Spring 5-15-2021

# Characterization of an Urban Watershed: The Case for Rowlett Creek Watershed Impaired by Bacteria and Nutrient Concerns

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## Recommended Citation

Firn, Heather, "Characterization of an Urban Watershed: The Case for Rowlett Creek Watershed Impaired by Bacteria and Nutrient Concerns" (2021). *Civil and Environmental Engineering Theses and Dissertations*. 16.
https://scholar.smu.edu/engineering_civil_etds/16

# CHARACTERIZATION OF AN URBAN WATERSHED: THE CASE FOR ROWLETT CREEK WATERSHED IMPAIRED BY BACTERIA AND NUTRIENT CONCERNS

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# CHARACTERIZATION OF AN URBAN WATERSHED: THE CASE FOR ROWLETT CREEK WATERSHED IMPAIRED BY BACTERIA AND NUTRIENT CONCERNS

A Thesis Presented to the Graduate Faculty of
Lyle School of Engineering
Southern Methodist University
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science
with a
Major in Environmental Engineering
by

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May 15, 2021

# ACKNOWLEDGEMENTS

Many thanks to the City of Plano Environmental Quality Division for supporting the original grant that lead to this thesis project and encouraging me to accept the graduate student position, the City of Plano Public Works Department for assisting with installation of the ISCOs, the City of Plano Geographic Information Services division for helping with development of maps, the City of Plano Parks and Recreation Department for keeping an eye on our equipment, the City of Garland for permitting access and the install of the equipment on their golf courses and nature preserve. The finalization of the research would not have been possible without the flexibility and support provided to me by the Trinity River Authority Technical Services and Basin Planning Department. Thank you to Avery Blair and Lauren Stapleton, who through their internship with Texas A&M AgriLife, helped with sampling and additional analysis throughout the summer. Thank you to Kai Cheng and Gloria Ruiz from SMU who helped with sampling and lab analysis. Thank you to Cynthuja Partheeban of AgriLife for SWAT modeling. Finally, thank you to Dr. Jaber and Dr. Sun for endless support with sampling, analysis, troubleshooting and review of this research.

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Characterization of an Urban Watershed: The Case for Rowlett Creek Watershed Impaired by Bacteria and Nutrient Concerns

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Master of Science conferred May, 15, 2021

Thesis completed April, 27, 2021

Water quality and its relationship with urbanization is one of many nationwide environmental concerns. Rowlett Creek is located in an urban watershed in the Dallas-Fort Worth Metroplex. Since 2014, it has been listed by the Texas Commission on Environmental Quality as impaired for bacteria and as a screening limit concern for nitrate. Water quality samples were collected and analyzed for several parameters including flow, *Escherichia coli* (*E. coli*), total suspended solids (TSS), nitrate ($NO_3^-$), nitrite ($NO_2^-$), total Kjeldahl nitrogen (TKN), ammonia as Nitrogen ($NH_3$), total phosphorus (TP), pH, specific conductivity, dissolved oxygen (DO), and temperature. Load duration curves were developed to identify non-point source and point source pollutant concerns. The influence of land cover on water quality was also investigated. Analyzation of this watershed showed that *E.coli*, Nitrate + Nitrite, and TSS are non-point source concerns. Low flows indicate pollutants stem from point source and potentially non-point source. High flow conditions, Moist conditions, and Mid-range conditions are a source of non-point pollutants. Land cover between Rowlett Creek headwaters and outlet to Lake Ray Hubbard impacts pollutant concentration in the watershed, increasing flow and concentrations per acre. Best management practices are needed for all flow conditions. Green infrastructure, such as rain gardens and bioretention areas, is an implementation strategy to mitigate non-point source pollutants during rainfall events. Public outreach and education as a pollutant mitigation strategy are needed for all flow conditions, specifically low flows, to change human practices. Wastewater effluent into Rowlett Creek also needs to be further investigated.

## TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# LIST OF ACRONYMS

| | |
|---|---|
| AgriLife | Texas A&M AgriLife Extension |
| BMP | best management practice |
| CWA | Clean Water Act |
| DO | dissolved oxygen |
| *E. coli* | *Escherichia coli* |
| EPA | Environmental Protection Agency |
| IR | Texas Integrated Report on Surface Water Quality Standards |
| LDC | load duration curve |
| MPN | most probable number |
| $NO_2$ | nitrite |
| $NO_3$ | nitrate |
| OP | orthophosphate |
| OSSF | on-site sewage facility |
| QAPP | Quality Assurance Project Plan |
| SELECT | Spatially Explicit Load Enrichment Calculation Tool |
| Sp. Cond | specific conductance |
| St. Dev | standard deviation |
| SWAT | Soil and Water Assessment Tool |
| SWQM | Surface Water Quality Monitoring |
| TAC | Texas Administrative Code |
| TCEQ | Texas Commission on Environmental Quality |
| TKN | total Kjedahl nitrogen |
| TMDL | Total Maximum Daily Load |
| TP | total phosphorous |
| TSS | total suspended solids |
| TSWQS | Texas Surface Water Quality Standards |
| US | United States |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| WPP | watershed protection plan |

# CHAPTER 1

# INTRODUCTION

## 1.1 Water Quality of an Urban Watershed

Water quality is one of many nationwide environmental concerns that is receiving growing attention (Brown & Froemke, 2012). A large variety of pollutants due to human activities and natural processes continue to stress and impair the United States (U.S.) waterways. Typically, these pollutants can be classified as point source pollution or non-point source pollution depending on their pathway of discharge. Point source pollution can be defined as a discharge of pollutants from a clearly defined, fixed point such as a pipe, ditch, channel, sewer, drain, or outfall that commonly discharges directly into a waterway. Non-point source pollution can be defined as a widely dispersed threat through human activity and/or natural processes in which pollutants are transported through runoff (e.g. stormwater runoff, agricultural runoff, etc.) over land and into waterways. It does not originate from a clearly defined, fixed location. Non-point source pollution is regarded as the most challenging to contain. The types and amounts of pollutants entering the waterway are influenced by many factors, albeit primarily by land use and land cover. Non-point sources pollutants can stem from farms, roadways, golf courses, urban and/or suburban landscapes. Examples of specific sources of pollutants may include fluids from improperly maintained vehicles, waste runoff from pets, wildlife, livestock, and feral hogs, or excessive agricultural or residential fertilizers, pesticides or herbicides.

### 1.1.1 Nationwide

Brown and Froemke (2012) assessed over 15,000 watersheds in the U.S. and found that the eastern areas in the U.S. are under greater stress and of higher risk for pollution due to the high densities of road, agriculture and housing in the east than the lesser developed western US. The nationwide risk of water-quality impairment can be viewed in *Figure 1* (Brown & Froemke, 2012). The watershed risk levels are evaluated based on sediment, nutrients and toxics that collectively encompass percentages or amounts of housing units, road and railroad kilometers, agricultural land cover, livestock, confined animal feeding units, mining land cover, active and inactive mine sites, potentially damaging wildfire and atmospheric deposition within specific watersheds that are associated with causes of freshwater impairment in rivers and streams.

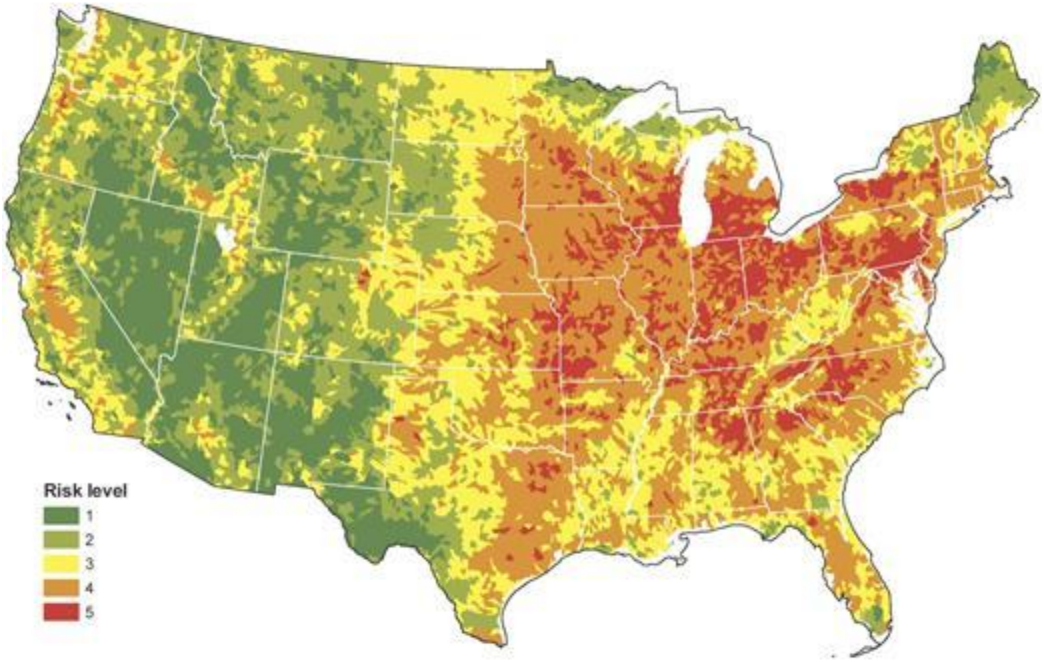


Figure 1 Overall risk of water-quality impairment for 15,272 watersheds. (Brown & Froemke, 2012)

In addition, as shown in *Table 1* (Brown & Froemke, 2012) the distribution of watershed risk levels was determined by assessing problems of sediment, nutrients and toxics for all watersheds. Most watersheds in U.S. were determined to be at medium risk levels (2–4), where very low-risk and very high-risk watersheds were less common according to the three criteria of sediment, nutrients and toxics. Texas as an entire state falls into low to high risk level. The more urbanized the area, the higher the risk level of the watershed in Texas.

Table 1 Distribution of watershed risk levels by problem (Brown & Froemke, 2012)

| Risk level | Sediment | Nutrients | Toxics | All three problems |
|---|---|---|---|---|
| 1 | 2459 | 2683 | 2418 | 2370 |
| 2 | 3865 | 3170 | 3482 | 3508 |
| 3 | 4069 | 2989 | 3727 | 3542 |
| 4 | 3786 | 4142 | 4331 | 4561 |
| 5 | 1093 | 2288 | 1314 | 1291 |
| All five risk levels | 15,272 | 15,272 | 15,272 | 15,272 |

### 1.1.2 Regionwide

According to the report of "*National Rivers and Streams Assessment 2013-2014: A Collaborative Survey*", in the Southern Plains ecoregion that includes central and northern Texas sixty percent (60%) of the rivers and streams are rated poor for total phosphorous and fifty-seven percent (57%) are rated poor for total nitrogen (USEPA, 2020). This report presents consistent findings with the previous study by Brown and Froemke in 2012, which assessed that Texas risk level, specifically rivers and streams in urbanized areas, are at high risk for nutrient impairment. Another assessment conducted in 2008-2009 demonstrated that the decline in good quality streams for nutrients was statistically significant (USEPA, 2020). In addition, the data collected indicated that biological conditions of good streams based on benthic macroinvertebrates declined with statically significant change from 2008-2009 (USEPA, 2020). The reduction of nutrients into the streams would improve the health of the rivers and streams. Moreover, this report evaluated the bacterial level using *Enterococcus*, which is commonly found in the intestinal tracts of humans and all warm-blooded animals. However, *Enterococcus* is not used as an indicator species for recreational use in Texas freshwater streams. *Escherichia coli* (*E. coli*) is the indicator organism used to determine support of recreation use in Texas freshwater streams.

### 1.1.3 Statewide

The Texas Commission on Environmental Quality (TCEQ) produces the Texas Integrated Report of Surface Water Quality every two (2) years. The most recent publication in May 2020 identified that of the 2,681 assessment units (AUs) in Texas, 325 AUs are impaired for bacteria, 148 AUs are listed as concerned with near nonattainment for bacteria, 231 AUs are listed as a concern for nitrate, and 164 AUs are listed as a concern for total phosphorus (TCEQ, 2020). Rowlett Creek was placed on the 2014 Texas Integrated Report -303(d) List (IR) for bacteria and is still currently listed in the 2020 IR. Rowlett Creek was also listed on the 2014 Texas IR for Water Bodies with Concerns for Use Attainment and Screening Levels as having a concern for nitrate and is still currently listed in the 2020 IR.

### 1.1.4 Local

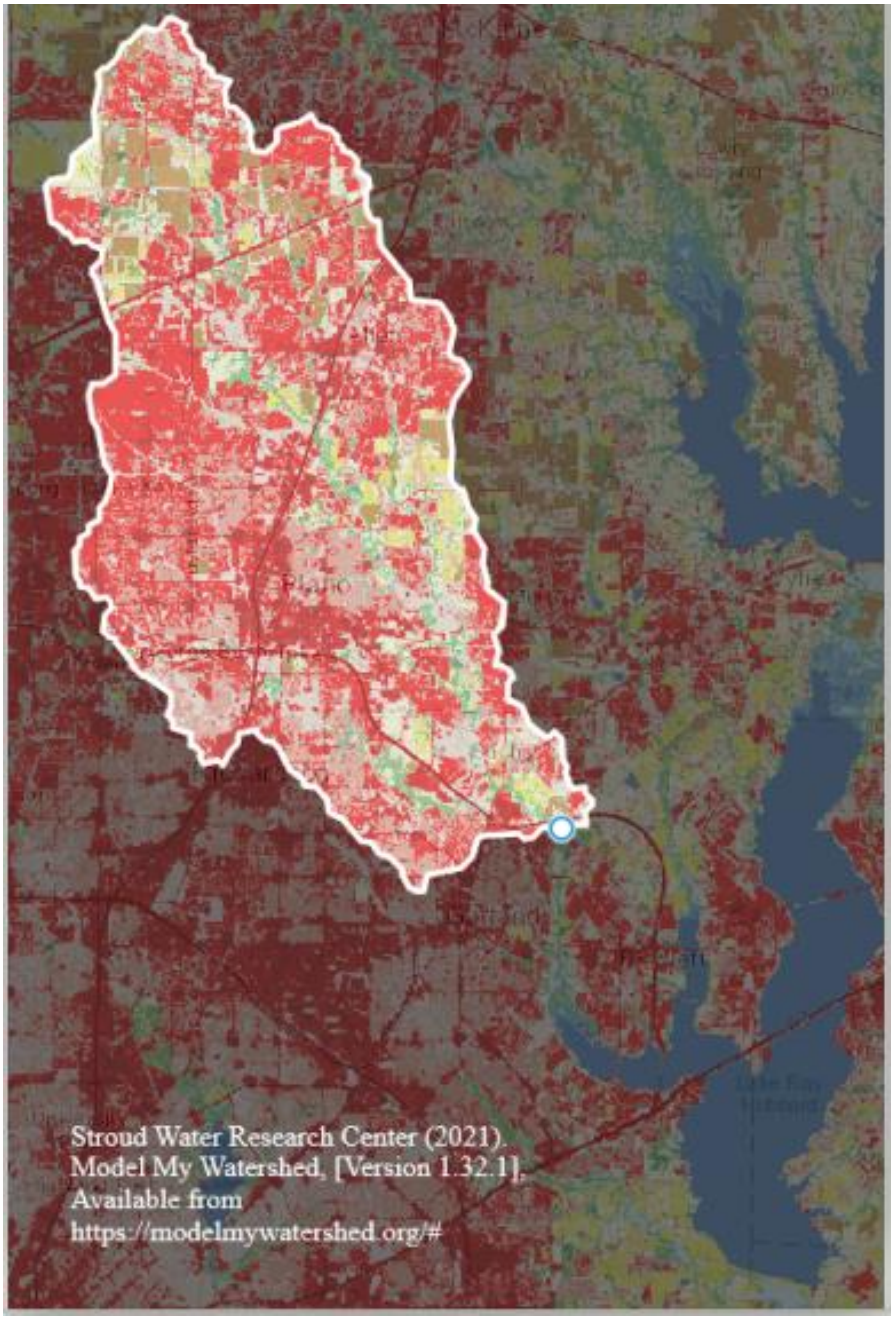
Rowlett Creek, AU 0820B and its tributaries make up a significant portion of the East Fork Trinity River drainage and Lake Ray Hubbard watershed. Rowlett Creek flows through the DFW Metroplex cities of Plano (the ninth most populated in city in the state of Texas (2010 Census)), Garland, McKinney, Frisco, Allen, and Murphy, which constitute a highly urbanized watershed. The creek also flows to a major water supply reservoir, Lake Ray Hubbard, owned by the City of Dallas. The majority of the creek is within the city limits of Plano. With continuous growth in the region, Rowlett creek is exposed to water quality and habitat degradation caused from human activity, urban runoff, and erosion (Jaber *et al*., 2019).

Spring Creek and its tributaries, Pittman Creek and Prairie Creek, make up a significant portion of the Rowlett Creek basin that drains into the East Fork Trinity River and Lake Ray Hubbard. The City of Plano makes up the headwaters of the Spring Creek basin, eventually flowing downstream through other Texas cities including Richardson and Garland. The land surfaces making up the Spring Creek drainage in Plano are mostly impervious, including roadways, alleys, buildings, parking lots, driveways, and sidewalks. Due to the lack of pervious surfaces and natural buffers in this drainage area, over 90% of the precipitation that falls here flows to the stream, rather than being absorbed by the historical natural prairie habitat. Because of the large impervious areas, Spring Creek is exposed to water quality and habitat degradation caused from human activity, urban runoff, and erosion.

Rowlett Creek watershed is composed of 77.9% developed land composed of parks, low, medium and high intensity; 13.44% riparian or forest land; and 8.41% of agricultural land. The remaining 0.16% is composed of open water *Table 2*, Figure 2. The soil group distribution is composed of 68% Type D, very slow infiltration, 26% Type C – slow infiltration, 6% Type B – moderate infiltration, and 0.16% Type A – high infiltration (USDA Gridded Soil Survey Geographic, 2016). These soil types confirm that the soil infiltration capabilities of the watershed are already limited. There is extensive runoff because of the clay, in the summer they contract and in the winter they expand. If storms are light the soil will be able to allow percolation and adsorption whereas if storms are heavy the rainwater will max out and runoff.

