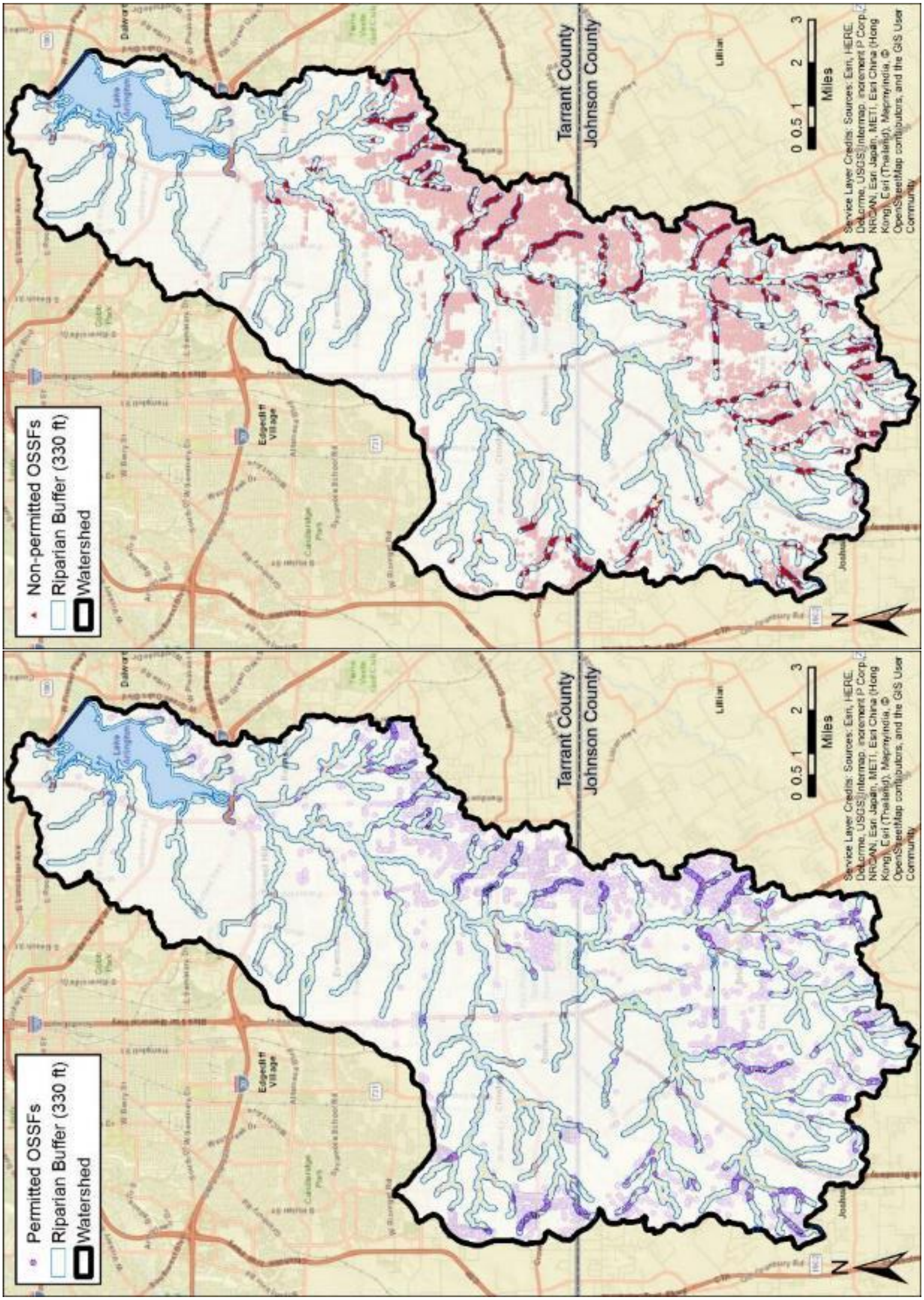
Permitted OSSFs in Johnson County were pulled directly from County's hard copy records of permits using addresses. Instances of errors like duplicate permits, repeating block numbers, and inconsistent street names were removed. The remaining addresses were geocoded using the "Awesome Table" add-in for Google Sheets, and exported to ArcMap. The produced points were spot-checked and obvious errors were removed. Additional quality control was conducted on several presumably correct points for accuracy using the fishnet grid to track progress. Finally, special attention was paid to the overlap area near the border with Tarrant County by comparing points from both datasets that fell within close proximity. Overlapping points were placed in one county or the other.

Mapping the *non-permitted* OSSFs was more straightforward in Johnson County, due to the availability of 9-1-1 address data provided by Johnson County through NCTCOG, as well as Burleson's own records that exist in Johnson County. These geocoded points were imported to ArcMap, where the previous removal/exclusion operations used in Tarrant County were employed (municipal sewer CCNs, municipal sewer infrastructure shapefiles, aerial open lot review). Finally, points that overlapped with known permitted OSSFs were removed.

Load Calculation

For the purposes of OSSF *E. coli* load calculation, no distinction was made between businesses and residences. The equation to calculate the EC for OSSFs is:

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



Data source: Tarrant/Johnson Counties. Upland areas masked to emphasize OSSFs in riparian zones.

Figure 2-9. Permitted and non-permitted OSSFs in the watershed.

Failure rates of 50% for unpermitted systems and 12% for permitted systems were assumed to calculate the number of failing systems (Reed, Stowe, 2001). The *E. coli* load assigned to OSSFs: $5*10^5$ cfu/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, 2007). With an average household size of approximately 2.8 persons between Tarrant and Johnson Counties (USCB, 2010a, 2010b). A 90% contribution to the stream is assumed within 330-ft (100-m) riparian buffer, with a zero contribution from upland areas, per stakeholder recommendation. Total *E. coli* calculations for each subwatershed (in cfu/day) are then normalized across the watershed by dividing by the subwatershed's area (cfu/ac-day).

2.5 Optical Brightener Detection Analysis

OBs are dye compounds that are added to laundry detergent to make clothing seem whiter or brighter in color after washing. Although not a direct measurement of bacterial contamination, the presence of OBs in the water found at the monitoring site may be an indicator of human sewage contamination, which is a potential source of *E. coli* in the watershed. In most cases, “greywater” from laundry washing, sinks, and dishwashers is combined with “blackwater” from toilets and urinals in the waste stream leaving a residence and travels to either an OSSF or centralized municipal WWTF. This allows for the OBs to be used as a reliable indicator for human sewage contamination. Common sources of OBs include 1) malfunctioning OSSFs, 2) non-permitted “straight pipes” that offer no treatment, and 3) leaking, damaged, or otherwise malfunctioning WWTF infrastructure, either within the conveyance lines to the facility, or within the facility’s treatment train itself. However, other household, personal care, and industrial products can contain similar dyes, which can present ‘false positives’ in the test. These include, but are not limited to, antifreeze, car wash detergents, lawn grass dyes, and some viral-vector pesticides.

Left: Typical instream OB sampling setup.
Right: Instream OB sample compared to fluorescence references under UV lamp.

The method used in this project was adapted from similar ones employed within municipal stormwater conveyance systems by various municipalities in the DFW area. However, deployed samplers more closely followed those used in studies to withstand the more continuous flow presented by natural systems (Hanson, 2013).OB testing at various sites in the watershed included the 11 sites at which routine and flow-biased monitoring were conducted, and at additional sites where further investigation of OB presence was required. This testing consisted of anchoring natural untreated cotton sampling medium in rigid flow-through containers in the stream for a period of time (24 to 48 hours). The sample medium was later collected and checked for fluorescence from detectable OBs. As noted earlier, these compounds are found in many laundry detergents and can therefore indicate the presence of sewage leaks or failing septic systems. OB detection results may help identify potential human sources of *E. coli* in the watershed and inform the selection of BMPs to manage these sources.

2.6 Illegal Dumping

Significant quantities of refuse and potentially hazardous materials were found in and near tributaries during water quality sampling activities. To address this challenge, further reconnaissance in the watershed was conducted at rural/urban bridge crossings and cul-de-sacs with known or expected uses as illegal dumping sites. 22 sites were selected using aerial imagery, based on roadway access and proximity to Lake Arlington. A standard field data sheet was created that included parameters such as waste type, streambank erosion, homeless occupation, stream flow, and waste quantity. These parameters were further broken down into sub-categories with assigned point values based on potential water quality impacts. Hazardous waste was assigned the highest value of 5, whereas common litter items (cans, cups, fast food containers, bags, bottles, etc.), were assigned the lowest value of 1. Each site's cumulative point value was multiplied by a factor of 1-2 if the refuse was purposely dumped and then multiplied by 1-2 again based on the quantity. This created a standard grading rubric for each site where higher severity scores indicated more severe potential negative impacts on water quality. During the survey, field scientists completed data sheets, recorded GPS points, and took photographs to support their findings.

Field data were entered into a spreadsheet and used to create a mapping geodatabase. Using the total severity score, sites were distributed into four categories: 1) *minimal impact*, 2) *some impact, 3) significant impact, and* 4) *critical impact.*

Example of a site with minimal impacts from illegal dumping.

Example of a site with some impacts from illegal dumping.

Example of a site with significant impacts from illegal dumping.

Example of a site with critical impacts from illegal dumping.

3.0 Results and Discussion

3.1 Statistical analysis

For Figure 3-1 through Figure 3-4, investigators related flow to *E. coli* and the presences of OBs. Flow is represented by black horizontal bars. *E. coli* is represented by the vertical bars, with light blue representing measurements with negative OB detection, and purple bars representing positive OB detection. 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 most of the sites on Village Creek (upstream from station 21762), *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. Beginning at station 21762, however, dilution from incoming flows from the TRWD outfall significantly reduces *E. coli* concentrations. Here, the relationship between concentration and flow is confounded when the outfall is active. During these release events, there were expected increases to flow, but *E. coli* concentrations tended to remain low, only exceeding the standard when the high flow was associated with a precipitation event (Figure 3-2). The direct relationship between increases to flow and *E. coli* concentration breaks down even further at sites closer to the lake (10781, 10780, 10793). Here, backwater conditions that result as the lake approaches its capacity further reduce the predictability of the flow-concentration relationship. However, as seen in the example shown in Figure 3-3, high *E. coli* can still reliably be predicted using recent rainfall at these three sites.

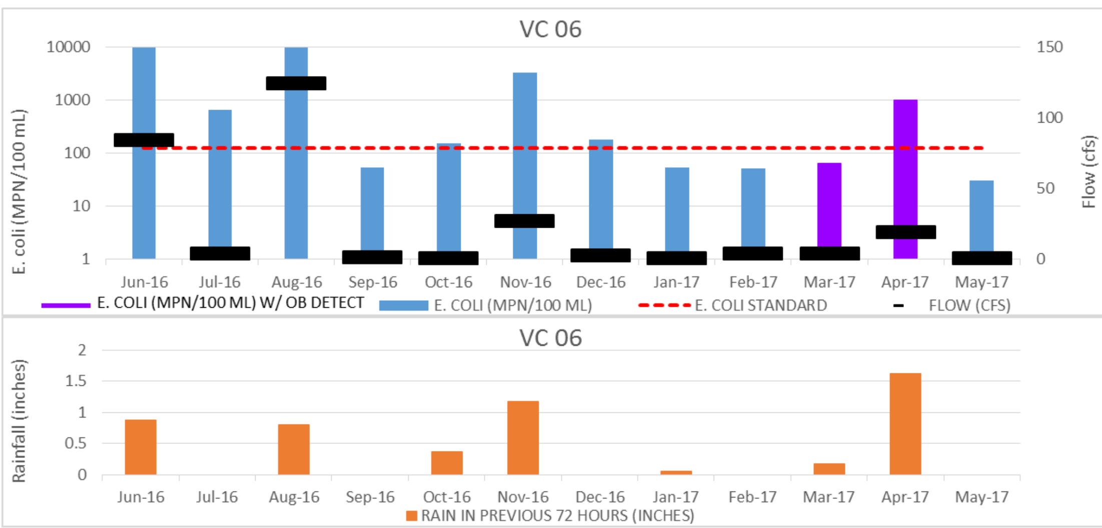


Figure 3-1. Hydrology and E. coli parameters, Village Creek at Everman Drive (13671).

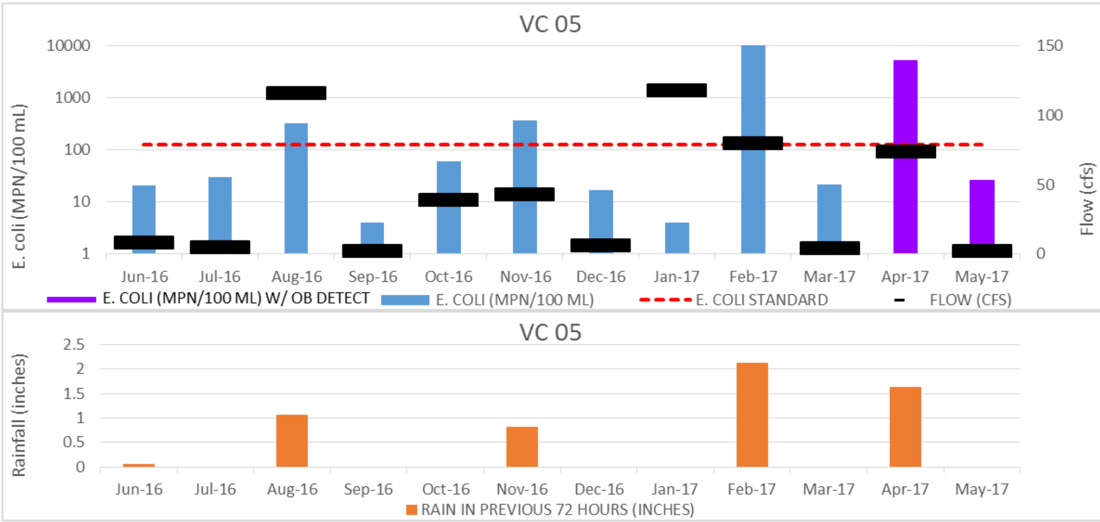


Figure 3-2. Hydrology and E. coli parameters, Village Creek near Freeman Drive (21762).

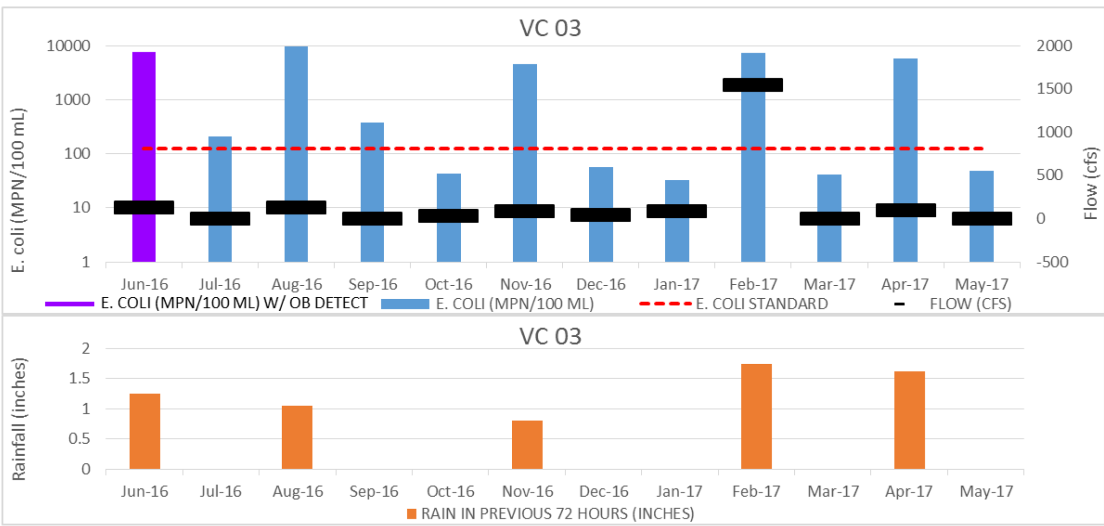


Figure 3-3. Hydrology and E. coli parameters, Village Creek at IH-20 (10780).

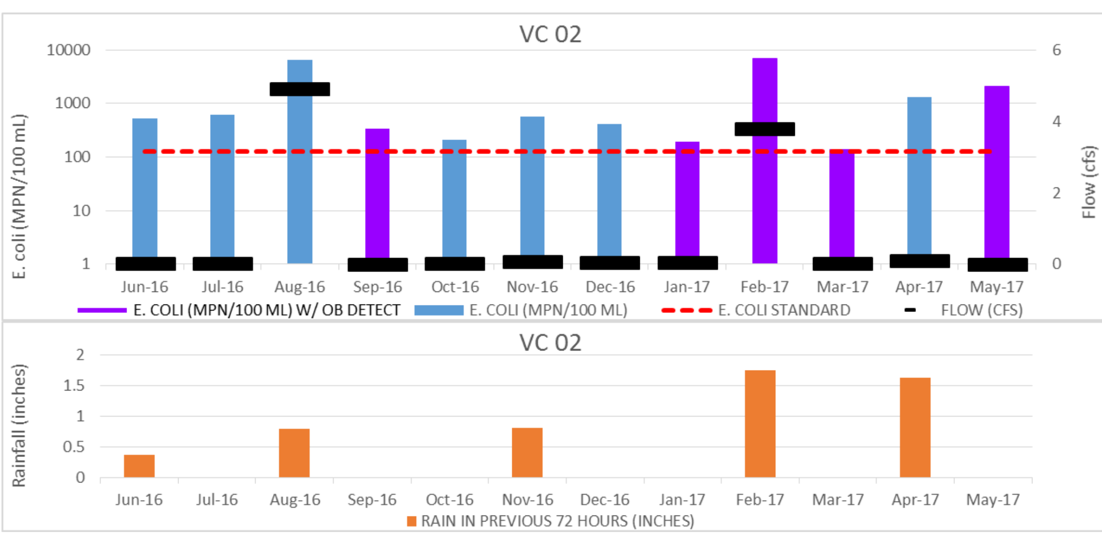


Figure 3-4. Hydrology and E. coli parameters, Tributary of Lake Arlington (10798).

The unnamed tributary to the lake (10798) displayed distinct flow-concentration relationships that were unlike any of the other sites. For instance, 10798 was the only site with *E. coli* concentrations consistently elevated above the water quality standard, despite regularly being the site with the lowest flow (Figure 3-4). It was also the only site that appeared to maintain consistent flow, even during the "flash drought" conditions encountered in the summer of 2015 when even the main stem of Village Creek exhibited disconnected pools and zero recorded flow at the Rendon USGS gage (site 10786). This assumption of continuous flow conditions is supported by the anoxic substrate conditions encountered in several portions of the reach, particular in concrete-lined portions where black substrate is often indicative of continuously-wet conditions in the bed and banks. Further analysis of the site revealed that point source issues may play a part in the consistently elevated values, but definitive conclusions have yet to be made.

3.1.1 *E. coli*

The additional monitoring conducted in 2016 and 2017 indicates that contact recreational use is not supported in Village Creek or its tributaries due to elevated *E. coli* levels. The data also indicates that the additional two tributaries to Lake Arlington that were sampled (stations 10798 and 10793) may also not support contact recreational uses. Often, evaluations of supported uses employ a 10% margin of safety (MoS) to account for one or several sources of uncertainty related to data collection and analysis, including field collection and laboratory errors. When applied in water quality, the MoS is often observed to provided additional confidence that the noted water quality action level is being met.

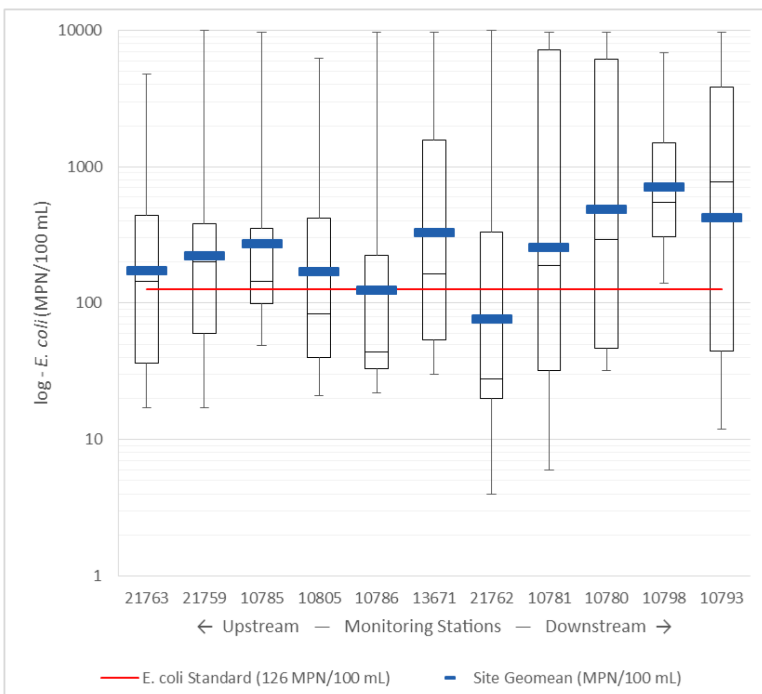


Figure 3-5. Boxplots and geomeans for E. coli samples collected June 2016 – May 2017.

A boxplot analysis of all stations (Figure 3-5) revealed that only one station (21762) maintained a geomean concentration well below the 10% MoS (113 MPN/100 mL) at 76 MPN/100 mL, with another (10786) just below the water quality standard (126 MPN/100 mL) at 124 MPN/100 mL. With the exception of these two sites and Deer Creek (10805), the boxplots indicate that more than half of the samples collected at each site exhibited *E. coli* concentrations higher than the standard, with geomeans varying from 171 (10805) to 713 MPN/100 mL (10798). As indicated earlier, it is worth reiterating that flow-biased sampling methods were a component of this data collection effort, and several high- and flood-flow events represented in the boxplot were intentionally sought so that a variety of flows would be available to conduct a thorough LDC analysis and load estimations. As such, only the routinely collected data will be represented in future biennial integrated reports.

3.1.2 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. However, given the potential point source influence encountered at site 10798, along with several elevated geomeans in upper reaches of the watershed (Figure 3-6), TDS became a prominent parameter of interest from a water supply perspective.

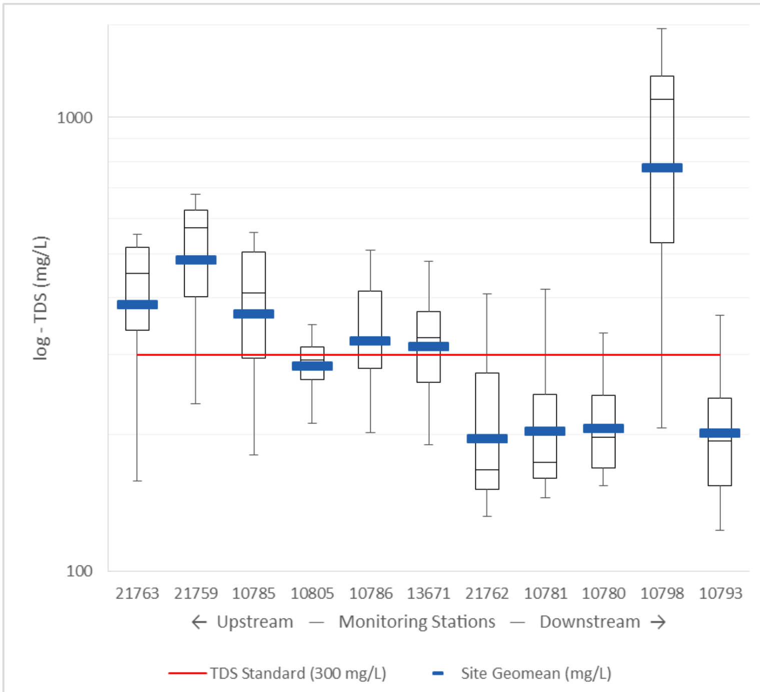


Figure 3-6. Boxplots and geomeans for TDS samples collected June 2016 – May 2017.

Viewed in tandem with the E coli boxplots, the TDS data also support a case for point source wastewater influence within the unnamed tributary, since high TDS values are often associated with raw human sewage. However, inflows from lawn irrigation leaving one of the many residential properties that drain to the tributary may just as easily be the cause. Frequent, low-duration irrigation cycles can cause solids to build up in lawns due to evapotranspiration. In the event an irrigation cycle does produce runoff, it can carry these accumulated solids, along with *E. coli* from any pet feces currently left in the yard, to the stream. This may explain why high TDS and *E. coli* concentrations are encountered in the unnamed tributary outside of storm events. Yet another explanation may lie in the geology specific to the tributary's drainage. Studies conducted by the University of Texas-Arlington (UTA) indicate that groundwater feeding the area is rich in cobalt and nickel, along with several other solids (UTA, n.d.). This constant inflow of groundwater would explain both the elevated TDS and consistent flow, but does not explain why *E. coli* values remain elevated. Field staff from the Trinity River Authority (TRA) conducted supplemental investigations in the tributary. Staff discovered that specific conductivity values (which are related to TDS) below the wastewater line crossing doubled when compared to readings taken above the wastewater pipeline crossing. Although not definitive, these results add to speculation that sewage influence in the area may be partially responsible for the elevated *E. coli*. However, additional studies are needed for full confirmation.

With the exception of the Deer Creek tributary (10805), high TDS values were also apparent in all monitoring sites above the TRWD outfall, with geomeans for the five sites exceeding the water quality standard (300 mg/L) (Figure 3-6). The Quil Miller Creek tributary (21759) exhibited the 2nd highest geomean in the dataset, but in general, both the site geomeans and overall TDS ranges tended to decrease in Village Creek with downstream progression, indicating that additions of flow from other tributaries (dilution) played a role in the TDS reduction.

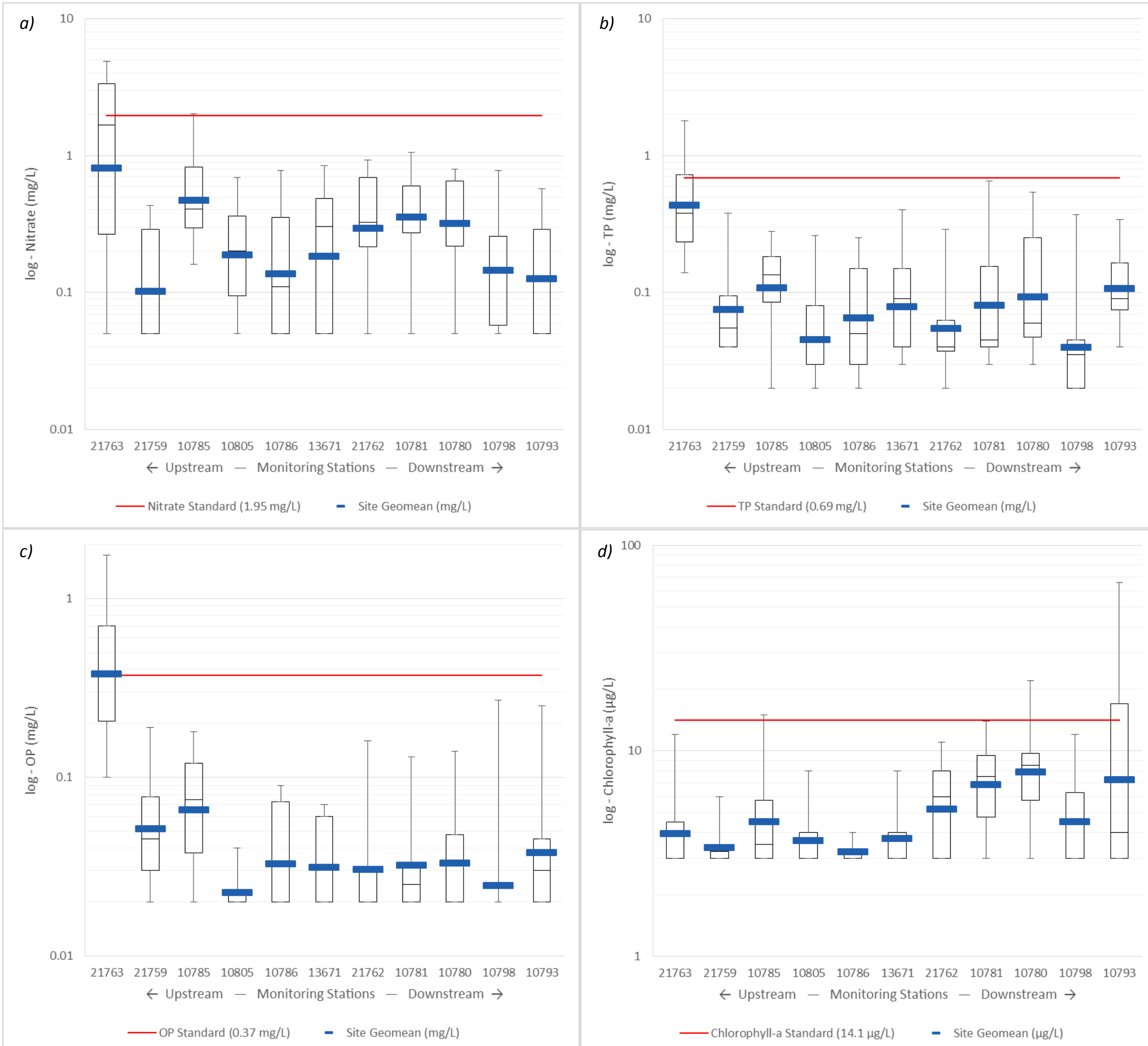
3.1.3 Nutrients

Although several nutrients remain concerns within the lake, no one nutrient was particularly concerning within any of the lake's tributaries. However, values for nitrogen and phosphorus species at the at the most upstream Village Creek site (21763) were slightly elevated when compared to other sites (Figure 3-7). In contrast to the TDS trend, it would appear that the two tributaries, Quil Miller Creek and Deer Creek, are now providing the dilution, this time for nutrients. This indicates that the primary source of nitrogen and phosphorus in the watershed originates in the headwaters of Village Creek's main branch. Initial assumptions on sources were tied to the higher instance of agricultural land use near the headwaters as compared to areas further downstream, but similar, if not greater, agricultural land use in the Quil Miller Creek subwatershed prompted re-evaluation of that hypothesis. After further review of aerial imagery, it became apparent that there were two golf courses upstream of site 21763, one which bordered the west bank of Village Creek, and another through which Village Creek bisected. Golf courses can be a prominent source of nutrients from extensive fertilizer use. Proposed supplemental monitoring will further explore this possibility in the future. Effluent from the nearby WWTF may also be a contributor to the elevated values within this reach of the main stem, with wastewater discharges (and thus nutrient enrichment) being more significant here than in either of the tributaries providing dilution.

This trend reversed direction with respect to chl-a, where the three highest geomeans were exhibited by the three sites (10781, 10780, and 10793) that were under influence of the lake for at least a portion of the project's duration (Figure 3-7). Higher chl-a concentrations here are likely due to decreased flow velocity, which allows for free-floating algal species to populate an area more easily.

Despite the lack of distinct nutrient-related water quality concerns in the tributaries, caution should be exerted when drawing conclusions on how tributary inputs impact the lake. 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.

Both TKN and nitrite were also collected, but boxplots were not generated. In the case of TKN, no management trigger levels exist, although reference concentrations do (USEPA, 2000b). For nitrite, there is also a lack of a formalized management trigger, nor has any reference concentration been developed, since most sources refer to a combination nitrate + nitrite measurement instead. However, nearly all nitrite samples analyzed by the lab were reported below the limit of quantitation, so no realistic estimate of environmental nitrite could be made at any of the monitoring locations. For these reasons, stakeholders chose to focus on nitrate as the single parameter of interest for informing decisions related to nitrogen management.



Boxplots for parameters of interest include a) nitrate, b) total phosphorus, c) orthophosphate-phosphorus, and d) chlorophyll-a.

Figure 3-7. Boxplots and geomeans for nutrients in samples collected June 2016 – May 2017.

3.1.4 Correlation Analysis

The correlation coefficients for the combined dataset of all parameters indicate that significant associations exist between rainfall, *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 nonpoint source runoff, and thus should be addressed primarily through management practices targeted to these events. Of note are correlations between a) rainfall vs. *E. coli* and b) recent rainfall vs. TSS and VSS. Other notable correlations include a) TKN vs. VSS, *E. coli,* and chl-a and b) nitrate vs. TP and OP.

Table 3-1. Correlation coefficients for data collected June 2016 - May 2017.