Table 2 Land Cover Distribution Rowlett Creek Watershed, NLCD

| Class Name | Area (ac) | Coverage (%) |
|---|---:|---:|
| Open Water | 128.44 | 0.16 |
| Perennial Ice/Snow | 0 | 0 |
| Developed, Open Space | 9941.75 | 12.59 |
| Developed, Low Intensity | 19206.72 | 24.33 |
| Developed, Medium Intensity | 25623.78 | 32.45 |
| Developed, High Intensity | 6735.69 | 8.53 |
| Barren Land (Rock/Sand/Clay) | 66.69 | 0.08 |
| Deciduous Forest | 3660.54 | 4.64 |
| Evergreen Forest | 165.49 | 0.21 |
| Mixed Forest | 0 | 0 |
| Shrub/Scrub | 0 | 0 |
| Grassland/Herbaceous | 6547.97 | 8.29 |
| Pasture/Hay | 1805.57 | 2.29 |
| Cultivated Crops | 4833.79 | 6.12 |
| Woody Wetlands | 212.42 | 0.27 |
| Emergent Herbaceous Wetlands | 19.76 | 0.03 |
| Total | 78951.08 | 100 |



Stroud Water Research Center (2021).
Model My Watershed, [Version 1.32.1].
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https://modelmywatershed.org/#

Figure 2 Land Cover for Rowlett Creek Watershed, NLCD 2011

The headwaters of Rowlett creek subwatershed is included within the Rowlett Creek watershed and are specifically composed of 67% developed land composed of low, medium and high intensity; 5.48% riparian and forest lands; and 27.08 agricultural; with 0.13% open water Table 3, Figure 3. The soil group distribution is composed of 62% Type D, very slow infiltration, 34% Type C – slow infiltration, 6% Type B – moderate infiltration, and 3% Type B – moderate infiltration (USDA Gridded Soil Survey Geographic, 2016).

Stroud Water Research Center (2021)
Model My Watershed, [Version 1.32.1].
Available from https://modelmywatershed.org/

Figure 3 Land Cover in Upper Rowlett Creek Subwatershed, NLCD, 2011

Table 3 Land Cover Rowlett Creek Upper Subwatershed, NLCD 2011

| Class Name | Area (Ac) | Coverage (%) |
|---|---|---|
| Open Water | 34.58 | 0.13 |
| Perennial Ice/Snow | 0 | 0 |
| Developed, Open Space | 3196.18 | 12.74 |
| Developed, Low Intensity | 4250.87 | 16.95 |
| Developed, Medium Intensity | 8131.24 | 32.41 |
| Developed, High Intensity | 1267.11 | 5.05 |
| Barren Land (Rock/Sand/Clay) | 61.75 | 0.24 |
| Deciduous Forest | 1227.59 | 4.89 |
| Evergreen Forest | 125.97 | 0.51 |
| Mixed Forest | 0 | 0 |
| Shrub/Scrub | 0 | 0 |
| Grassland/Herbaceous | 2645.37 | 10.55 |
| Pasture/Hay | 684.19 | 2.72 |
| Cultivated Crops | 3443.18 | 13.73 |
| Woody Wetlands | 19.76 | 0.08 |
| Emergent Herbaceous Wetlands | 0 | 0 |
| Total | 25087.79 | 100 |

## 1.2 Watershed Management

A watershed is an area of land that channels water to creeks, streams, or rivers and inevitably ends up in a lake, wetland, or ocean. Watersheds can be small, such as the ground one stands on or a portion of a park that then channels to a local stream in a neighborhood. These small watersheds, such as Rowlett Creek, form larger watersheds, such as the Trinity River Basin, that then drain large portions of Texas to the Gulf of Mexico. As stormwater runoff cascades across the landscape, it transports sediment and other substances, including pollutants, as it drains into a waterway. The cumulative impact of various activities on the land will affect water quality and water volume, thereby affecting the function and health of the entire basin.

The Clean Water Act (CWA) (33 USC § 1251.303) was reorganized and expanded from the 1948 Federal Water Pollution Control Act in 1972. The CWA "establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters" (EPA, 2020). Since the establishment of the CWA, the EPA was able to achieve substantial reductions to our nation's air and water systems by focusing on point sources of pollution  (EPA, 1996). However, even though discharges from industrial or municipal sources are now regulated, the U.S. waters are still threatened by multiple sources of polluted runoff stemming from urban, agricultural land uses, for example, and continuous land development, among many other threats such as overharvesting and exotic species introduction, for example, not focused on in this research (EPA, 1996). Therefore, the U.S. EPA increased emphasis on a watershed management approach in the 1990s because nearly 40 percent of surveyed waters in the U.S. remained too polluted for fishing, swimming and other uses (EPA, 1996). The leading causes of impairment found in the survey include silt, sewage, disease-causing bacteria, fertilizer, toxic metals, oil and grease.

Since then, the U.S. EPA established water quality standards and created a list known as the 303(d) list that identifies and describes all impaired waterbodies that do not meet the water quality standards(40 CFR § 130.7).  The CWA also created the ability for States to build on these standards by creating and applying localized water quality standards. However, prior to acceptance, they must be first approved by the U.S. EPA. In Texas specifically, the Texas Water Code outlines the designated uses and the water quality standards that are in place to support the requirements in the CWA. In summary, the CWA aids in narrowing the focus on waterways impaired by pollution and hazardous substances by establishing standard water quality procedures. These standard procedures ensure that waterways are maintained and restored to biological integrity; that they are protecting fish, wildlife, and recreational uses by remaining "swimmable and fishable"; and that they are continuously assessed based on the designated water uses and concentrations established by the state, i.e., public water supply, agricultural, industrial, wildlife, recreation.

The watershed management approach established by the U.S. EPA now requires that states restore water quality in the impaired waterbodies by developing strategies (40 CFR § 130.7). There are two acceptable strategies, a regulatory mechanism known as total maximum daily loads (TMDL) and non-regulatory mechanism known as a watershed protection plan (WPP). A TMDL sets budgets for pollutants in a waterbody, identifies a waterbodies maximum pollutant loading capacity, and the reduction in loading required to meet the TMDL. A TMDL is an enforcement from the government with input from the public. A WPP is all encompassing and utilizes stakeholders to identify and address water quality impairments that have been identified through research as well as establish goals for protecting waterbodies that do not have impairments. The main goal of a WPP is to develop an effective watershed management strategy that will show a measurable impact on the water quality of a waterbody. An effective watershed management approach requires an examination of all human activities and natural process that occur within a watershed.

### 1.3 Watershed Planning

In 2008, U.S. EPA published the *Handbook for Developing Watershed Plans to Restore and Protect our Waters* (the Handbook) to provide a guide for users to develop watershed protection plans in order to improve and to protect the nation's water quality (EPA,2008). The Handbook also outlines how the nine minimum elements within the CWA section 319 non-point source program are to be included within the WPP. The nine elements are labeled from a through i to replicate how they are presented in the 319 guidelines. The first three elements (a through c) are considered during the characterization and goal-setting phases to address the primary sources of pollution in the watershed and to determine the management strategies needed in specific areas to reduce the pollution to meet water quality goals (EPA, 2008). The remaining six elements (d through i) are used to develop a specific plan of action with measurable targets and milestones, as well as the necessary financial and technical resources needed to restore the waterbody (EPA, 2008). These nine minimum elements (EPA, 2008) are:

a. Identify causes and sources of pollution
b. Estimate pollutant loading into the watershed and the expected load reductions
c. Describe management measures that will achieve load reductions and targeted critical areas
d. Estimate amounts of technical and financial assistance and the relevant authorities needed to implement the plan
e. Develop an information/education component
f. Develop a project schedule
g. Describe the interim, measurable milestones,
h. Identify indicators to measure progress
i. Develop a monitoring component.

The six steps in watershed planning and implementation are depicted in Figure 4 and incorporate all nine elements the EPA requires in a WPP.

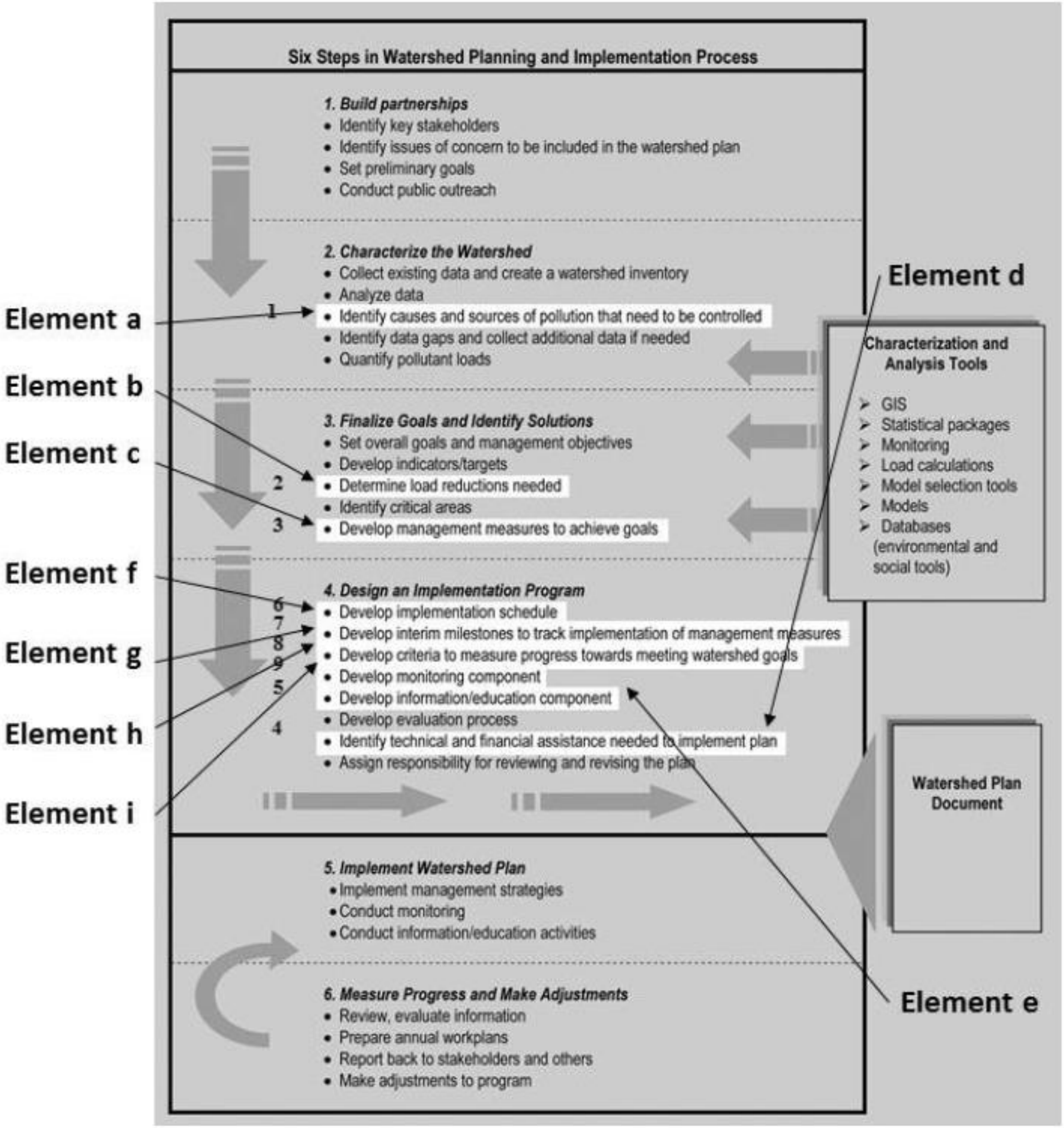

Figure 4 Six Steps in Watershed Planning (EPA, 2008)

## 1.4 Non-point Pollution Sources and Implementation Strategies of Best Management Practices

The primary method to control pollutant runoff into impaired water bodies is the use of best management practices (BMPs). Depending on the concerns identified, certain BMPs can be implemented to combat threats. *E. coli* impairments or threats can stem from pet waste, livestock, wildlife, sanitary sewer overflows, and Onsite Septic Facilities (OSSF) failures. Nutrient concerns can stem from overirrigation, residential fertilization and pesticide application (that can suppress natural nitrogen cycles), and agricultural practices. Ways to combat these require a multi-faceted approach.

One implementation strategy consists of pet waste management. This includes homeowner education on impacts of pet waste as a pollutant source and proper disposal as well as installation of pet waste stations. A second implementation strategy would be to focus on livestock management. This would entail technical assistance from agencies such as Texas State Soil and Water Conservation Board (TSSWCB), National Resource Conservation Service (NRCS), local Soil and Water Conservation Service (SWCS), and local Texas AgriLife Extension staff who are familiar with the specific needs of the area. Landowner education would be needed in order to inform them that overgrazing of upland areas can lead to increased runoff and manure deposited by livestock will be transported to waterbodies by runoff if not directly deposited into the waterbody. Finally, the riparian buffer can be degraded due to migration of livestock as well as grazing habits. A third implementation strategy can be targeted towards feral hog management. Education would need to be provided to landowners with information that summarizes multiple aspects of feral hog control that would stem from TPWD and Texas AgriLife Extension. Feral Hogs are a non-point source concern because of their ability to proliferate uncontrolled in the watershed and in doing so degrade riparian buffer zones and deposit manure either directly or by runoff into the waterbody. Wildlife can also be considered a non-point source pollutant, albeit one that is difficult to address. Concerns related to wildlife are similar to pet waste, livestock, and feral hogs.

Sanitary sewer overflows (SSOs) are one non-point source that would require multiple municipal and regional staff to assist with development of BMPs and implementation. SSOs occur when there is stormwater inflow and infiltration due to age of the infrastructure, land erosion or construction damage. Implementation strategies would require funding to identify problematic areas and capital improvement plans to address infrastructure. Wastewater Treatment Facilities (WWTF) are typically considered point source, but can cause non-point source pollution due to direct or indirect loadings to waterbodies from failing infrastructure or overloaded systems that cause overflows or leaks as well as illicit connections. On-Site Sewage Facilities or OSSF’s are a significant non-point source contributor. As of 2018, there are 30,437 OSSF’s in Collin County and 14,732 OSSF’s in Dallas County (https://ossf.tamu.edu/test-map/). Improper installation that leads to illicit discharge, improper treatment of effluent applied to land or general infrastructure failure due to age, improper design or lack of maintenance cause the majority of non-point source contribution to waterbodies. BMPs and implementation strategies would require assistance from county Designated Representatives (DR) that are responsible for regulation and enforcement of OSSF’s. Implementation strategies could include development of model ordinances, promotion of the established OSSF inspection/pump out programs, improved communication between real estate groups in rural communities and county DR’s.

Nutrient concerns also require a multifaceted approach. Excessive nitrogen and phosphorus can enter the waterbody from improper disposal of yard clippings and excessive application of fertilizer, herbicide or pesticides on residential, commercial, industrial and agriculture lands. Implementation strategies could require homeowner outreach and education on proper disposal and application as well as promotion of resources for landowners on land management, proper irrigation, herbicide and pesticide application as well as green infrastructure.

Floatables, litter accumulation and illegal dumping can also be deemed a non-point pollutant source of *E. coli*, nutrients, and hazardous materials depending on the composition of the waste, for example, household or construction waste, animal carcasses or hunting remains, or vehicle, furniture, appliance disposal near or in waterbodies. In addition, litter accumulation can also cause stream flow obstruction or alteration of the stream system, which would result in erosion of creek banks or impoundment of water.

### 1.4.1 Green Infrastructure

Vegetation, soils, and natural processes are used as green infrastructure to mitigate stormwater runoff. In undeveloped areas, these processes naturally absorb the water and filter out pollutants. Green infrastructure is promoted as a best management practice by the EPA. Green infrastructure not only provides stormwater pollution mitigation, but can also provide improved air quality, water resource preservation, and climate and public health protection (EPA, 2014) One BMP that can be implemented at a watershed wide, neighborhood wide, or even a small site scale could be to disconnect impervious cover that would allow for increased infiltration to mitigate water quality impacts to streams as well as allow for the reduction in velocity and volume of surface runoff. Another example of a BMP could be rainwater harvesting that involves disconnection or redirection of rain gutter downspouts to rain barrels and cisterns and using that for outdoor irrigation. This would mitigate stormwater pollution, reduce the volume of water entering the stream system, and conserve water supply.  Other examples include: Bioretention, bioswales, permeable pavers, planter boxes, green roofs, sand filters, cisterns, vegetated swales and vegetated filter strips, and stormwater wetlands.

In order to develop proper watershed management and watershed planning for improving water quality of impaired watershed in the United States, the first and essential step is to identify the sources and loadings of pollutants and propose reasonable actions to combat non-point source pollution.

## 1.5 Objectives of this Study

The main objectives of this study are to address water quality impairments and concerns, support the development of a watershed protection plan in Rowlett Creek (Jaber *et. al*, 2019) by characterizing water quality conditions across the watershed, and understand the sources and locations of pollutant loadings. This includes a full analysis of a heavily urbanized area in the DFW metroplex. Questions answered included how an urban creek behaves; how water quality of urban creeks are impacted by the high urbanization rates. To answer these questions, water quality and flow characteristics are analyzed in this urban watershed. The main water quality parameters of concern are *E. coli* and nutrients including nitrogen and phosphorus. The specific objectives are to collect surface water quality and flow data to supplement existing data for Rowlett Creek watershed characterization; to analyze quantitative and qualitative information regarding measurement data for quarterly grab samples; to estimate pollutant loads and reductions for current and future conditions; and to establish the cause-and-effect relationship between pollutant loads from the sources in the watershed and the response in the water body during current and future anticipated conditions.

Water quality samples are collected and analyzed for the parameters including flow, *Escherichia coli* (*E. coli*), total suspended solids (TSS), nitrate ($NO_3^-$), nitrite ($NO_2^-$), total Kjedahl nitrogen (TKN), ammonia as Nitrogen ($NH_3$), total phosphorus (TP), pH, specific conductance, dissolved oxygen (DO), and temperature. The sampling locations include Site 1 at the headwaters of Rowlett Creek and Site 5 at the outlet to Lake Ray Hubbard. Existing historical data of Rowlett Creek are acquired and used to assess the current conditions and document water quality trends of Rowlett Creek. Load Duration Curves (LDC) are prepared and used to determine the pollutant load for each parameter of interest and prioritization of areas of concern in the watershed in order to better identify best management practices. A watershed model developed by AgriLife (SWAT) is used to estimate daily streamflow. Data from the watershed model is used to develop load duration curves in order to determine pollutant loading. Existing and collected data are used to calibrate and validate the watershed model for streamflow.

# CHAPTER 2

# MATERIALS AND METHODS

## 2.1 Rowlett Creek Watershed

Rowlett Creek watershed is located within the East Fork Trinity River, subwatershed of the Trinity River watershed, as presented in *Figure 5*. The subwatersheds are identified in Figure 5 and ISCO automatic water quality sampling devices were located at the outlet of each subwatershed, five in total, for the project. Based on the access and location of subwatershed confluence with other streams, two (2) stream sites were selected within Rowlett Creek Watershed based on site access, stream bank characteristics, and similarity in geomorphology. The detailed information of two stream sites are summarized in Table 4. Two sites (site 1, head of Rowlett Creek, and site 5, outlet of Rowlett Creek) are sampled weekly, and five sites across Rowlett Creek are sampled quarterly.

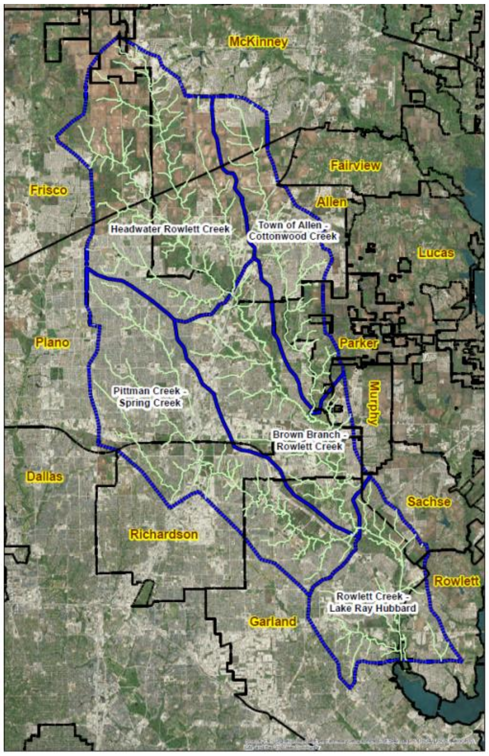

Figure 5 Rowlett Creek Watershed (CoP GIS Division)

Table 4 Original Sampling Locations

| | | | | | |
|---|---|---|---|---|---|
| Site 1 | Equipment Location | Headwater Rowlett Creek | 33.075623 | -96.687035 | Off Bluebonnet Trail in Plano (upstream of 75) |
| Site 2 | Equipment Location | Cottonwood Creek | 33.013925 | -96.640277 | in Pecan Hollow Golf Course near Hole 10 in Plano |
| Site 3 | Equipment Location | Brown Branch-Rowlett Creek | 32.965432 | -96.620853 | Off Golf Cart Path in Firewheel Golf Course in Garland off E brand RD |
| Site 4 | Equipment Location | Spring Creek | 32.954497 | -96.625544 | In Firewheel Golf Course downstream of PBGT tollway in |
| Site 5 | Equipment Location | Rowlett Creek -Lake Ray Hubbard | 32.929813 | -96.592312 | Downstream of Firewheel Pkw in Garland |

## 2.2 Rowlett Creek watershed sampling sites selection and characterization

### 2.2.1 Site Characterization

As presented in *Figure 6*, stream survey consisting of a cross-section and slope calculation were conducted to measure the characteristics of each site. Cross-section characterization methodology in summary required a level being set up at a location where the entire cross-section was visible. The level instrument was placed at a location above the highest point in the cross-section. The distance was then measured across the channel with surveyors’ tape and then stretched perpendicular to flow. Measurements were taken and values calculated. The cross-section data was used to support the results of the SWAT modeling.

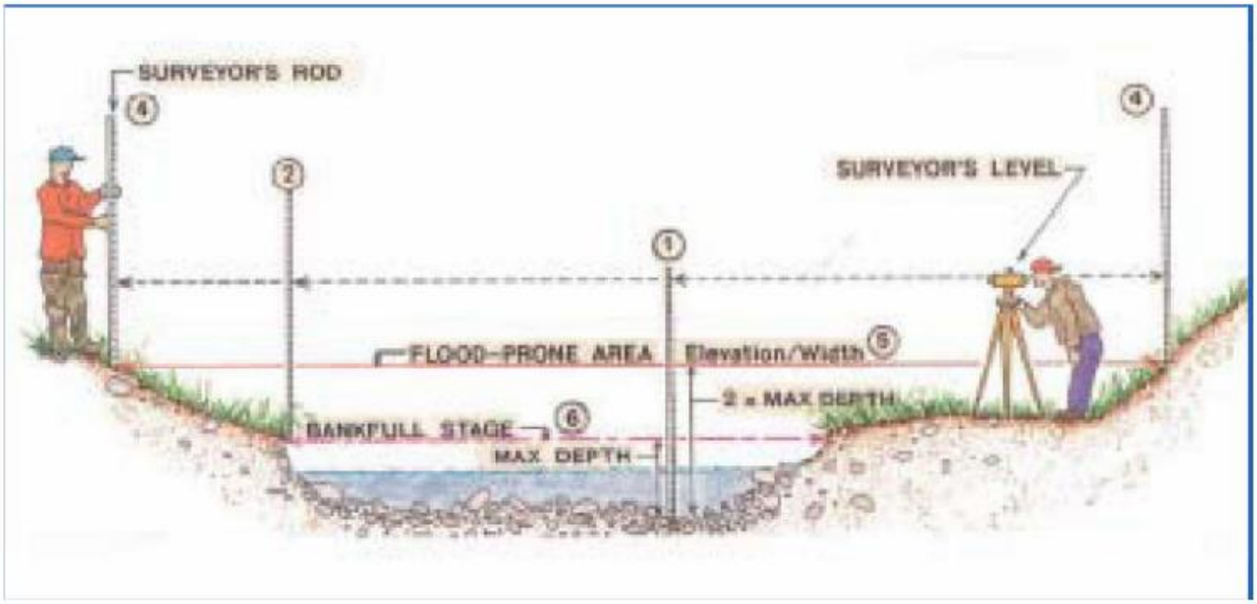

Figure 6 Texas A&M AgriLife Cross-section characterization methodology

### 2.2.2 Site Selection Criteria

Sites were selected based on the following criteria: safety, access to the stream, access to the centroid of flow, location of stream confluences, location of potential sources of pollution, and placement at downstream locations to maximize watershed capture. Specific site selection criteria for each site are detailed below.

Site 1 located at Rowlett Creek headwaters subwatershed off Bluebonnet Trail upstream of U.S. Highway 75 (33.075623, -96.687035).

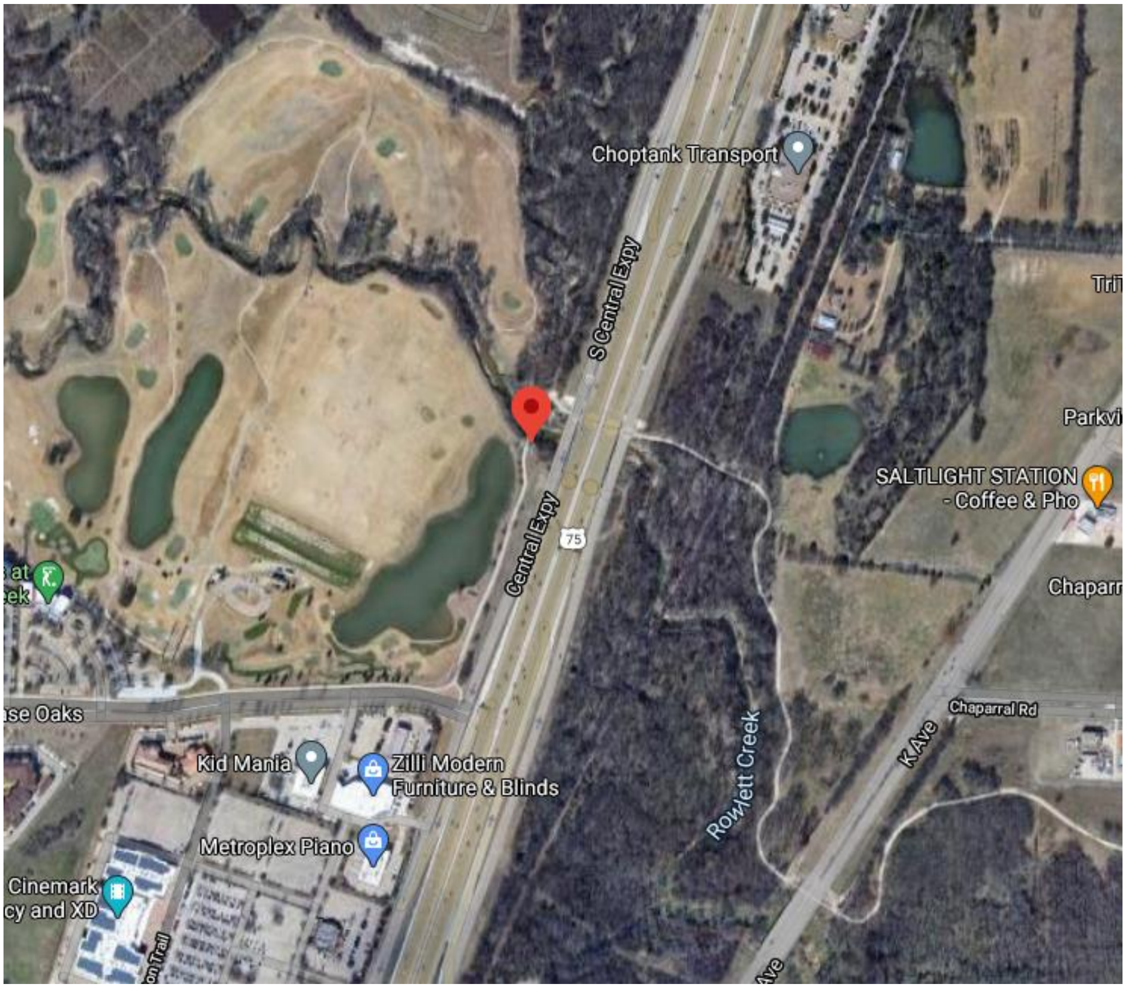

Figure 7 Site 1 on Rowlett Creek
(Google Maps 2021)

Site 5 is located at the most downstream point of Rowlett Creek prior to confluence with Lake Ray Hubbard, specifically downstream of Firewheel Parkway in Garland, TX (32.929813, -96.592312 )

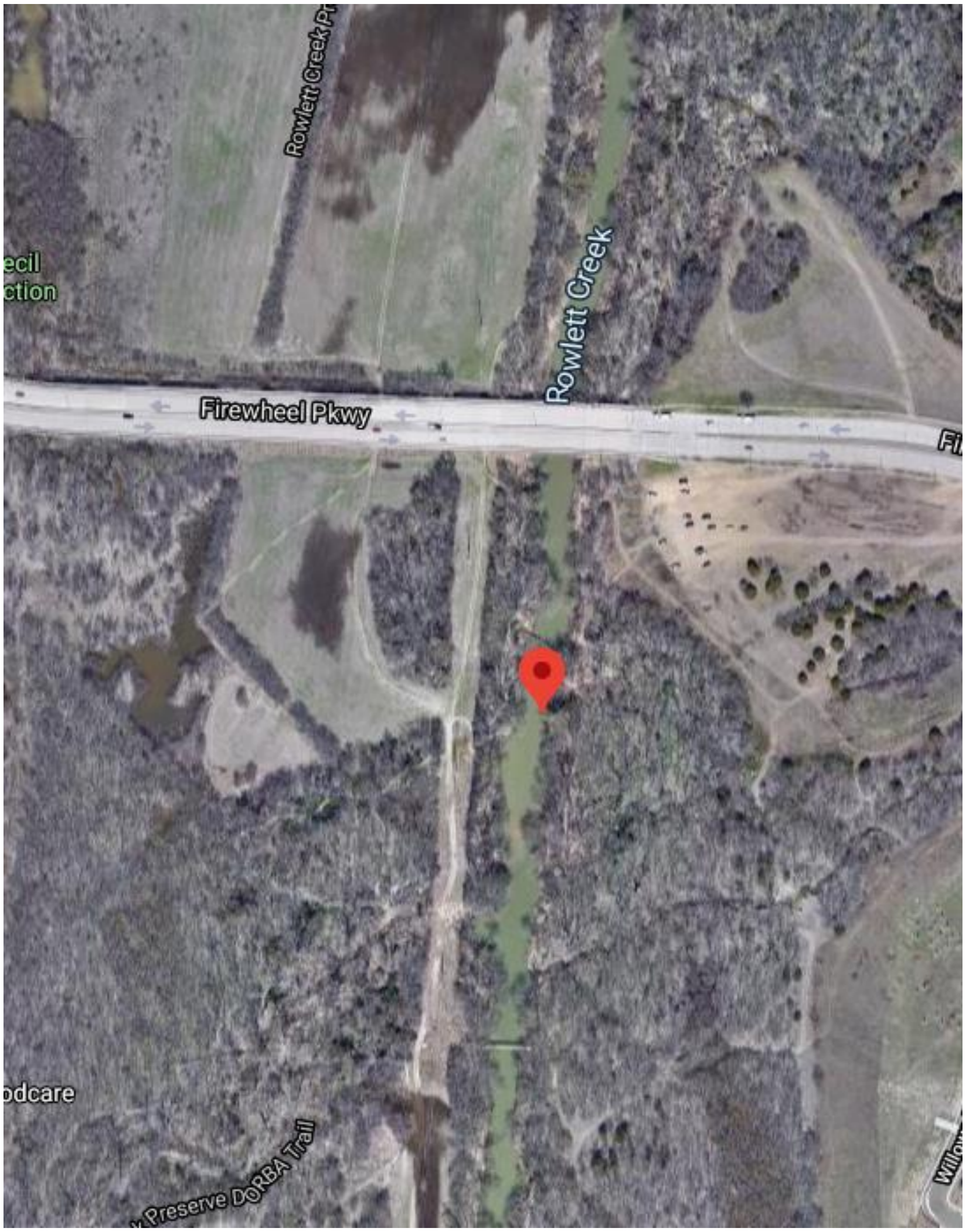

Figure 8 Site 5 on Rowlett Creek (Google Maps, 2021)

### 2.2.3 Water Quality Parameters Characterization

This study conducted water quality sampling and analysis for a large variety of water quality parameters (particularly for *E. coli*, $NO_2^-$, $NO_3^-$, TKN, TP, and TSS) in order to determine the technical information needed to ascertain impairment and build the subsequent Rowlett Creek WPP in the future. Field parameters collected and analyzed included pH, DO, conductivity, temperature, and flow using TCEQ SOP V1 (TCEQ, 2008). A detailed description of the analyses can be found in Table 11 and Table 12. Parameters were subsequently compared to Surface Water Quality Standards and Nutrient Screening Levels as outlined by TCEQ, as described in Table 5 and Table 6.

Table 5 Surface Water Quality Standards for Rowlett Creek AU 0820B

| Parameter | Criteria | Segment ID<br>0820B_01 | Corresponding Designated use |
|---|---|---|---|
| DO (mg/L) | Grab minimum | 3 | Aquatic Life |
| DO (mg/L) | Grab screening level | 4 | |
| pH range | | 6.5-9.0 | |
| Temperature (°F; °C) | | 95; 35 | |
| E. coli (MPN/100ml) | Geomean | 126 | Contact Recreation |

Table 6 Nutrient Screening Levels for Rowlett Creek AU 0820B

| Parameter | | TCEQ Screening Levels | | EPA Reference Criteria | | | | Other Sources |
|---|---|---|---|---|---|---|---|---|
| | | Lake/Reservoir | Stream | Lake/Reservoir | | Stream | | |
| TKN | mg/L | - | - | 0.38[a] | 0.41[b] | 0.3[a] | 0.4[b] | |
| $NO_2^-$ | mg/L | - | - | - | - | - | - | 0.02[c] |
| $NO_3$- | mg/L | 0.37 | 1.95 | - | - | - | - | |
| $NO_2^-+NO_3^-$ | mg/L | - | - | 0.017[a] | 0.01[b] | 0.125[a] | 0.078[b] | |
| TP | mg/L | 0.2 | 0.69 | 0.02[a] | 0.019[b] | 0.037[a] | 0.038[b] | |
| $NH_3$ | mg/L | 0.11 | 0.33 | - | - | - | - | |

(a) reference conditions for aggregate Ecoregion IX waterbodies, upper 25th percentile of data from all seasons, 1990-1999.

(b) reference conditions for level III Ecoregion 29 waterbodies, upper 25th percentile of data from all seasons

(c) for nitrate, concentrations above 0.002 mg/L (ppm) usually indicate polluted waters (Mesner, N., J. Geiger. 2010. Understanding Your Watershed: Nitrogen. Utah State University, Water Quality Extension.

### 2.2.4 Field Parameters

*Water Temperature*

Water temperature as a water quality parameter is an important indicator of health in an aquatic ecosystem. The temperature of water is directly associated with aquatic organisms physiological processes. Dissolved oxygen (DO) decreases in the water column as the temperature increases. This results in an increased oxygen demand by the aquatic community and subsequent stress on higher-level organisms. Further, rapid variations in water temperature are detrimental to aquatic species, especially for organisms that may lack the biological advantages of adapting quickly to the change.

*Dissolved Oxygen*

Dissolved Oxygen (DO) is a physiological requirement of aquatic communities. DO is influenced by both temperature and nutrient concentrations for example organic matter, albeit indirectly. The amount of DO in the water column is also impacted by decomposition processes and primary productivity.

#### *Specific Conductance*

Specific conductance is best described as the effectivity of a liquid conducting electricity and a standard temperature of 25°C. Specific conductance increases in a waterbody when ionic dissolved solids levels increase. Nutrients and salts make up ionic dissolved solids. Reduced water quality occurs when ionic dissolved solids, specifically nutrients, increase, salinity increases, and DO subsequently decreases.

#### *Potential Hydrogen (pH)*

A healthy aquatic waterbody falls within a pH range of 6.5 to 9.0 and is considered neutral if the pH is 7.0. Values less than 7.0 would classify the body as acidic whereas values greater than 7.0 would classify the waterbody as alkaline.

### 2.2.5 Flow Measurement

#### *Flow Method*

In order to calculate bacteria and nutrient loads in the watershed, streamflow measurements are needed (Meals and Dressing, 2008). Non-point source pollutants are all driven by runoff and subsequently streamflows that generate, transport and deliver the pollutants downstream. Instantaneous streamflow measurement is the TCEQ preferred method, however the use of U.S. Geological Survey (USGS) Flow-Gauging Station and calibration and validation of a hydrologic model are also accepted methods by the TCEQ.

### 2.2.6 *E. coli* as Bacteria Indicator

*E. coli* is a bacterium found in the intestines of humans and warm-blooded animals and humans. If the waste is excreted in the open then, during a rain event, it can be picked up by stormwater runoff and be either channeled into surface water and/or ground water or directly deposited into the waterbody. If *E. coli* is found at high concentration in waterbodies it could indicate, for example, the presence of wildlife and livestock in the watershed, illicit wastewater connections and subsequent discharges, and improperly treated wastewater for example sanitary sewer overflows and poorly maintained onsite sewage facilities (septic). Depending on the strain, toxins may be produced and will cause illness on ingestion. Waterbodies are defined by their ability to host recreational activities and are based on levels of *E. coli.* The U.S. EPA has designated a standard *E. coli* concentration based on the geometric mean of a certain number of samples because the concentration can vary by orders of magnitude. The method for detection of *E. coli* is used as a proxy for the possibility of human illness when humans are recreating in water. The higher the concentration of *E. coli* the greater the possibility that there will be more toxic *E. coli* strains, other bacteria or viruses that can be ingested while swimming, wading or boating in waterbodies.