	24 Hr rain	72 Hr rain	Water Temp (C)	DO (mg/L)	Sp. Cond (uS/cm)	Turbidity (NTU)	Flow (cfs)	Secchi Depth (m)	TSS (mg/L)	VSS (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	TKN (mg/L)	TP (mg/L)
DO (mg/L)			-0.599											
pH (SU)				0.620										
Turbidity (NTU)	0.539													
Flow (cfs)	0.514					0.766								
Secchi Depth (m)	-0.646	-0.624												
TSS (mg/L)	0.636					0.793	0.893							
VSS (mg/L)	0.606					0.782	0.862		0.944					
TDS (mg/L)					0.990									
Nitrate (mg/L)											0.574			
TKN (mg/L)										0.614				
TP (mg/L)												0.797		
OP (mg/L)												0.838		0.936
E. coli (MPN/100mL)	0.782	0.598						-0.749	0.539	0.506			0.524	
Chlorophyll-a (ug/L)													0.530	

notes: All coefficients in table have p-values less than 2.39E-09, therefore these correlations are considered to be actual and significant. An arbitrary cut-off of +/- 0.5 was defined to indicate those correlations which may be significant.

3.2 LDC analysis

3.2.1 *E. coli*

As represented by the data collected at site 10781, the LDC analysis indicates that elevated *E. coli* concentrations are primarily associated with high flow, moist conditions, and mid-range conditions flow categories, indicating that nonpoint source inputs and in-stream resuspension of *E. coli* from bed sediments are primarily responsible for the exceedances (Figure 3-8). Similar conditions are represented at other stations along Village Creek. To ensure that water quality goals are achieved, an annual reduction of 1.61×10^{14} MPN/yr during mid-range conditions is needed at this site (Table 3-2).

In contrast to all other monitored sites, the LDC analysis for site 10798 revealed that reductions were required at all flow conditions, including low flows (Table 3-3). This was also exemplified in the graphical interpretation, as it was the only site where the regression curve for the calculated loads (in blue) never intersected the curve for the maximum allowable load (in red) (Figure 3-9). Here, reductions during mid-range conditions are expected to be 1.83×10^{11} MPN/yr.

Table 3-2. *E. coli* load reduction goals at site 10781.

Flow Condition at Site 04 (10781)	% of Time Flow Exceeds	Daily Loading (MPN/day)	% Daily Reduction Needed for Goal	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)
High Flows	0-10%	8.90E+13	96	3.25E+16	3.10E+16
Moist Conditions	10-40%	1.71E+12	81	6.23E+14	5.14E+14
Mid-Range Conditions	40-60%	5.89E+11	72	2.15E+14	1.61E+14
Dry Conditions	60-90%	2.49E+10	12	9.08E+12	2.13E+12
Low Flows	90-100%	3.78E+09	-	1.38E+12	-

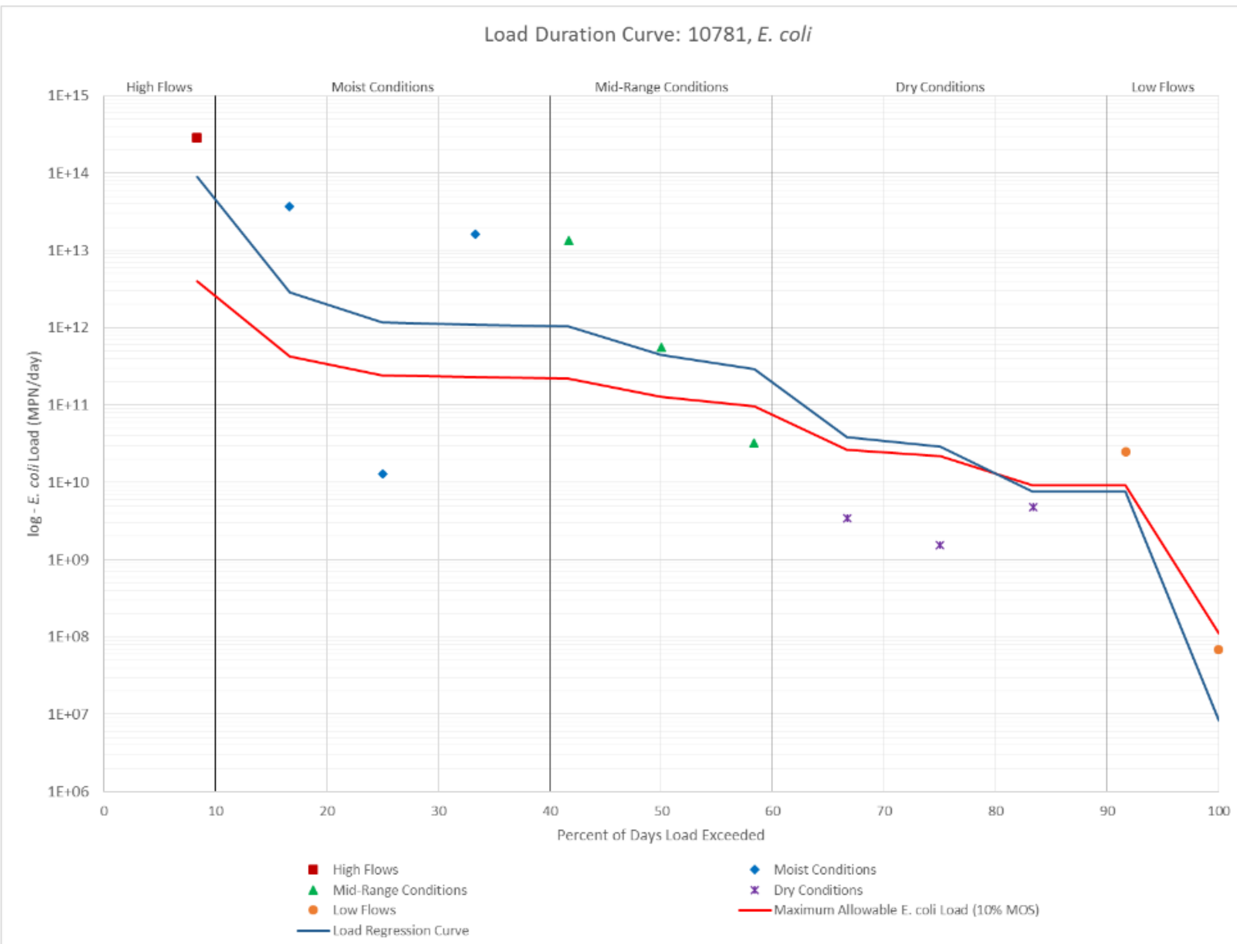


Figure 3-8. LDC for E. coli at site 10781.

Table 3-3. *E. coli* load reduction goals at site 10798.

Flow Condition at Site 02 (10798)	% of Time Flow Exceeds	Daily Loading (MPN/day)	% Daily Reduction Needed for Goal	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)
High Flows	0-10%	6.36E+11	98	2.32E+14	2.27E+14
Moist Conditions	10-40%	1.47E+11	90	5.36E+13	5.23E+13
Mid-Range Conditions	40-60%	6.22E+08	80	2.27E+11	1.83E+11
Dry Conditions	60-90%	2.36E+08	73	8.60E+10	6.34E+10
Low Flows	90-100%	7.09E+07	61	2.59E+10	1.57E+10

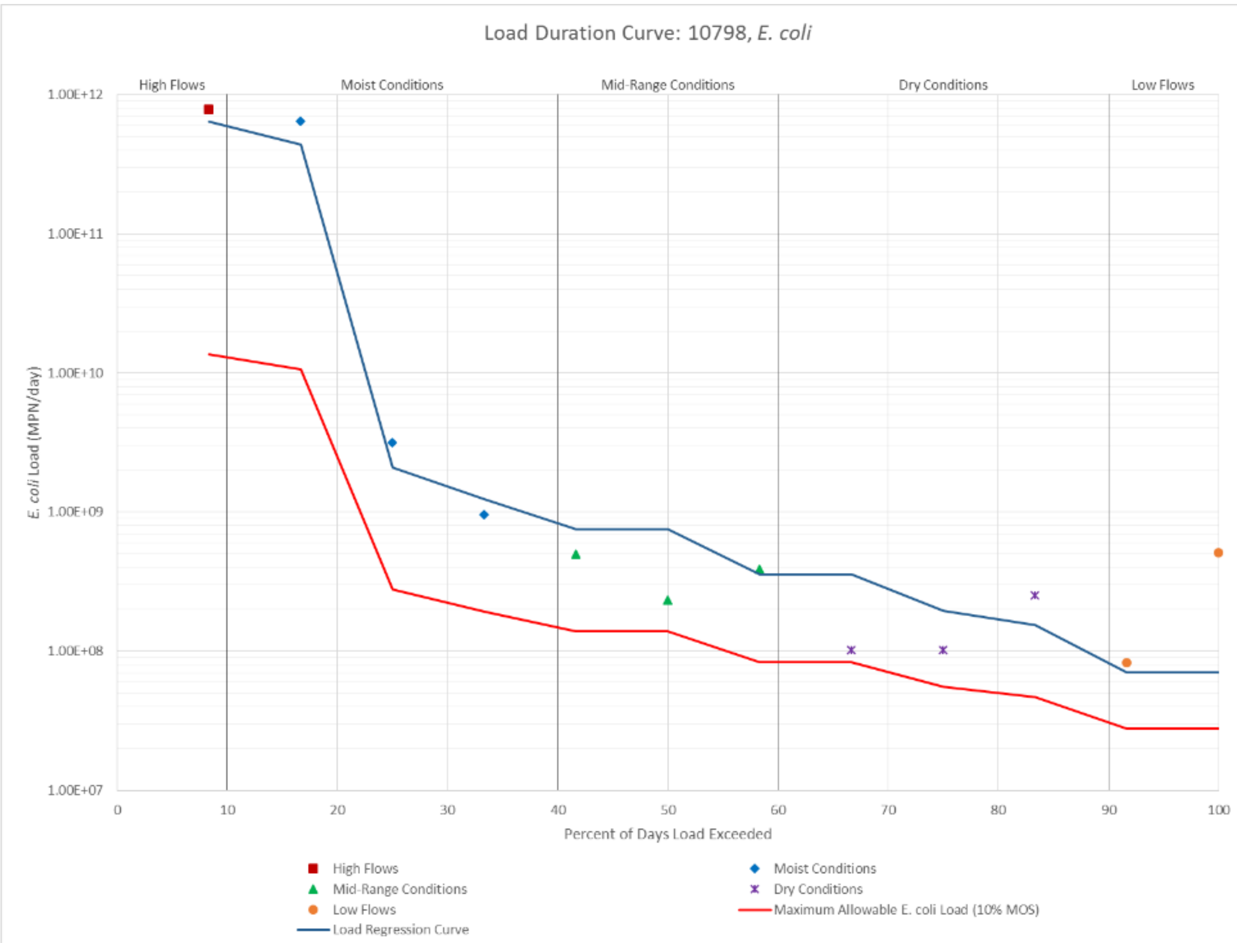


Figure 3-9. LDC for E. coli at site 10798.

3.2.2 Solids

Although several upstream sites exhibit exceedances for TDS at some of the lower flow conditions, likely due to baseflow influence from the nearby WWTFs, these impacts become negligible at site 10781. Thus, no reductions specifically targeted to the TDS load were recommended by stakeholders for the main stem of Village Creek.

For the unnamed tributary, exceedances were prevalent at all flow conditions except high flows. However, TDS is primarily used in this study as a supplemental source of information to further identify potential sources of *E. coli* and nutrient pollution. Therefore, no load reduction goals were identified. This was justified by the fact that steps taken to reduce both *E. coli* and nutrient loads would likely also reduce TDS loads.

3.2.3 Nutrients

As indicated in Section 3.1.3, Lake Arlington is listed for both nitrate and chl-a concerns. Although several collected samples surpass nutrient screening levels for nitrate and TP in the two most upstream sites (21762 and 21759), no overall nutrient concerns currently exist in any of the lake's tributaries. However, it should be noted that the screening level thresholds for nitrate and TP are higher in streams than in lakes (Table 2-2). This means that a nutrient concentration in a stream may meet the screening level there, but would likely surpass the lake's screening level if a sample was taken near the stream-lake confluence where dilution effects were not yet significant. Therefore, while stakeholders did not specifically outline water quality goals in terms of a reduction, several protective measures to mitigate future increases will be recommended. These protective measures are expected to minimize increases to chl-a by limiting the nutrients available to algal species, thus limiting eutrophic potential.

For an in-depth look at LDCs for all parameters of interest at all 11 stations, please refer to Appendix C.

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 analyses. *E. coli* loads were similar for all livestock species (cattle, sheep, goats, and horses), being generally more prevalent in the more rural areas just south of the lake near Everman and Rendon, and further south in Johnson County, with minimal impacts in the urban areas east and west of the lake and in the vicinity of Burleson and Crowley. In particular, per-acre loads were most concentrated in subwatersheds 29, 50, 27, 54, and 32 (Figure 3-10).

Impacts from deer *E. coli* loads were not as widespread, with noticeably less impacts near urban centers, with rare exception. The greatest impacts for deer occurred in the same subwatersheds impacted by livestock, with subwatersheds 29, 54, 50, and 30 bearing the highest per-acre loads (Figure 3-11). The highest *E. coli* loads for feral hogs were exhibited in subwatersheds 13, 54, 29, 30, and 50, but impacts were slightly higher in several urban subwatersheds closer to the lake when compared to other sources. In contrast, *E. coli* loads from pets tended to be highest in these smaller, urban watersheds, with the highest loads encountered in subwatersheds 10, 7, 20, 11, and 22, all occurring along the rim of the lake.

As expected, *E. coli* loads from OSSFs were most significant in the rural areas to the south and east, with the highest loads coming from subwatersheds 36, 31, 53, 45, and 55. Impacts from SSOs were more scattered, with the highest *E. coli* loads borne by subwatersheds 17, 46, 35, 23, and 8. For WWTFs, the three subwatersheds containing active facilities, 50, 44, and 54, were the only ones with measureable loads (Figure 3-12).

As with any spatial analysis, aberrations can occur, and unexpected results should be discussed with stakeholders. In one example, stakeholders questioned the high *E. coli* load for feral hogs in subwatershed 13, as well as in several of the other undeveloped watersheds on the west side of the lake. While feral hog presence is possible since the species commonly uses wooded riparian buffers as passageways between and amongst urbanized areas, their presence here is unlikely given that these areas isolated from other forested areas by dense urban and industrial land uses nearby. Similar situations occurred with several smaller urbanized subwatersheds in the southwest corner of the lake, where it is unlikely that impacts from livestock species are valid concerns due to the fact that development in this area consists primarily of medium-density subdivisions. In this case, it is likely that several open lots in the area have skewed the land cover analysis in the direction of agricultural use, despite no such use being obvious in the area. Stakeholders must be mindful of such situations during the implementation phase of this project so that BMPs are properly applied.

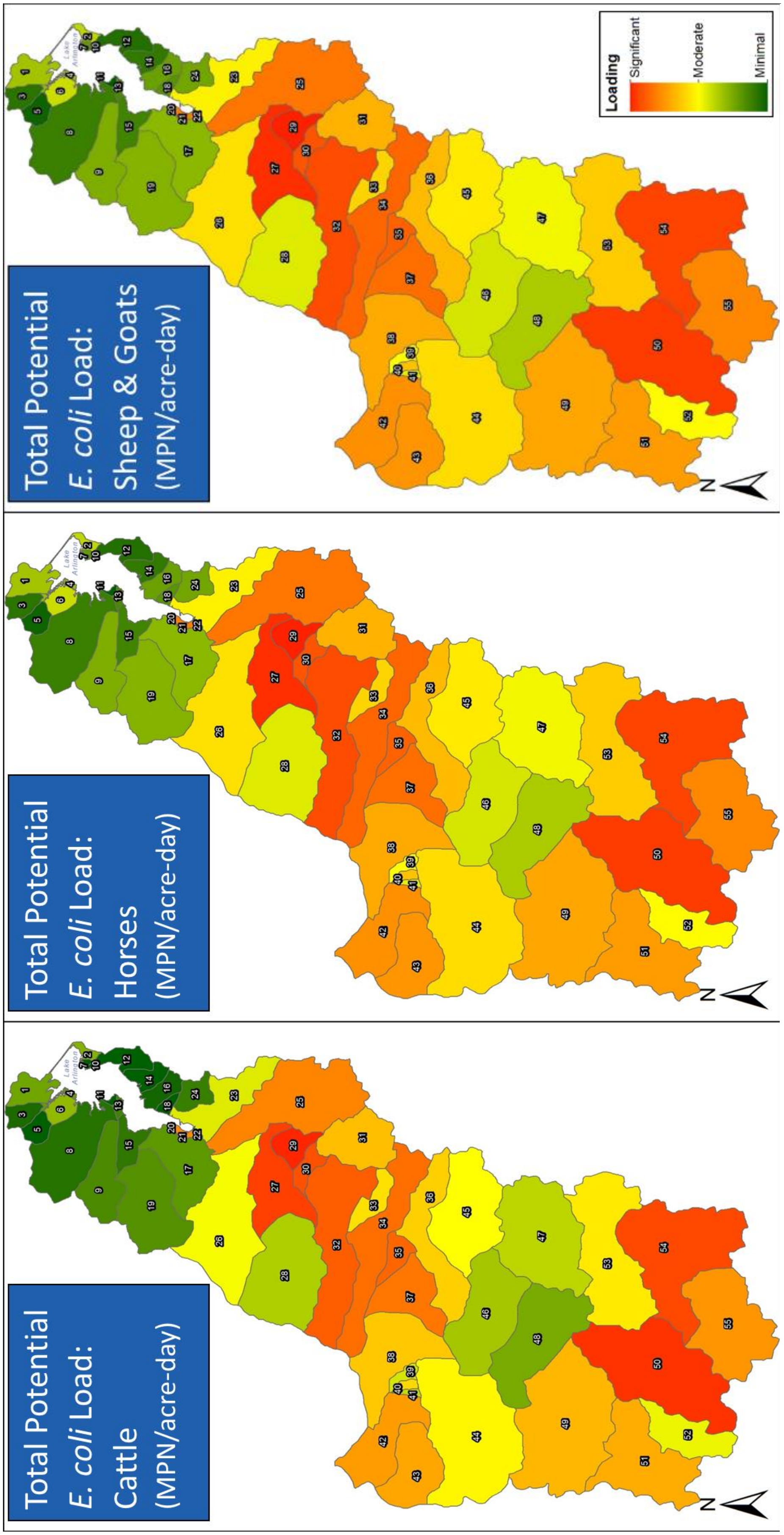


Figure 3-10. Relative severity of E. coli loads from livestock, by subwatershed.

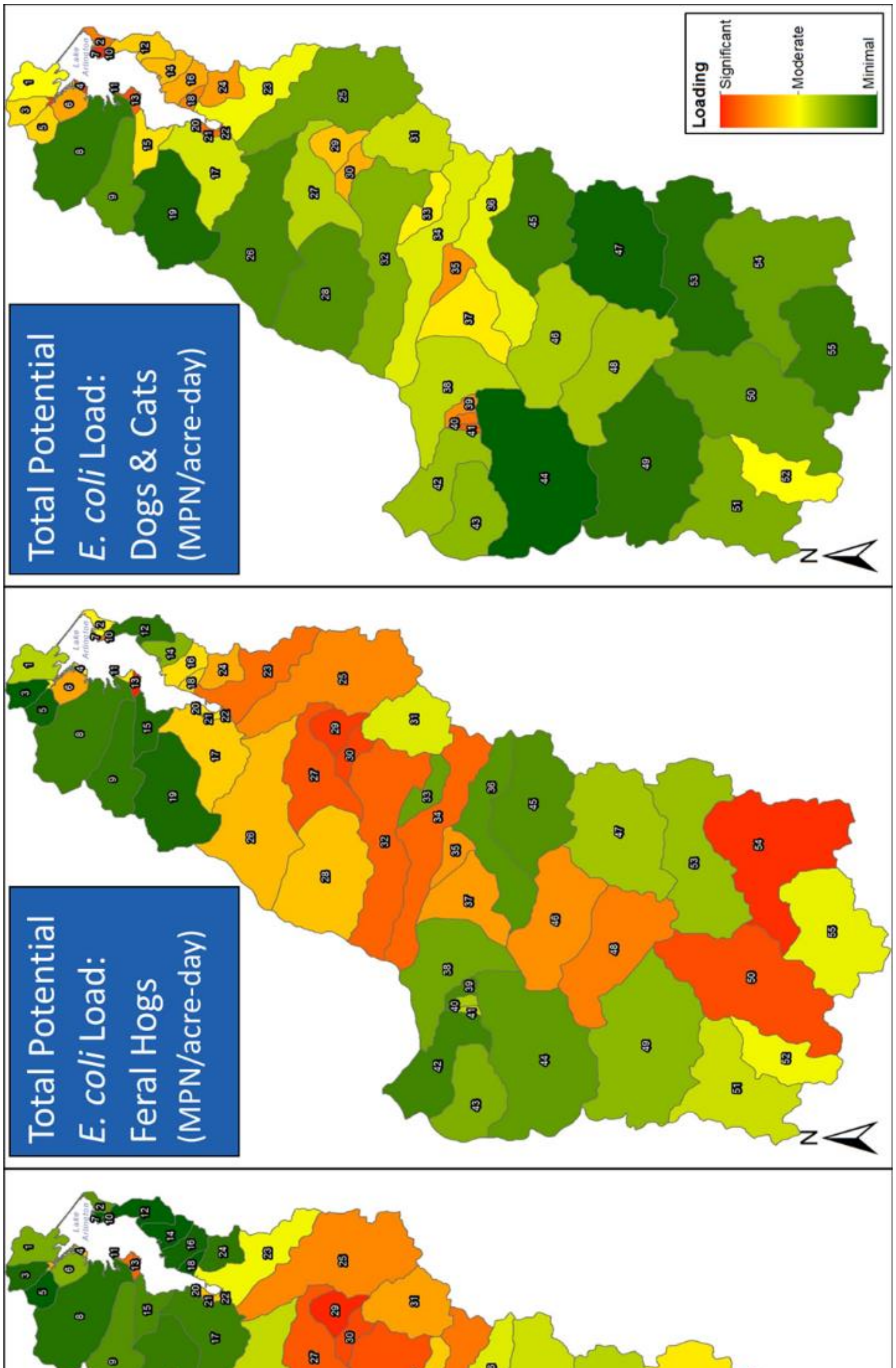


Figure 3-11. Relative severity of E. coli loads from deer, feral hogs, dogs, and cats, by subwatershed.

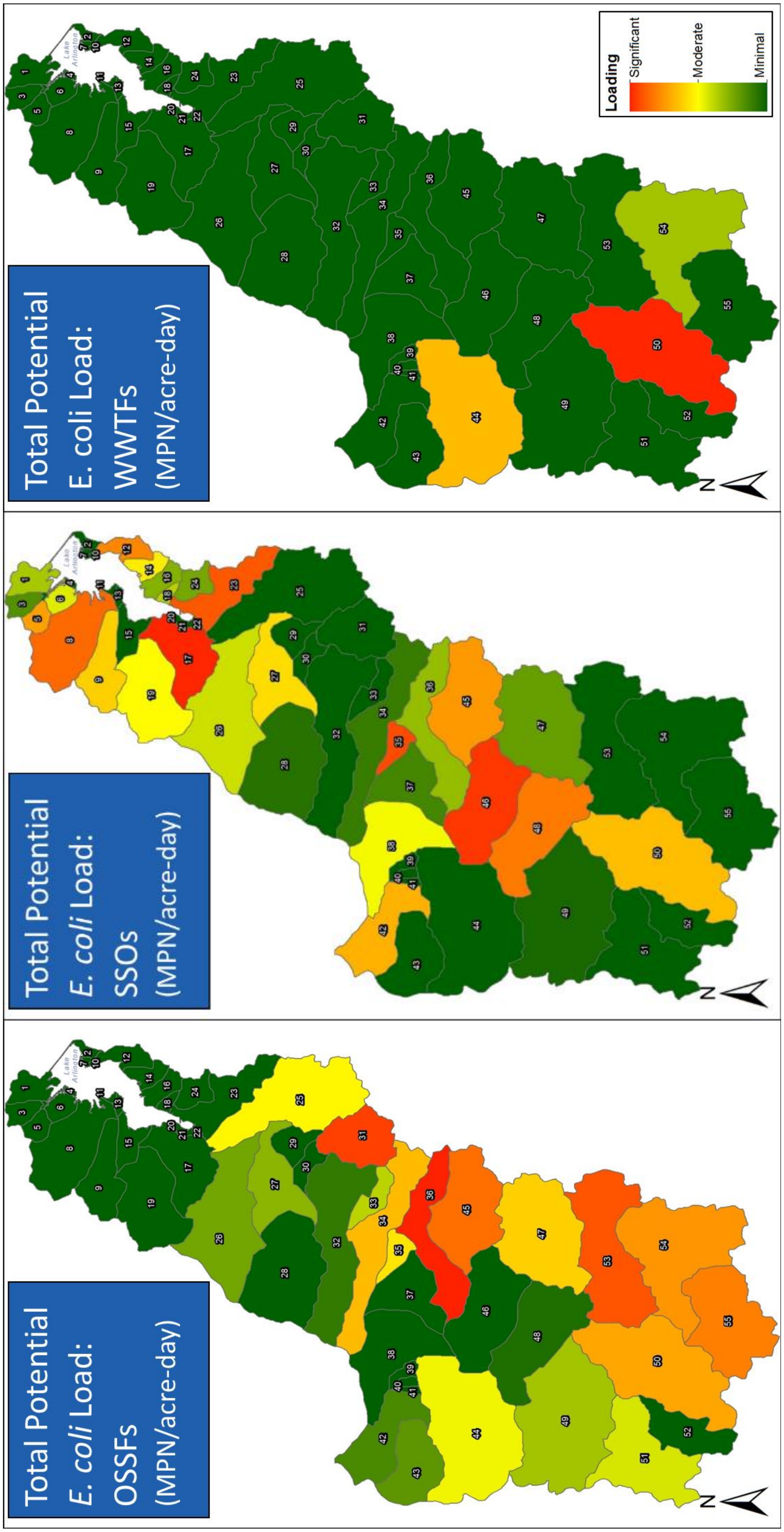


Figure 3-12. Relative severity of E. coli loads from human waste sources, by subwatershed.

Overall, impacts from all combined *E. coli* sources appeared to be most prevalent in three collective categories: 1) in smaller subwatersheds surrounding the lake, 2) near the center of the watershed downstream of the Deer Creek-Village Creek confluence, and 3) in subwatersheds near the headwaters with a relatively high percentage of riparian-to-upland area. Of these, 8 of the 10 subwatersheds with the highest per-acre *E. coli* loads were located on the lake rim (Figure 3-13).

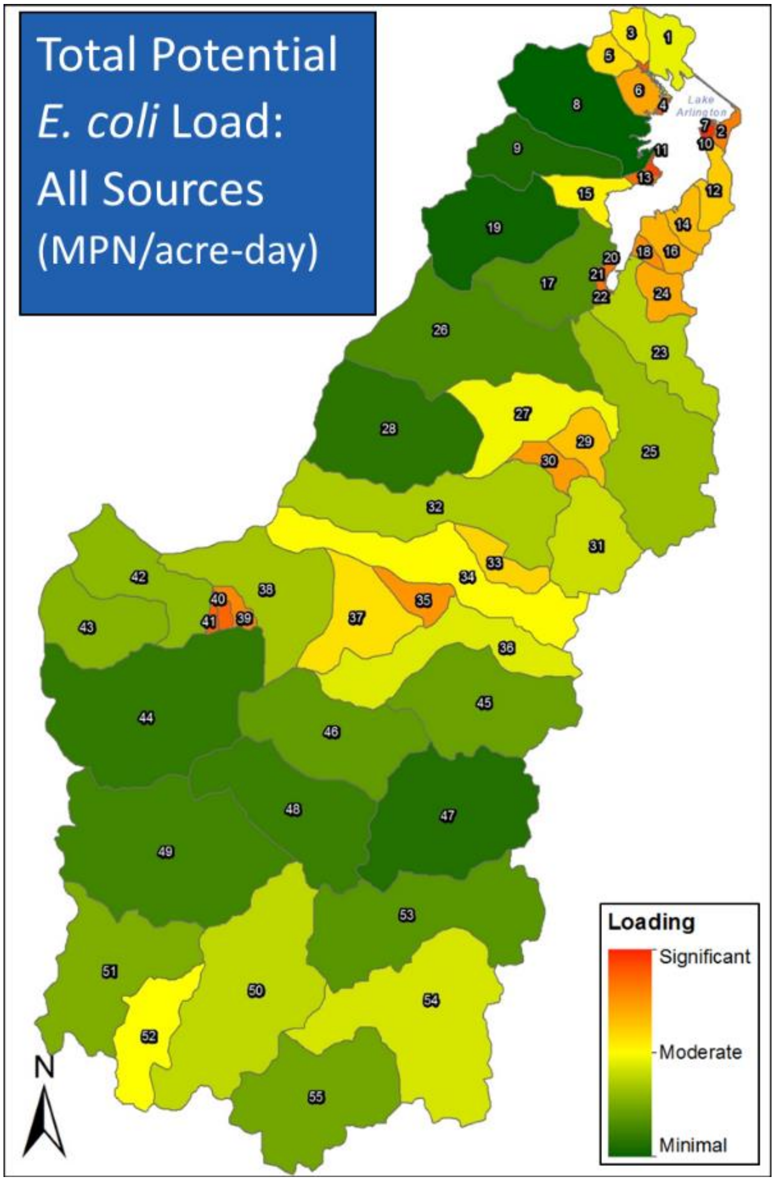


Figure 3-13. Relative severity of E. coli loads for all sources by watershed.

On the west side of the lake, these contributions are likely from wildlife in large forested areas that compose a significant portion of the coastline. In the more urbanized areas around the lake, much of this influence likely comes from dog/cat populations. Pets were by far the most prominent source, with all watersheds contributing at least some amount of *E. coli*. The pets category exhibited both the highest maximum and minimum contributions, highlighting the importance for management of this *E. coli* source. *E. coli* contributions from sheep and goats followed in prominence, with loads from cattle being very similar. OSSFs also supplied significant loads. Figure 3-14 provides a visual comparison of the minimum and maximum loading values for all evaluated *E. coli* sources for the watershed, while Table 3-4 provides an in-depth analysis of all evaluated sources in all 55 subwatersheds. Please note that Figure 3-14 uses units of MPN/ac-day for comparison between pollutant source classes, while Table 3-4 uses units of MPN/day to establish the scope of the reductions needed to meet water quality goals.

As mentioned previously, there exist several potential *E. coli* sources that could not be included reliably, but that stakeholders still recognize 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.

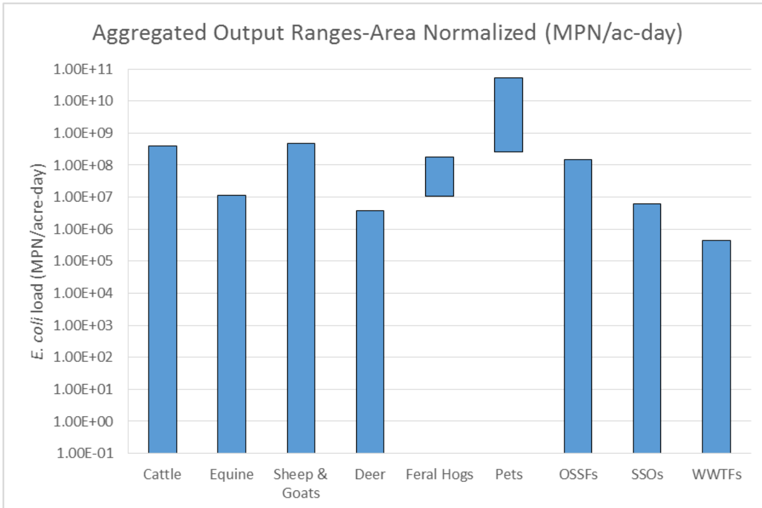


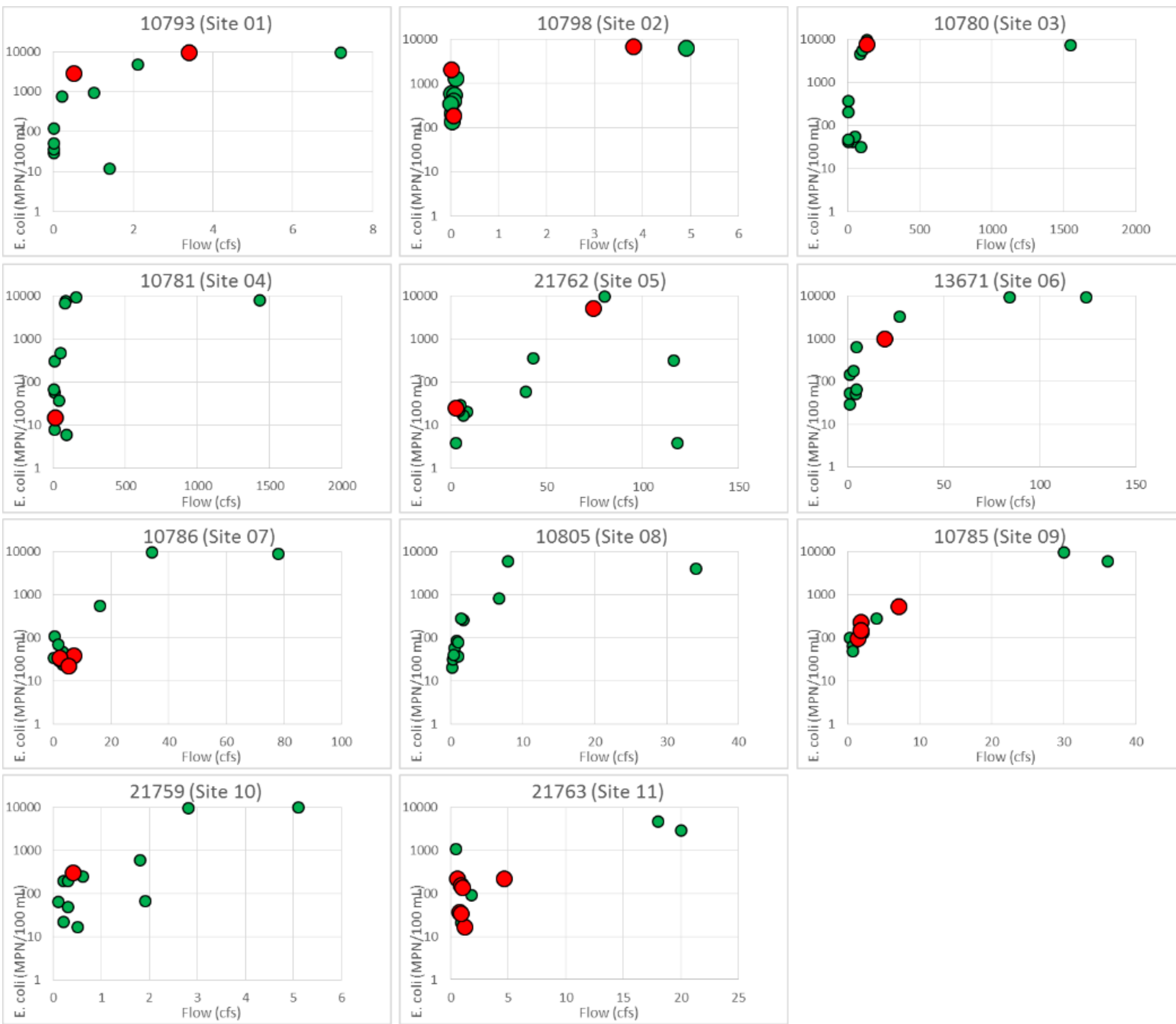
Figure 3-14. Daily Potential E. coli load ranges for all source categories.

Table 3-4. Potential *E. coli* loads for all subwatersheds and evaluated sources (MPN/day).

Sub-watershed	Cattle	Horses	Sheep & Goats	Deer	Feral Hogs	Dogs & Cats	OSSFs	SSOs	WWTFs	Total E. coli
1	3.67E+10	1.18E+09	5.08E+10	4.49E+08	2.93E+10	7.57E+11	—	2.18E+06	—	**8.76E+11**
2	8.77E+09	3.04E+08	1.30E+10	8.57E+07	1.73E+10	1.18E+12	—	—	—	**1.22E+12**
3	1.24E+09	8.27E+07	3.54E+09	8.12E+06	3.28E+09	6.07E+11	—	3.24E+05	—	**6.15E+11**
4	3.04E+09	9.50E+07	4.07E+09	9.65E+07	6.76E+09	1.19E+12	—	—	—	**1.20E+12**
5	—	5.42E+07	2.32E+09	—	3.38E+09	6.01E+11	—	2.18E+07	—	**6.06E+11**
6	2.26E+10	8.11E+08	3.47E+10	3.04E+08	4.70E+10	1.03E+12	—	1.46E+06	—	**1.14E+12**
7	—	1.61E+07	6.91E+08	—	3.71E+09	1.14E+12	—	—	—	**1.14E+12**
8	1.66E+10	7.94E+08	3.40E+10	5.74E+08	7.65E+10	6.94E+11	—	4.43E+08	—	**8.23E+11**
9	1.63E+10	8.53E+08	3.66E+10	5.55E+08	4.16E+10	6.30E+11	—	3.43E+07	—	**7.26E+11**
10	—	1.19E+07	5.11E+08	—	4.22E+09	1.39E+12	—	—	—	**1.40E+12**
11	—	—	—	1.23E+08	5.88E+09	1.05E+12	—	—	—	**1.05E+12**
12	—	9.10E+07	3.90E+09	—	1.10E+10	8.98E+11	—	3.97E+07	—	**9.13E+11**
13	9.29E+08	2.90E+07	1.24E+09	2.29E+08	1.27E+10	1.19E+12	—	—	—	**1.21E+12**
14	—	9.54E+07	4.09E+09	—	1.58E+10	1.02E+12	—	4.84E+06	—	**1.04E+12**
15	4.59E+09	1.92E+08	8.23E+09	1.77E+08	1.12E+10	8.93E+11	—	—	—	**9.18E+11**
16	5.97E+08	2.27E+08	9.71E+09	3.91E+06	5.75E+10	1.15E+12	—	7.85E+05	—	**1.21E+12**
17	5.70E+10	2.24E+09	9.61E+10	5.41E+08	2.53E+11	1.01E+12	—	1.01E+10	—	**1.42E+12**
18	—	5.51E+07	2.36E+09	—	1.75E+10	1.01E+12	—	4.60E+05	—	**1.03E+12**
19	6.48E+10	2.20E+09	9.45E+10	6.28E+08	4.65E+10	6.79E+11	—	2.43E+07	—	**8.87E+11**
20	1.49E+09	4.60E+07	1.97E+09	1.34E+07	1.26E+09	5.57E+11	—	—	—	**5.62E+11**
21	2.01E+10	5.76E+08	2.47E+10	1.38E+08	1.12E+10	1.15E+12	—	—	—	**1.21E+12**
22	—	6.06E+06	2.60E+08	—	4.88E+09	7.86E+11	—	—	—	**7.91E+11**
23	2.09E+11	6.53E+09	2.80E+11	2.28E+09	2.37E+11	1.40E+12	—	4.79E+08	—	**2.13E+12**
24	5.27E+09	2.94E+08	1.26E+10	1.12E+08	6.81E+10	1.50E+12	—	8.33E+05	—	**1.58E+12**
25	1.01E+12	3.02E+10	1.29E+12	9.19E+09	5.69E+11	1.26E+12	1.67E+11	—	—	**4.34E+12**
26	5.23E+11	1.65E+10	7.06E+11	5.40E+09	5.54E+11	1.07E+12	4.01E+10	1.52E+07	—	**2.92E+12**
27	6.67E+11	1.98E+10	8.48E+11	5.57E+09	2.85E+11	9.49E+11	2.00E+10	2.56E+07	—	**2.79E+12**
28	3.32E+11	1.07E+10	4.58E+11	5.17E+09	4.95E+11	9.69E+11	—	2.54E+06	—	**2.27E+12**
29	2.15E+11	6.27E+09	2.69E+11	2.11E+09	9.02E+10	9.87E+11	—	—	—	**1.57E+12**
30	1.35E+11	3.85E+09	1.65E+11	1.25E+09	5.93E+10	1.03E+12	—	—	—	**1.40E+12**
31	2.85E+11	8.45E+09	3.62E+11	3.25E+09	1.08E+11	1.20E+12	2.20E+11	—	—	**2.19E+12**
32	1.25E+12	3.72E+10	1.59E+12	1.15E+10	5.38E+11	1.25E+12	1.00E+10	—	—	**4.70E+12**
33	8.93E+10	2.56E+09	1.10E+11	1.00E+09	2.38E+10	8.93E+11	1.34E+10	—	—	**1.13E+12**
34	9.60E+11	2.80E+10	1.20E+12	8.08E+09	4.29E+11	1.63E+12	1.87E+11	2.20E+06	—	**4.44E+12**
35	1.60E+11	4.64E+09	1.99E+11	1.18E+09	6.73E+10	1.99E+12	2.00E+10	1.48E+08	—	**2.44E+12**
36	3.73E+11	1.09E+10	4.69E+11	3.21E+09	8.60E+10	1.88E+12	3.24E+11	5.01E+06	—	**3.15E+12**
37	5.12E+11	1.53E+10	6.58E+11	3.81E+09	2.34E+11	1.72E+12	—	1.30E+06	—	**3.14E+12**
38	4.46E+11	1.33E+10	5.71E+11	4.00E+09	1.07E+11	1.85E+12	—	1.32E+07	—	**2.99E+12**
39	2.05E+10	6.33E+08	2.71E+10	1.85E+08	6.15E+09	1.53E+12	—	—	—	**1.58E+12**
40	1.61E+10	4.60E+08	1.97E+10	1.42E+08	4.95E+09	1.58E+12	—	—	—	**1.63E+12**
41	8.00E+09	2.36E+08	1.01E+10	9.40E+07	3.64E+09	1.63E+12	—	—	—	**1.65E+12**
42	4.12E+11	1.22E+10	5.23E+11	2.99E+09	6.27E+10	1.04E+12	6.68E+09	8.67E+07	—	**2.06E+12**
43	3.69E+11	1.07E+10	4.60E+11	3.26E+09	7.37E+10	8.62E+11	6.68E+09	—	—	**1.79E+12**
44	7.93E+11	2.36E+10	1.01E+12	6.58E+09	2.09E+11	1.31E+12	1.94E+11	—	2.25E+08	**3.55E+12**
45	4.37E+11	1.28E+10	5.48E+11	4.31E+09	1.06E+11	1.26E+12	2.84E+11	2.27E+08	—	**2.66E+12**
46	2.71E+11	8.87E+09	3.80E+11	3.28E+09	4.40E+11	1.42E+12	—	2.19E+09	—	**2.53E+12**
47	4.31E+11	1.30E+10	5.58E+11	5.53E+09	1.93E+11	9.95E+11	1.74E+11	4.53E+06	—	**2.37E+12**
48	2.13E+11	7.50E+09	3.21E+11	2.42E+09	4.73E+11	1.35E+12	3.34E+09	4.05E+08	—	**2.37E+12**
49	9.98E+11	2.93E+10	1.25E+12	9.31E+09	2.47E+11	1.54E+12	1.00E+11	2.16E+05	—	**4.17E+12**
50	1.78E+12	5.27E+10	2.26E+12	1.64E+10	7.64E+11	1.43E+12	3.27E+11	2.16E+08	2.14E+09	**6.63E+12**
51	6.20E+11	1.82E+10	7.82E+11	6.14E+09	1.88E+11	1.38E+12	1.07E+11	—	—	**3.10E+12**
52	1.92E+11	5.83E+09	2.50E+11	2.42E+09	1.27E+11	1.62E+12	—	—	—	**2.20E+12**
53	6.13E+11	1.84E+10	7.87E+11	6.67E+09	1.92E+11	1.09E+12	4.41E+11	—	—	**3.14E+12**
54	1.68E+12	4.96E+10	2.12E+12	1.60E+10	7.45E+11	1.50E+12	3.27E+11	—	8.16E+07	**6.43E+12**
55	7.46E+11	2.21E+10	9.49E+11	7.36E+09	2.20E+11	1.07E+12	2.54E+11	—	—	**3.27E+12**
Totals										
Daily	1.70E+13	5.11E+11	2.19E+13	1.64E+11	8.69E+12	6.48E+13	3.23E+12	1.45E+10	2.45E+09	**1.16E+14**
Annual	*6.21E+15*	*1.86E+14*	*7.99E+15*	*5.99E+13*	*3.17E+15*	*2.36E+16*	*1.18E+15*	*5.29E+12*	*8.94E+11*	***4.24E+16***

3.4 OB detection analysis

Positive results for OB detection are provided above for selected sites in Figure 3-1 through Figure 3-4. Results for all sites are provided in Appendix B. A simplified version relating *E. coli,* flow, and OB detection is provided below in Figure 3-15, with positive OB detection results noted in red. The method itself, while providing some insight into what are believed to be several false positives, did not necessarily provide any solid evidence of human waste contamination at any point in the watershed, either as a consistent load or as a periodic occurrence. In particular, the continued use of the intensely reflective grass dyes on the golf courses upstream of site 11 (21763) likely masks any sewage influence that may exist in the water column. It may also be that there are simply too many variables to account for in natural waterways that do not exist in heavily channelized municipal stormwater conveyance systems where this method has proven effective. However, due to the cost-effectiveness and simplicity of the analysis, TRA will continue to conduct OB studies in the event that the analysis does, in fact, provide early detection of human waste contamination during future field sampling operations.



Negative or indeterminate results represented in green, positive results represented by larger red markers.

Figure 3-15. OB detection results for 11 sites in the watershed.

3.5 Illegal Dumping Site Identification

Of the 22 sites, 5 were classified as *critical impact*, 3 were *significant impact*, 4 had *some impact*, and 9 had *minimal impact* on water quality (Figure 3-16, Table 3-5). In addition to common items like household waste, landscaping/yard waste, basic litter, and automobile tires, field staff also observed items such as furniture, appliances, medical waste, hazardous chemical waste containers, human waste, and dead animal carcasses. Impacts specific to occupation by homeless individuals were also well-represented in the area of interest (Figure 3-16). Of note are sites WS19 and WS21, which are located on Village Creek, on the bank opposite of the nearby municipal landfill. Here, frequent, ongoing, and high-volume illegal dumping activity from homeowners - and potentially even local businesses - is occurring. Similar behavior is occurring at WS09, within an enclosed area once suspected to be a roll-off dumpster enclosure. The dumpsters are still present, but have not been emptied in some time, and users have since resorted to piling trash inside the enclosure outside of the dumpsters. WS20, which is within the normal pool level of the lake, is another notable site due to its use as a frequent dumping area for large furniture and animal carcasses. Photographic evidence for several example items and sites is provided in Appendix D.

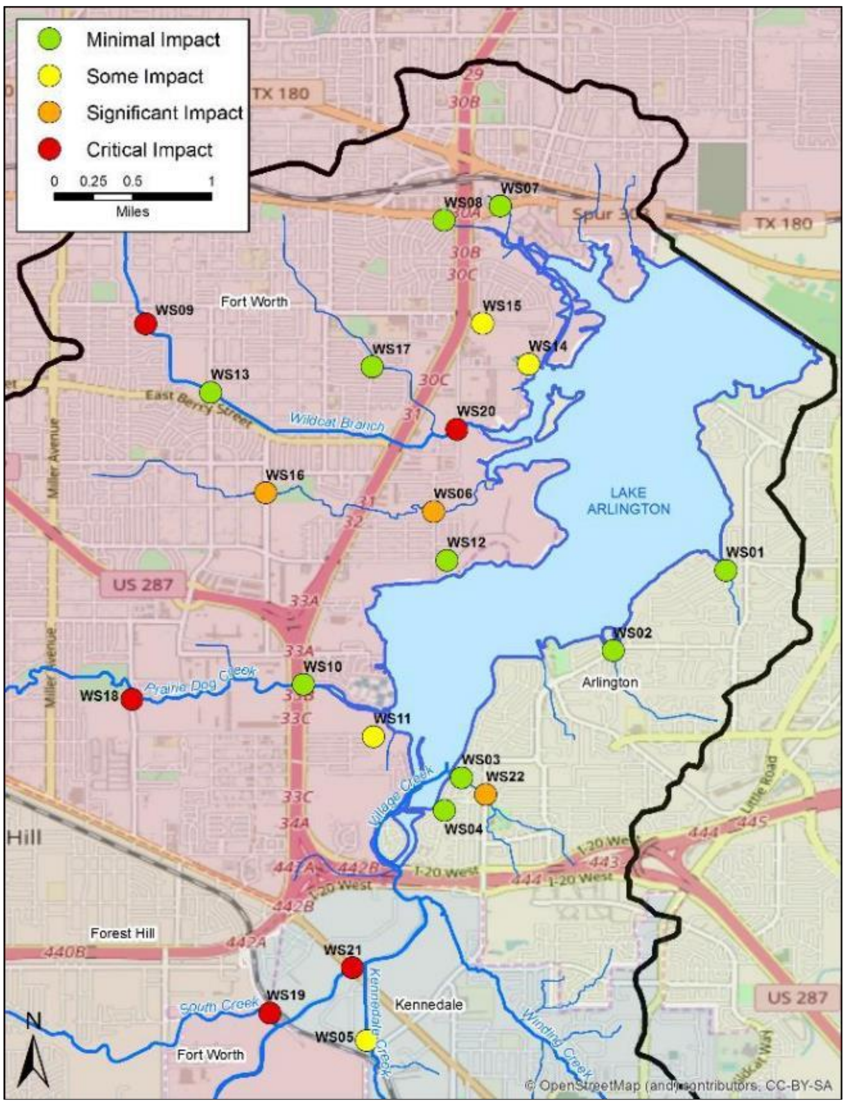


Figure 3-16. Site location and impact severity for illegal dumping near Lake Arlington.

Table 3-5. Preliminary Lake Arlington Illegal Dumping Survey.

Site_I.d.	Waste_Type	Waste_Quantity	Erosion	Homeless	Estimated_Flow	Trash	Total_Severity
WS01	Basic litter	< trash can	Yes	No	1-10CFS	From Offsite	11
WS02	basic litter	< trash can	No	No	1-10CFS	From Offsite	6
WS03	Basic litter, Fishing	< trash can	No	No	1-10CFS	Unknown	7
WS04	Beer cans	< trash can	No	No	<1CFS	Placed or Dumped	8
WS05	construction	> trash can < dumpster	No	No	1-10CFS	Placed or Dumped	16.8
WS06	potential sewer leak, basic litter, automotive fluids, graffiti	> trash can < dumpster	Yes	No	1-10CFS	From Offsite and Dumped at site	38
WS07	basic litter	< trash can	No	No	1-10CFS	From Offsite	7
WS08	basic litter at a park	< trash can	Yes	No	1-10CFS	From Offsite	11
WS09	toxics, house waste, construction, dead animals, basic litter, tires	> trash can < dumpster	No	No	1-10CFS	From Offsite and Dumped at site	50.4
WS10	basic litter	< trash can	No	No	1-10CFS	From Offsite	6
WS11	house waste	> trash can < dumpster	No	Yes	1-10CFS	Placed or Dumped	16.8
WS12	basic litter	< trash can	No	No	No Flow	Unknown	1
WS13	minimal	< trash can	No	No	<1CFS	Unknown	0
WS14	Basic litter, Fishing, Beer cans	> trash can < dumpster	No	No	1-10CFS	From Offsite and Dumped at site	19.2
WS15	House waste, basic litter, tires	< trash can	Yes	No	1-10CFS	From Offsite	14
WS16	house waste, basic litter, beer cans	> trash can < dumpster	Yes	No	1-10CFS	From Offsite and Dumped at site	33.6
WS17	construction, basic litter	< trash can	No	No	<1CFS	From Offsite and Dumped at site	4
WS18	Toxic, house Waste, construction, basic litter, tires	> Dumpster	No	No	1-10CFS	From Offsite and Dumped at site	64
WS19	toxics, construction, human waste, basic litter, medical waste, tires	> Dumpster	No	Yes	>10CFS	Placed or Dumped	192
WS20	Toxic, construction, dead animals, tires, graffiti	> trash can < dumpster	Yes	No	>10CFS	From Offsite and Dumped at site	84
WS21	Toxic, construction, human waste, graffiti, homeless habitation, tires	> Dumpster	Yes	Yes	>10CFS	From Offsite and Dumped at site	192
WS22	Basic litter	> trash can < dumpster	No	No	<1CFS	From Offsite and Dumped at site	24

4.0 Conclusions

Based on these analyses, nonpoint source pollution is the main driver of water quality impairments in Village Creek and its tributaries. This may also be true for the small unnamed tributary to Lake Arlington, although some evidence of point source influence does exist for that subwatershed. 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. Soil permeability also appears to play a significant role in the sharp increases in *E. coli* loading seen downstream of the site near Enon Rd (21763), where any water quality improvements afforded by the addition of water from the TRWD outfall are quickly masked by runoff inputs from other tributaries from areas with highly impermeable soils off to the west (Figure 2-8).

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 VCLA 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 VCLA 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 the $1.61*10^{14}$ MPN/yr reduction on Village Creek and the $1.83*10^{11}$ MPN/yr reduction needed for the unnamed tributary.

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 VCLA watershed. This expectation also extends to the illegal dumping surveys. The event detailed in this report only serves as a snapshot of watershed conditions, which may or may not be indicative of future conditions at these sites. Therefore, it is imperative that ongoing surveys occur to reassess progress at these sites as implementation gets underway. Expansion of the site survey further towards the headwaters will provide further insight into the issue, and may afford field and analysis staff a broader view of illegal dumping behavior throughout the watershed. This information will ensure that the proper management methods are used to meet the water quality needs of the VCLA watershed and the citizens that depend on it as a drinking water source.

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Appendix A. Geospatial Data Sources Used for Watershed Analysis

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Aerial imagery	NAIP, TOP	2014, 1996	Mosaic and clip raster files to watershed	Determine ground conditions of watershed
Topographic maps (1:24,000 scale)	USGS		Isolate DOQQs situated inside/tangent to watershed boundary	Characterize watershed, reference for hydrologic features
Detailed streets and highways	ESRI		None	Public outreach component, orient map viewers to watershed extents
City boundaries	TCEQ		Clip features to watershed boundary	Public outreach component
County boundaries	TCEQ		Clip features to watershed boundary	Public outreach component
Lake Arlington-Village Creek watershed	NHD		Aggregate of HUC 12 subwatersheds above Lake Arlington 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		Clip source points to watershed boundary	Determine location, density of structures
SWQM stations	TRA, TCEQ		Relate to surface water quality data sampling results	Document locations of surface water quality monitoring stations
County Soils Maps	NRCS (SSURGO)		Identify areas that may prove problematic for modeling and/or pollutant transport	Characterize watershed, watershed delineation
General Soils Maps	NRCS (STATSGO)		Identify areas that may prove problematic for modeling and/or pollutant transport	Characterize watershed, watershed delineation
NLCD	TNRIS	2011	Clip database to watershed boundary, identify areas that may prove problematic for modeling and/or pollutant transport	Determine land use/land cover in watershed, watershed delineation
LULC field verification points	TRA		Compare to NLCD database	Determine accuracy of NLCD data
SWCD boundaries	TSSWCB		Isolate Dalworth/Johnson SWCDs	Public outreach strategy
List of steering committee member locations	TRA		Gather geographic information at stakeholder meetings, personal communication, email	Determine distribution of committee member locations to ensure adequate watershed representation
RUAA sampling locations	TCEQ		Generalize sampling location results to applicable extents within watershed	Determine extent of recreational use in watershed for bacteria standards applicability
Digital Elevation Models (DEMs)	USGS		Mosaic and clip raster files to watershed mask, process to develop stream network.	Watershed delineation
Weather data	NWS		Isolate precipitation, evaporation, and temperature data; isolate for time period dictated by SWAT modeling constraints	Watershed delineation

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Hydrology - existing lakes and reservoirs	NHD		Ground truth feature margins for accuracy	Watershed delineation
Hydrology – streams	NHD		Clip NHD features to watershed boundary	Watershed delineation
Named streams	NHD		Generalize NHD data for streams, isolate named streams to new layer	Public outreach – use for general information maps
TCEQ stream segments	TCEQ		Clip features to watershed boundary	Watershed delineation
TCEQ assessment units	TCEQ		Clip features to watershed boundary	Watershed delineation
Aquifers – major and minor	TWDB		None	Public outreach component
TCEQ surface water quality monitoring stations	TCEQ		Identify new/existing station locations at strategic points along stream path	Watershed delineation
Floodplain data	National Flood Hazard Layer – FEMA		Compare and adjust LULC maps as appropriate	Used to update LULC maps as necessary, public outreach component
Oil & natural gas wells	RRC of Texas		Clip features to watershed boundary	Locate and determine density of oil/natural gas wells for potential pollutant point source identification
Public water system wells & surface water intakes	TCEQ		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		Verify activity & history of sites clipped to watershed	Potential pollutant point source identification
Solid waste sites/landfills/ illegal dump site field verification	TRA		Compare to 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		Comparison and integration of TRA and NRCS records	Identify and verify significant impoundments in watershed
Superfund sites	TCEQ		Clip database to watershed boundary	Potential pollutant point source identification
Petroleum storage tanks	TCEQ		Clip database to watershed boundary	Potential pollutant point source identification
Permitted industrial/ hazardous waste sites	TCEQ		Clip database to watershed boundary – **none in watershed**	Locate sites for potential pollutant point source identification
CAFOs	TCEQ		Clip database to watershed boundary – **none in watershed**	Locate sites for potential pollutant point source identification
Cattle – population density	USGS National Agricultural Statistics Service	2007	Clip database to watershed boundary	*E. coli* load calculation
Sheep – population density	USGS National Agricultural Statistics Service	2007	Clip database to watershed boundary	*E. coli* load calculation

Geospatial Data	Source	Date	Analysis and/or Processing	Data Use
Goats – population density	USGS National Agricultural Statistics Service	2007	Clip database to watershed boundary	*E. coli* load calculation
Horses – population density	USGS National Agricultural Statistics Service	2007	Clip database to watershed boundary	*E. coli* load calculation
Deer – population density	TPWD deer density study (Lockwood 2007)	2007	Clip database to watershed boundary	*E. coli* load calculation
Waterfowl – population density	Stakeholder input, using other WPP data as benchmarks		Bias to riparian buffers, other areas of interest identified by stakeholders	*E. coli* load calculation
Other avian – population density	Stakeholder input, using other WPP data as benchmarks		Bias to bridge crossings, 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		Bias to riparian buffers, other areas of interest identified by stakeholders	*E. coli* load calculation
WWTFs	TCEQ		Clip to watershed boundary, verify operational state	*E. coli* load calculation
Certificates of Convenience and Necessity (CCNs)	Public Utility Commission of Texas		Clip to watershed, verify extents	*E. coli* load calculation
OSSFs	Census Bureau	2010	Census data, total households – CCNs = total households w/OSSFs	*E. coli* load calculation
Domestic dogs	Census Bureau and stakeholder input	2010	Census data, households *0.8 = dogs	*E. coli* load calculation

Appendix B. Site Summaries for *E. coli*, Optical Brighteners, and Streamflow

Figure B-1 through Figure B-11 correlate flow, *E. coli* measurements, and OB test results to rainfall events. Flow is represented by black horizontal bars. *E. coli* is represented by the horizontal bars, with light blue representing measurements with negative OB detection, and purple bars representing positive OB detection. 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.

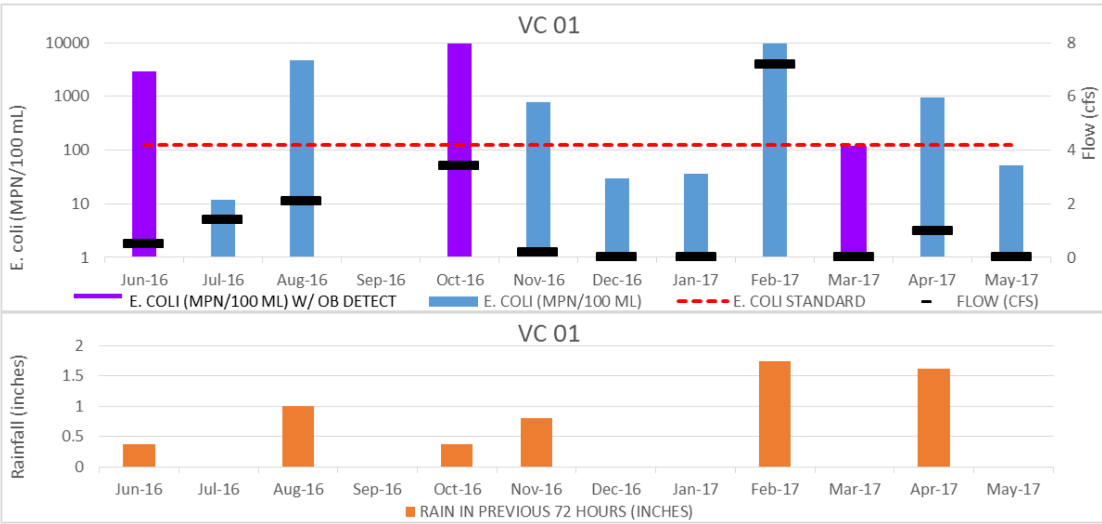


Figure B-1. Hydrology and E. coli parameters, Wildcat Branch at Cravens Road (10793).

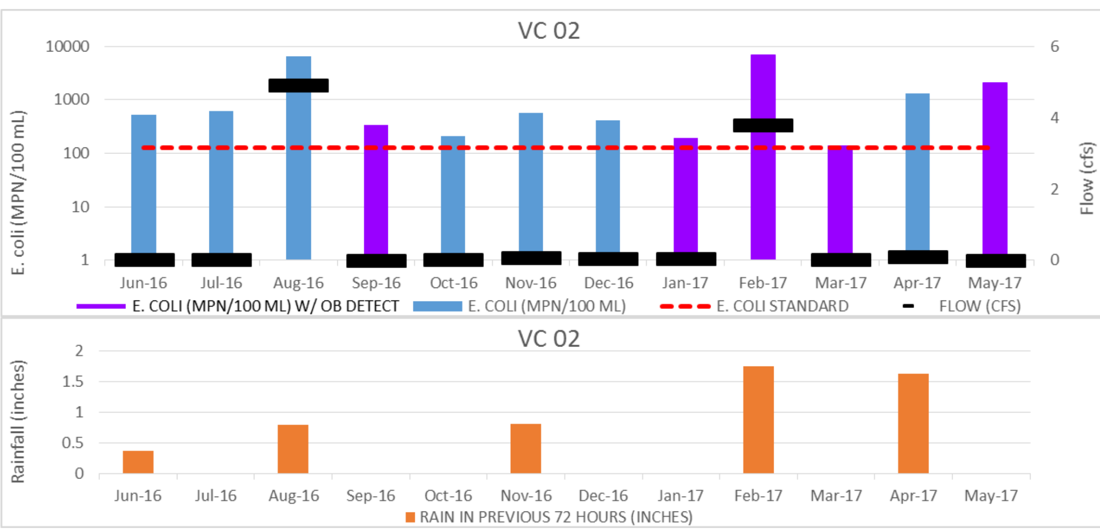


Figure B-2. Hydrology and E. coli parameters, Tributary of Lake Arlington (10798).

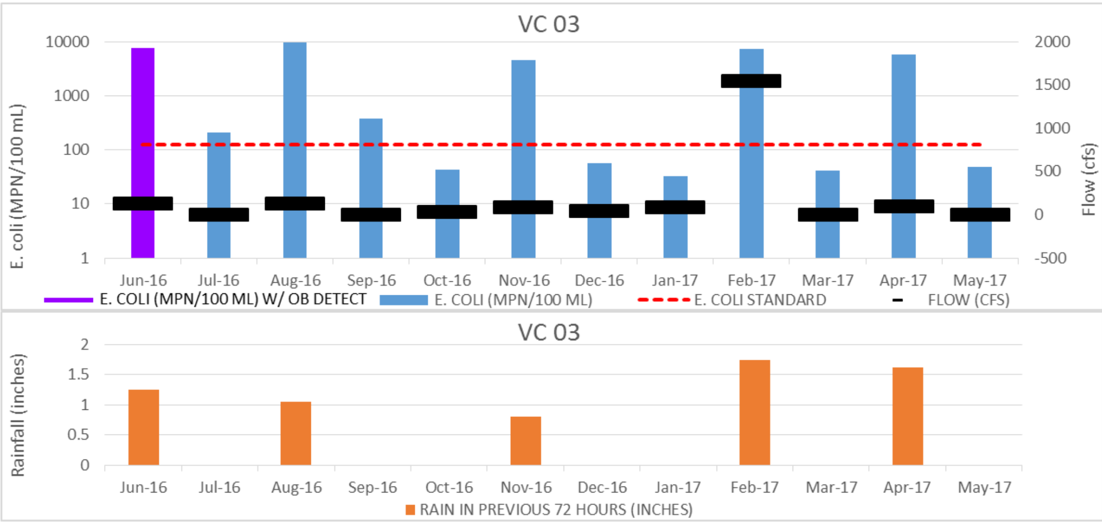


Figure B-3. Hydrology and E. coli parameters, Village Creek at IH-20 (10780).