### 2.2.7 Conventional Parameters

#### *Solids*

Total suspended solids (TSS) are suspended particles in a water column that, when sampled, are not capable of passing through a specific pore sized filter. Solids are made up of organic matter that can include algal, bacterial cells or organisms as well as inorganic matter that includes soil sediments due to erosion.

#### *Nutrients*

Nitrogen and phosphorus are limiting nutrients in the aquatic environment. They are essential, but can also cause detrimental effects in riverine and reservoir ecosystems if found in overabundance. Stormwater runoff carries residential and agricultural fertilizers that are full of nutrients. Runoff can also carry animal waste and pollutants from sanitary sewer overflows. Further, WWTP effluent is a large contributor of nutrients to waterbodies.  Total nitrogen is composed of nitrate, nitrite and total Kjedahl nitrogen (TKN). Nitrate is very abundant as an inorganic, oxidized form of nitrogen and nitrite is not as common as an inorganic, oxidized form of nitrogen. TKN contains organic nitrogen and ammonia, the inorganic form of reduced nitrogen. Total phosphorus (TP) is a parameter used to analyze a water sample for all forms of phosphorus. Forms of phosphorus include organic and inorganic forms as well as dissolved and particulate forms.

## 2.3 Rowlett Creek Watershed Existing Data Collection and Modeling

This section summarizes the sources of existing data, quality control of data and modeling methodology.

### 2.3.1 Existing Data

Existing data were compiled from the databases created by the City of Plano (CoP), North Central Texas Council of Governments (NCTCOG), and Trinity River Authority Clean Rivers Program (TRA CRP).  All the data were reviewed and quality assured to satisfy the data and information needed for this project. The collection and qualification of the TRA CRP data and the CoP data were addressed in the TCEQ SWQM QAPP (Kilpatrick, 2021). The collection and qualification of the NCTCOG data were addressed in the Regional Stormwater Monitoring Program: Monitoring Program and Quality Assurance Project Plan for Wet Weather Equipment Deployment and Sampling Protocol 2011-2015 approved by TCEQ (Atkins, 2016). The sources of monitoring data are summarized in  Table 7.

Table 7 Sources of Monitoring Data

| Data Type | Monitoring Project/Program | Collecting Entity | Dates of Collection | QA Information | Data Use(s) |
|---|---|---|---|---|---|
| Bacteria (*E.coli*) | TCEQ SWQM Program | TCEQ | 11/8/2006 – 07/25/2017 at station numbers 17845 10765 21478 10759 10753 | TCEQ SWQM QAPP; SWQMIS database | summary statistics, trend analysis |
| Monitoring Data (Field measurements: Temperature, dissolved oxygen, pH, specific conductance) | TCEQ SWQM Program | TCEQ | 12/27/1984 10/1/1995 and 6/31/1996 - 05/15/2018 at station numbers 17845 10765 21478 10759 10753 | TCEQ SWQM QAPP; SWQMIS database | summary statistics, trend analysis |
| Flow Data | United States Geological Survey (USGS) flow data and TCEQ SWQM Program | USGS and TCEQ | For the period of record collected by the USGS at station no. 08061540 and TCEQ station numbers 17845 10765 21478 10759 10753 | USGS QAPP; USGA database; TCEQ SWQM QAPP; SWQMIS database | Flow duration curves, Loading calculations; summary statistics, trend analysis |
| Precipitation Data | National Weather Service (NWS) | NWS | Most up-to-date precipitation data will be downloaded from the NWS website following storm events. | NWS Website | Loading calculations and extrapolation analysis |
| Precipitation Data | City of Plano | City of Plano | Up-to-date data will be provided by the City of Plano | Plano database | Loading calculations and extrapolation analysis |

### 2.3.2 Modeling Methodology

This study used the Soil and Water Assessment Tool model (TAMU, 2012), which has been widely used for watershed simulation and modeling subwatersheds, specifically hydrologic response units that consist of land use, soil type, and slope within the given subwatershed. The major model components include weather, hydrology, soil properties, plant growth, nutrients and sediment loading, microorganisms, and land management (Gassman et. al, 2007). In this specific study, AgriLife pulled daily stream flow data from USGS 08061540 Rowlett Ck nr Sachse, TX station, calibrated and validated the SWAT model using data obtained from USGS including elevation and land use and soils data from NRCS, then ran the model for years 1980 to 2020 and obtained daily flows for Site 1 and Site 5. In some instances, low flows were modeled as 0 flows in the model, thereby requiring, for these dates, an average percentage of USGS station for each site location. More specifically, for each subwatershed calculated, the summation of each subwatershed was subsequently individually divided by Site 5 total daily flow. This was converted to a percentage. The zero values that represented low flows were replaced with the percentage of Site 5. The SWAT model produced flows that were used in load duration curve (LDC) development (personal communication, Partheeban & Jaber, 2021).

### 2.3.3 Flow and Load Duration Curves

Flow duration curves (FDC) and load duration curves (LDC) are not specific models, but data calculators. The calculation of flow and load duration curve graphs have been shown to be an effective method for determining load reductions (Cleland, 2003). A duration curve is a graph that displays a given parameter’s value that has been met or exceeded related to the percent of time. Percent of time is scaled ranging between 0 and 100. For example, Figure 9 displays an FDC using a hydrograph of observed stream flows in order to calculate and express the percentage of time the flows are exceeded or equaled. Figure 10 shows an LDC displaying the relationship between the loadings and stream flow conditions. Pollutant loadings, point sources or non-point sources, for example are displayed to enable the determination of patterns depending on the conditions of stream flow. BMPs and implementation strategies can be determined based on the observed pattern in order to direct focus on a specific pollutant source. Figure 10 displays exceedances of allowable loads at low flows and thus could allow focus on point sources. In addition, LDCs can be used as a method to evaluate current impairments in order to narrow the focus to non-point source or point source pollution.

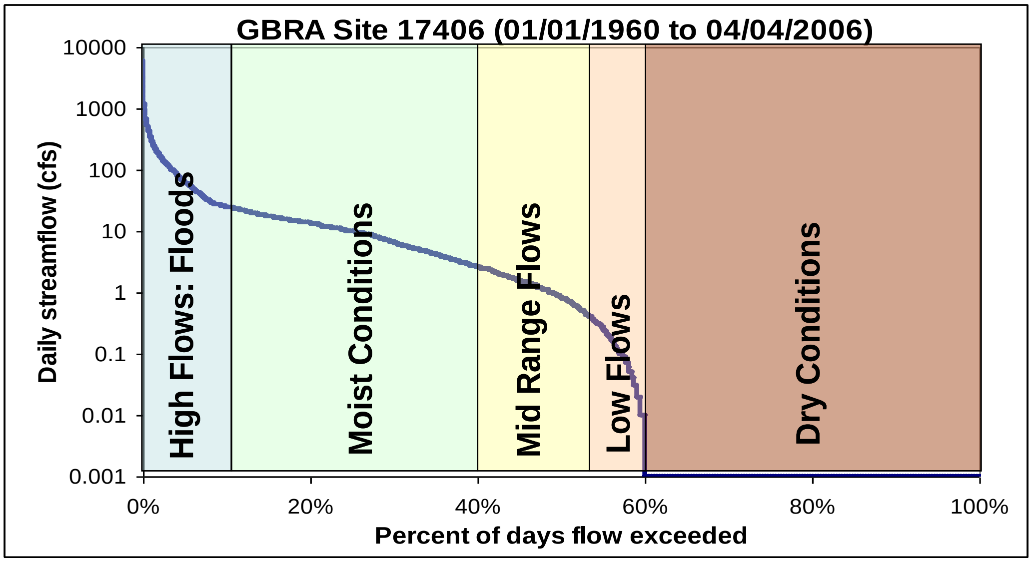

*Figure 9 Example of Flow Duration Curve*

*Source: Flow Duration Curve (FDC) for streamflow conditions at GBRA monitoring station 17406 on Plum Creek, near Uhland, TX. The flow data at 17406 was obtained from the nearest USGS gage station 8172400, after adjusting for subwatershed aerial contribution during runoff events.*

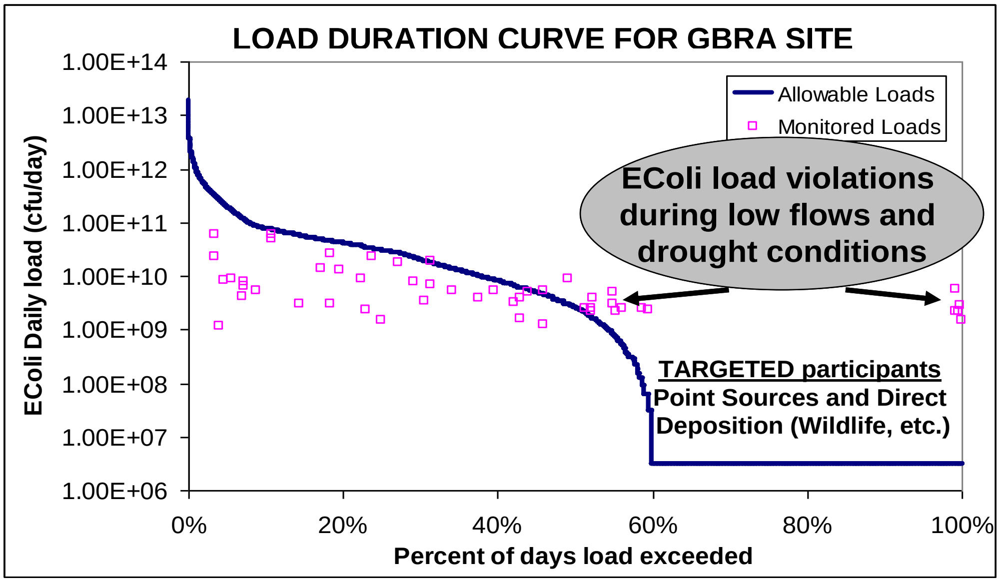

*Figure 10 Example Load Duration Curve*

*Source: Load Duration Curve for E. coli at GBRA monitoring station 17406 on Plum Creek, near Uhland, TX. The flow data at 17406 was obtained from the nearest USGS gage station 8172400, after adjusting for subwatershed aerial contribution during runoff events.*

### 2.3.4 Development of FDC and LDC Curves

Flow duration curves (FDC) demonstrate the flows of streams and rivers by predicting the frequency with which flows of various sizes will occur. They are also necessary in the development of load duration curves, which can effectively demonstrate the relative loadings of constituents from different tributaries (Cleland, 2003). The first step in developing FDCs and LDCs is to estimate continuous daily streamflows spanning multiple years at tributary sites in Rowlett Creek Watershed. Estimates of streamflow data for all tributary locations were derived using an existing US Geological Survey (USGS) record from USGS 08061540 Rowlett Ck nr Sachse, TX near Site 5. The records from this gauge were then modeled to adjust for upstream flows for the contributing subwatershed to Site 5. FDCs indicate the percentage of time during which a certain value of flow is equaled or exceeded. The estimated streamflows span years January 1980 to December 2020. A flow exceedance of less than 10% typically indicates that the stream flows are directly impacted by storm runoff events (Cleland, 2003). Daily average discharge rates are downloaded from the nearest the USGS station and sorted from highest cubic feet per second (cfs) to lowest cfs. The percentage or flow duration interval is determined by associating zero with the highest stream discharge and 100 with the lowest stream discharge. Five zones are then established on the graph identifying high flows as 0-10%, moist conditions as 10-40%, mid-range flows as 40-60%, dry conditions as 60-90%, and low flows as 90-100%.

## 2.4 Rowlett Creek Watershed Sampling Criteria and Analysis

### 2.4.1 Overview

Two stream sites were selected based on the headwaters of Rowlett Creek (site 1) and output to Lake Ray Hubbard (site 5) within Rowlett Creek Watershed, site access, stream bank characteristics, and similarity in geomorphology. Teledyne ISCO Model 6712 automated water samplers (Lincoln, NE) were used to collect routine grab water samples weekly, from a fixed sampling location. Instantaneous field measurements are also collected. The grab samples were collected and taken to the NTMWD's environmental lab for the analysis of TSS, *E. coli*, nitrate, nitrite, TKN, ammonia and total phosphorus immediately following fieldwork on a quarterly basis or to Southern Methodist University's environmental lab on a weekly basis. The parameters are listed in Table 8. All parameters for SMU were collected in 1 Liter Nalgene bottles. NTMWD analysis can be found in more detail in Table 10 and samples were collected in multiple bottles based on EPA standard methods.

Table 8 SMU Parameter Analysis

| Parameter | Matrix | Container | Preservation*** | Sample Volume | Holding Time |
|---|---|---|---|---|---|
| TSS | water | plastic | Cool to 4°C | 1 L | 7 days |
| *E. coli* | water | plastic | Cool to 4°C | 1 L | 6 + 2 hours* |
| Nitrate + nitrite-N | water | plastic | Cool to 4°C, | 1 L | 28 days** |
| Ammonia | water | plastic | Cool to 4°C | 1 L | 28 days** |

**E.coli* samples analyzed by SM 9223-B should always be processed as soon as possible and within 8 hours. When transport conditions necessitate delays in delivery longer than 6 hours, the holding time may be extended and samples must be processed as soon as possible and within 24 hours since the nature of this project is research and not regulatory.

**Nutrient samples will be preserved after filtration and stored in cold room.

### 2.4.2 Sampling Process Design

The sampling of all pertinent media was conducted according to TCEQ SWQM Procedures Vol. 1 and only approved analytical methods were used to assure that the measurement data represented the conditions at the sites. Routine monitoring conducted with the intent to collect data for water quality assessment are considered to be spatially and temporally representative of routine water quality conditions, were collected on a routine frequency, and the monitoring events were separated by approximately even time intervals. At a minimum, samples were collected over at least two seasons (to include inter-seasonal variation) and include some data collected during an index period (March 15- October 15). Although data may be collected during varying regimes of weather and flow, the data sets were not biased toward unusual conditions of flow, runoff, or season (Jaber *et. al*, 2019). The overview of the water quality monitoring plan is outlined in Table 9.

Samplers are physically located above the visible high-water mark and set back from the stream as much as 40 feet to reduce potential for floodwaters to disturb the instrument set up. Surface water grab samples were collected weekly at the two sites. Grab samples were collected at Site 1 and Site 5. Automated sampler was manually activated to grab sample from creek. The ISCO bubbler and suction tubing were placed in the center of the stream where possible. On sites where the water was inaccessible due to the depth of the river, the bubbler tubing and suction lines were placed at the farthest accessible point from the bank. The position of the lines was placed on the surveyed cross section of the stream to accurately calculate the flow rate at each site. The flow rate during the grab sample was recorded from the ISCO screen at that moment. Upon sampling initiation, the sampler ran the pump in reverse to purge the suction line and strainer, it then rinsed the line with ambient stream water and purged it again prior to sample collection.

Collected samples in 1-L ISCO bottles were poured into 1-L Nalgene bottles previously washed and rinsed with DI water for transport to SMU. In addition, water quality data (pH, temperature, conductivity, and dissolved oxygen) were measured in situ using a YSI 63 (pH, Specific Conductance, and Temperature) and a YSI ProOBOD (DO) when retrieval of routine water samples occurred.  The probes were calibrated per SWQM procedures. Bubbler depth readings were adjusted as needed. Samples collected for TSS, *E. coli*, nitrate and nitrite, TKN, ammonia and TP analysis were transported to SMU weekly or sent to the NTMWD lab within the same day quarterly.

In addition, the samplers also recorded the depth using ISCO Model 730 bubbler flow modules. We obtained depth data form the ISCOs and used the SWAT model to convert the depth data into flow. Flow rate estimates and total flow volume were reported for routine events.

Table 9 Overview of water quality monitoring plan

| Stream Section | Sample Type | Start Date | End Date | Monitoring Frequencies | Parameters Measured |
|---|---|---|---|---|---|
| (Site 1) | Grab Sample | March 2020 | December 2020 | Weekly | pH, Specific Conductance, DO, TSS, Depth, Temperature, *E.coli*, Nitrate + nitrite, Ammonia, TKN and Total phosphorus |
| (Site 5) | Grab Sample | March 2020 | December 2020 | Weekly | pH, Specific Conductance, DO, TSS, Depth, Temperature, *E.coli*, Nitrate + nitrite, Ammonia, TKN and Total phosphorus |

### 2.4.3 Sampling Methods

*Field Sampling Procedures*

All the sampling procedures followed the basic rules for recording information. Loose-leaf field notes and field forms were recorded legibly in indelible ink (preferred) or pencil with no erasures, modifications, write-overs, or multi-line cross-outs. Bound field notes and forms and in-house field and lab records (multiprobe calibration logs, bench logs, etc.,) were recorded in indelible ink with no modifications, write-overs or multi-line cross-outs. Errors were corrected with a single line-through followed by initials and a date. Incomplete pages were closed out with an initialed and dated diagonal line (Jaber et. al, 2019).

The samples were collected using a Teledyne ISCO® 6712 full-size portable sampler with 24-bottle configuration and collected weekly. A Teledyne ISCO® 730 Bubbler Flow Module was attached to each automated sampler to determine the water depth in the stream by measuring the pressure needed to force air bubbles out of the line. Upon sampling initiation, the sampler ran the pump in reverse to purge the suction line and strainer, and then rinsed the line with ambient stream water and purge it again prior to sample collection. To prevent cross-contamination, composite subsamples were transferred directly from the filled composite container into 1-L sterile plastic bottles.

Grab samples were collected in 1-L sterile, plastic bottles provided by the lab and AgriLife (Table 8 for SMU and Table 10 for NTMWD for specific containers used for analysis). Composite samples were collected in clean polyethylene 1-L sampler bottles. Composite subsamples were transferred directly into a sterile 5-gallon container and then into 1-L sterile, plastic bottles provided by the lab and AgriLife. The water in the 5-gallon container was thoroughly mixed with a sterile plastic rod immediately prior to filling the 1-L bottles to ensure homogeneity. The automated water sampler bottles were cleaned according to TCEQ SWQM

Procedures Volume 1: Physical and Chemical Monitoring Methods for Water, Sediment and Tissue (August 2012). Field QC samples were collected to verify that cross-contamination has not occurred.