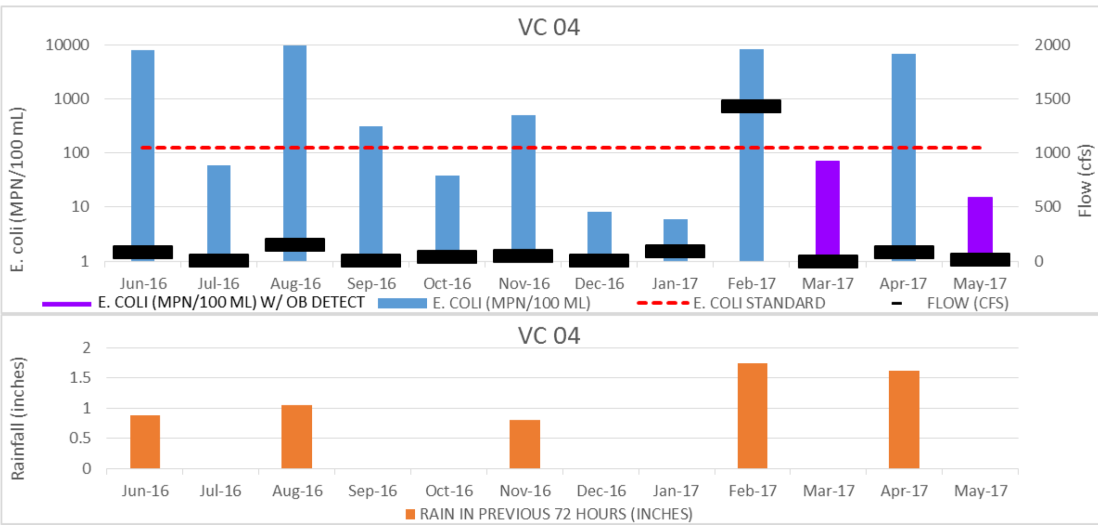


Figure B-4. Hydrology and E. coli parameters, Village Creek Downstream of US BUS 287 (10781).

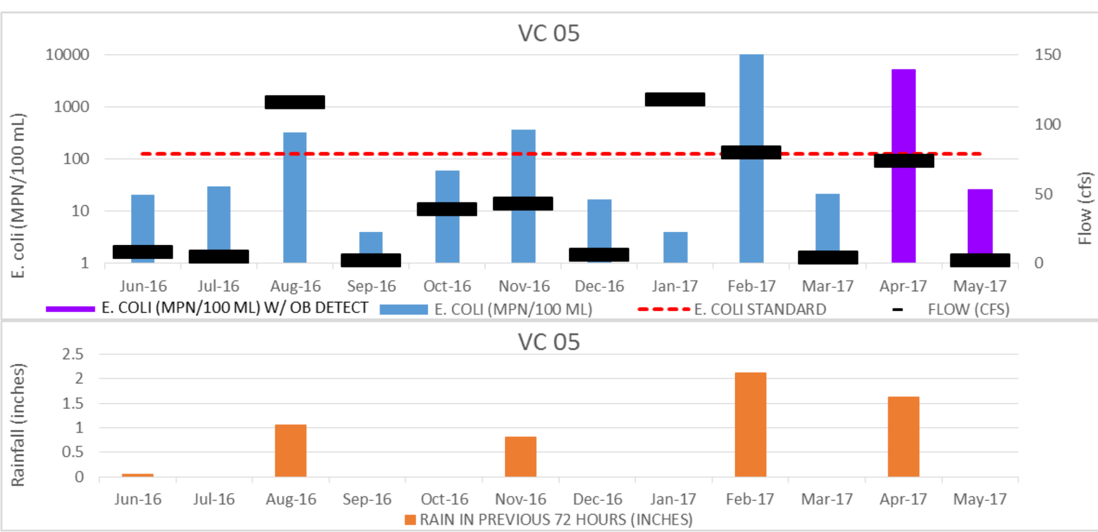


Figure B-5. Hydrology and E. coli parameters, Village Creek near Freeman Drive (21762).

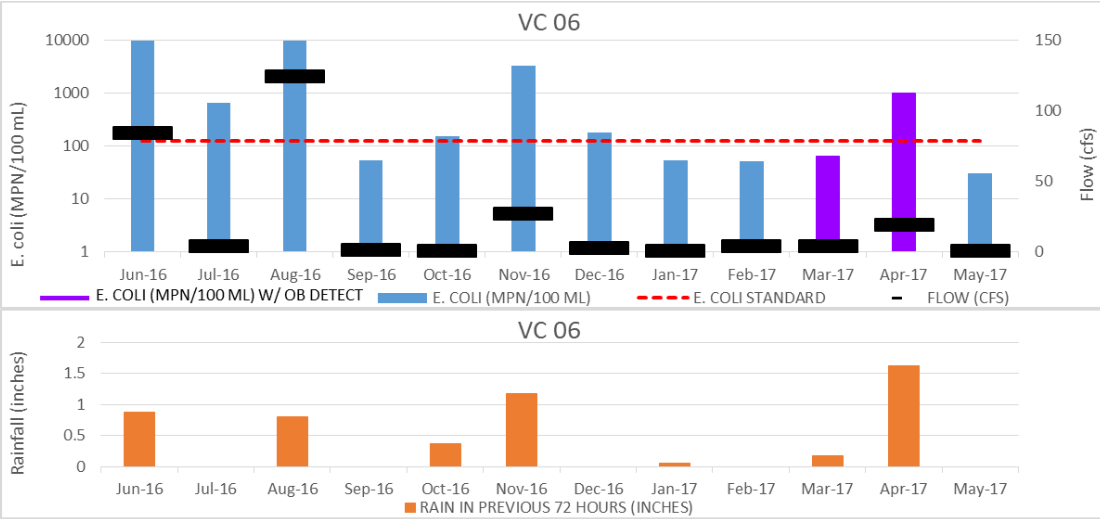


Figure B-6. Hydrology and E. coli parameters, Village Creek at Everman Drive (13671).

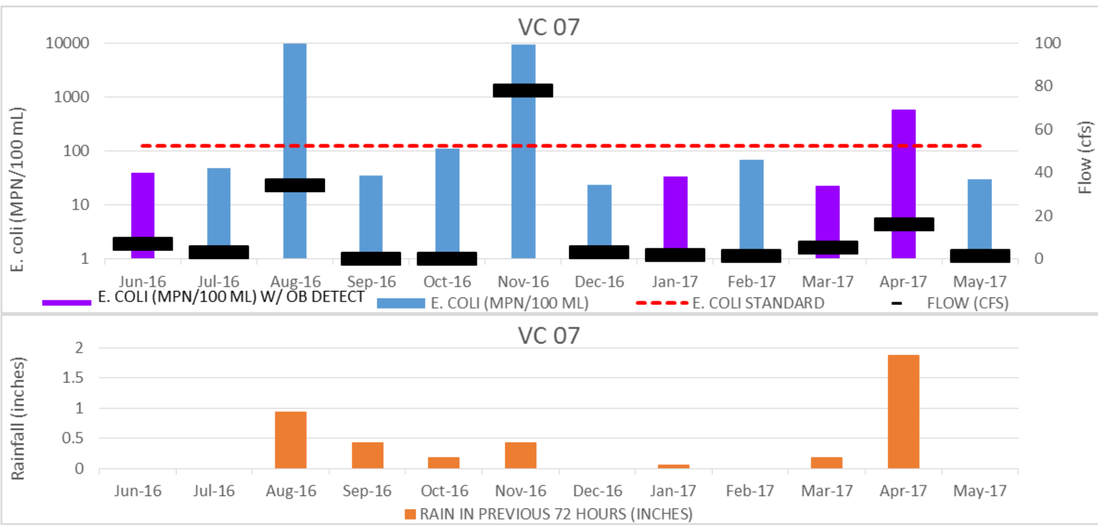


Figure B-7. Hydrology and E. coli parameters, Village Creek at Rendon Road (10786).

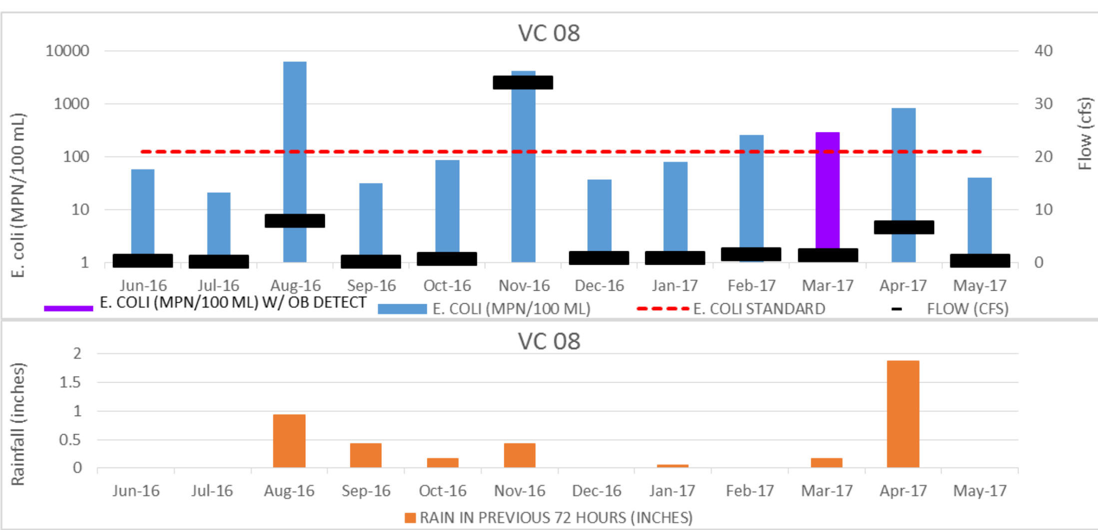


Figure B-8. Hydrology and E. coli parameters, Deer Creek at Oak Grove Road (10805).

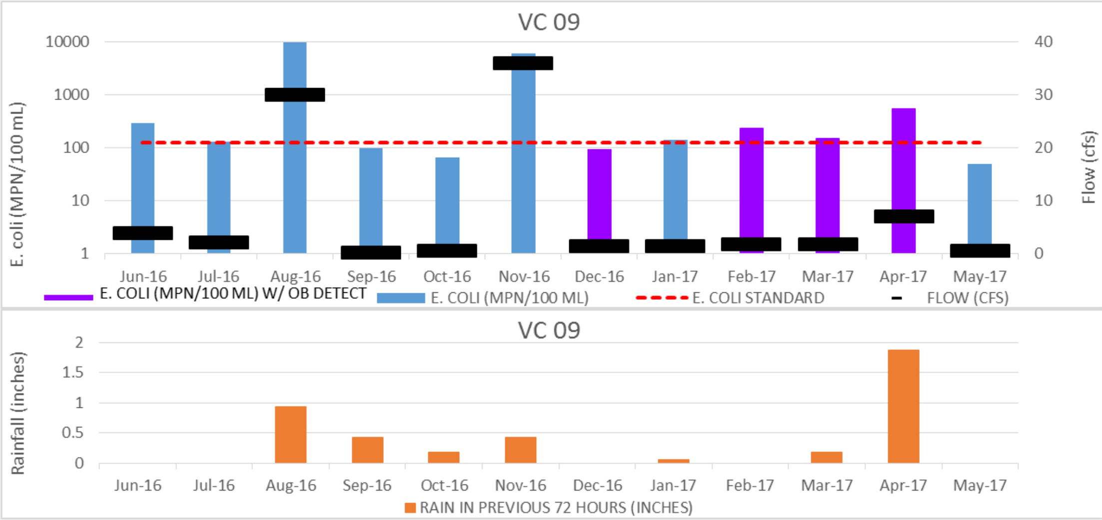


Figure B-9. Hydrology and E. coli parameters, Village Creek upstream of Oak Grove (10785).

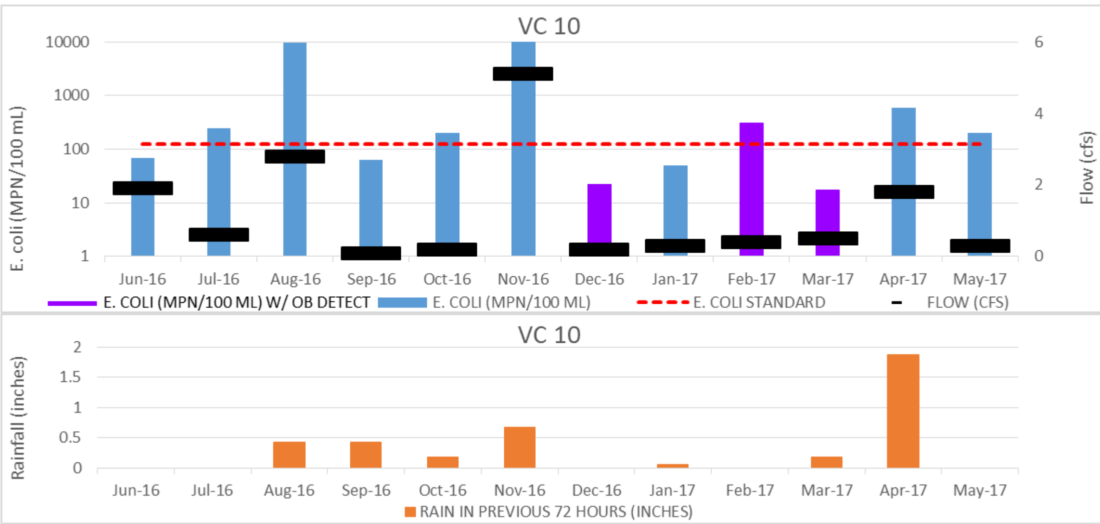


Figure B-10. Hydrology and E. coli parameters, Quil Miller Creek at County Road 532 in Burleson (21759).

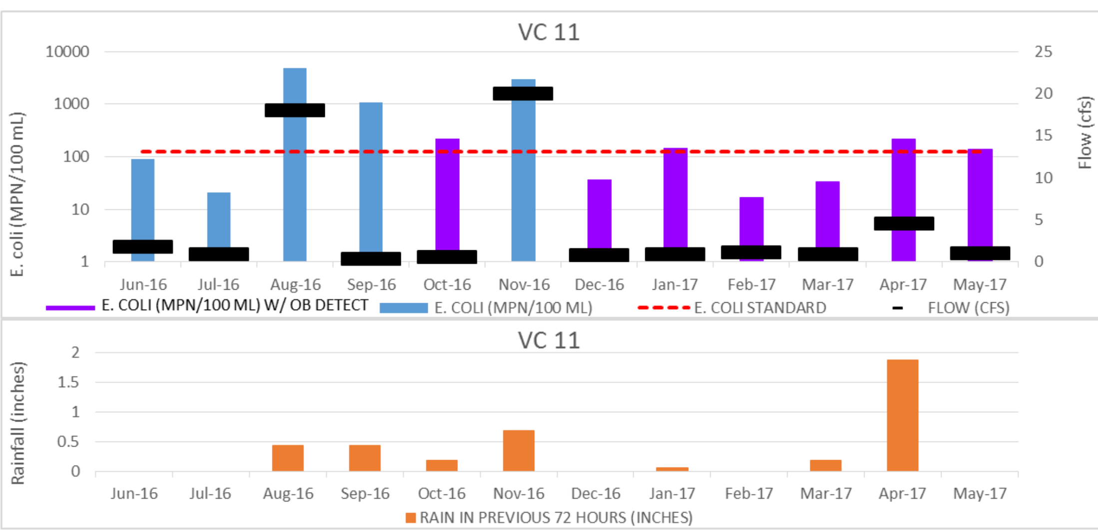


Figure B-11. Hydrology and E. coli parameters, Village Creek at FM 3391 (21763).

Appendix C. LDC Results

Site 01 – Wildcat Branch at Cravens Road (10793)

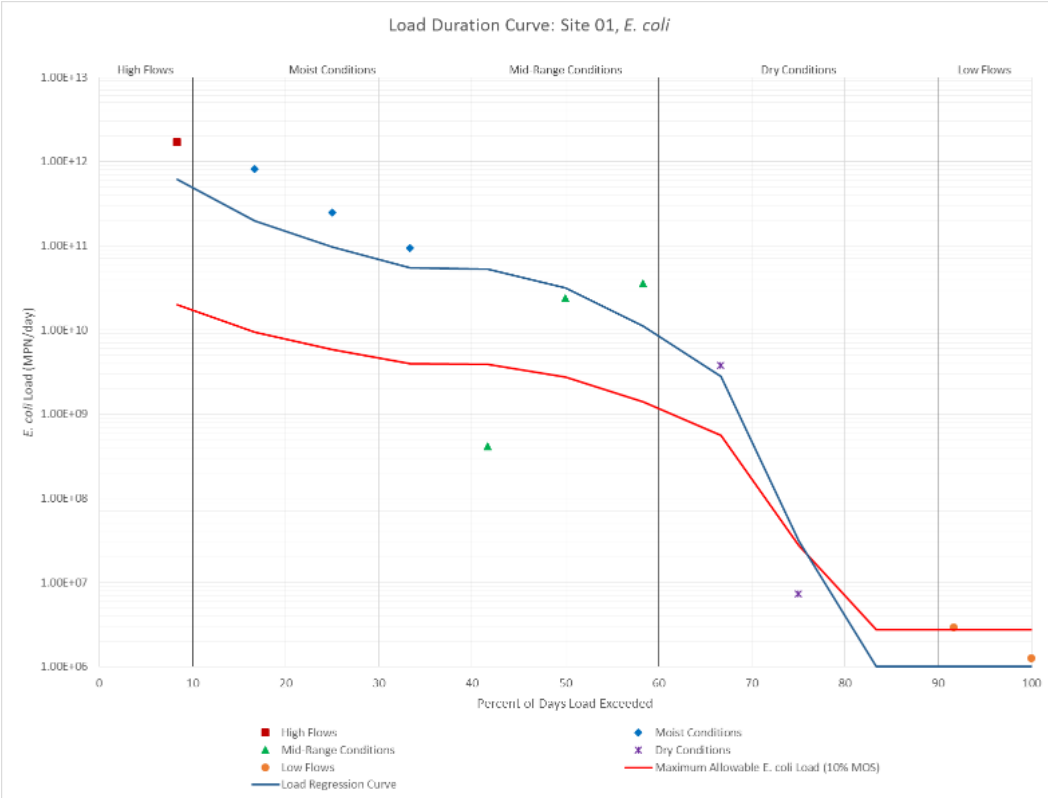


Figure C-1. LDC for E. coli, Wildcat Branch at Cravens Road (10793).

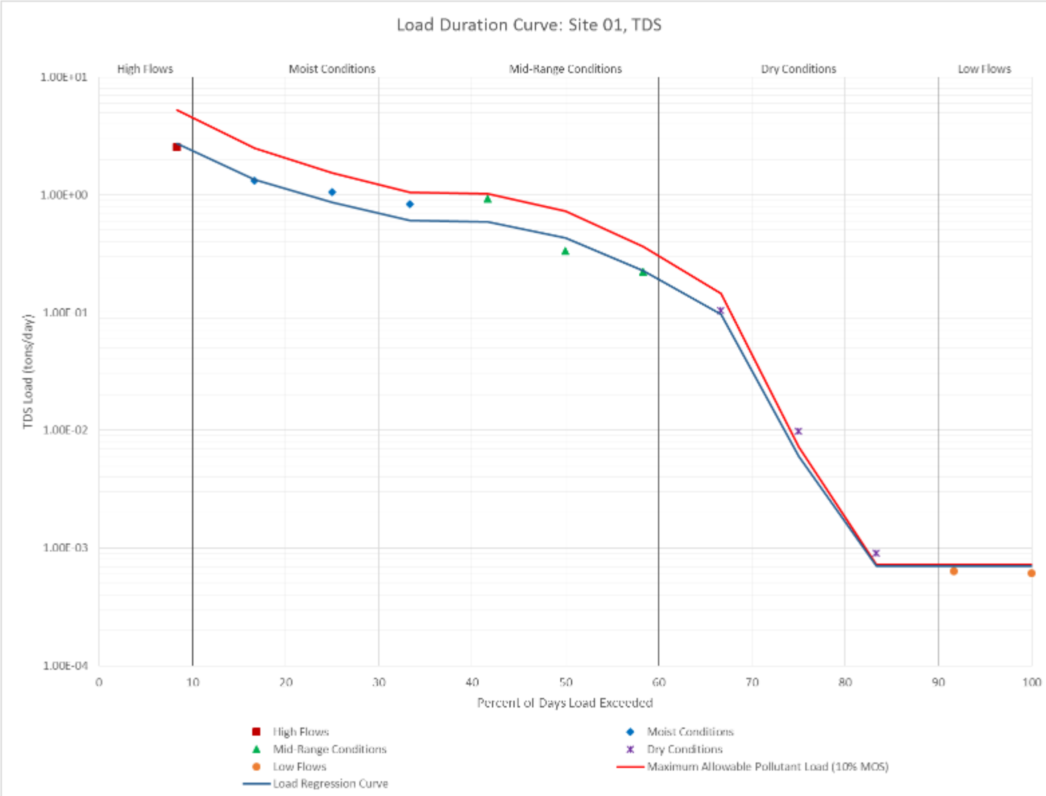


Figure C-2. LDC for TDS, Wildcat Branch at Cravens Road (10793).

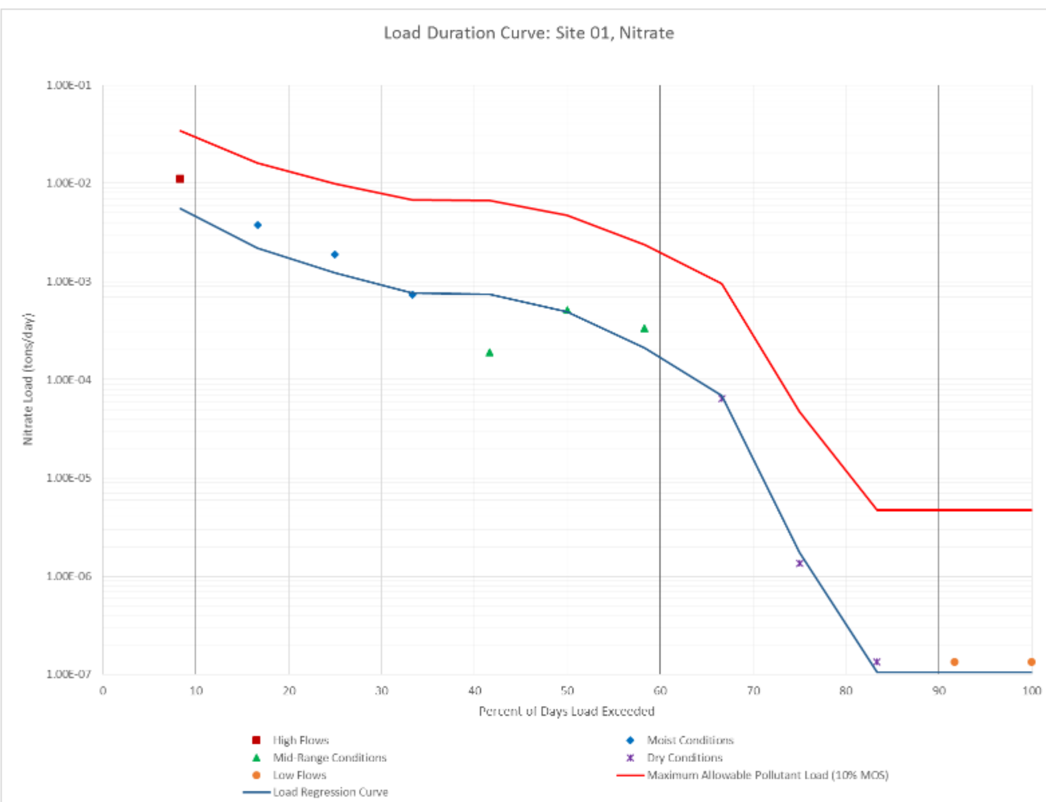


Figure C-3. LDC for* nitrate*, Wildcat Branch at Cravens Road (10793).

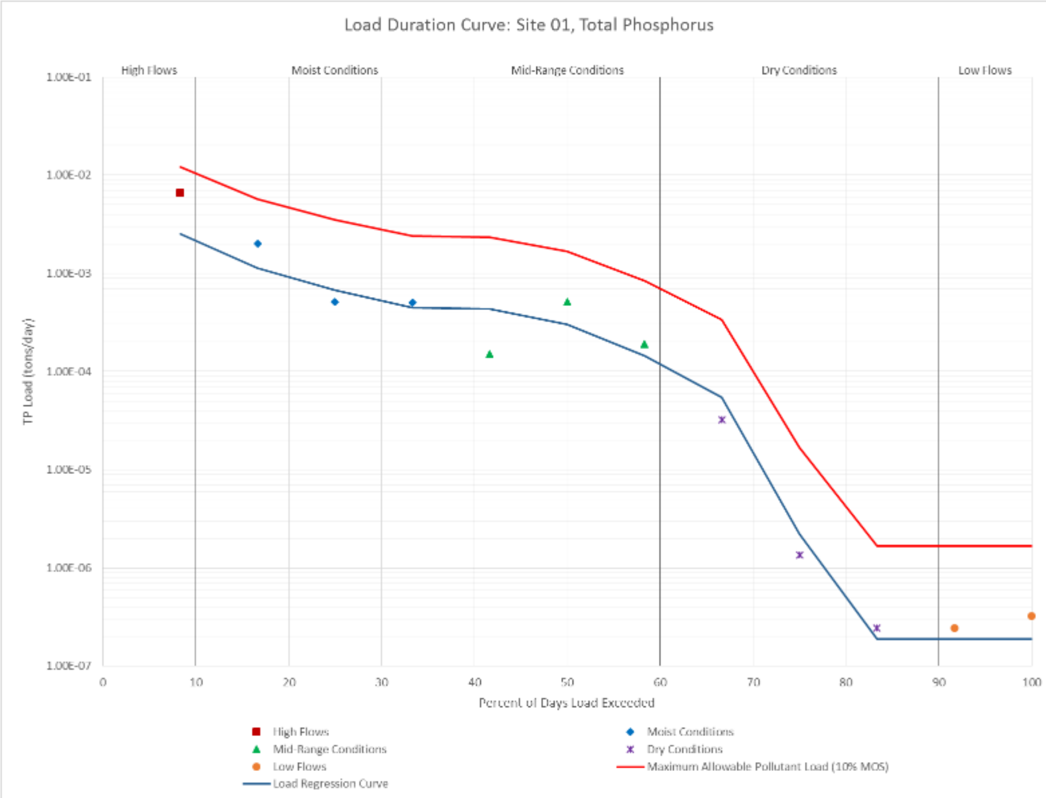


Figure C-4. LDC for total phosphorus, Wildcat Branch at Cravens Road (10793).

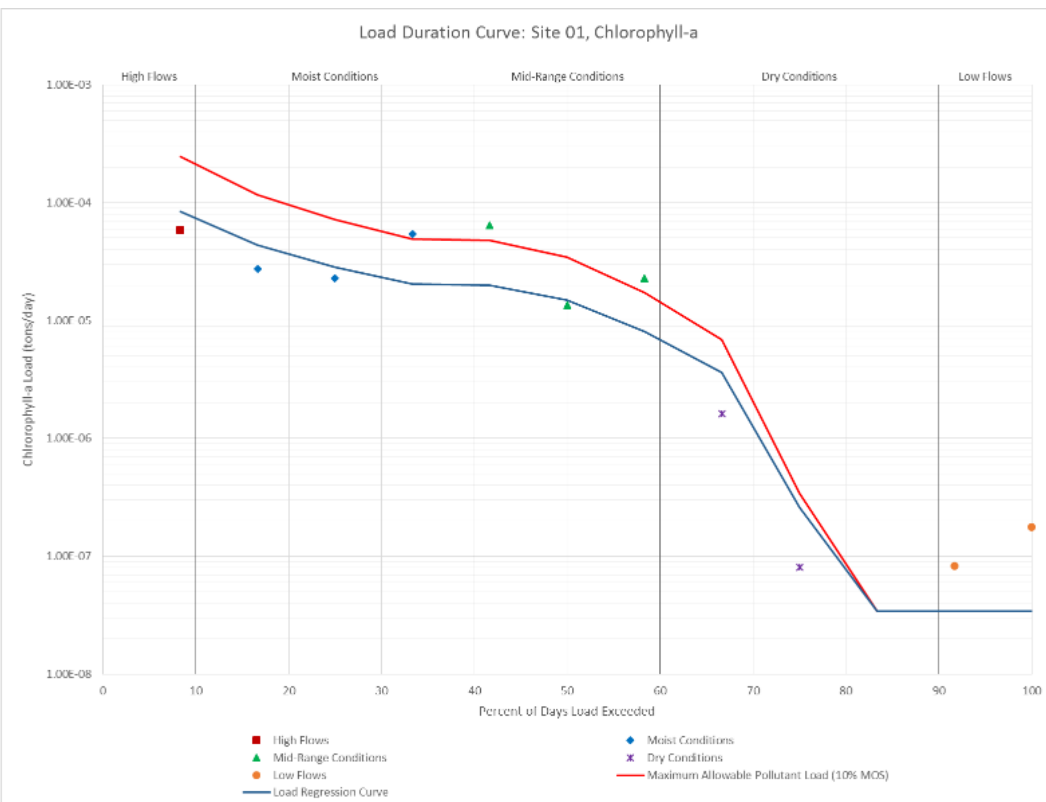


Figure C-5. LDC for chlorophyll-a, Wildcat Branch at Cravens Road (10793).

Site 02 – Tributary of Lake Arlington (10798)

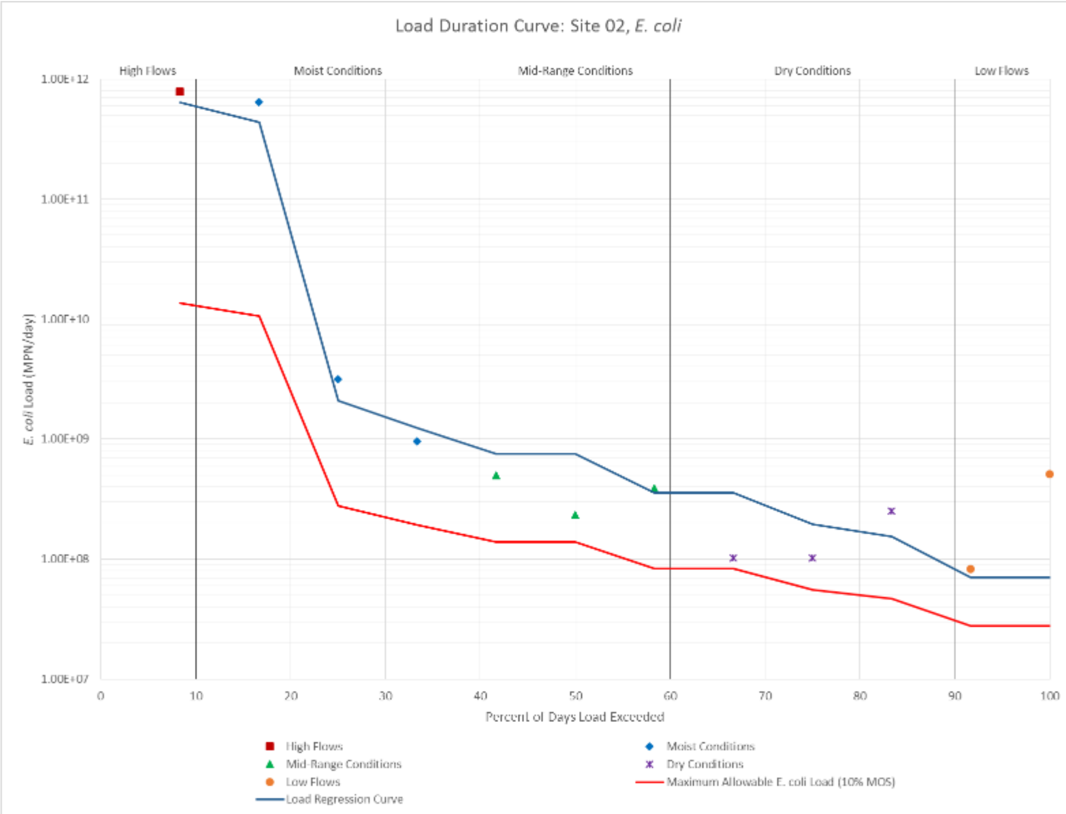


Figure C-6. LDC for E. coli, Tributary of Lake Arlington (10798).

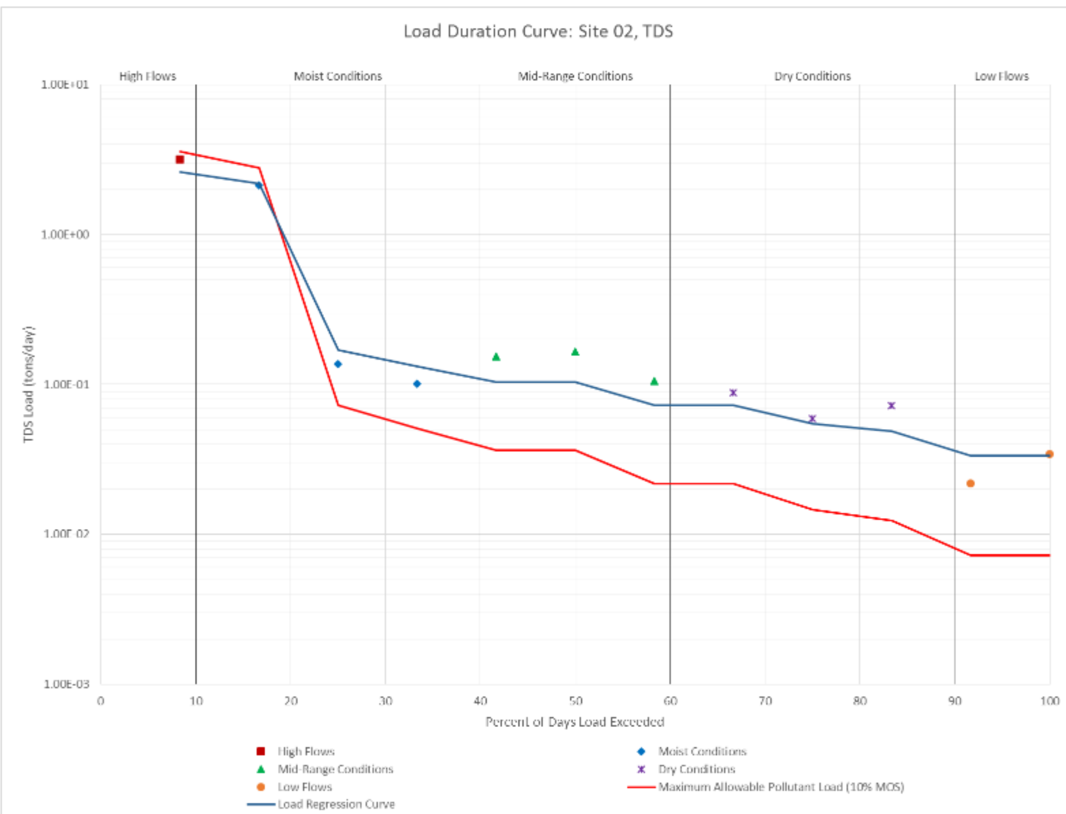


Figure C-7. LDC for TDS, Tributary of Lake Arlington (10798).

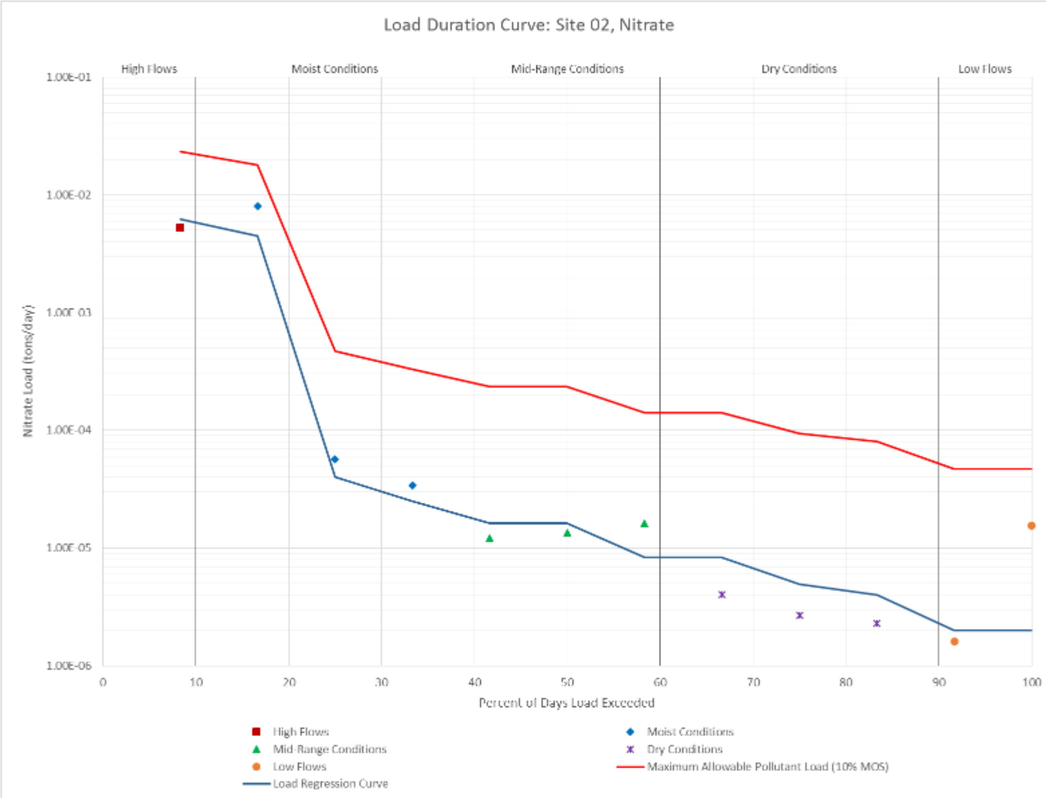


Figure C-8. LDC for nitrate, Tributary of Lake Arlington (10798).

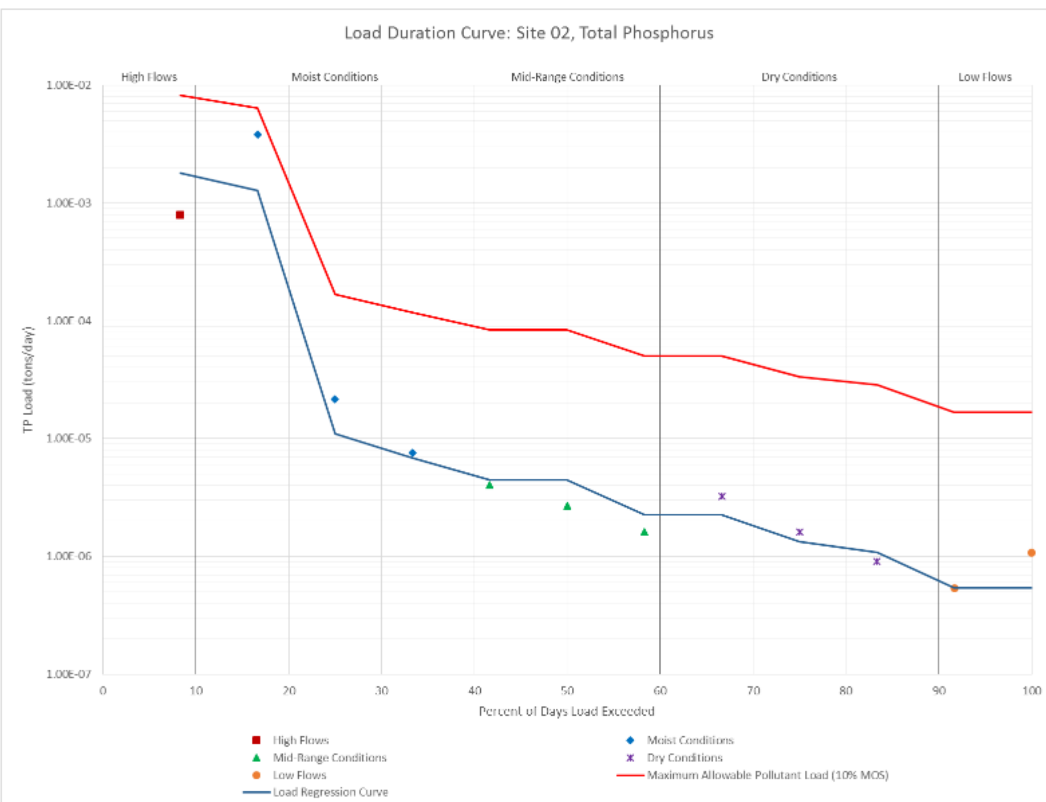


Figure C-9. LDC for total phosphorus, Tributary of Lake Arlington (10798).

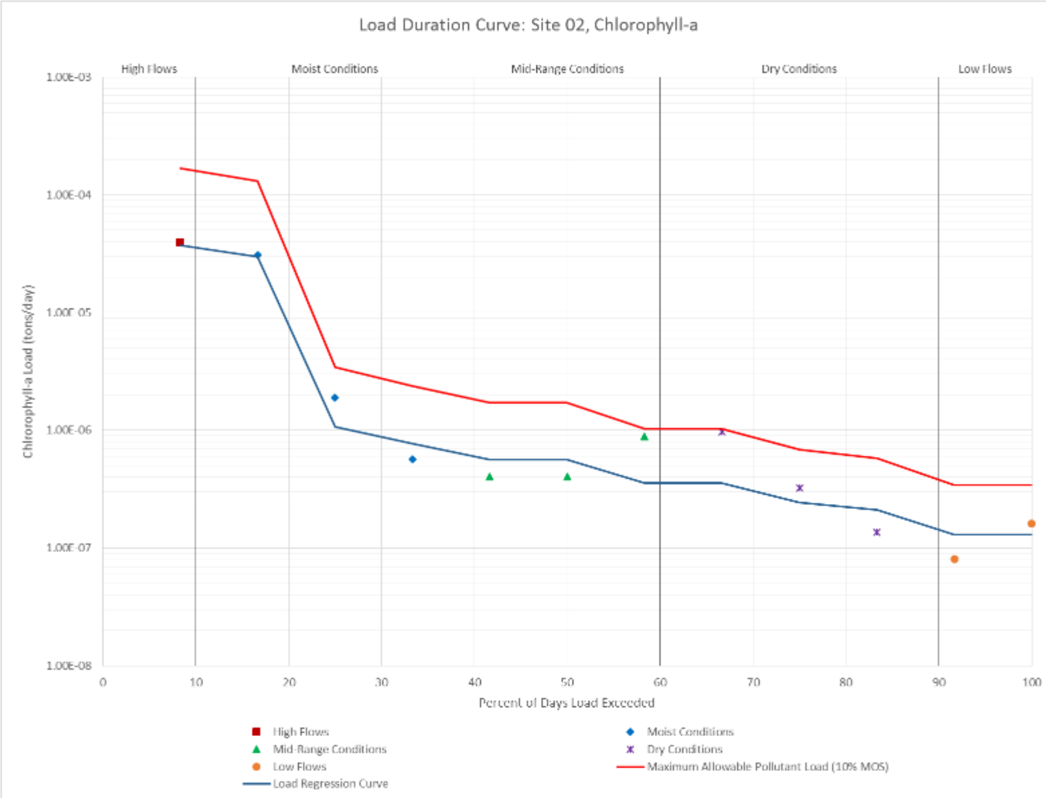


Figure C-10. LDC for chlorophyll-a, Tributary of Lake Arlington (10798).

Site 03 – Village Creek at IH-20 (10780)

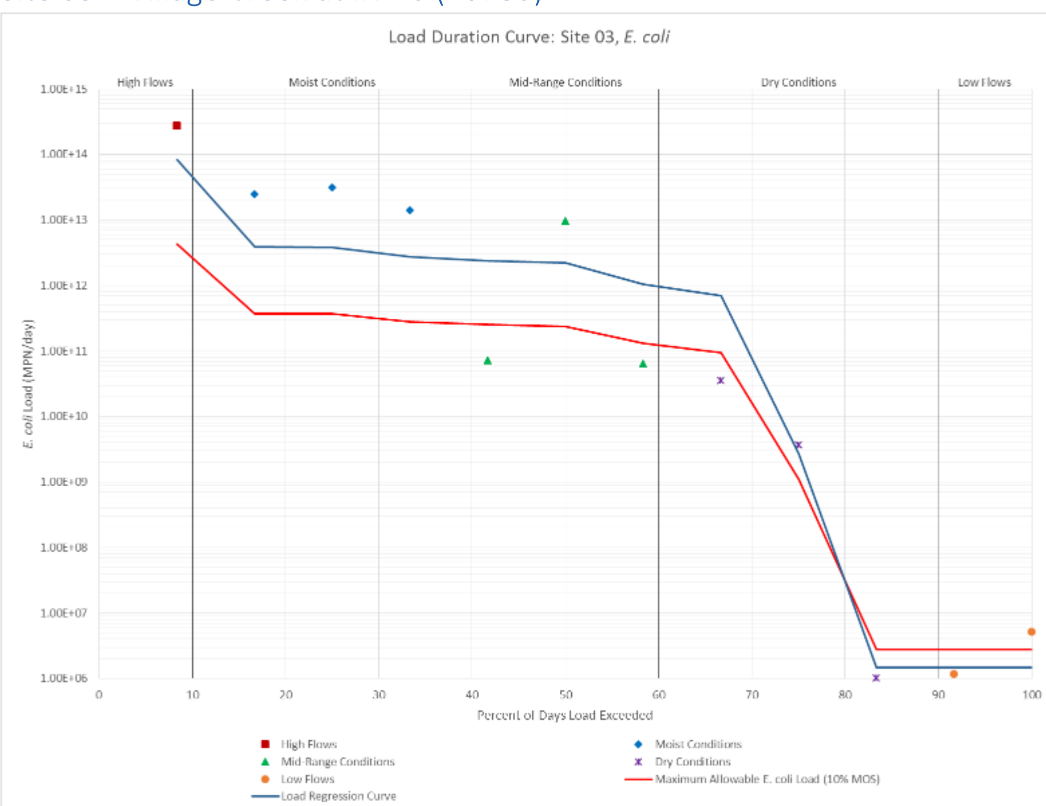


Figure C-11. LDC for E. coli, Village Creek at IH-20 (10780).

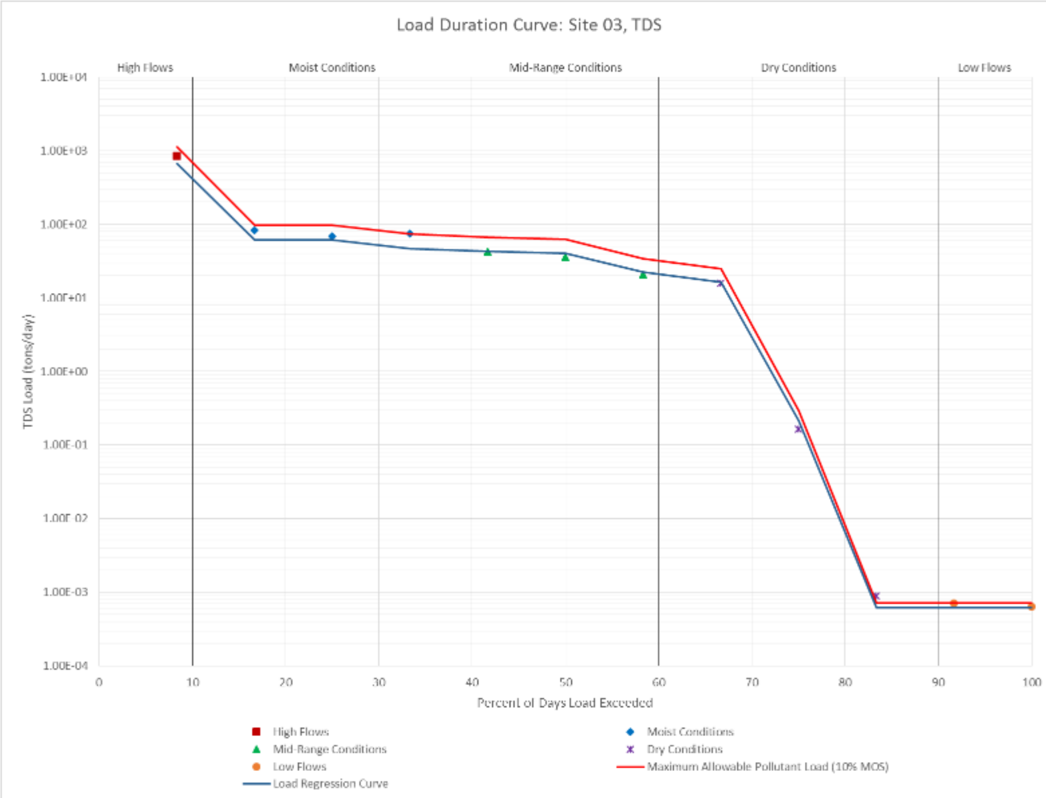


Figure C-12. LDC for TDS, Village Creek at IH-20 (10780).

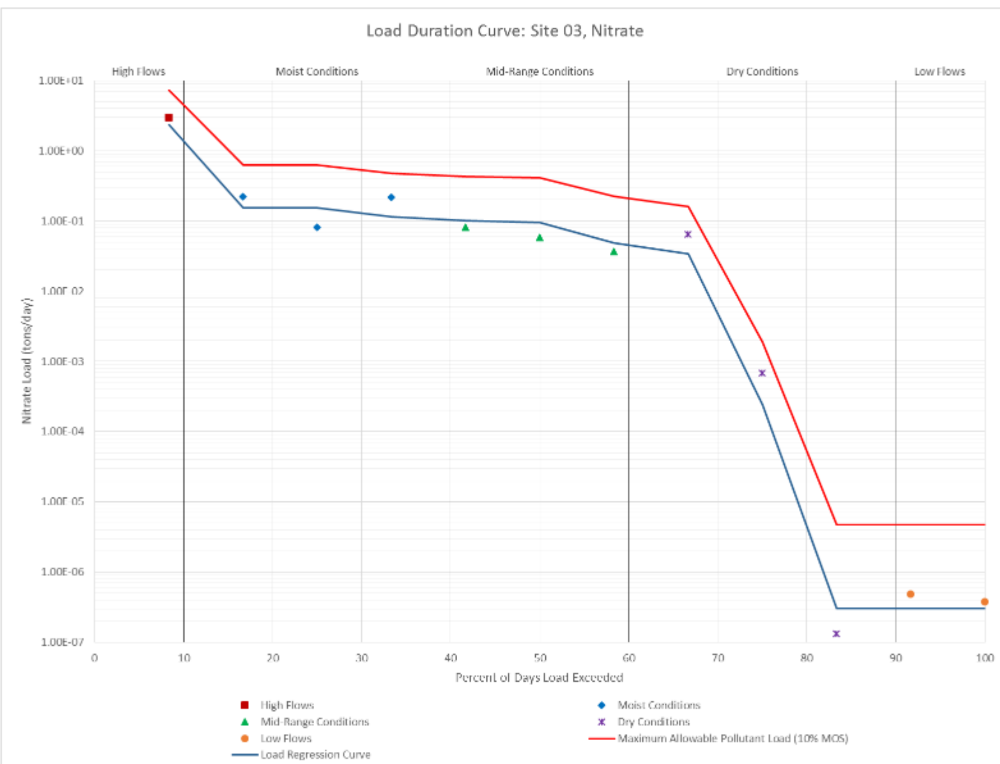


Figure C-13. LDC for nitrate, Village Creek at IH-20 (10780).

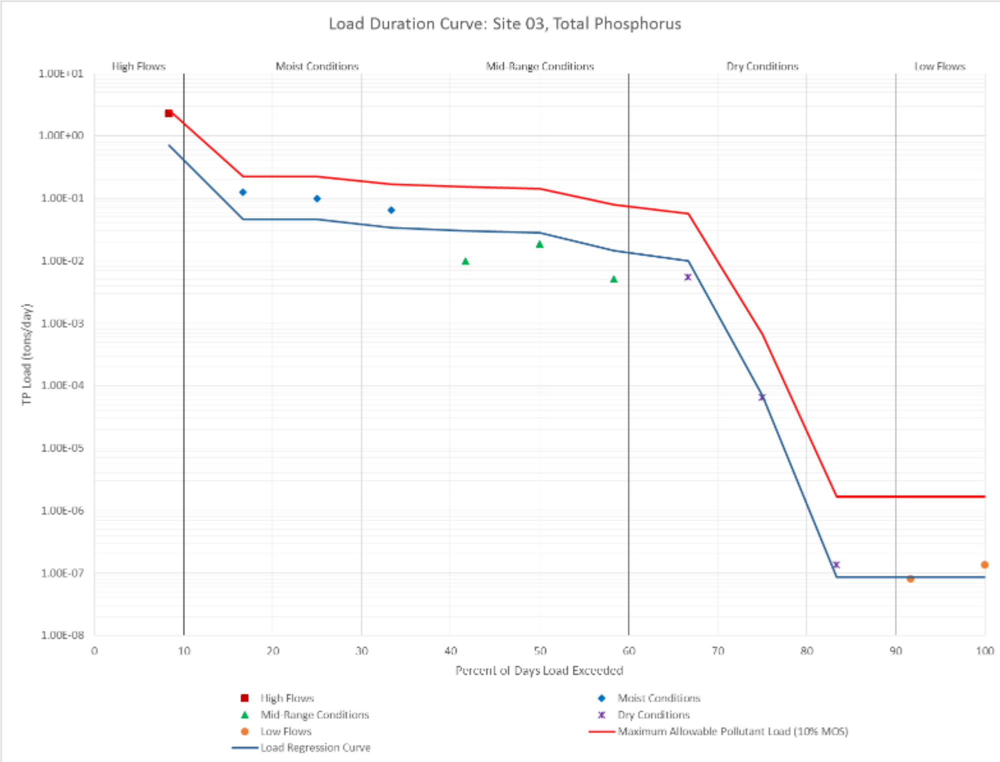


Figure C-14. LDC for total phosphorus, Village Creek at IH-20 (10780).

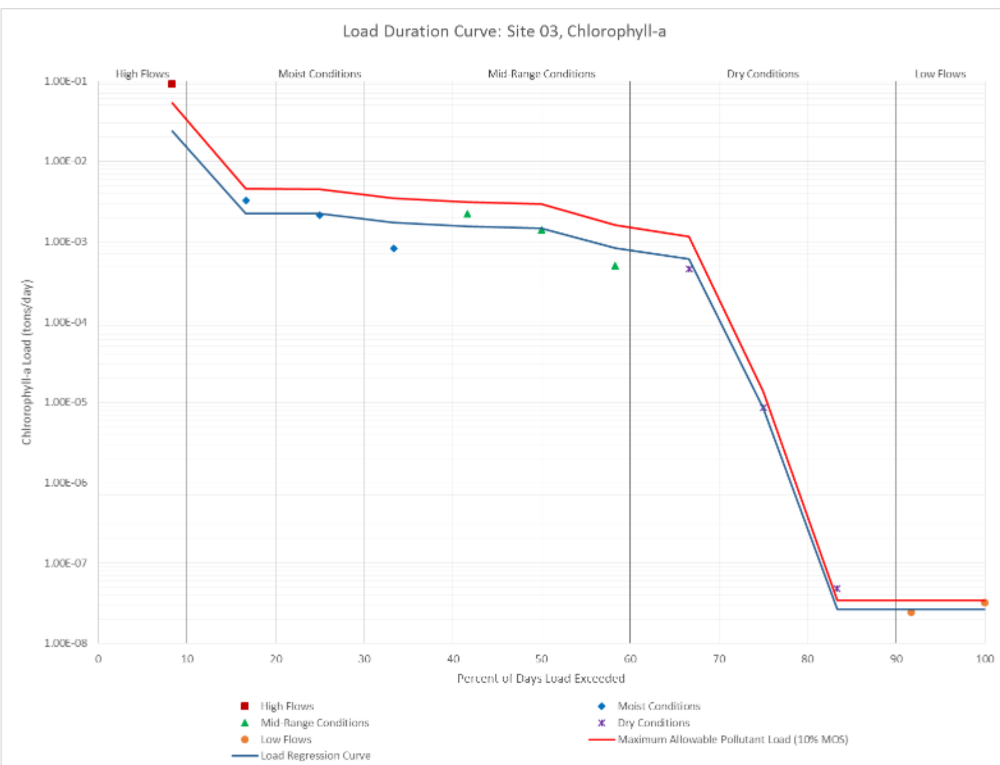


Figure C-15. LDC for chlorophyll-a, Village Creek at IH-20 (10780).

Site 04 – Village Creek Downstream of US BUS 287 (10781)

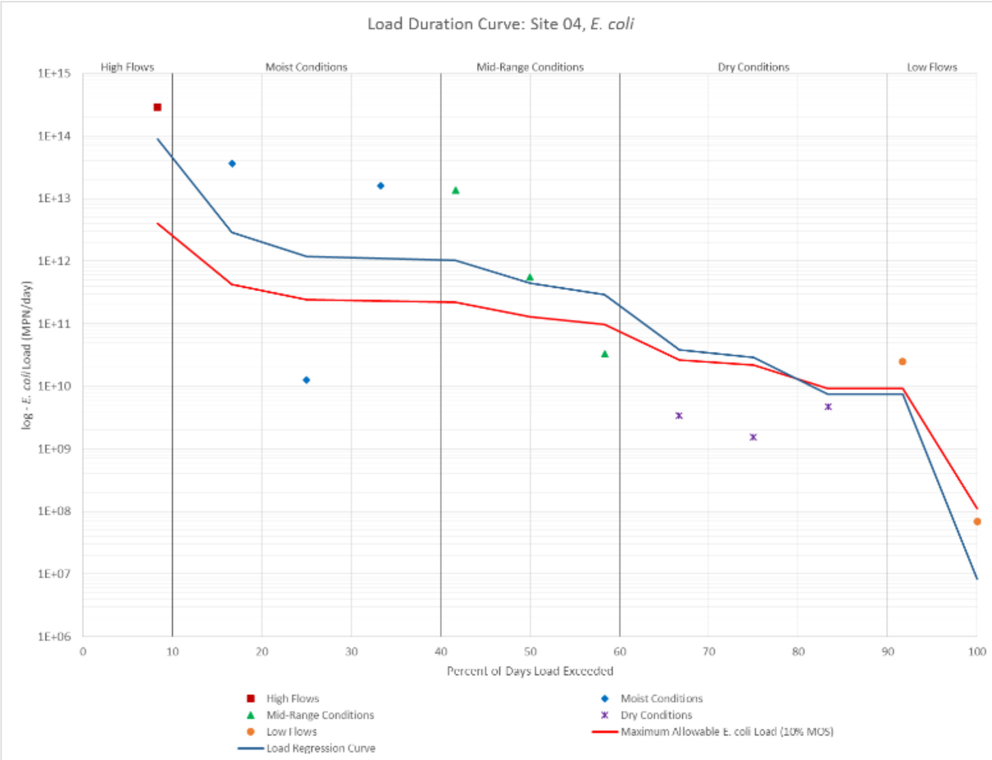


Figure C-16. LDC for E. coli, Village Creek Downstream of US BUS 287 (10781).

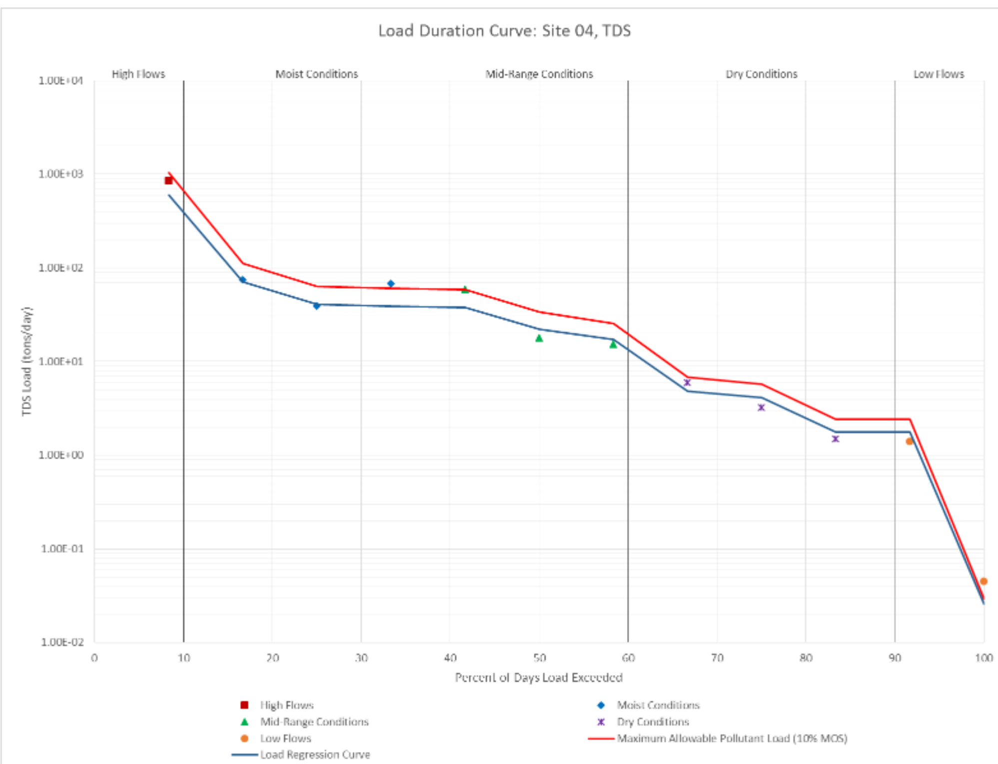


Figure C-17. LDC for TDS, Village Creek Downstream of US BUS 287 (10781).

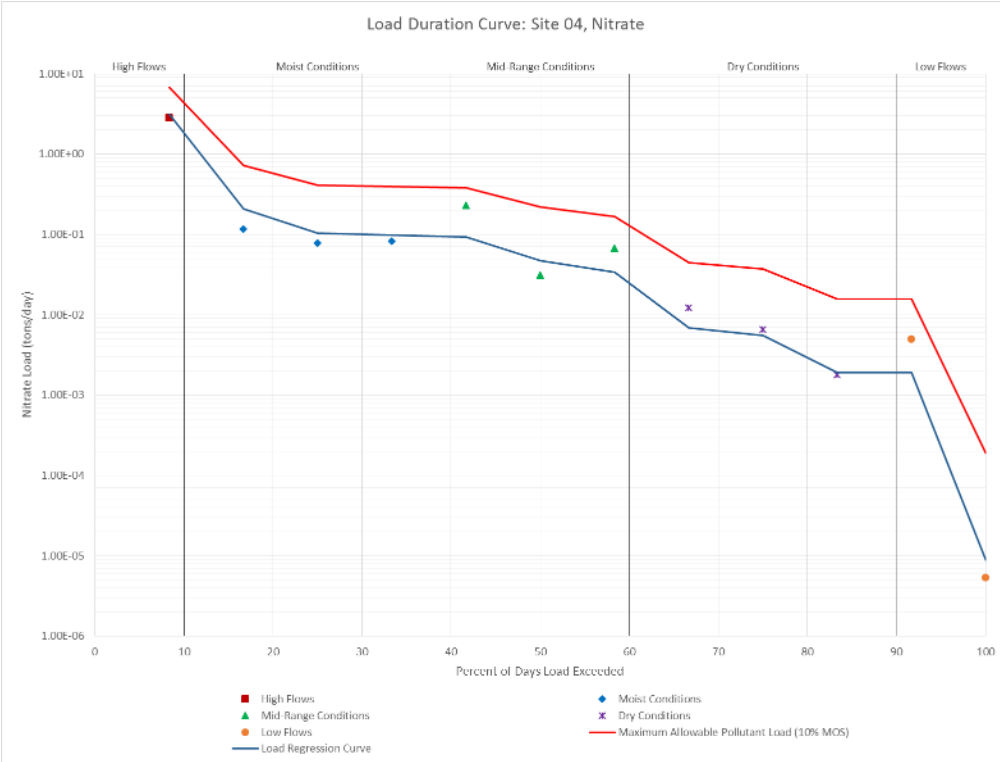


Figure C-18. LDC for nitrate, Village Creek Downstream of US BUS 287 (10781).