The composite samples were kept on ice onsite to ensure the preservation temperature ⩽ 4 °C. Samples were delivered within 6 hours (when transport conditions allowed) after the first sample was collected and transported on ice to the lab in time to complete *E. coli* analysis within 8 hours of first sample collection (and within 24 hours regardless of transport conditions), and were analyzed for TSS, *E. coli*, total phosphorus, nitrate and nitrite, ammonia, and TKN analysis. Additionally, following each sample collection, each 1-L bottle was replaced with a clean bottle that has been washed with dilute soapy (P-free) water, rinsed three times with tap water and three times with DI water, air dried upside down and on its side to allow complete drying and finally, capped when completely dry.

Water temperature, pH, specific conductance, and dissolved oxygen were measured and recorded in situ with YSI probes when weekly grab samples were collected. Surface water grab samples were collected using 4 1-L sterile, plastic containers provided by the lab for routine sampling. The samples collected were transported to the lab for analysis. All samples were transported in a container with cubed ice to the laboratory for analysis.

### *Field Parameters*

#### ***Water Temperature, Specific Conductance and Potential Hydrogen (pH)***

Water temperature, pH, and specific conductance in water samples were measured immediately and recorded in situ in aplastic bottle using a YSI 63 probe after samples were collected. The pH and specific conductance sensors were calibrated each day of use. The readings on the sensors were allowed to equilibrate for at least 2 minutes before recording. The water temperature data was recorded to the nearest tenth of a degree Celsius. Specific conductance measurements are recorded in microsiemens per centimeter (µS/cm).

### ***Dissolved Oxygen***

The DO was measured using a YSI ProOBOD, which was calibrated each day of use. The DO sensor was allowed to equilibrate for at least 2 minutes before recording. The DO data was recorded to the nearest tenth of a mg/L.

### *Flow Measurement*

### ***Flow Method***

In order to calculate bacteria and nutrient loads in the watershed, streamflow measurements are needed at all routine freshwater stream monitoring sites (Meals and Dressing, 2008). Non-point source pollutants are all driven by runoff and subsequently streamflow that generate, transport and deliver the pollutants downstream. Instantaneous streamflow measurement is the TCEQ preferred method, however the use of U.S. Geological Survey (USGS) Flow-Gauging Station and calibration and validation of a hydrologic model are also accepted methods by the TCEQ.

Flow values were reported in cubic feet per second (ft3 /s) under TCEQ parameter code 00061.

### 2.4.4 Sample Handling and Custody

### ***Sample Labeling***

Samples from the field were labeled on the container with an indelible marker. Label information includes the site identification and station ID, the date and time of the sample collection, the type of preservative added, if applicable, and the type of analysis to be performed.

### ***Sample Handling***

TSS, *E. coli*, total phosphorus, ammonia, nitrite and nitrate samples for weekly events were collected and labeled in the field before being placed on ice for transport to the lab, accompanied by the chain of custody form. The holding time for TSS samples was 7 days. The holding time for *E. coli* was 24 hours. The holding time for total phosphorus and nitrate was 28 days after preservation with sulfuric acid ($H_2SO_4$). However, the samples arrived at the NTMWD lab and/or SMU lab the same day of sampling. After receipt at the NTMWD lab and/or SMU lab, the samples were stored in the refrigeration unit or analyzed immediately. Only authorized NTMWD laboratory personnel or SMU graduate student handled samples received by the laboratory.

### 2.4.5 SMU Sampling Analysis

#### *E. coli*

The following information comes from Weber Scientific protocol. Coliscan™ Easygel medium is used to cultivate E. coli on the plate and to count E. coli from water samples. Coliscan ™ Easygel Media incorporates a "patented combination of color-producing chemicals and nutrients that mark coliforms and *E. coli* in differing colors for easy identification and isolation" (Weber Scientific, 2021). In order to analyze *E.coli* colonies, water is added to the provided medium from Weber Scientific. Once incubated for 48 hours, *E.coli* colonies will grow as purple-blue colonies, coliform bacteria (not analyzed) will grow as pink-magenta colonies and other types will grow as non or white colored colonies. Coliscan™ Easygel medium was thawed prior to plating. 1 mL of water sample was added directly into the bottle of Coliscan™ Easygel media, swirled, poured into a pretreated petri dish. The media was solidified for 45 minutes and incubated for 24-28 hours in order to form. *E. coli* colonies are counted in the Lab-Aids®, Inc. Colony Counter. Only the individual dark blue or purple colonies on the Coliscan™ petri dish (disregarding any light blue, blue-green or white colonies) were counted as *E. coli* colonies. Finally, the *E. coli* colonies were reported as number of *E. coli* per 100 mL water sample under warm conditions (32 - 37°C).

### *Analysis of ammonia, nitrite, nitrate, and phosphate*

All water samples were filtered with membrane filters (0.45 um at 47 mm) before further analysis of ammonia, nitrite, nitrate, and phosphate. Thermo Scientific™ Orion™ high-performance ammonia electrode was used to determine the ammonia concentrations in the water samples. The instrument was calibrated using Thermo Scientific Orion application solution ammonia containing 1 mL of ammonia pH adjusting ISA standard before use. The water samples were also mixed with 1 mL of Ammonia pH adjusting ISA before measurement, and the ammonia concentration was calculated based on the standard calibration curve.

The anions of nitrite, nitrate and phosphate in water samples were analyzed by a suppressed conductivity ion chromatography (IC) using a Dionex Aquion IC system equipped with a Dionex IonPac AS22 analytical column (4 mm x 250 mm) and an AG22 guard column (4 mm x 50 mm). During each injection, carbonate (4.5 mM)/bicarbonate (1.4 mM) was used in the effluent solution for 20 minutes. The operational conditions included flow rate at 1.2 mL/minute with suppresser current at 31 mA under 30 ˚C.

### 2.4.5 NTMWD Sampling Analysis

North Texas Municipal Water District (NTMWD) has an accredited environmental laboratory through the National Environmental Laboratory Accreditation Program. All sampling procedures are approved by the EPA, established as an EPA standard, and listed in the TCEQ manual. Sample volume, container types, minimum sample volume, preservation requirements, and holding time requirements for each analytical parameter are given in Table 10, Table 11 and Table 12. Preservation of all samples was performed in the field immediately upon collection.

Table 10 NTMWD Water Quality Sample Storage, Preservation, and Handling Requirements

| Parameter | Matrix | Container | Preservation*** | Sample Volume | Holding Time |
|---|---|---|---|---|---|
| TSS | water | plastic | Cool to 4°C | 200 mL(2) | 7 days |
| *E. coli* IDEXX | water | plastic | Cool to 4°C | 120 mL | 6 + 2 hours* |
| Nitrate + nitrite-N | water | plastic | Cool to 4°C,<br>$H_2SO_4$ to pH <2 | 100 mL(3) | 28 days** |
| Phosphorus, total | water | plastic | Cool to 4°C<br>$H_2S0_4$ to pH <2 | 250 mL(3) | 28 days** |

**E.coli* samples analyzed by SM 9223-B should always be processed as soon as possible and within 8 hours. When transport conditions necessitate delays in delivery longer than 6 hours, the holding time may be extended and samples must be processed as soon as possible and within 24 hours since the nature of this project is research and not regulatory.
**Nutrient samples will be preserved within 60 minutes of the last collection

Table 11 NTMWD Measurement Performance Specifications for Characterization of Rowlett Creek Monitoring, Parameters in Water

| Parameter | Units | Method | Parameter Code | TCEQ AWRL | LOQ | LOQ Check Sample %Rec | Precision (RPD of LCS/LCSD) | Bias % Rec. of LCS | Lab | Completeness % |
|---|---|---|---|---|---|---|---|---|---|---|
| Field Parameters | | | | | | | | | | |
| pH (standard units), Field determined | s.u. | EPA 150.1 and TCEQ SOP, V1 | 00400 | NA | NA | NA | NA | NA | Field | 90 |
| Oxygen, dissolved (mg/L) (Field determined, actual reading from instrument) | mg/L | SM4500 O-G/TCEQ SOP, V1 | 00300 | NA | NA | NA | NA | NA | Field | 90 |
| Specific conductance, Field (us/cm @ 25C) | uS/cm | EPA 120.1/TCEQ SOP, V1 | 00094 | NA | NA | NA | NA | NA | Field | 90 |
| Temperature, Water Field determined, (Degrees Centigrade) | deg. C | SM2550B/TCEQ SOP, V1 | 00010 | NA | NA | NA | NA | NA | Field | 90 |
| Flow volume for duration of storm event | gallons | TCEQ SOP, V1 | 50052 | NA | NA | NA | NA | NA | Field | 90 |
| Total water depth | m | TCEQ SOP, V1 | 82903 | NA | NA | NA | NA | NA | Field | 90 |
| Flow (CFS) | CFS | TCEQ SOP, V1 | 00061 | NA | NA | NA | NA | NA | Field | 90 |

Table 12 NTMWD Measurement Performance Specifications for Characterization of Rowlett Creek Monitoring, Parameters in Water (Cont.)

| Parameter | Units | Method | Parameter Code | TCEQ AWRL | LOQ | LOQ Check Sample %Rec | Precision (RPD of L CS/LCSD) | Bias % Rec. of LCS | Lab | Completeness % |
|---|---|---|---|---|---|---|---|---|---|---|
| Conventional Parameters | | | | | | | | | | |
| *E.coli*, Colilert, IDEXX , Holding time, | hours | NA | 31704 | NA | NA | NA | NA | NA | NTMWD** | 90 |
| Residue, Total Nonfilterable (mg/L) | mg/L | SM 2540D | 00530 | 5 | 1* | NA | NA | NA | NTMWD** | 90 |
| Nitrite plus nitrate, Total one lab determined value (mg/L as N) | mg/L | EPA 353.2 | 00630 | .05 | .05 | 70-130 | 20 | 80-120 | NTMWD ** | 90 |
| Phosphorus, total, wet method (mg/L as P) | mg/L | EPA 365.3 | 00665 | .06 | .05 | 70-130 | 20 | 80-120 | NTMWD** | 90 |
| *E.coli*, Colilert, IDEXX Method, MPN/100ml | mpn / 100ml | Colilert Quanti-Tray | 31699 | 1 | 1 | NA | 0.5*** | NA | NTMWD** | 90 |
| Nitrogen, Kjeldahl, Total (mg/L as N) | mg/L | EPA 351.2 | 00625 | 0.2 | 0.2 | 70-130 | 20 | 80-120 | NTMWD** | 90 |
| Nitrogen, Ammonia, Total (mg/L as N) | mg/L | EPA 350.1 | 00610 | 0.1 | 0.1 | 70-130 | 20 | 80-120 | NTMWD** | 90 |

*TSS LOQ is based on the volume of sample used.
**The lab is TNI-accredited for the total nonfilterable residue, *E.coli*, nitrate and phosphorous procedures.

References:

United States Environmental Protection Agency (USEPA) Methods for Chemical Analysis of Water and Wastes, Manual #EPA-600/4-79-020
American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF), Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1998. (Note: The 21st edition may be cited if it becomes available.)
TCEQ SOP, V1 - TCEQ Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods, 2012 (RG-415).
TCEQ SOP, V2 - TCEQ Surface Water Quality Monitoring Procedures, Volume 2: Methods for Collecting and Analyzing Biological Assemblage and Habitat Data, 2014 (RG-416).

*** *E.coli* samples analyzed by IDEXX Colilert Quanti-Tray should always be processed as soon as possible and within 8 hours. When transport conditions necessitate delays in delivery longer than 6 hours, the holding time may be extended and samples must be processed as soon as possible and within 24 hours. This value is not expressed as a relative percent difference. It represents the maximum allowable difference between the logarithm of the sample result and the logarithm of the duplicate result.

# CHAPTER 3

# RESEARCH RESULTS AND DISCUSSION

## 3.1 Flow Duration Curve

Estimates of streamflow data for all tributary locations were derived using an existing US Geological Survey (USGS) record from USGS 08061540 Rowlett Ck nr Sachse, TX near Site 5. The records from this gauge were then modeled to adjust for upstream flows for the contributing subwatershed to Site 5. FDCs indicate the percentage of time during which a certain value of flow is equaled or exceeded. The estimated streamflow's span months (January 1980 to December 2020). A flow exceedance of less than 10% typically indicates that the stream flows are directly impacted by storm runoff events (Cleland, 2003). Site 5 is the most downstream point prior to entering Lake Ray Hubbard and is the largest subwatershed, it receives inflow from the Rowlett Creek WWTP in Plano as well as multiple tributaries. Flow never drops below 3 cubic feet per second at Site 5. Site 1 is located upstream at the point where all headwaters converge to form Rowlett Creek.

As shown in Figure 11, the flow duration curve was presented to show the percentage of time during which a certain value of flow is equaled or exceeded at site 1 and site 5. Specifically, the curve shows combined flow characteristics of a stream over the range of the discharge. For example, High Flows are generally associated with 20 to 100 year storms and are only expected to occur 0 to 10% of the time. Low Flows are flows that are expected to occur or to be naturally flowing in the stream 95% of the time.  Figure 12 and Figure 13 show the breakout FDCs for Site 1 and Site 5 respectively. In Figure 11 the blue line is Site 5 flow duration curve and the orange line is Site 1 flow duration curve. The vertical bars represent 10%, 40%, 60%, and 90%. From 0-10% High Flow conditions exist, 10%-40% Moist Conditions, 40%-60% Mid-Range Conditions, 60%-90% Dry Conditions, and 90%-100% Low Flow conditions. The results from Figure 11 confirm that the headwaters did have a significant contribution to the watershed, but that there was a greater amount of flow contribution between the headwaters and the output to Lake Ray Hubbard.

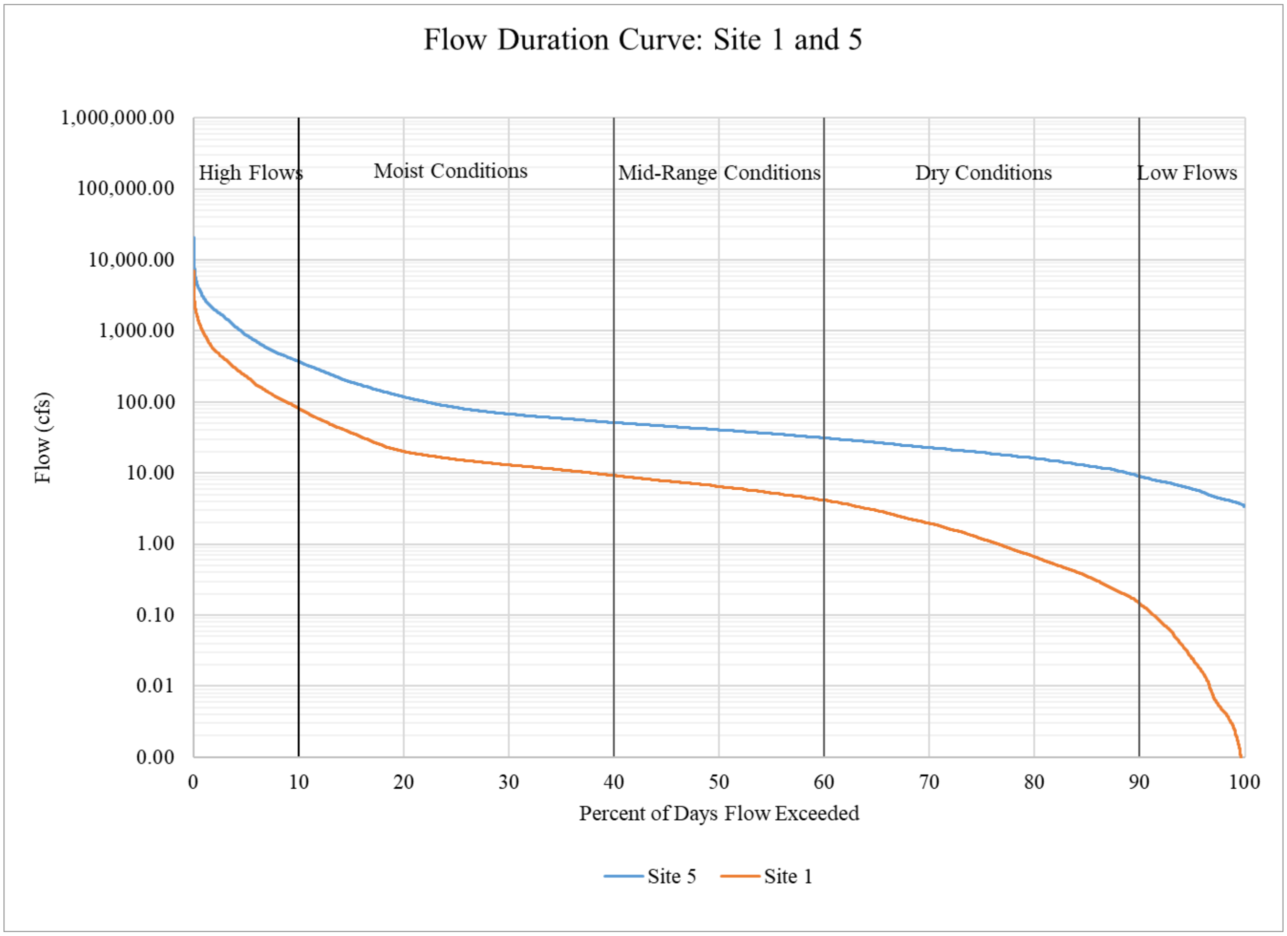

Figure 11 Flow Duration Curve comparing Site 1 and Site 5

In the Breakout FDC of Site 1, Figure 12, the blue line is the flow duration curve. The vertical bars represent 10%, 40%, 60%, and 90%. From 0-10% High Flow conditions exist, 10%-40% Moist Conditions, 40%-60% Mid-Range Conditions, 60%-90% Dry Conditions, and 90%-100% Low Flow conditions. The 5% percentile of High Flow is 229 cubic feet per second (cfs). The 25% percentile of Moist conditions is 15.49 cfs. The 50% percentile of Mid-Range conditions is

6.49 cfs. In Dry Conditions, flow is 1.18 cfs 75% of the time. Finally during Low Flows, flow is 0.025 cfs 95% of the time.

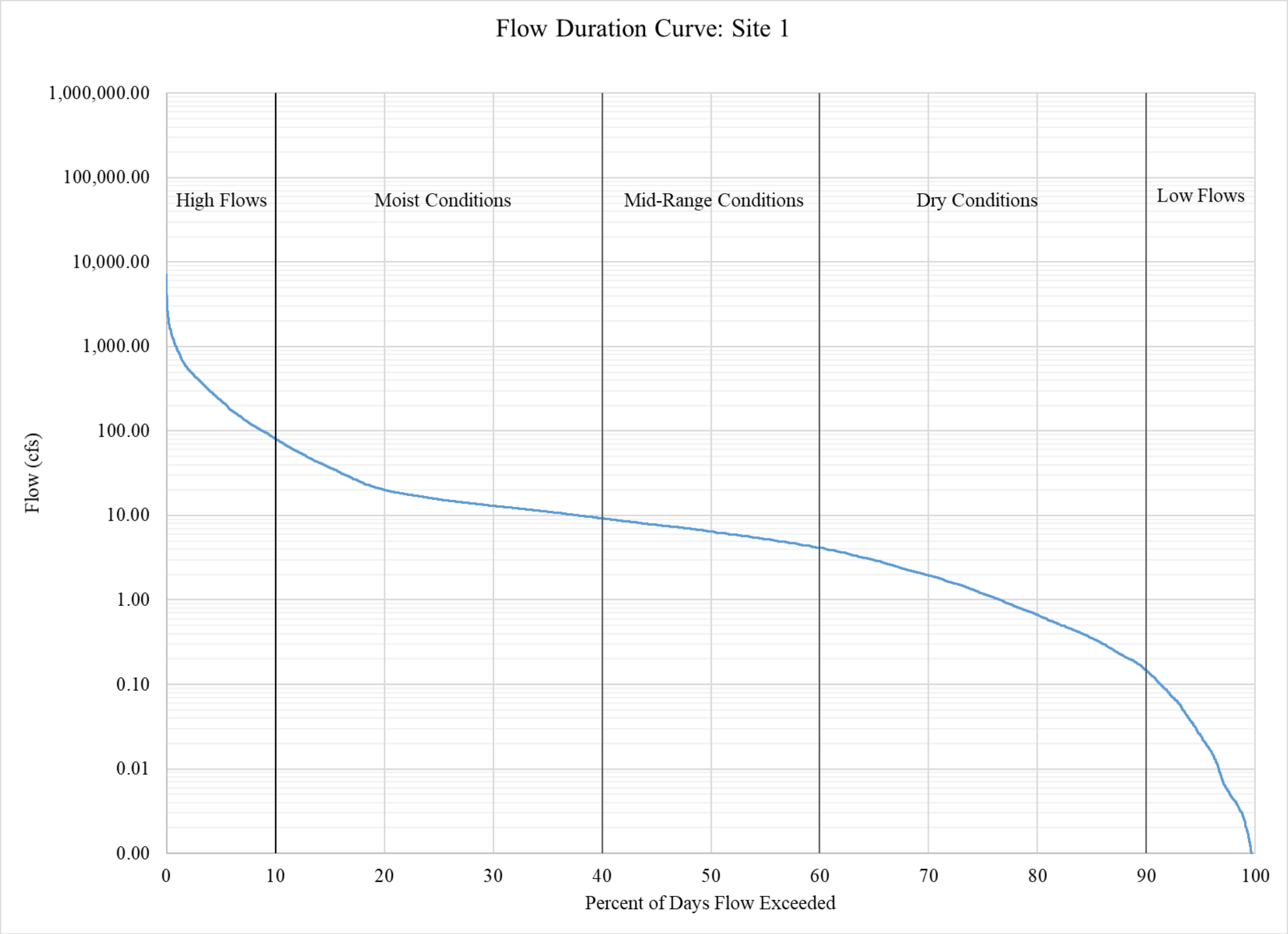

Figure 12 Breakout FDC Site 1

In the Breakout FDC of Site 5, *Figure 13*, the blue line is the flow duration curve. The vertical bars represent 10%, 40%, 60%, and 90%. From 0-10% High Flow conditions exist, 10%-40% Moist Conditions, 40%-60% Mid-Range Conditions, 60%-90% Dry Conditions, and 90%-100% Low Flow conditions. The 5% percentile of High Flow is 873.68 cubic feet per second (cfs). The 25% percentile of Moist conditions is 83.59 cfs. The 50% percentile of Mid-Range conditions is

40.79 cfs. In Dry Conditions, flow is 19.35 cfs 75% of the time. Finally during Low Flows, flow is 5.97 cfs 95% of the time.

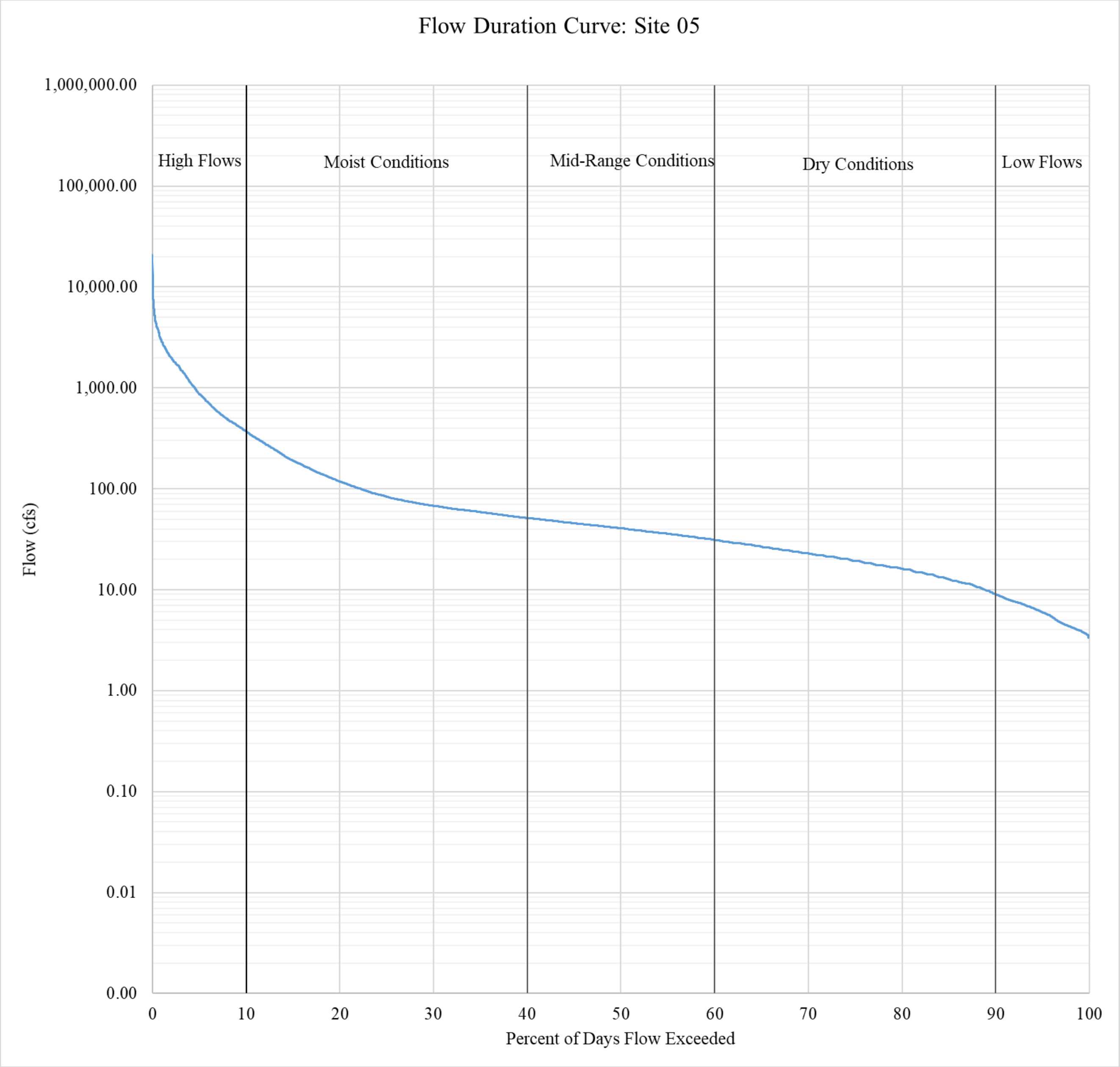

Figure 13 Breakout FDC Site 5

## 3.2 Load Duration Curve Analysis

Load Duration Curves (LDCs) allows for the estimation of existing and allowable loads of concerning constituents by utilizing the cumulative frequency distribution of stream flows and measured pollutant concentrations. The LDC can also be used to determine the hydrologic conditions under which high pollution load are typically occurring. LDCs were created for every constituent for which sufficient data existed.

### 3.2.1 *E. coli*

Rowlett Creek was listed for a recreational use impairment due to excessive levels of *E. coli* in the 2020 Integrated Report (IR) for surface water quality (TCEQ 2020). It was first listed in 2014 IR. A creek is listed as impaired for *E. coli* if the water quality sample exceeds 126 MPN/100ml. Based on historical and collected data analysis the Geomean of *E.coli* at Site 1 was 627.45 MPN/100mL of water, with the average *E.coli* counts ranging from 1 MPN/100mL of water to 30,000 MPN/100mL of water. As shown in Figure 14, the load duration curve (LDC) was presented to show the percentage of time during which a certain value of *E.coli* in MPN/day is equaled or exceeded at Site 1. At different flow conditions, for example High Flow, the *E.coli* load will exceed 0.05% percent of the time. Whereas at Low Flows, the *E.coli* load will exceed 95% percent of the time. The load duration curve is compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard) in order to determine the amount of reduction needed to meet the allowable load Table 13.

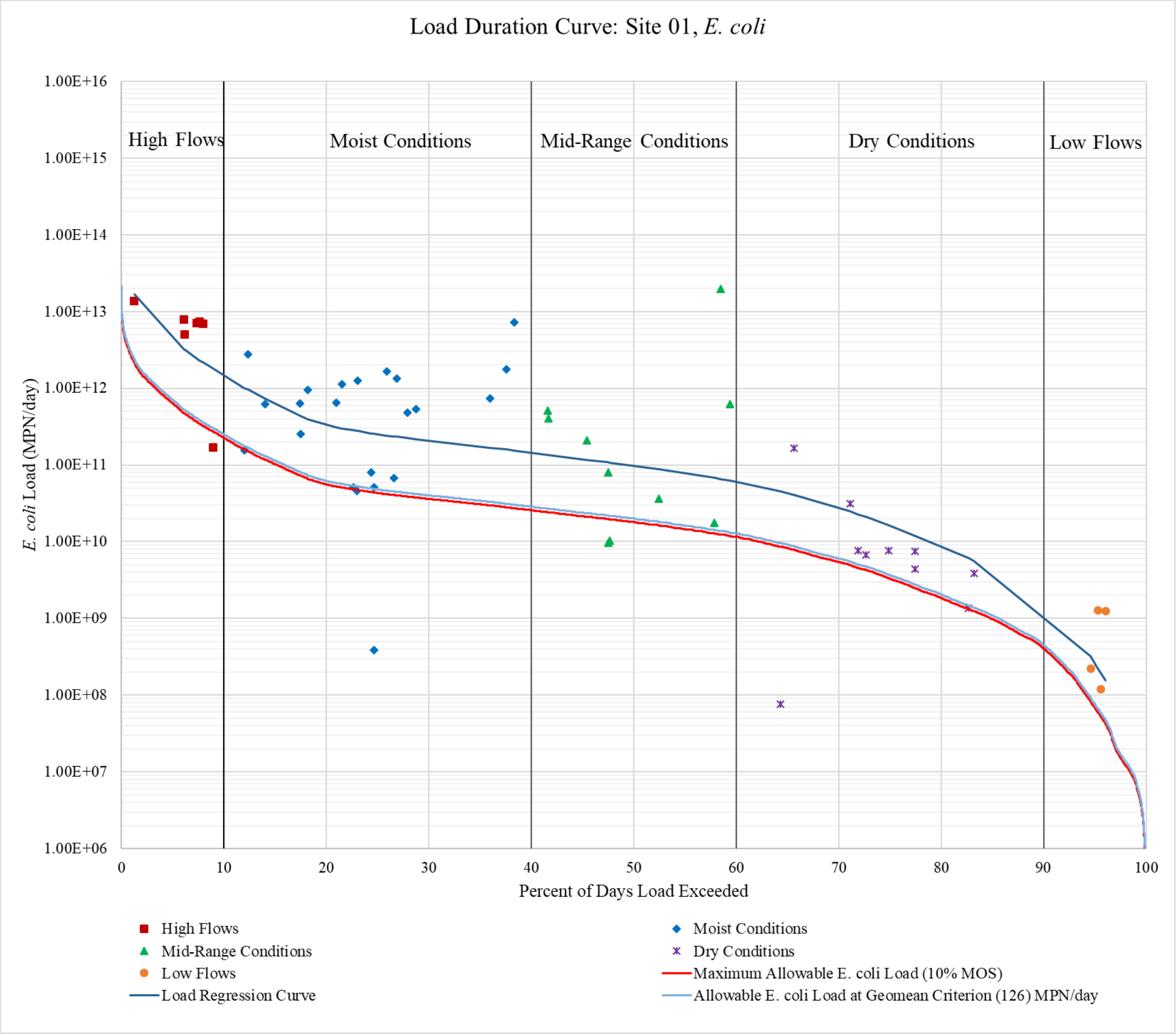

Figure 14 The Load Duration Curve of *E.coli* at Site 1.

Figure 14 displays the graphical representation of *E. coli* loading in high flows, moist conditions, mid-range conditions, dry conditions and low flows. Specifically, the load regression curve, allowable *E. coli* load at TCEQ geomean criteria 126 MPN/day, and the maximum allowable *E. coli* load 10%. As depicted, site 1 was impaired since the load regression curve was consistently higher than the allowable *E. coli* load and the maximum allowable *E. coli* load. Therefore, the headwaters of Rowlett creek are impaired for *E.coli*. Correlation coefficients were calculated for all data sets that consisted of using the statistical CORREL function in Excel that determines the relationship between flow and concentration of grab sample. Values are reported between negative one (-1) and positive one (+1). A strong relationship is greater than +0.5 or a -0.5. A positive relationship indicates that as one variable increases the compared variable increase and a negative relationship indicates that as one variable decreases the compared variable decreases. The correlation coefficient between flow and *E.coli* concentration in the grab samples was -0.05 indicating that the relationship is not strong, but this could be due to the timing of the sampling in relation to flow, some samples were taken immediately after a storm, some were taken during low flow periods, some were taken while it was storming. Moreover, the flow values for these correlations came from the SWAT model output calibrated to the USGS station significantly downstream from this site, influencing a very weak correlation. Furthermore, as shown in Table 13, the load reduction goals for *E.coli* at site 1 show that reduction is needed at all flow conditions including low flows. The load exceedances can be attributed to non-point sources as well as point sources.

Table 13 Load Reduction Goals for *E.coli* at Site 1

| **Flow Condition** | **% Exceedance** | **% Reduction** |
|---|---|---|
| High Flows | 0-10% | 85 |
| Moist Conditions | 10-40% | 83 |
| Mid-Range Conditions | 40-60% | 82 |
| Dry Conditions | 60-90% | 80 |
| Low Flows | 90-100% | 73 |

Based on the 2020 Texas Integrated Report for Surface Water Quality at site 5, 24 data points collected from 12/01/11 - 11/30/18 resulted in a geomean of 267.29 MPN/100 mL of water. In this study, the geomean was determined to be 423.67 MPN/100mL of water based on 93 samples using historical data and current data analyzed from 2009-2020. The average counts of *E.coli* ranged from 1 MPN/100mL of water to 24,000 MPN/100mL of water. The correlation coefficient between flow and grab sample was 0.3 indicating that the relationship is not as strong, but this could be due to the timing of the sampling in relation to flow. Some samples were taken immediately after a storm, some were taken during low flow periods, and others were taken while it was storming. In addition, the flow values for these correlations came from the USGS station that is upstream of this site, influencing a weaker correlation. As seen in Figure 15, the load regression curve for all flow conditions is greater than and does not intersect with maximum allowable *E.coli* load nor allowable *E.coli* load. Therefore, site 5 is impaired for *E.coli* and sources can be attributed to non-point source and point source contributions based on Figure 16 (EPA, 2007). The reduction goals for *E.coli* are presented in Table 14, which demonstrated that reduction is needed at all flows.

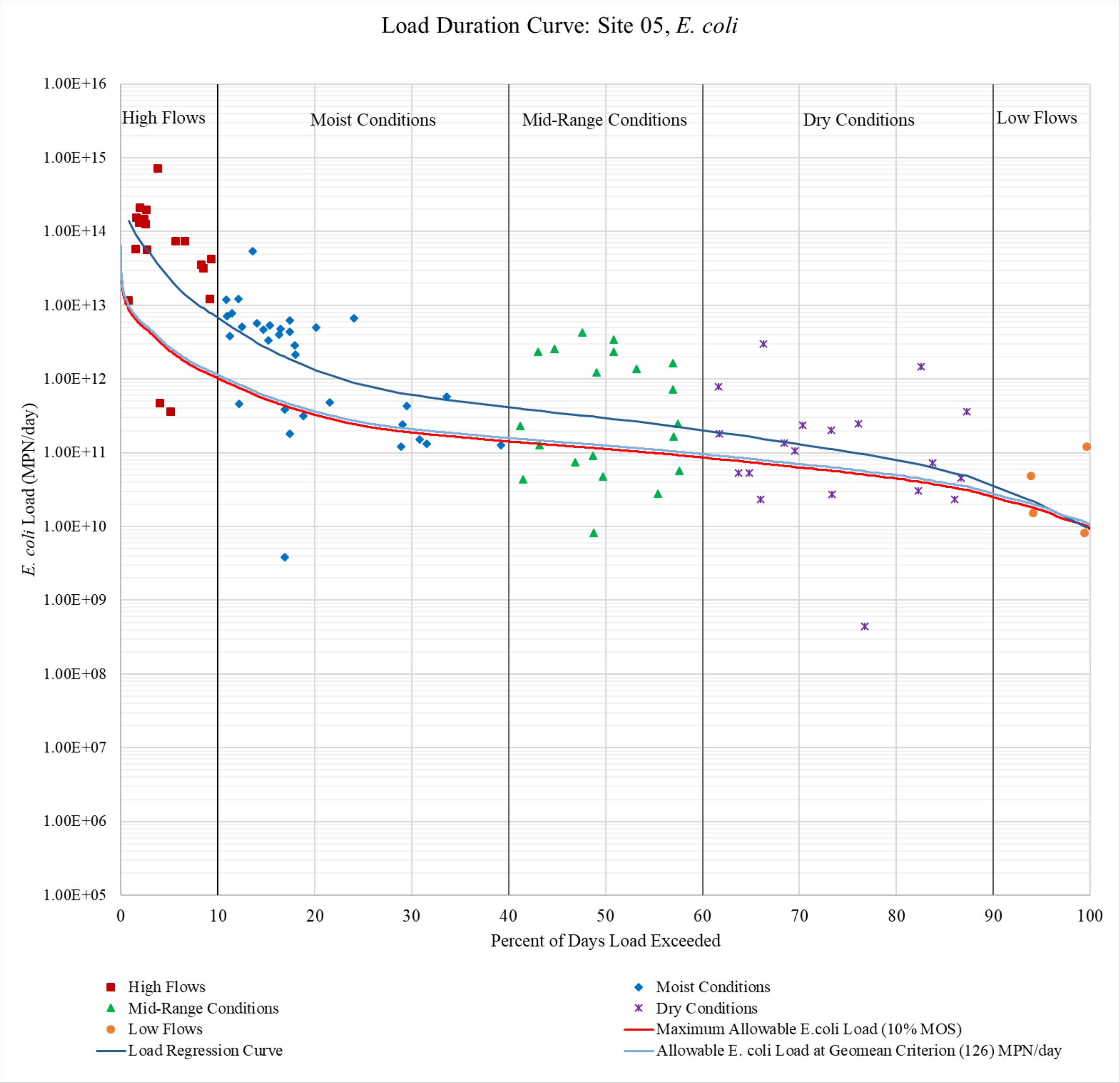

Figure 15 The Load Duration Curve for *E.coli* at Site 5.