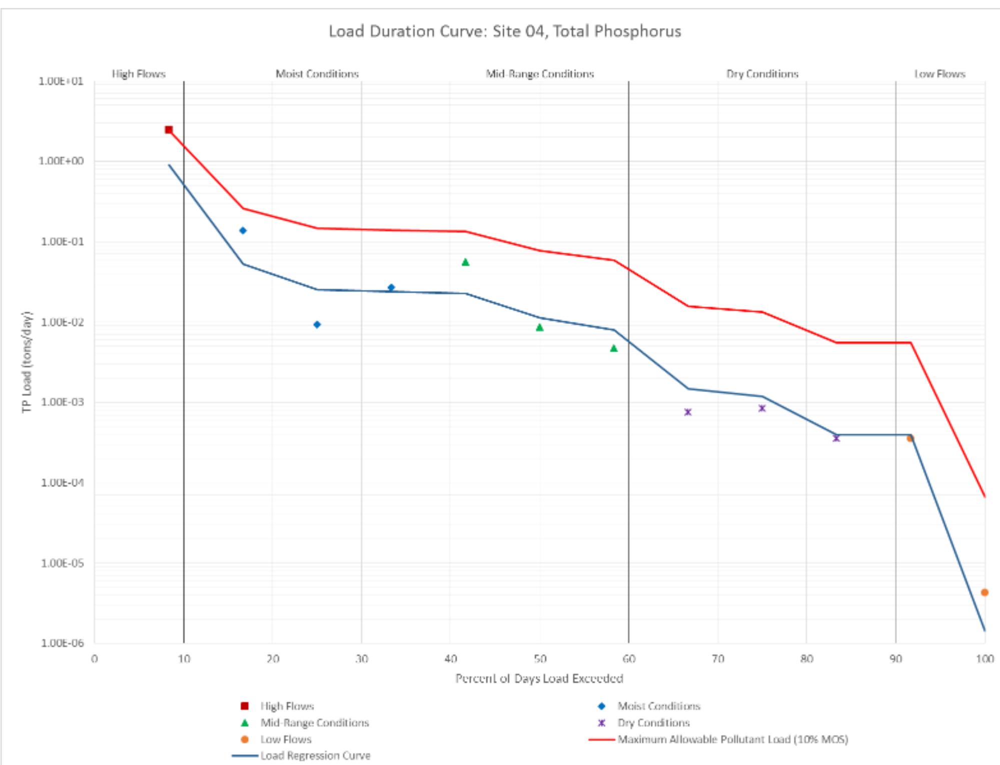


Figure C-19. LDC for total phosphorus, Village Creek Downstream of US BUS 287 (10781).

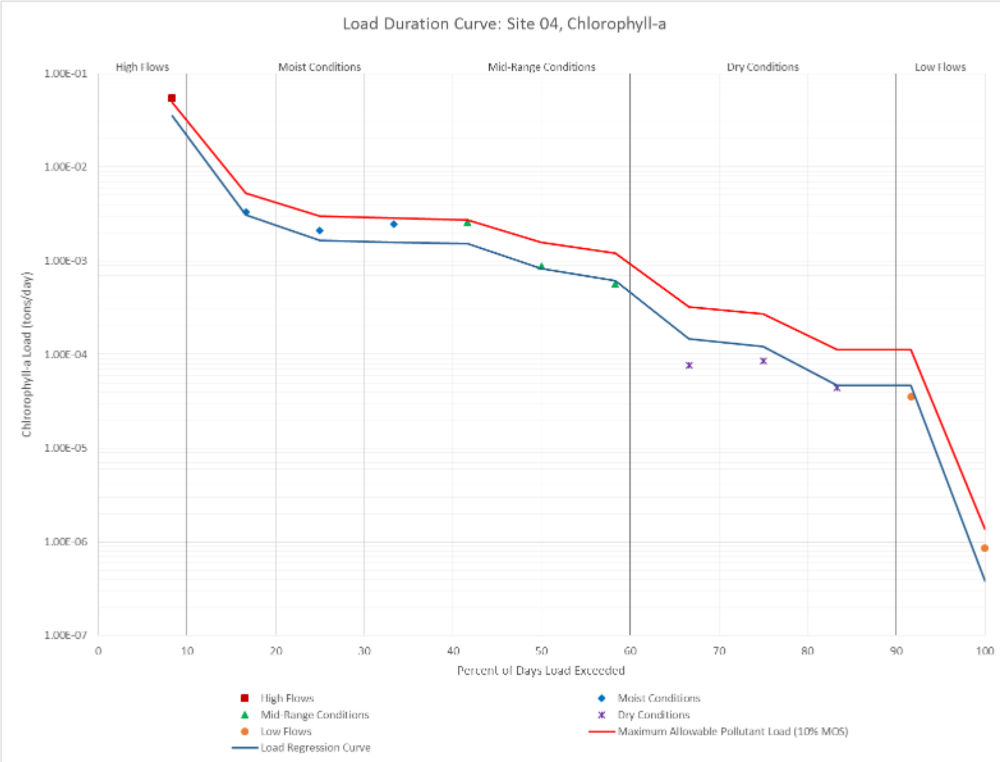


Figure C-20. LDC for chlorophyll-a, Village Creek Downstream of US BUS 287 (10781).

Site 05 – Village Creek Downstream of US BUS 287 (10781)

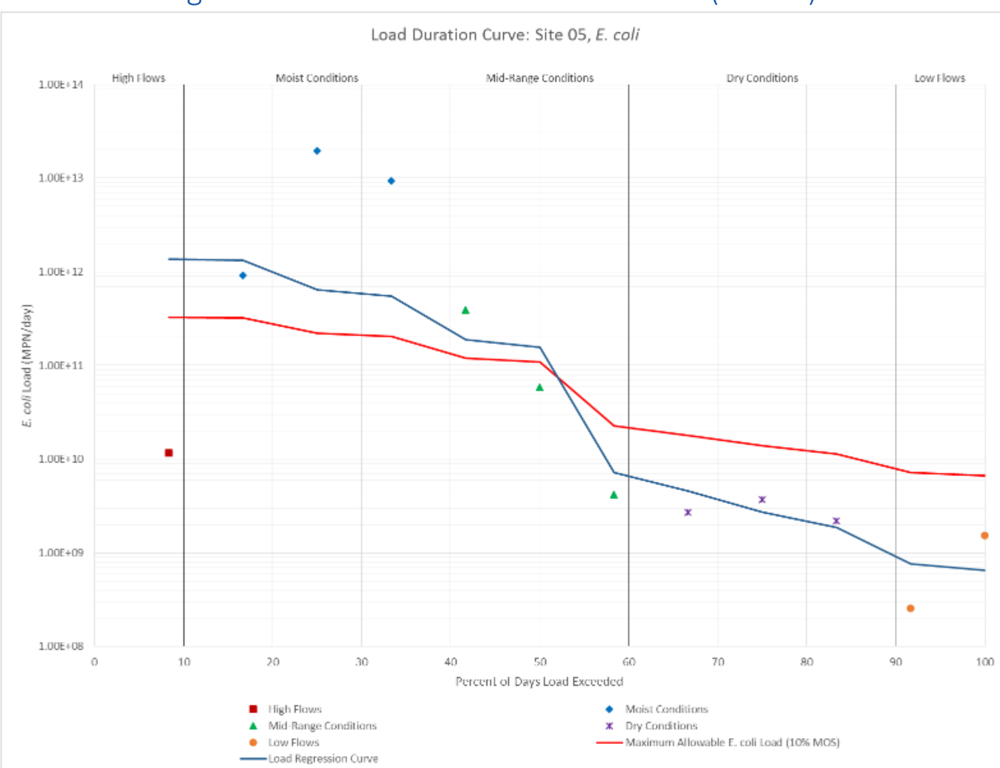


Figure C-21. LDC for E. coli, Village Creek near Freeman Drive (21762).

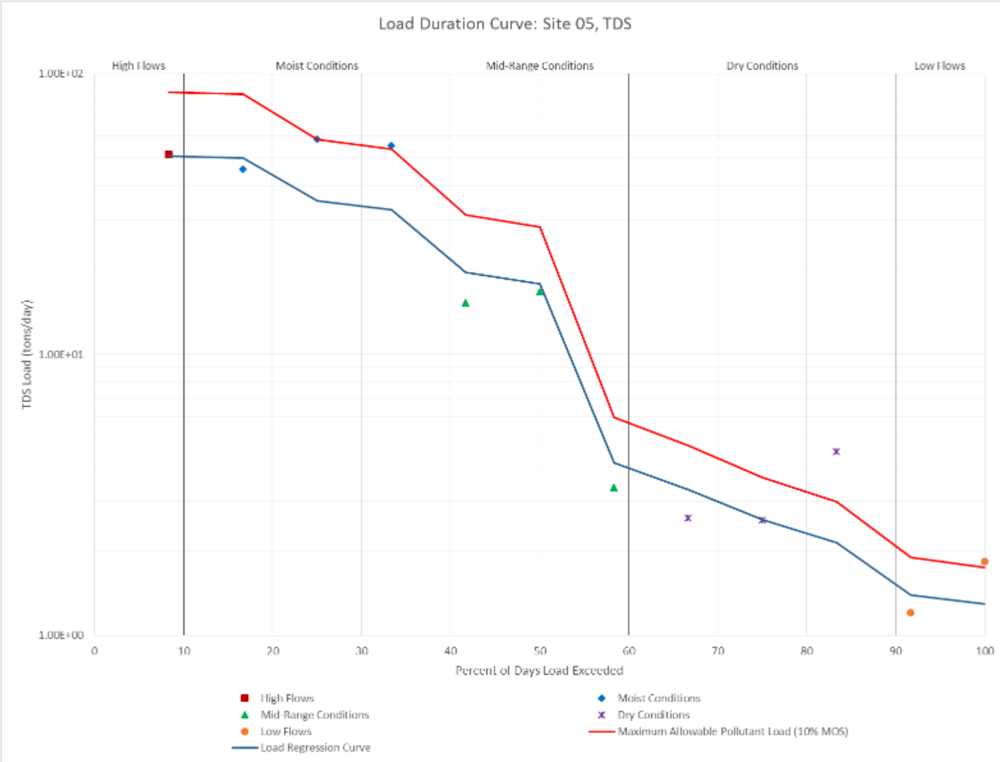


Figure C-22. LDC for TDS, Village Creek near Freeman Drive (21762).

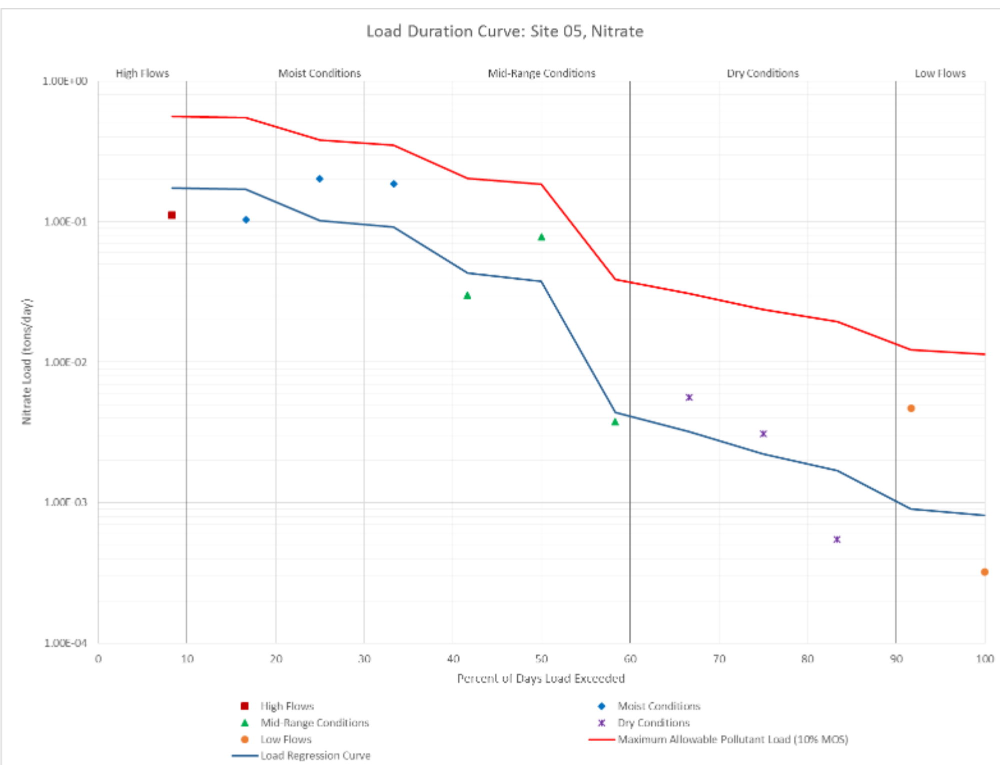


Figure C-23. LDC for nitrate, Village Creek near Freeman Drive (21762).

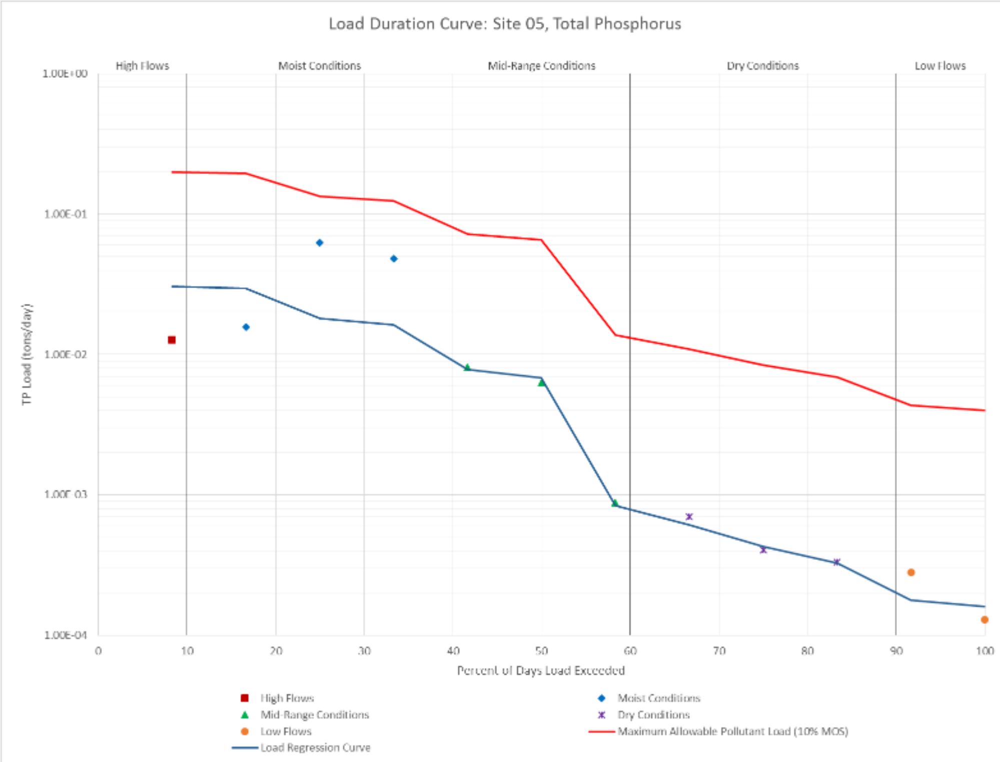


Figure C-24. LDC for total phosphorus, Village Creek near Freeman Drive (21762).

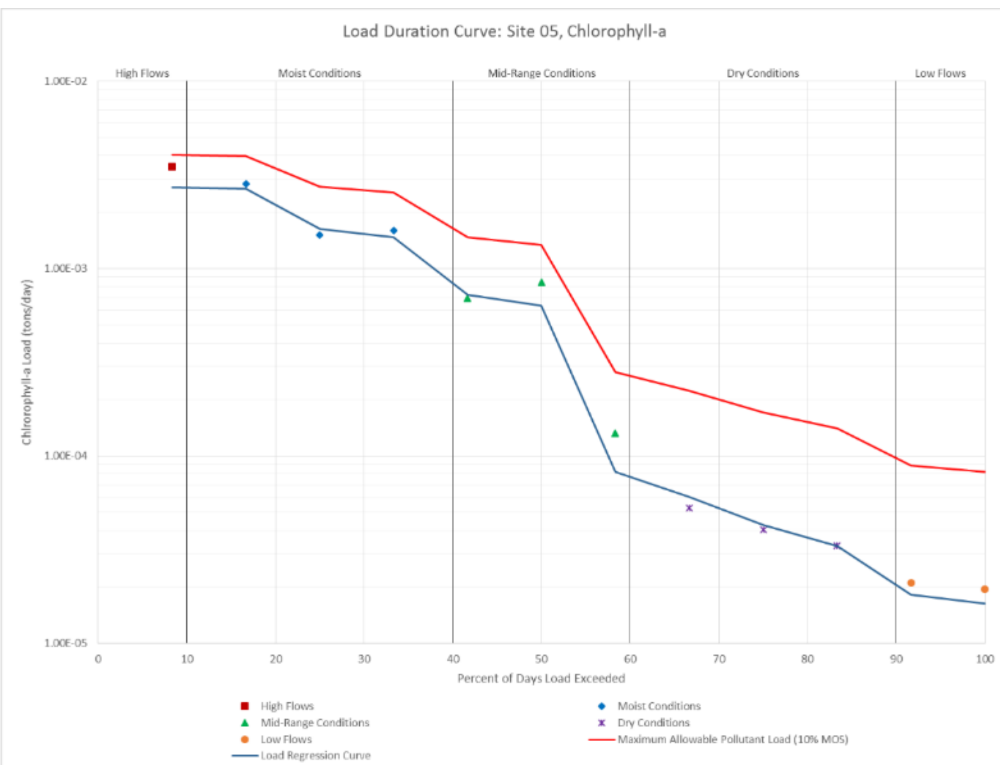


Figure C-25. LDC for chlorophyll-a, Village Creek near Freeman Drive (21762).

Site 06 – Village Creek at Everman Drive (13671)

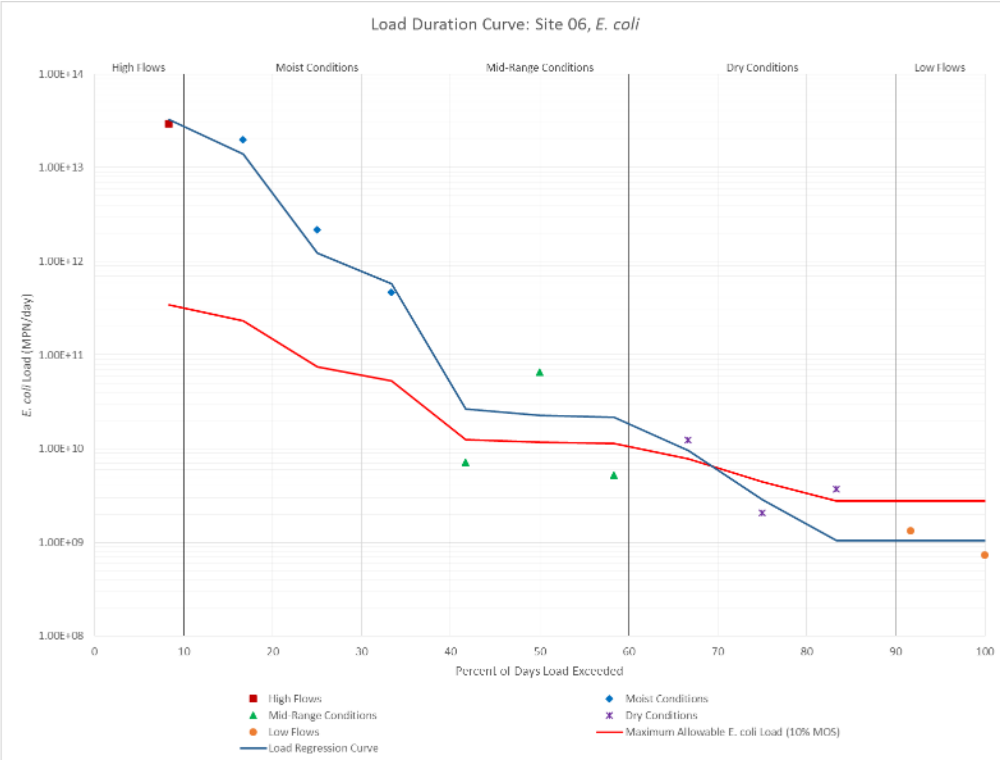


Figure C-26. LDC for E. coli, Village Creek at Everman Drive (13671).

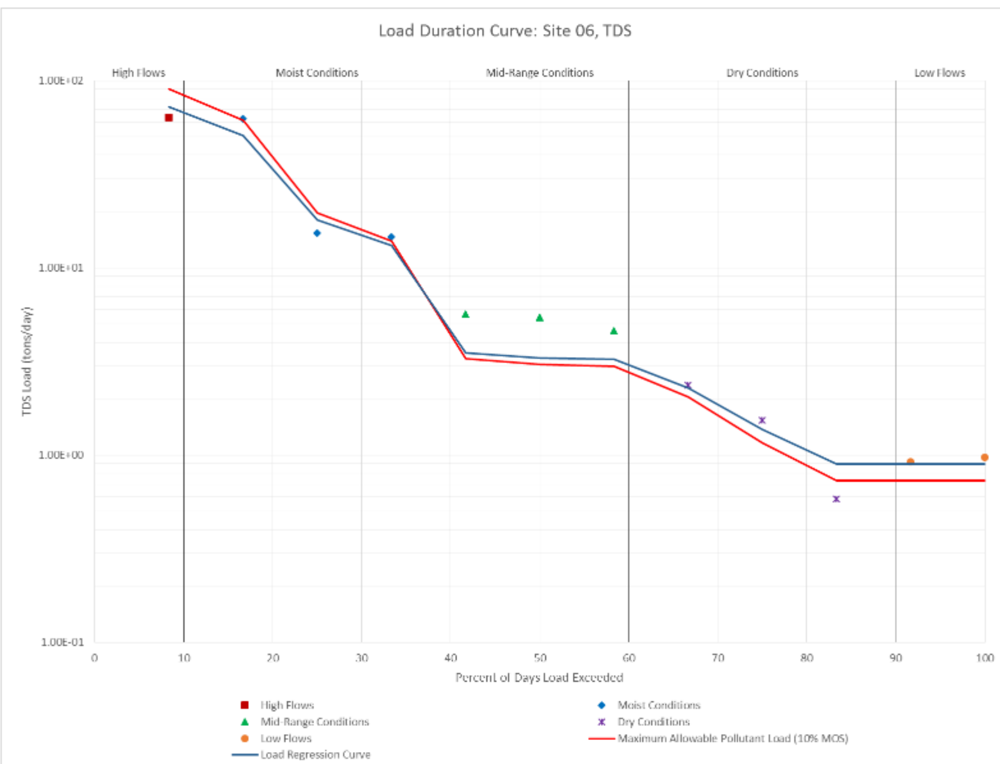


Figure C-27. LDC for TDS, Village Creek at Everman Drive (13671).

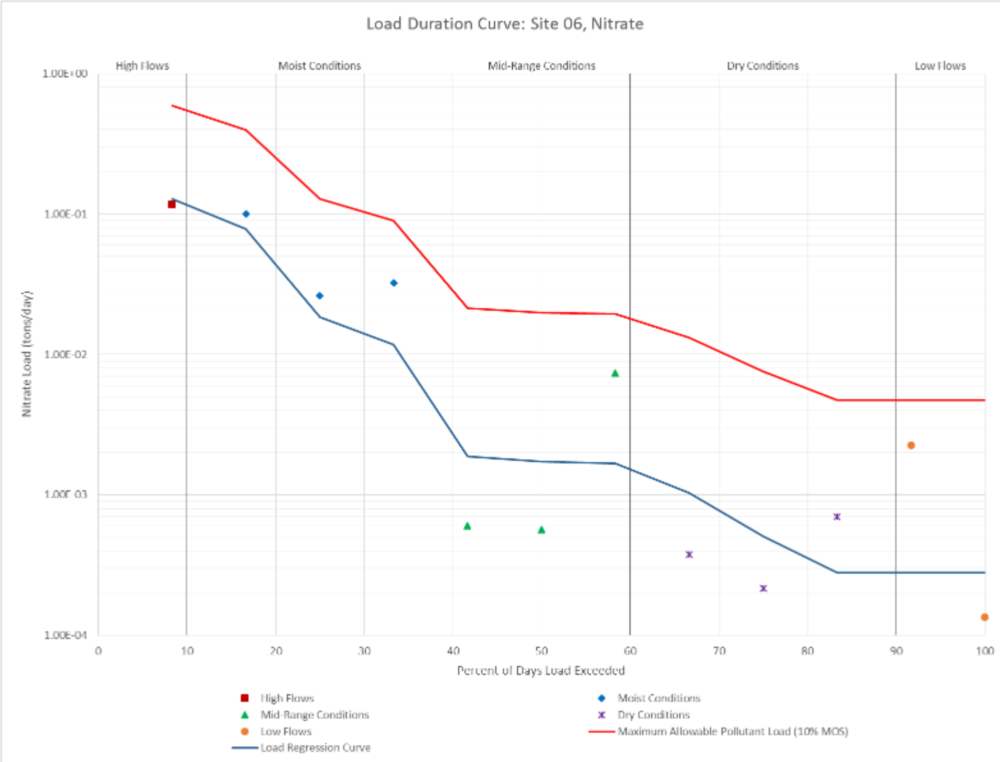


Figure C-28. LDC for nitrate, Village Creek at Everman Drive (13671).

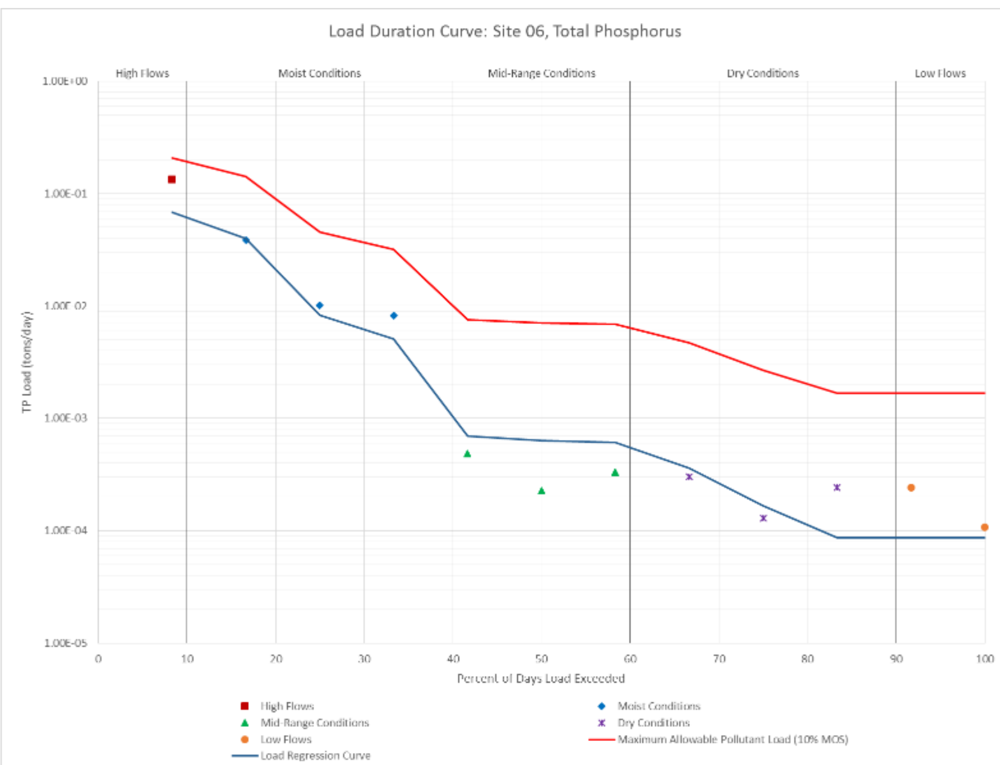


Figure C-29. LDC for total phosphorus, Village Creek at Everman Drive (13671).

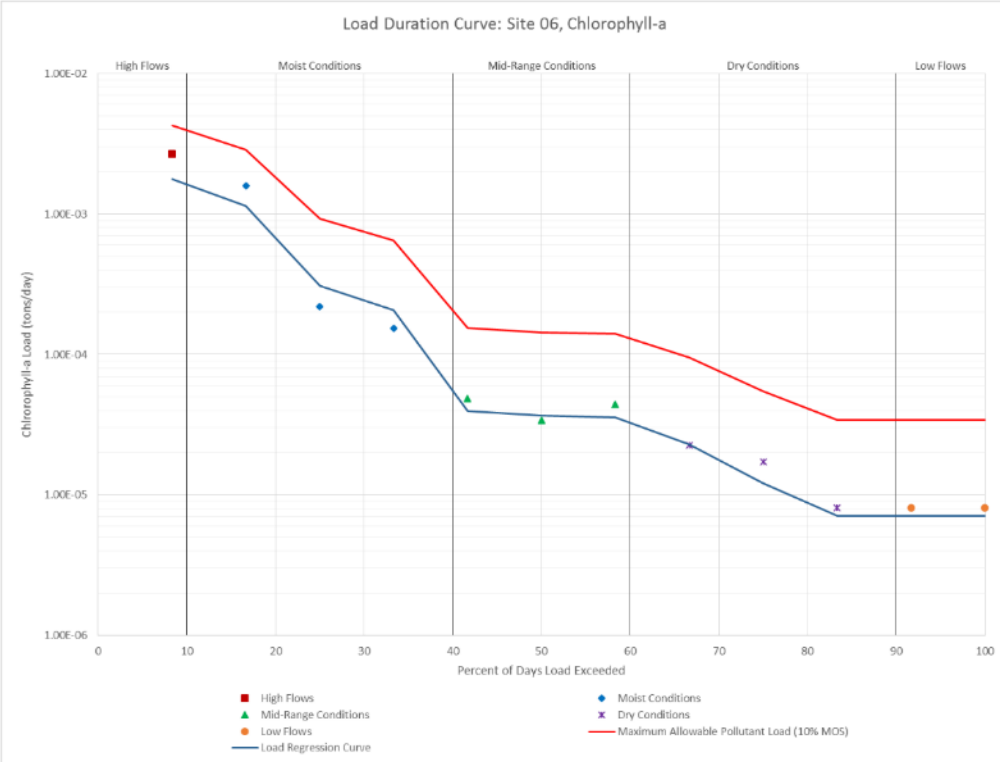


Figure C-30. LDC for chlorophyll-a, Village Creek at Everman Drive (13671).

Site 07 – Village Creek at Rendon Road (10786)

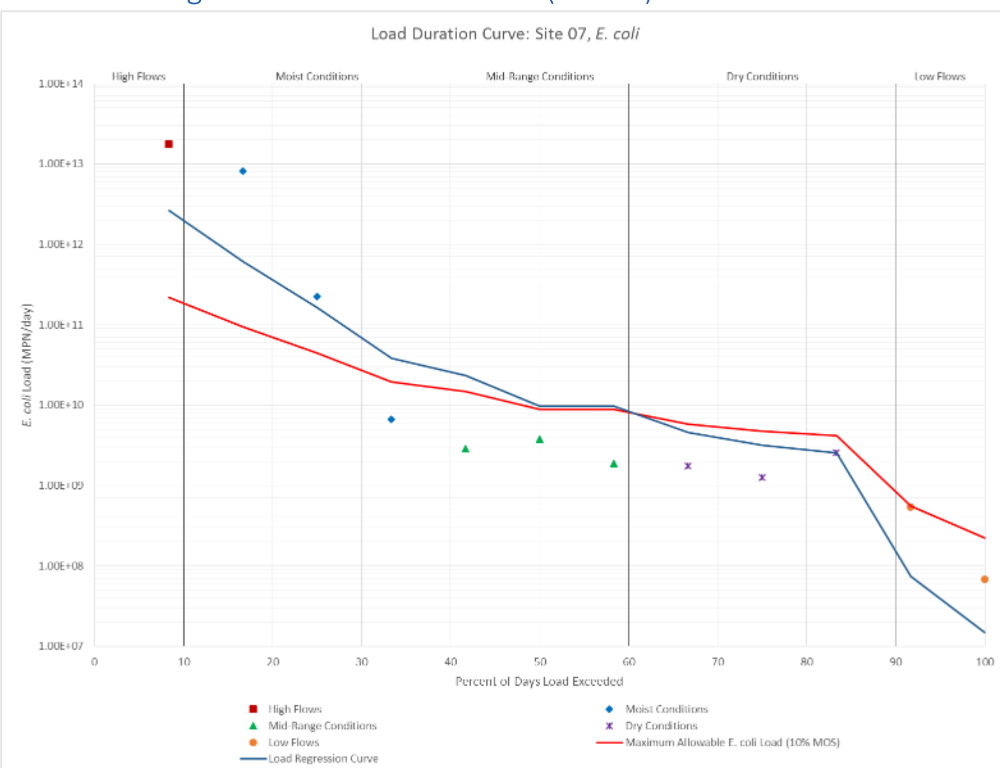


Figure C-31. LDC for E. coli, Village Creek at Rendon Road (10786).