Table 14 The Load Reduction Goals for *E.coli* at Site 5

| Flow Condition | % Exceedance | % Reduction |
|---|---|---|
| High Flows | 0-10% | 90 |
| Moist Conditions | 10-40% | 77 |
| Mid-Range Conditions | 40-60% | 61 |
| Dry Conditions | 60-90% | 48 |
| Low Flows | 90-100% | 8 |

As shown in *Figure 16*, a non-point vs point source graphical representation of an LDC depicting what would constitute unfeasible management and feasible management for non-point source and point source contributions (EPA, 2007). This specific graphical representation summarizes potential issues for Site 5 based on the load regression curve depicted in Figure 15.

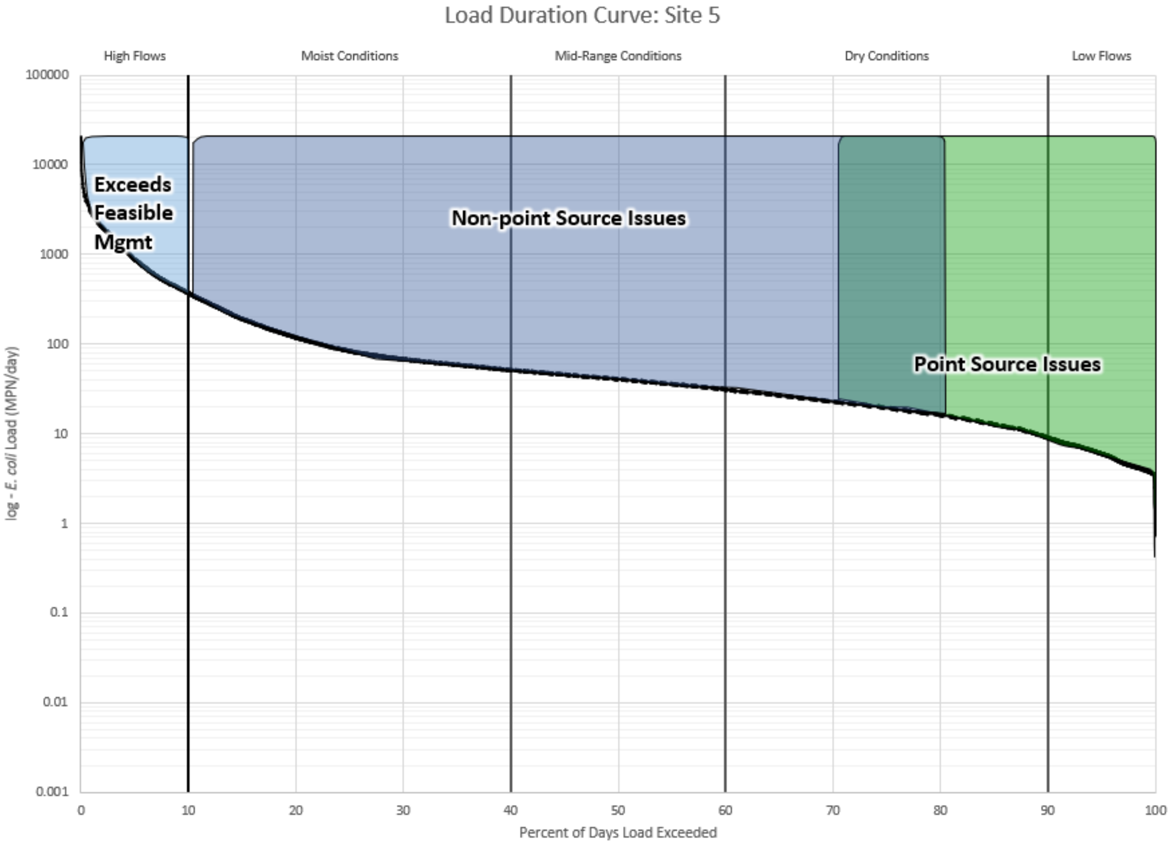

Figure 16 The LDC at Site 5 identifying Point and Non-point flow contributions for *E.coli.*

### 3.2.2 Nitrogen

Rowlett Creek was listed for a screening level concern due to heightened levels of nitrate in the 2020 Integrated Report for surface water quality (TCEQ 2020). It was first listed in 2014 IR. A creek is listed as screening level concern for nitrate if the water quality sample exceeds 1.95 mg/L. Based on historical and current data analysis at Site 1, the average concentration of nitrate was 1.24 mg/L and does not exceed the screening level limit upstream. Figure 17 displays the computation of load duration of nitrogen (nitrate +nitrite) in tons/day spanning high flows to low flows from dates ranging March 2020 to December 2020. The average nitrogen concentration ranged from 0.09 mg/L to 2.71 mg/L. The load duration curve was compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard) in order to determine the amount of reduction needed to meet the allowable load. The load regression curve depicted in Figure 17 was consistently just below the allowable nitrogen level and maximum allowable pollutant load, thus suggesting no load reduction is required (Table 15). The correlation coefficient between flow and grab sample was -0.02, indicating that the relationship was not strong. The results support the findings of the LDC that non-point source runoff of nitrogen (nitrate+nitrite) did not impact Rowlett Creek headwaters. Further, there is no WWTP in this subwatershed.

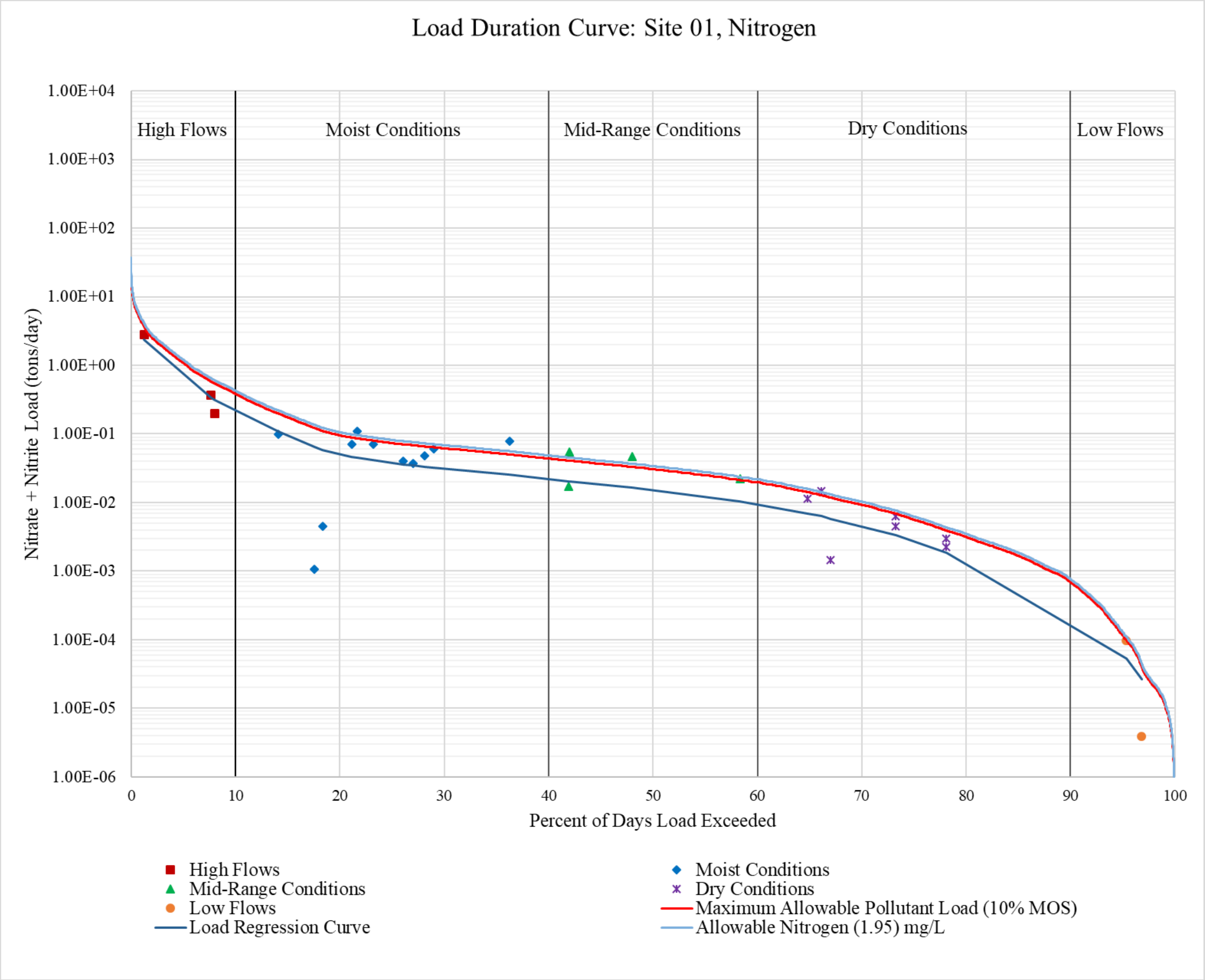

Figure 17 The Load Duration Curve of Nitrogen at Site 1

Table 15 The Reduction Goals for nitrogen needed at Site 1

| **Flow Condition** | **% Exceedance** | **% Reduction** |
|---|---|---|
| High Flows | 0-10% | 0 |
| Moist Conditions | 10-40% | 0 |
| Mid-Range Conditions | 40-60% | 0 |
| Dry Conditions | 60-90% | 0 |
| Low Flows | 90-100% | 0 |

As seen in Figure 18, the results at Site 5 showed that the load regression curve intersected at high flows and started to increase above the allowable screening limit under moist conditions, mid-range conditions, dry conditions and low flows. Based on historical and current data analysis from 1982 to 2020, the average nitrogen concentration at Site 5 was 3.92 mg/L and did meet the screening level concern. The average nitrogen concentration of existing and collected water quality data ranged from 0.23 mg/L to 13 mg/L. Figure 18 displays the computation of load duration of nitrogen (nitrate +nitrite) in tons/day spanning high flows to low flows. The load duration curve is compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard) in order to determine the amount of reduction needed to meet the allowable load as identified in Table 16. The load regression curve depicted in *Figure 18* below intersects with and surpasses the allowable nitrogen level and maximum allowable pollutant load thus showing load reduction is required in moist conditions, mid-range conditions, dry conditions and low flow. The correlation coefficient between flow and grab sample was -0.02 which is not a strong correlation. Similar to *E.coli* correlation coefficient, this could be due to when the sample was collected in relation to flow conditions and storm conditions. Further, USGS station farther upstream could be influencing a weaker correlation. However, this could also support a conclusion that nitrogen is not only a non-point runoff concern and but should be considered an effluent related source because of greater reductions needed in low flows. Low flows are usually associated with base flow and a WWTP upstream contributes to base flow.

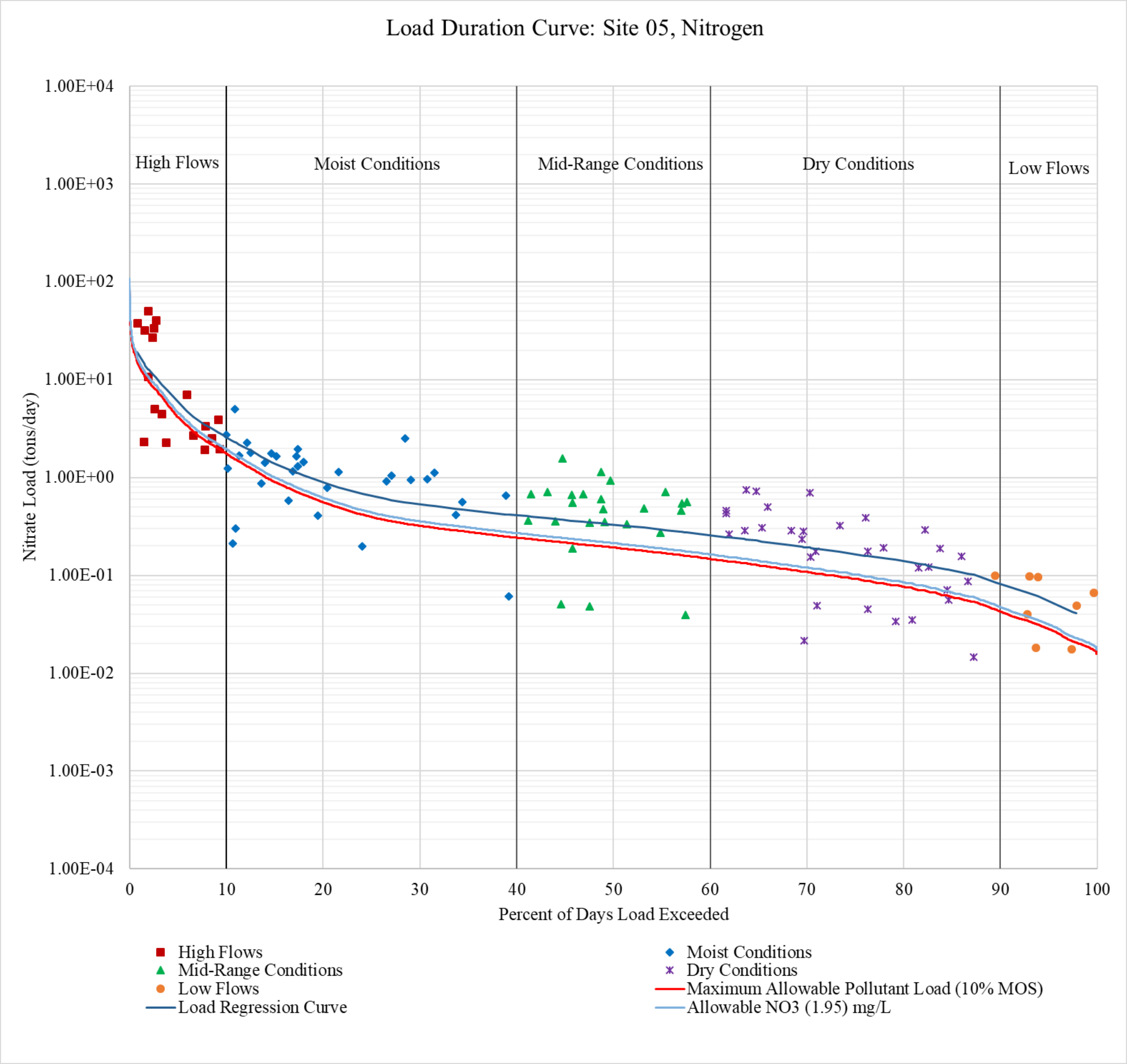

Figure 18 The Load Duration Curve of Nitrogen at Site 5

Table 16 Site 5: % Reduction of Nitrogen Loading

| Flow Condition | % Exceedance | % Reduction |
|---|---|---|
| High Flows | 0-10% | 1 |
| Moist Conditions | 10-40% | 23 |
| Mid-Range Conditions | 40-60% | 33 |
| Dry Conditions | 60-90% | 39 |
| Low Flows | 90-100% | 47 |

### 3.2.3 Total Kjedahl Nitrogen

TKN screening limit for streams regulated by EPA is 0.4 mg/L. There was no historical data that analyzed or detected for TKN near site 1. In addition, only 4 out of the 28 samples analyzed from March to December 2020 detected TKN, 3 out of 4 values were greater than the detection limit of 0.4 mg/L. Therefore, it is impossible to make any conclusive statement whether the TKN is of concern or not, since the limited data set did not allow for a quantitative analysis.

As for TKN at site 5, the average concentration was 1.63 mg/L and thus exceeds the EPA screening level concern. Based on historical and current data analysis, Figure 19 displays computation of load duration of TKN in tons/day spanning high flows to low flows from dates ranging 1982 to 2020. Compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard), the load regression curve is greater than and does not intersect with allowable or maximum allowable pollutant load, thus indicating load reduction is required. The correlation coefficient between flow and grab sample was 0.56 indicating a strong correlation which is consistent with the findings in the Load Duration Curve. Therefore, TKN is a non-point source runoff concern and potentially a point source concern (Table 17).