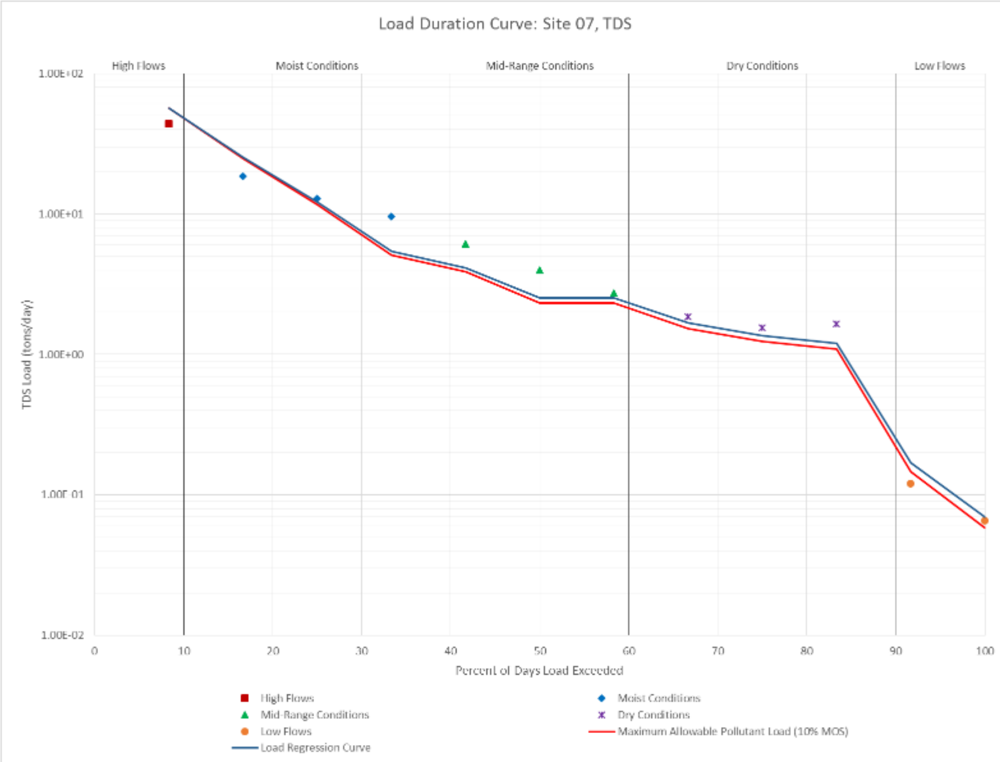


Figure C-32. LDC for TDS, Village Creek at Rendon Road (10786).

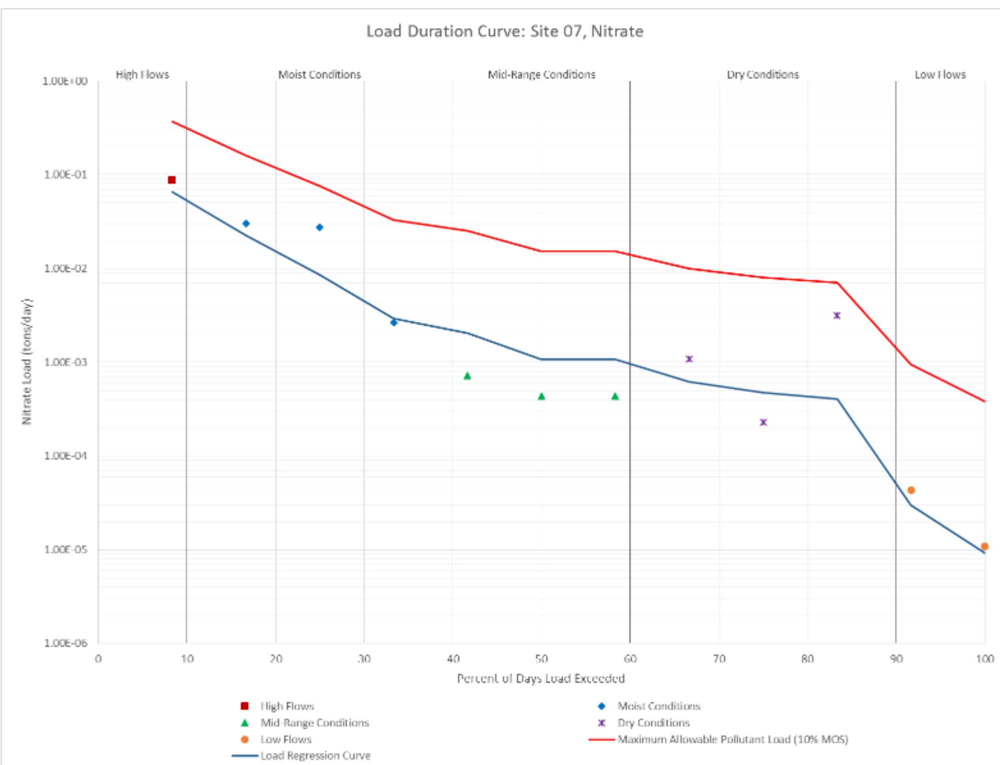


Figure C-33. LDC for nitrate, Village Creek at Rendon Road (10786).

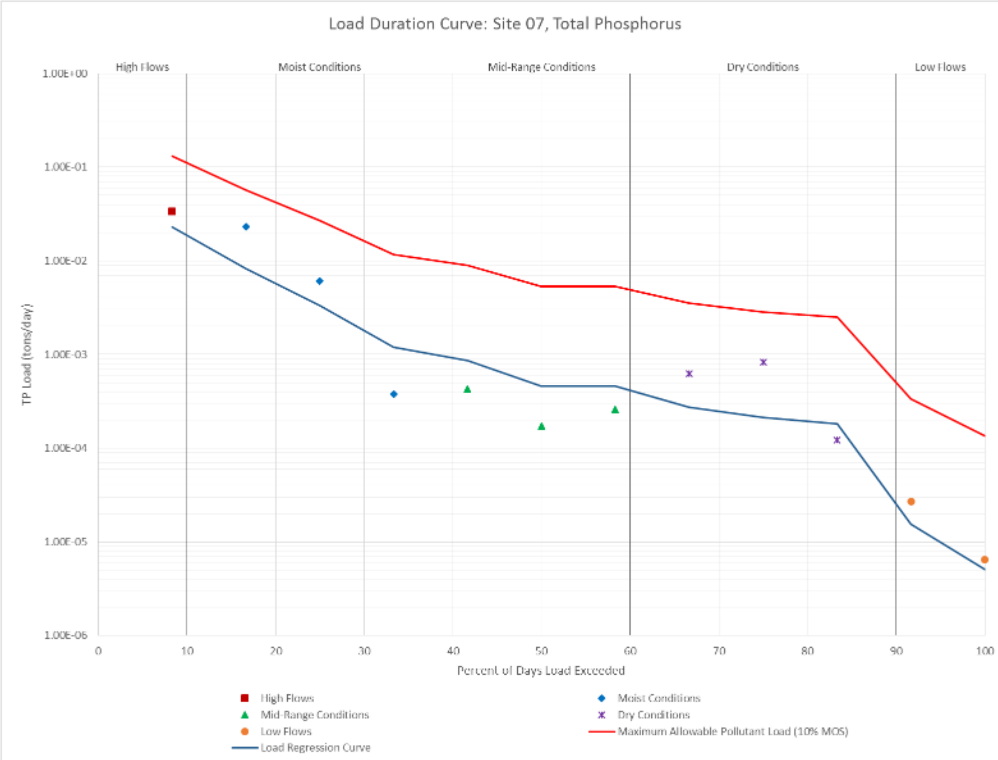


Figure C-34. LDC for total phosphorus, Village Creek at Rendon Road (10786).

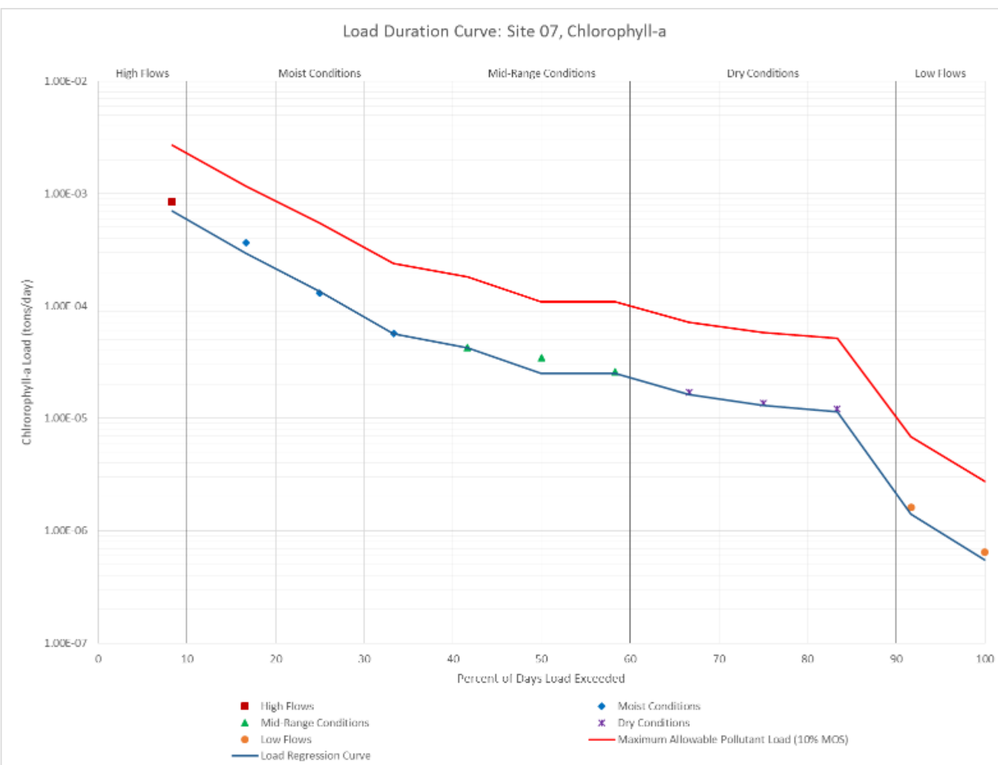


Figure C-35. LDC for chlorophyll-a, Village Creek at Rendon Road (10786).

Site 08 – Deer Creek at Oak Grove Road (10805)

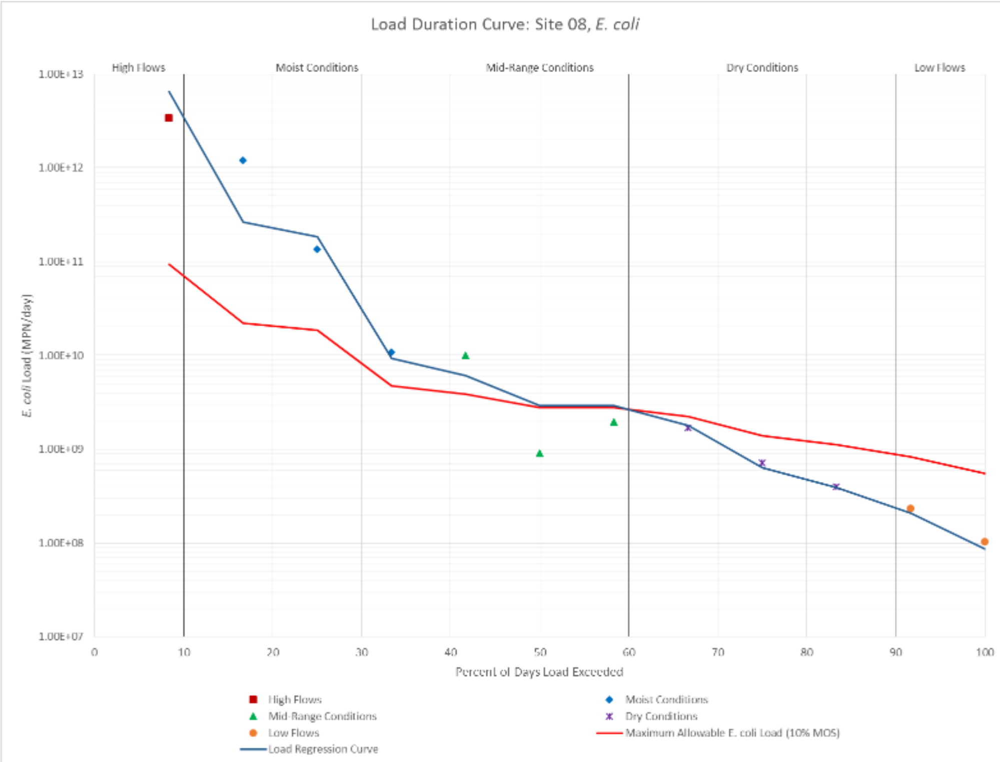


Figure C-36. LDC for E. coli, Deer Creek at Oak Grove Road (10805).

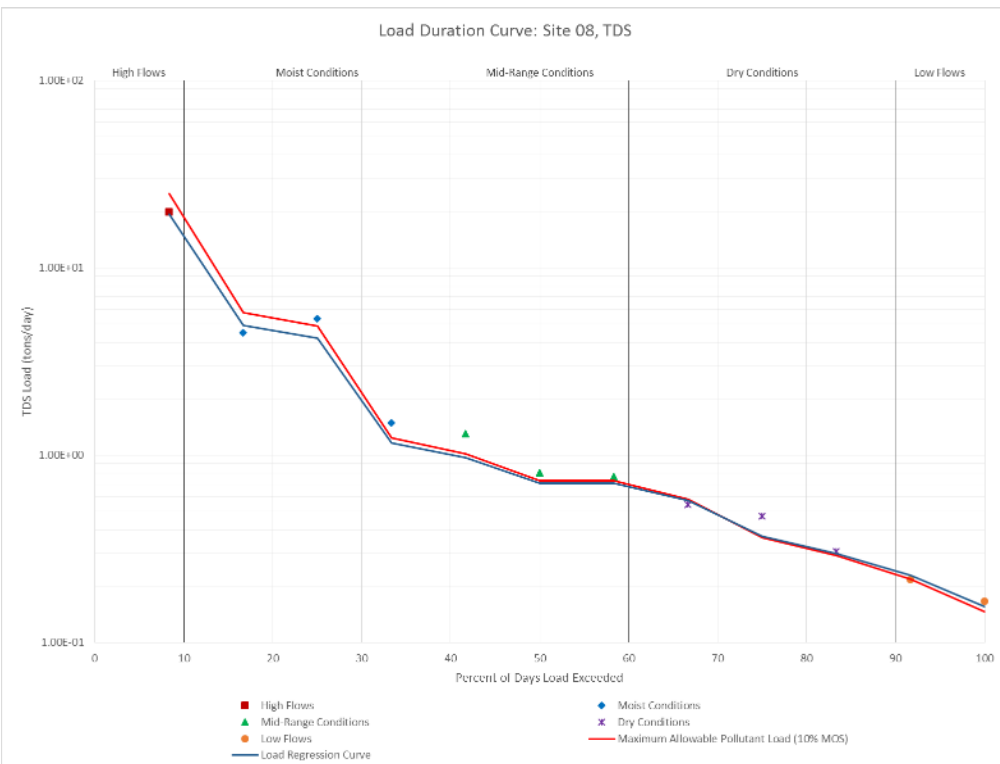


Figure C-37. LDC for TDS, Deer Creek at Oak Grove Road (10805).

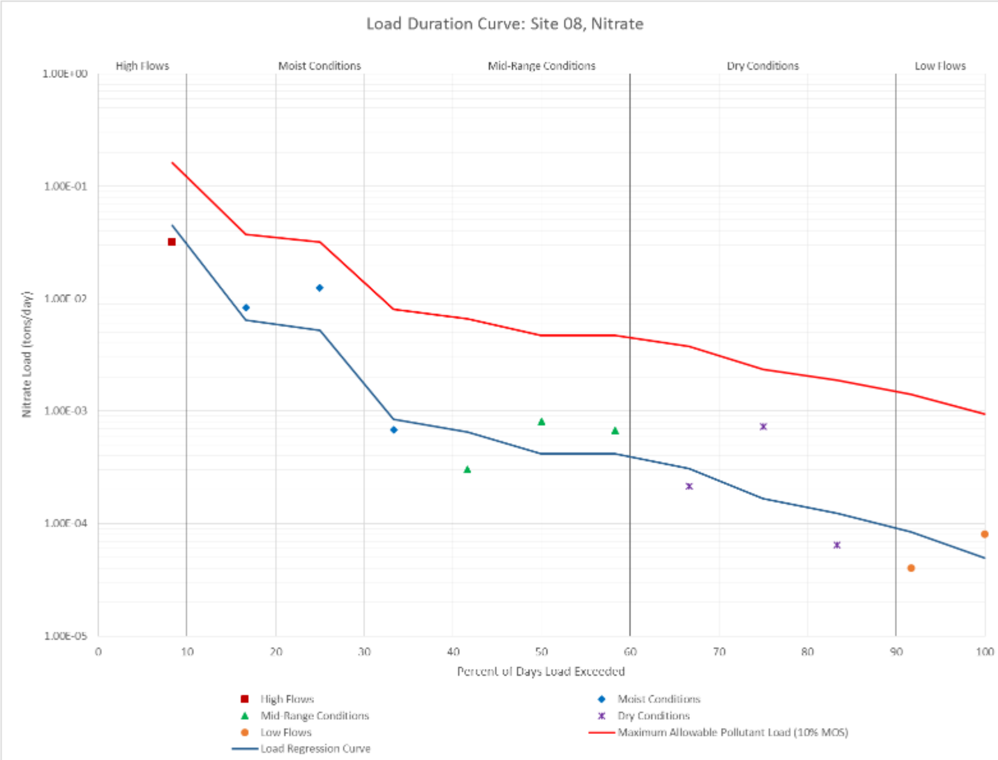


Figure C-38. LDC for nitrate, Deer Creek at Oak Grove Road (10805).

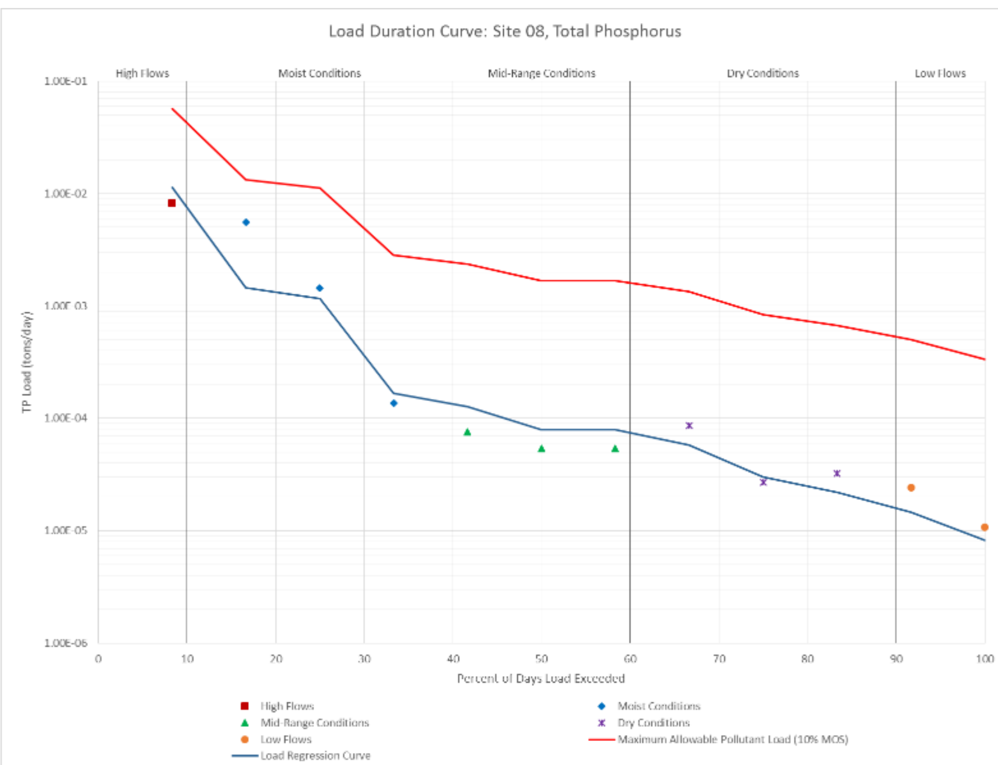


Figure C-39. LDC for total phosphorus, Deer Creek at Oak Grove Road (10805).

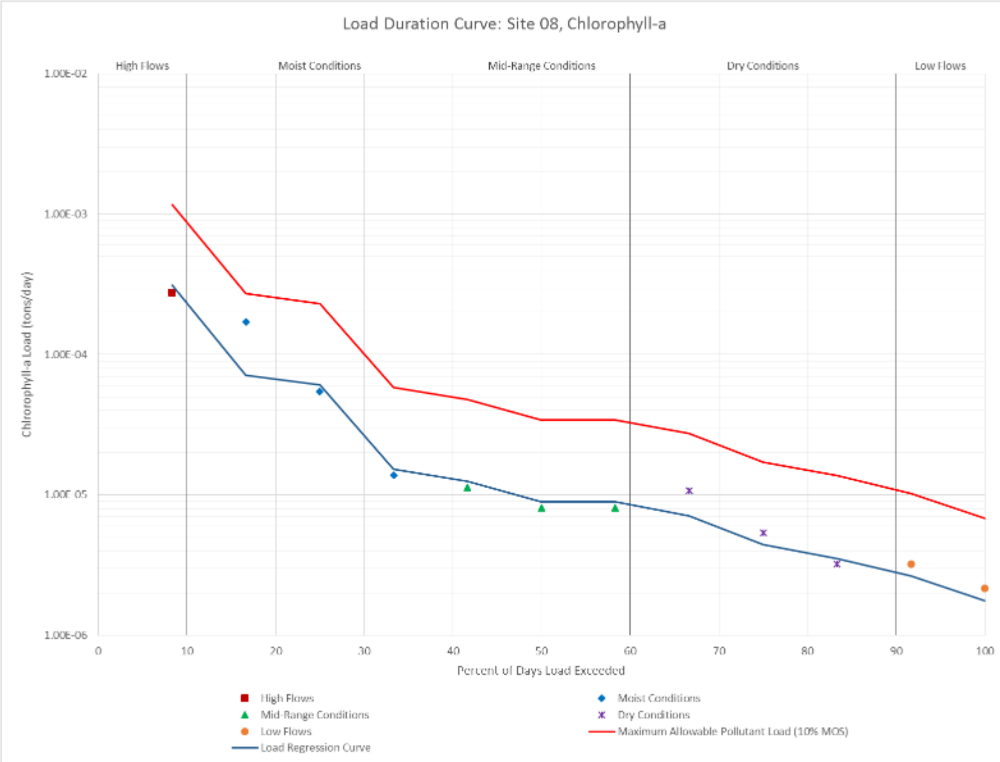


Figure C-40. LDC for chlorophyll-a, Deer Creek at Oak Grove Road (10805).

Site 09 – Village Creek upstream of Oak Grove (10785)

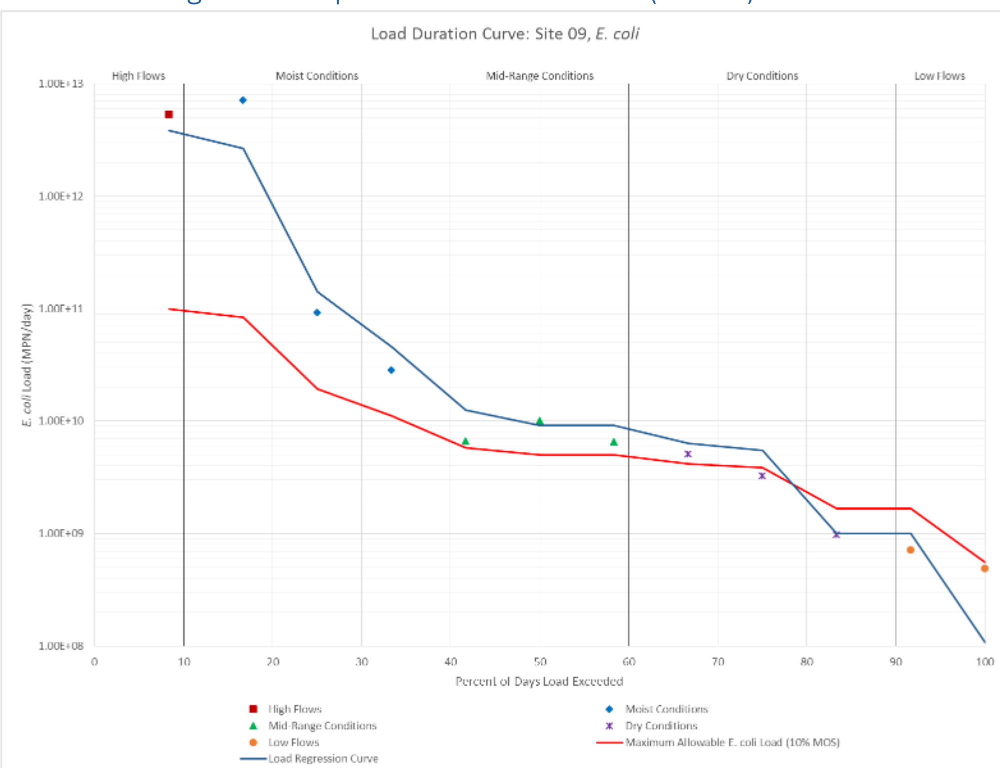


Figure C-41. LDC for E. coli, Village Creek upstream of Oak Grove (10785).

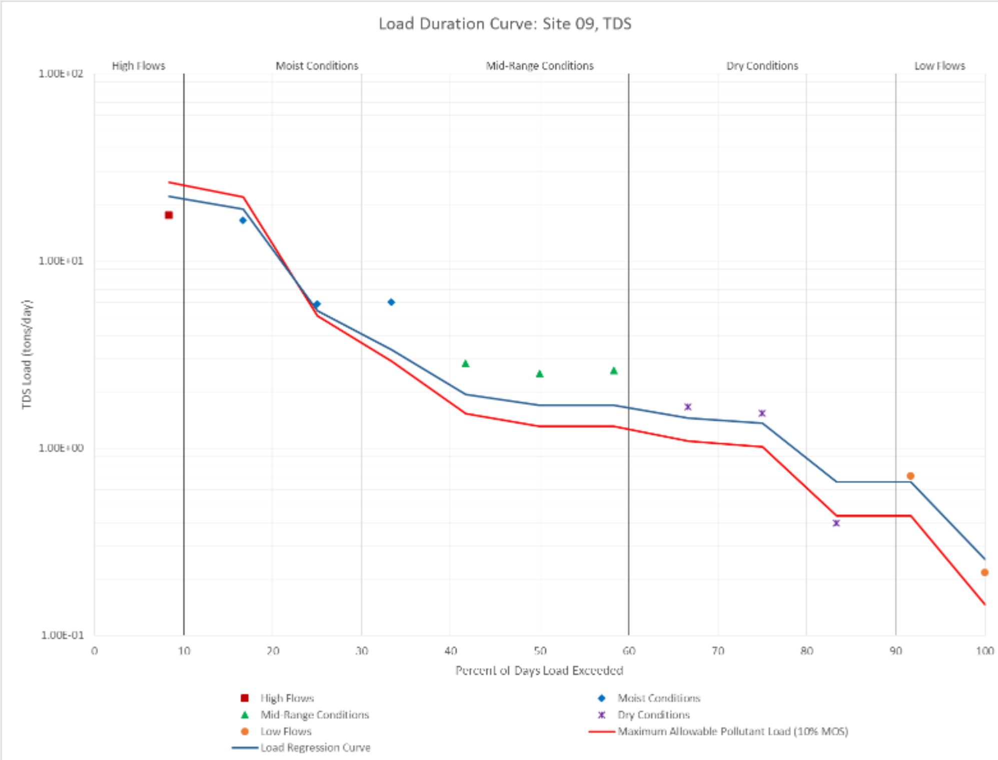


Figure C-42. LDC for TDS, Village Creek upstream of Oak Grove (10785).

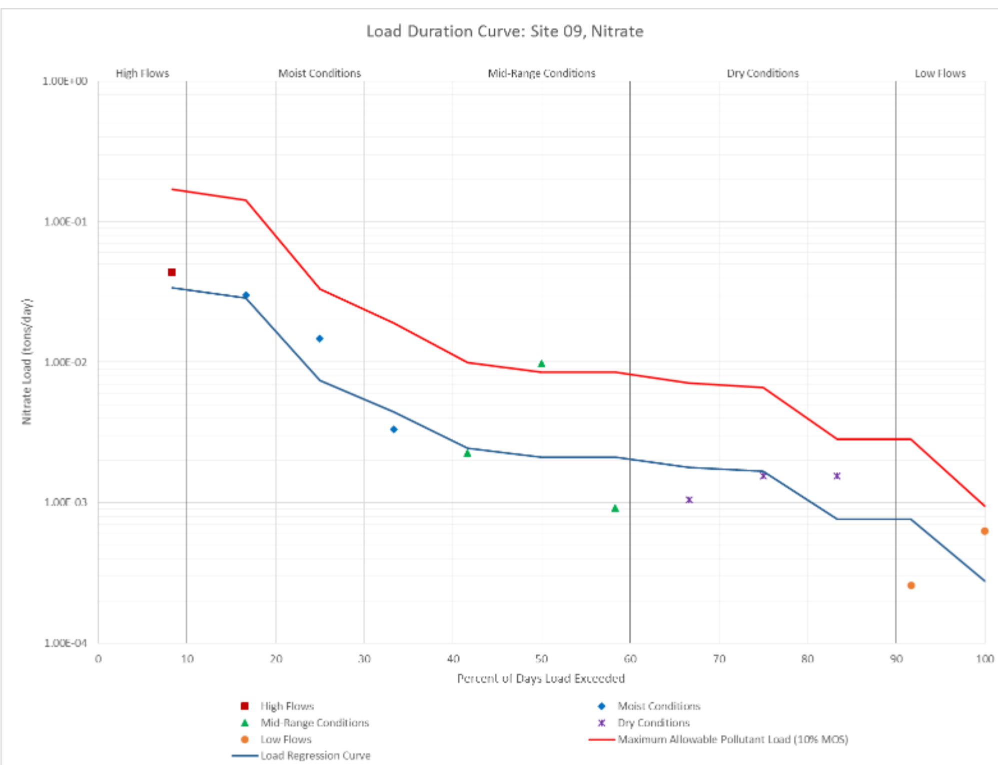


Figure C-43. LDC for nitrate, Village Creek upstream of Oak Grove (10785).

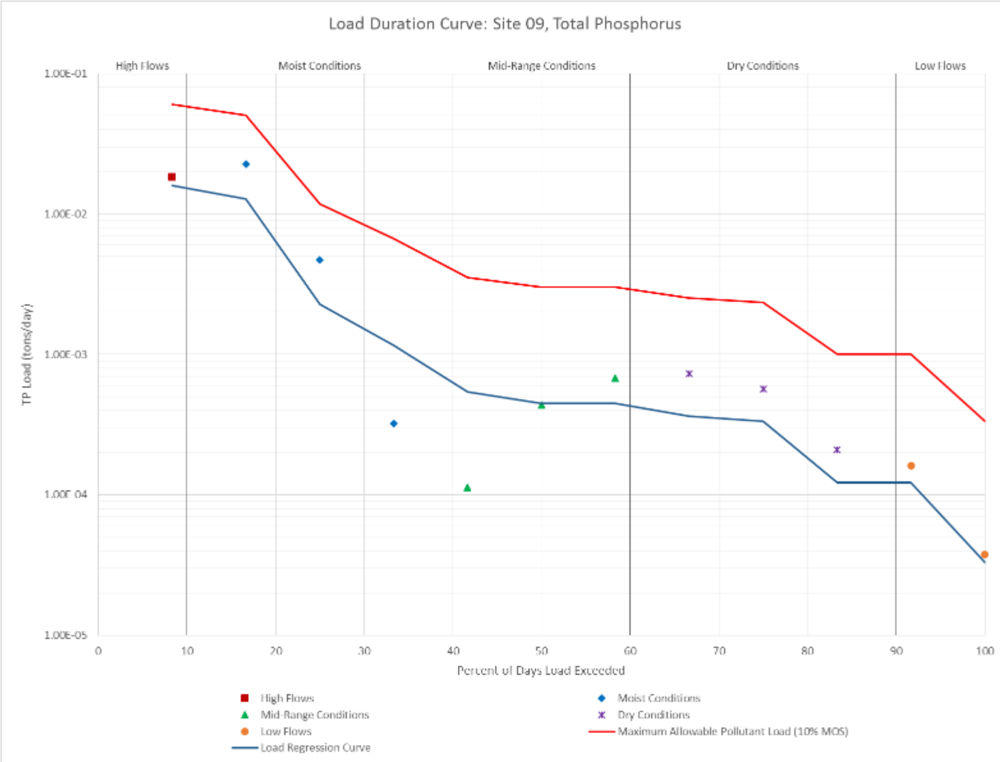


Figure C-44. LDC for total phosphorus, Village Creek upstream of Oak Grove (10785).

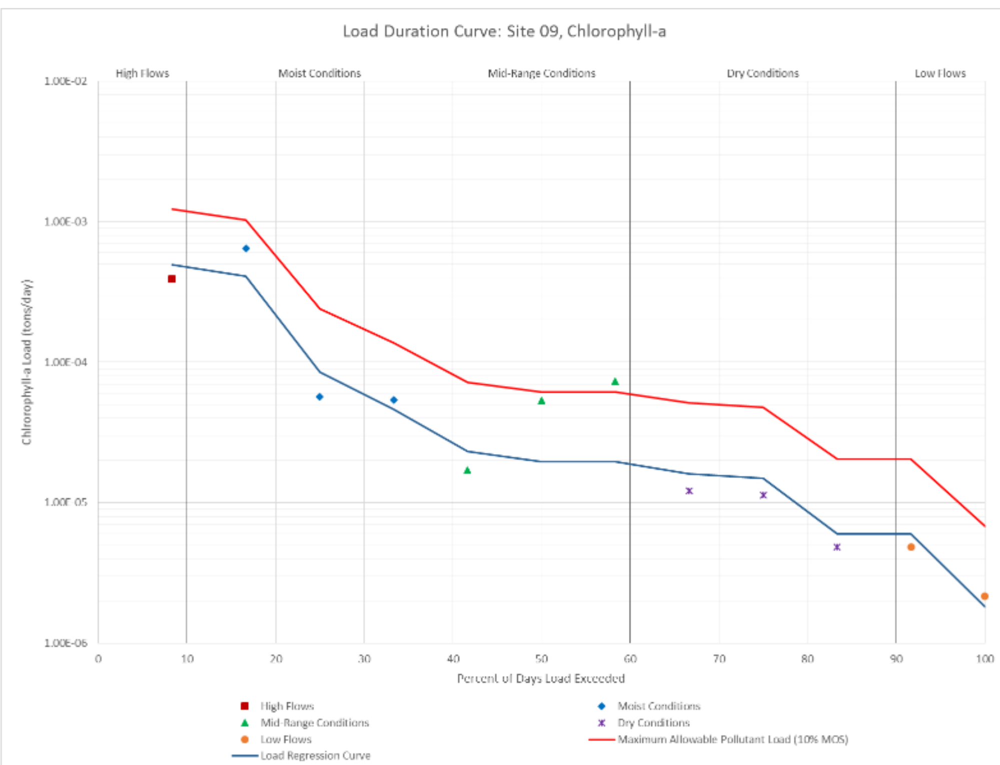


Figure C-45. LDC for chlorophyll-a, Village Creek upstream of Oak Grove (10785).

Site 10 – Quil Miller Creek at County Road 532 in Burleson (21759)

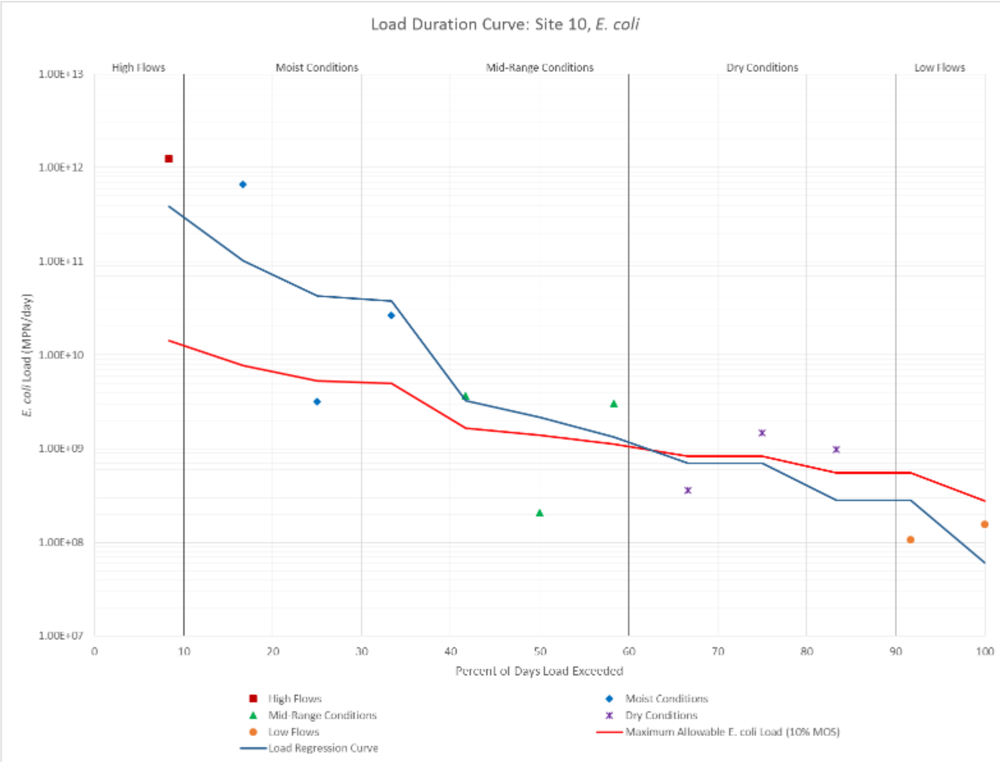


Figure C-46. LDC for E. coli, Quil Miller Creek at County Road 532 in Burleson (21759).

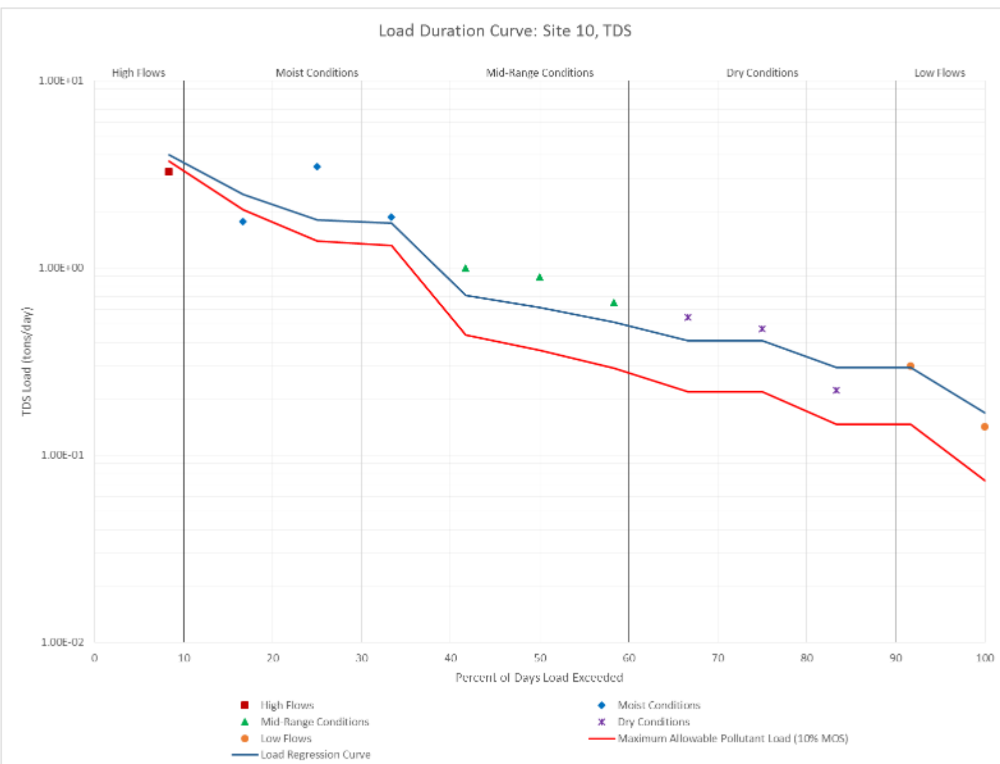


Figure C-47. LDC for TDS, Quil Miller Creek at County Road 532 in Burleson (21759).

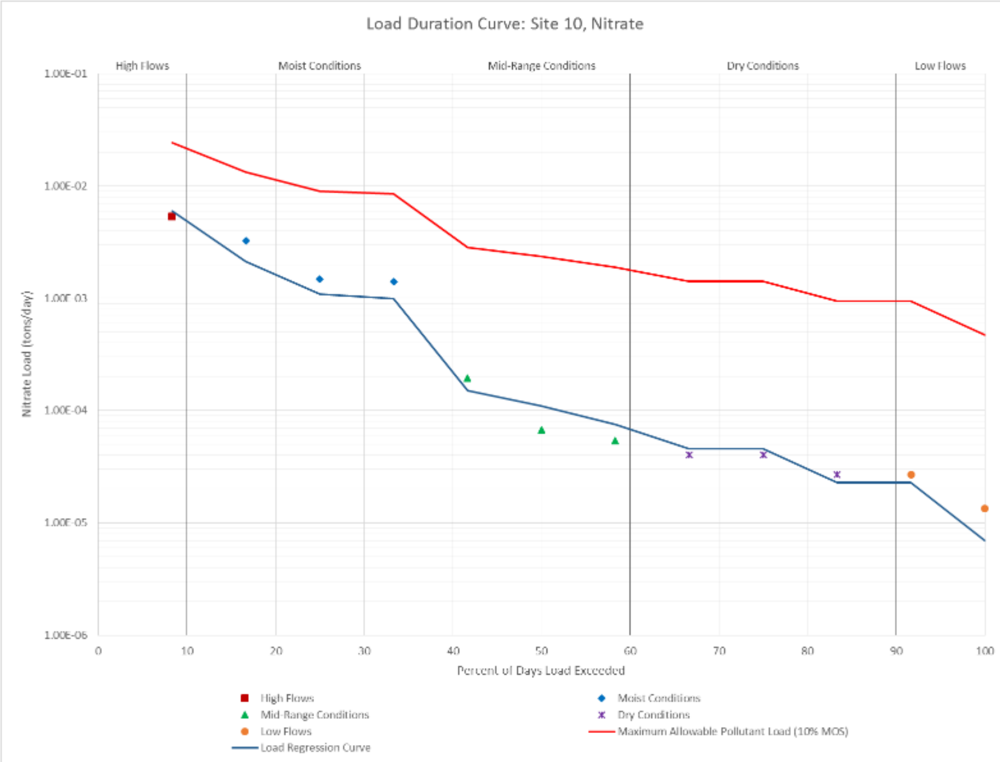


Figure C-48. LDC for nitrate, Quil Miller Creek at County Road 532 in Burleson (21759).

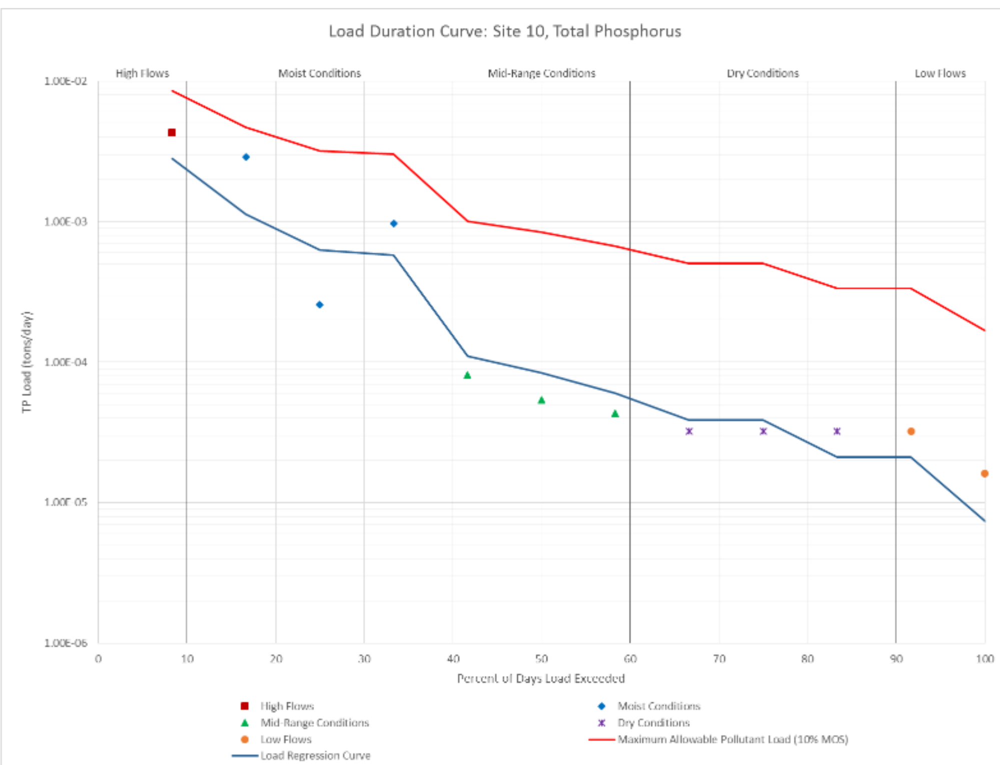


Figure C-49. LDC for total phosphorus, Quil Miller Creek at County Road 532 in Burleson (21759).

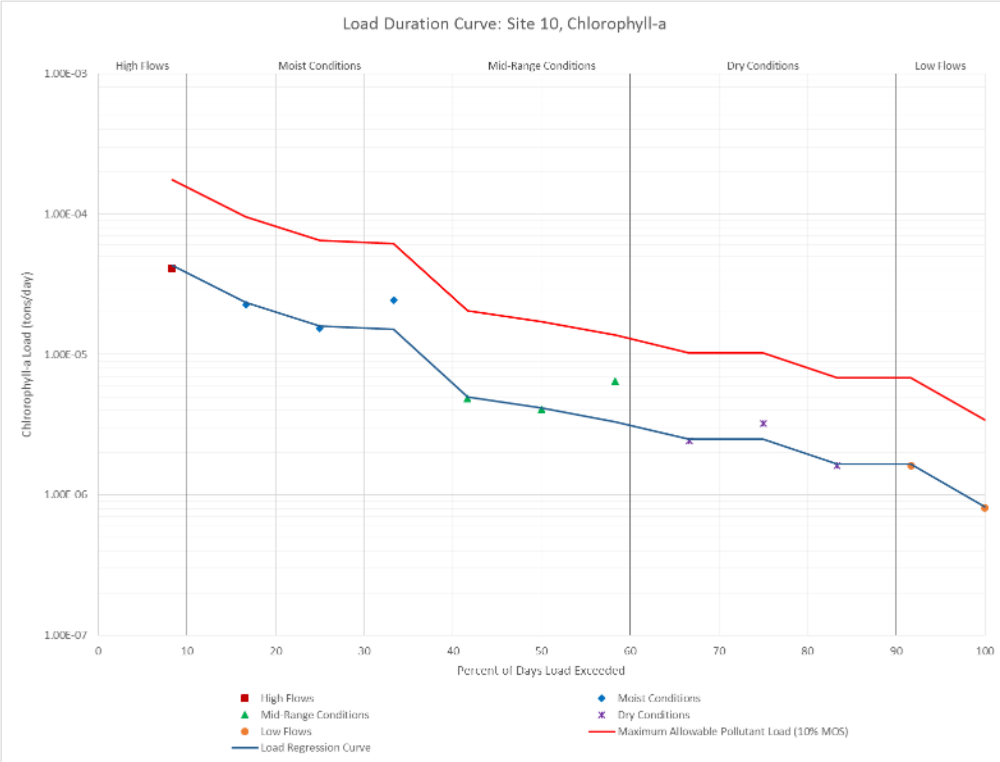


Figure C-50. LDC for chlorophyll-a, Quil Miller Creek at County Road 532 in Burleson (21759).

Site 11 – Village Creek at FM 3391 (21763)

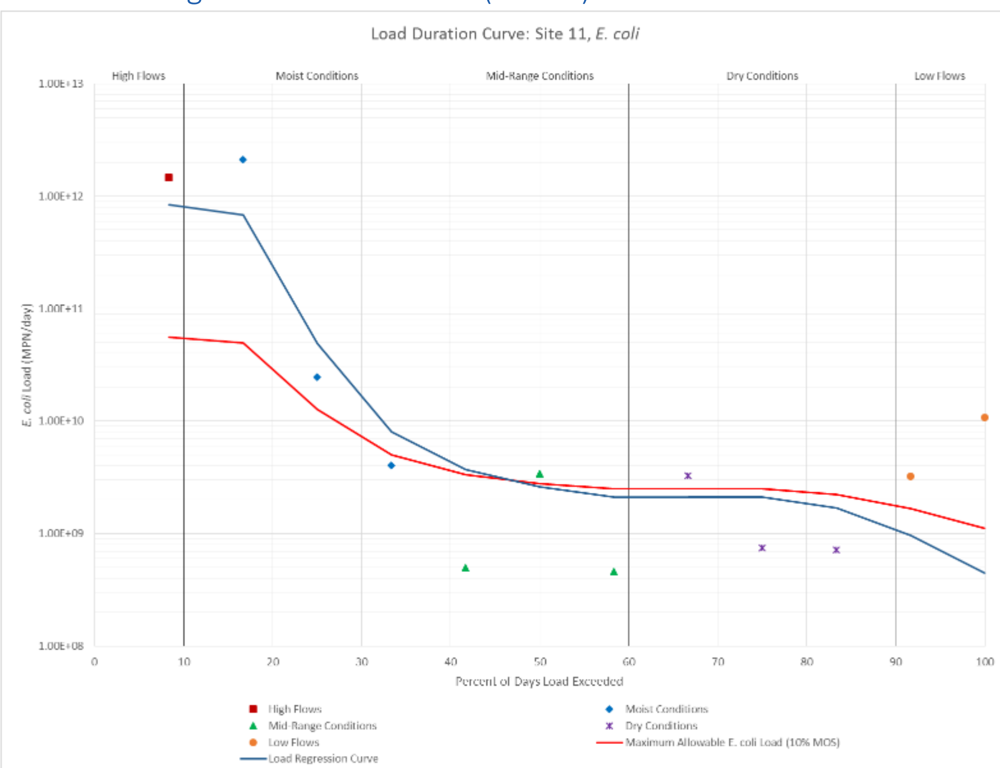


Figure C-51. LDC for E. coli, Quil Miller Creek at County Road 532 in Burleson (21759).

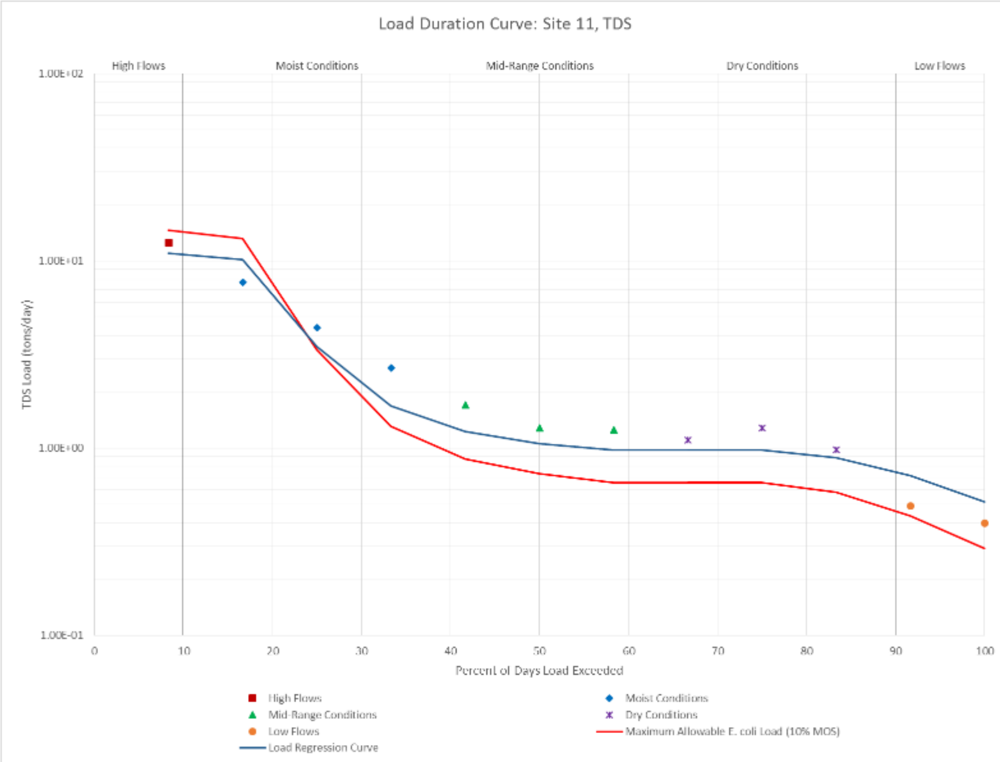


Figure C-52. LDC for TDS, Quil Miller Creek at County Road 532 in Burleson (21759).

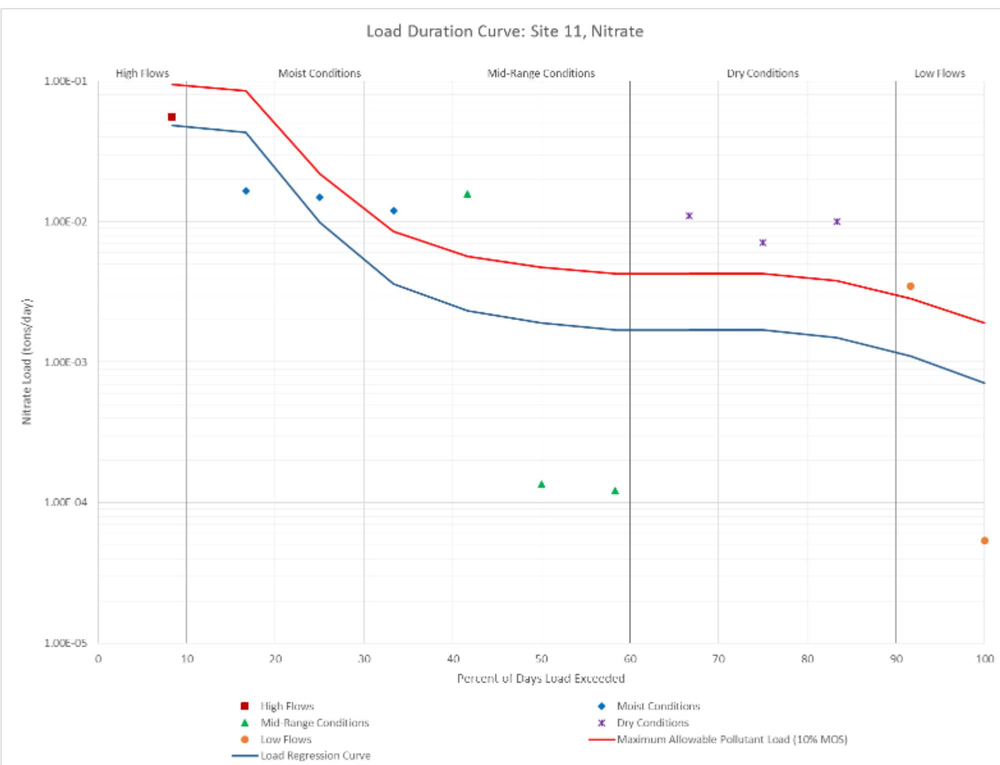


Figure C-53. LDC for nitrate, Quil Miller Creek at County Road 532 in Burleson (21759).

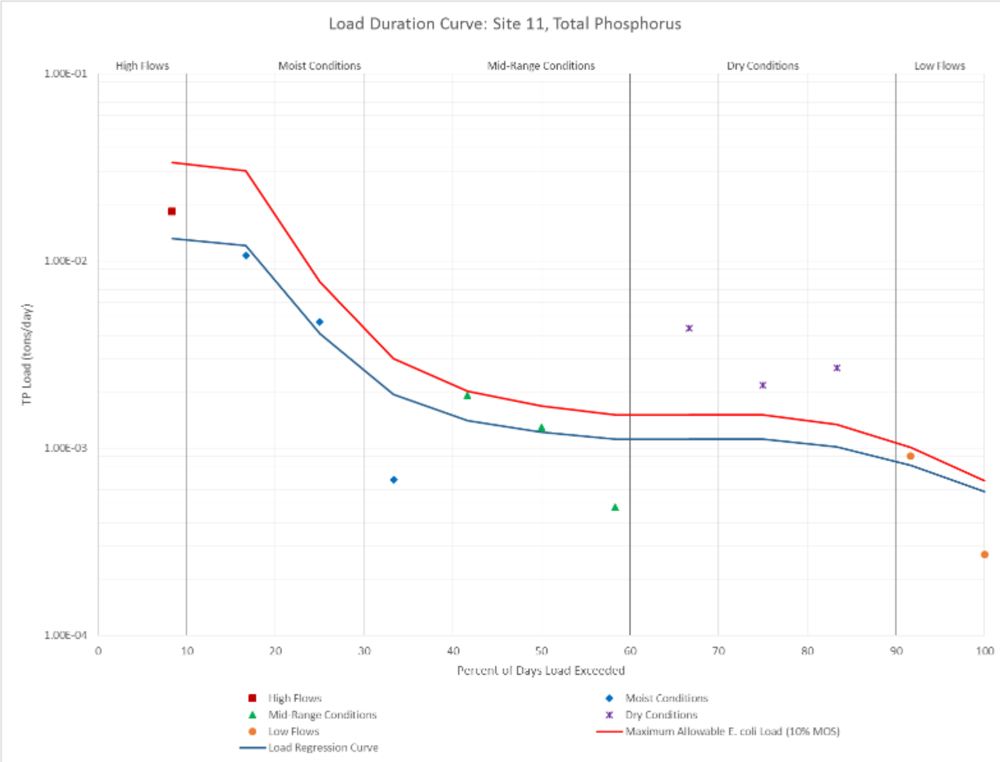


Figure C-54. LDC for total phosphorus, Quil Miller Creek at County Road 532 in Burleson (21759).

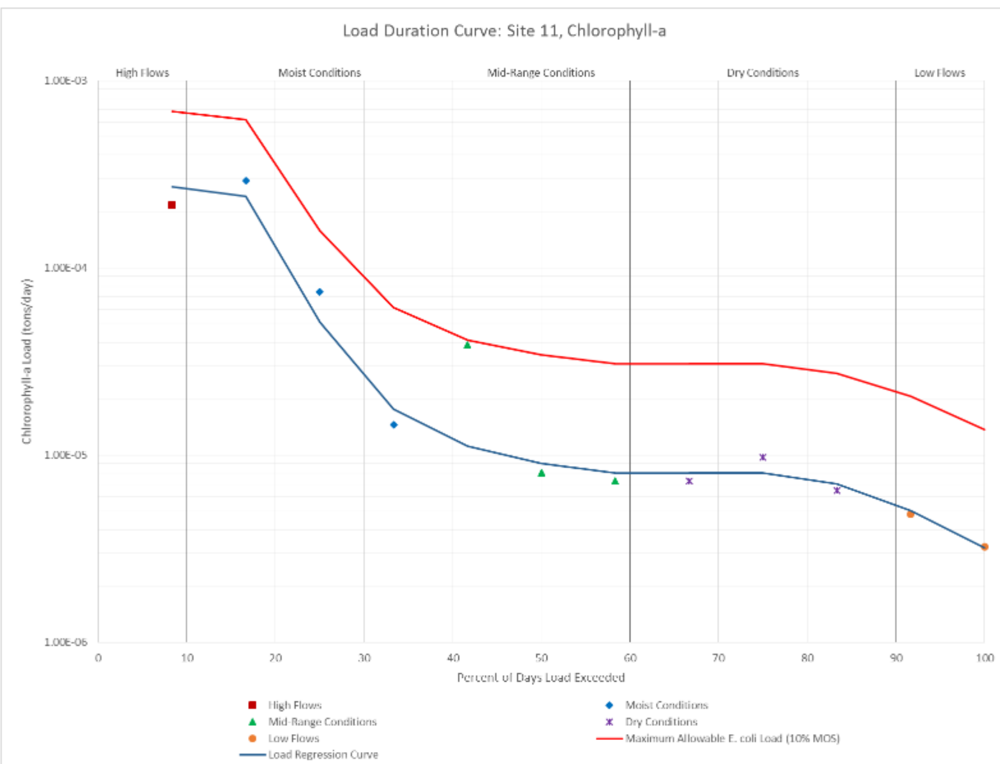
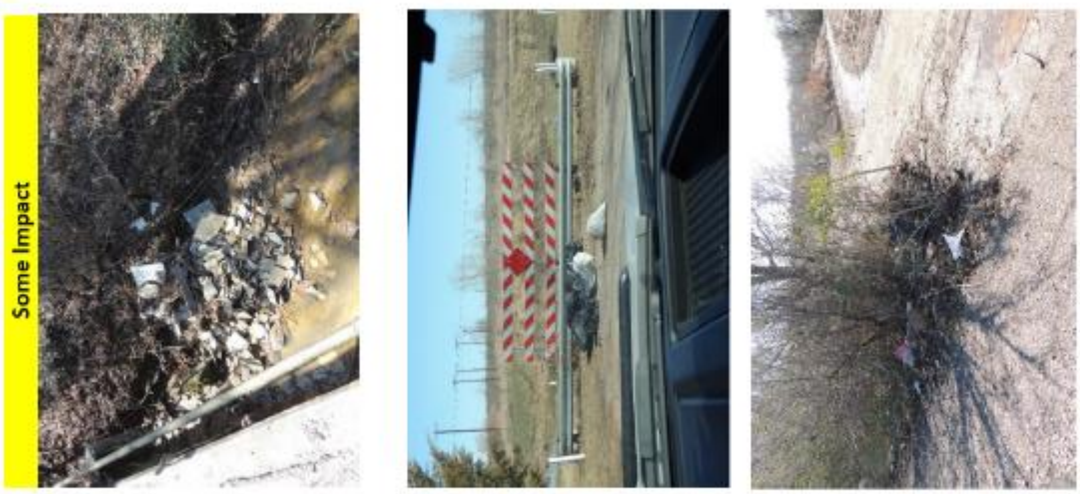


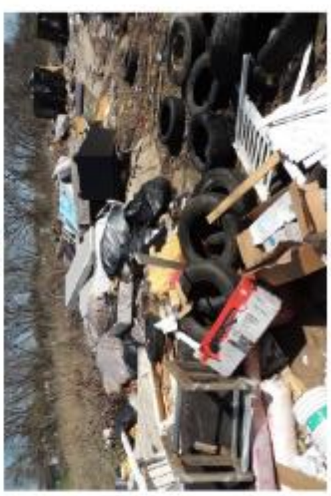
Figure C-55. LDC for chlorophyll-a, Quil Miller Creek at County Road 532 in Burleson (21759).

Appendix D. Photographic Records from Illegal Dumping Survey



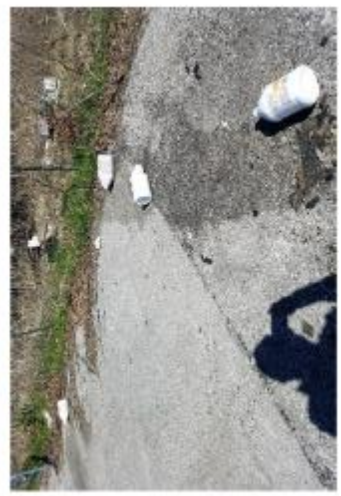
Critical impact

WS18



WS21

WS20



WS19