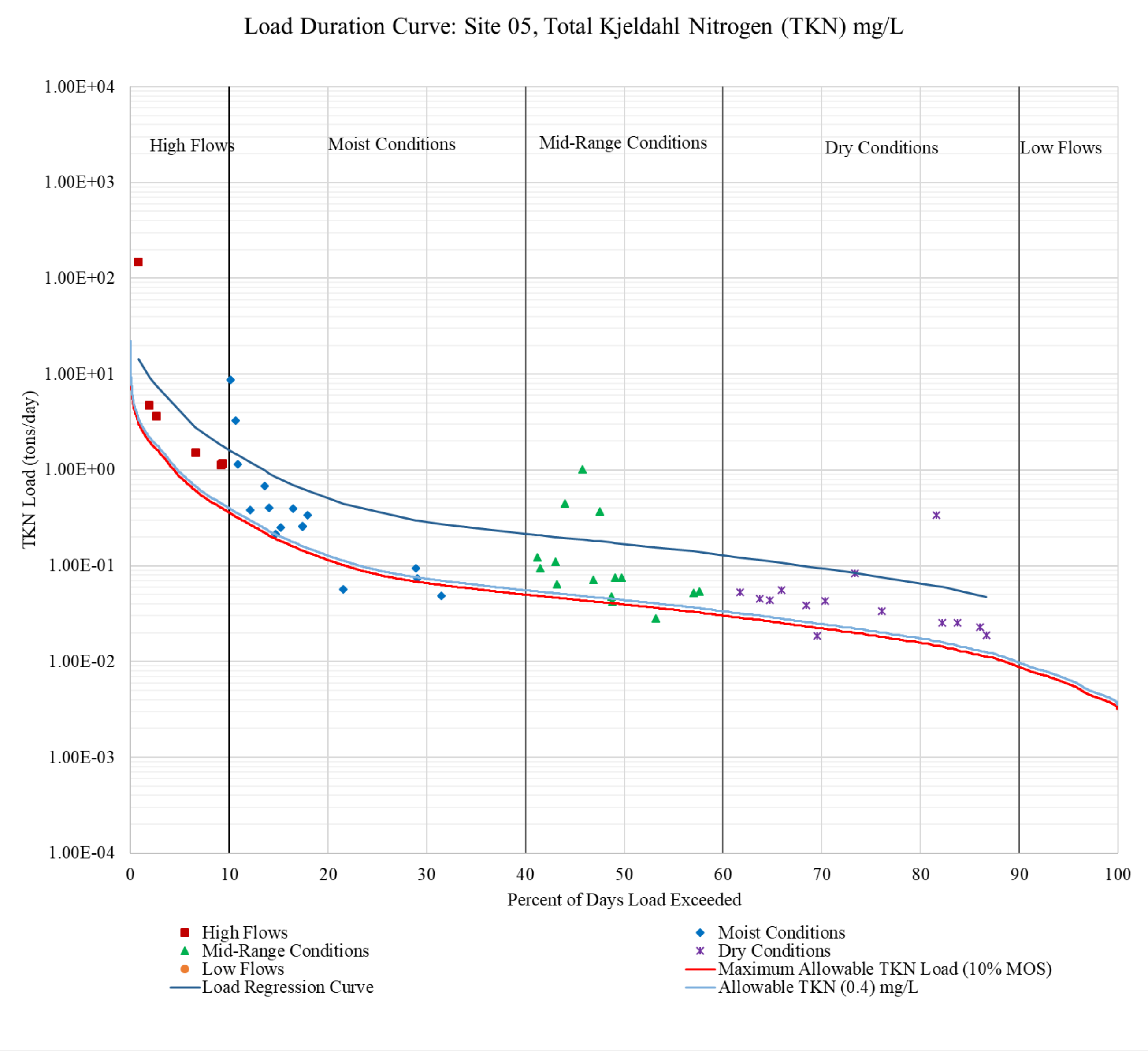

Figure 19 The Load Reduction for TKN at Site 5

Table 17 Reduction Goals for TKN at Site 5

| Flow Condition | % Exceedance | % Reduction |
|---|---|---|
| High Flows | 0-10% | 78 |
| Moist Conditions | 10-40% | 77 |
| Mid-Range Conditions | 40-60% | 77 |
| Dry Conditions | 60-90% | 76 |
| Low Flows | 90-100% | N/A |

### 3.2.4 Ammonia

Rowlett Creek was not listed for a screening level concern for ammonia as nitrogen even though one sample did exceed the level at 0.85 mg/L in the 2020 Integrated Report for surface water quality (TCEQ, 2020). A creek is listed as screening level concern for ammonia as nitrogen if the water quality sample exceeds 0.33 mg/L. Based on historical and current data analysis, the average concentration of ammonia was 0.15 mg/L at Site 1 and 0.510 mg/L at Site 5. Site 1 average does not exceed the screening level concern upstream, but Site 5 average screening level concern is exceeded. The range of data for Site 5 is 0.02 mg/L to 7.22 mg/L, where only 12 of 73 grab samples exceeded the screening level concern. The majority of grab samples do not exceed the screening level concern as seen in Figure 21. The load duration curve is compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard) in order to determine the amount of reduction needed to meet the allowable load. Figure 20 and Figure 21 displays the computation of load duration of ammonia in tons/day spanning high flows to low flows from dates ranging March 2020 to December 2020 at site 1 and 5. The load regression curve was below and never intersects with allowable ammonia level and maximum allowable ammonia load, and thus suggesting no load reduction is required. The correlation coefficient between flow and grab sample was -0.14 at site 1 and 0.07 at site 5 indicating the weak correlation. The results support the findings of the LDC that non-point source runoff of ammonia does not impact Rowlett creek headwaters (Table 18 and Table 19).

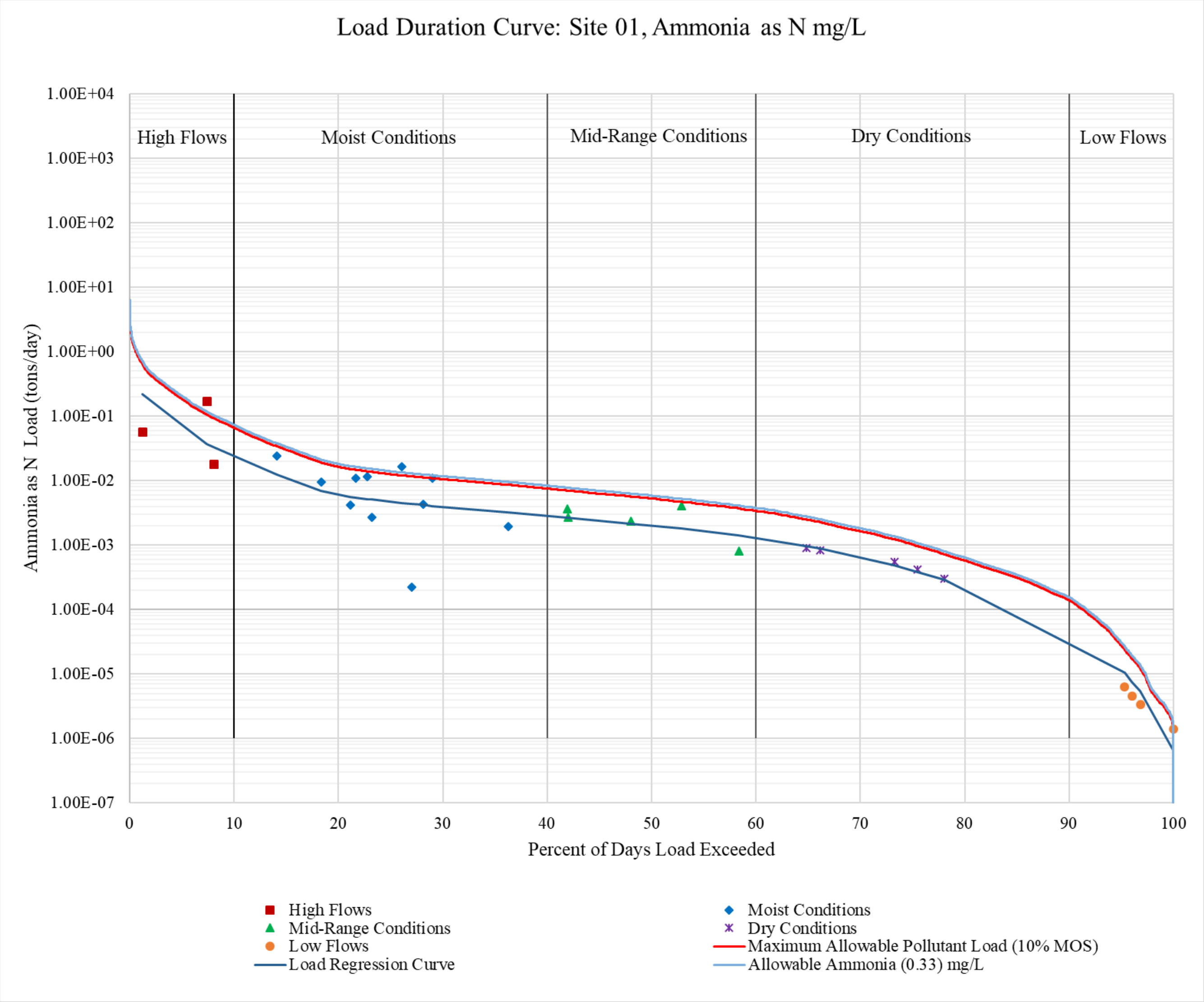

Figure 20 The Load Duration Curve for Ammonia at Site 1

Table 18 Reduction Goals for Ammonia at Site 1

| **Flow Condition** | **% Exceedance** | **% Reduction** |
|---|---|---|
| High Flows | 0-10% | 0 |
| Moist Conditions | 10-40% | 0 |
| Mid-Range Conditions | 40-60% | 0 |
| Dry Conditions | 60-90% | 0 |
| Low Flows | 90-100% | 0 |

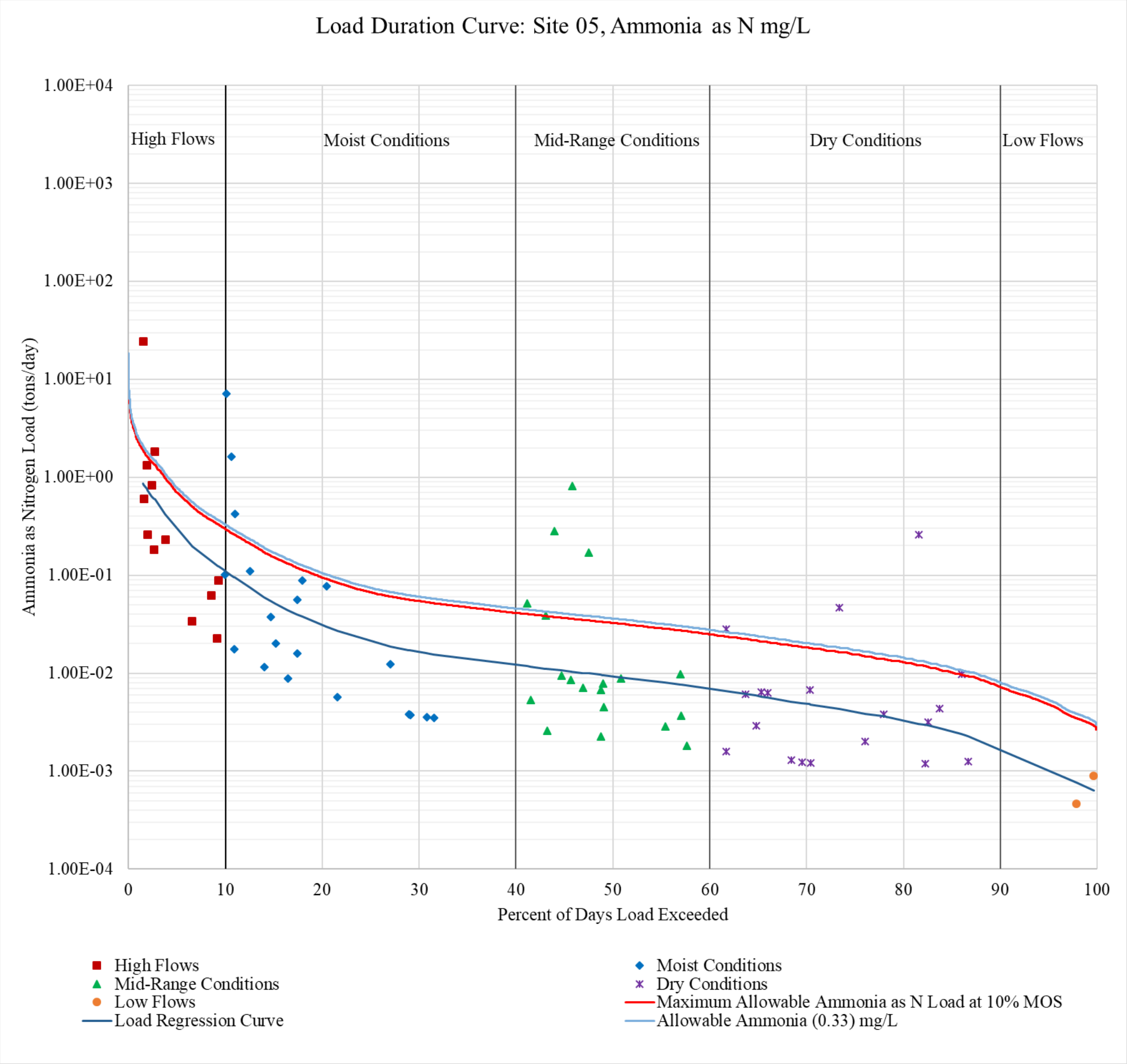

Figure 21 The Load Duration Curve for Ammonia at Site 5

Table 19 Reduction Goals for Ammonia at Site 5

| Flow Condition | % Exceedance | % Reduction |
|---|---|---|
| High Flows | 0-10% | 0 |
| Moist Conditions | 10-40% | 0 |
| Mid-Range Conditions | 40-60% | 0 |
| Dry Conditions | 60-90% | 0 |
| Low Flows | 90-100% | 0 |

### 3.2.5 Total Phosphorus

Total phosphorus screening limit for streams regulated by TCEQ is 0.69 mg/L. There was no historical data that analyzed or detected for total phosphorous near Site 1. In addition, only five out of the 28 samples analyzed from March 2020 to December 2020 detected total phosphorus at site 1, which were under the limit of 0.69 mg/L. Therefore, total phosphorus is not of concern at site 1, although the limited data set cannot allow for a quantitative analysis.

As for total phosphorus at site 5, the average concentration was 0.54 mg/L and thus does not exceed a screening level concern. Based on historical and current data analysis, Figure 22 displays the computation of load duration of total phosphorus in tons/day spanning high flows to low flows from dates ranging 1981 to 2020. Compared to the maximum allowable load (10% MOS) and the allowable load (TCEQ standard), the load regression curve never intersected with allowable or maximum allowable pollutant load, thus suggesting no load reduction is required. The correlation coefficient between flow and grab sample was -0.05 indicating a weak correlation which is consistent with the findings in the Load Duration Curve. Therefore, Total phosphorus is not a non-point source runoff concern (Table 20).

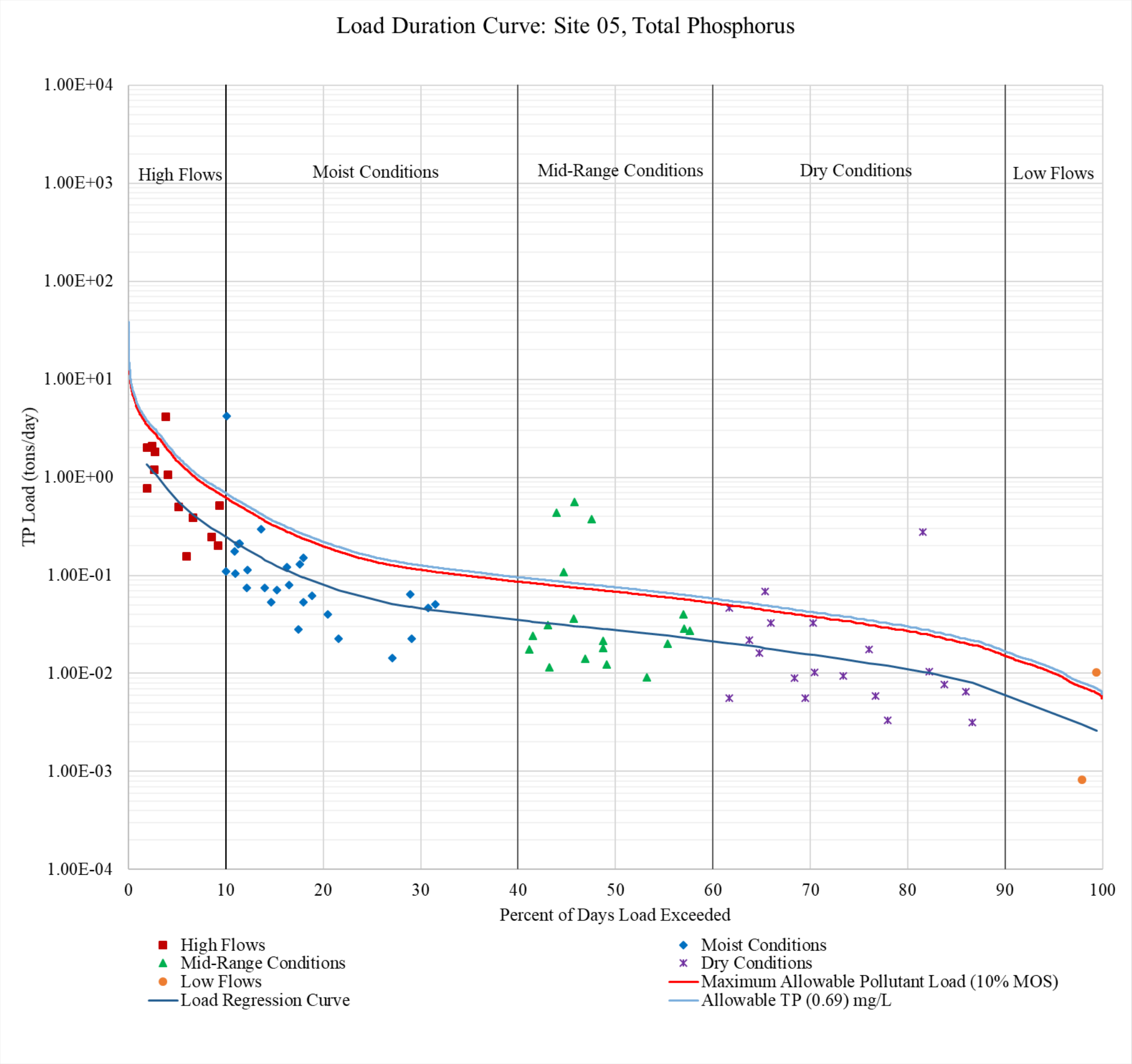

Figure 22 The Load Reduction for Total Phosphorus at Site 5

Table 20 The Reduction Goals for Total Phosphorus at Site 5

| **Flow Condition** | **% Exceedance** | **% Reduction** |
|---|---|---|
| High Flows | 0-10% | 0 |
| Moist Conditions | 10-40% | 0 |
| Mid-Range Conditions | 40-60% | 0 |
| Dry Conditions | 60-90% | 0 |
| Low Flows | 90-100% | 0 |

### 3.2.6 Total Suspended Solids

The Trinity River basin is naturally turbid and there is no screening limit or standard for TSS in Rowlett Creek. If waters are highly turbid or have high suspended sediment loads, it will decrease light penetration and thus limit productivity. Figure 23 and Figure 24 displays the computation of load duration of TSS in tons/day spanning high flows to low flows from dates ranging March 2020 to December 2020 at site 1 and 5. The correlation coefficient between flow and grab sample was 0.08 at Site 1 and 0.06 at Site 5, indicating that the relationship is not strong.

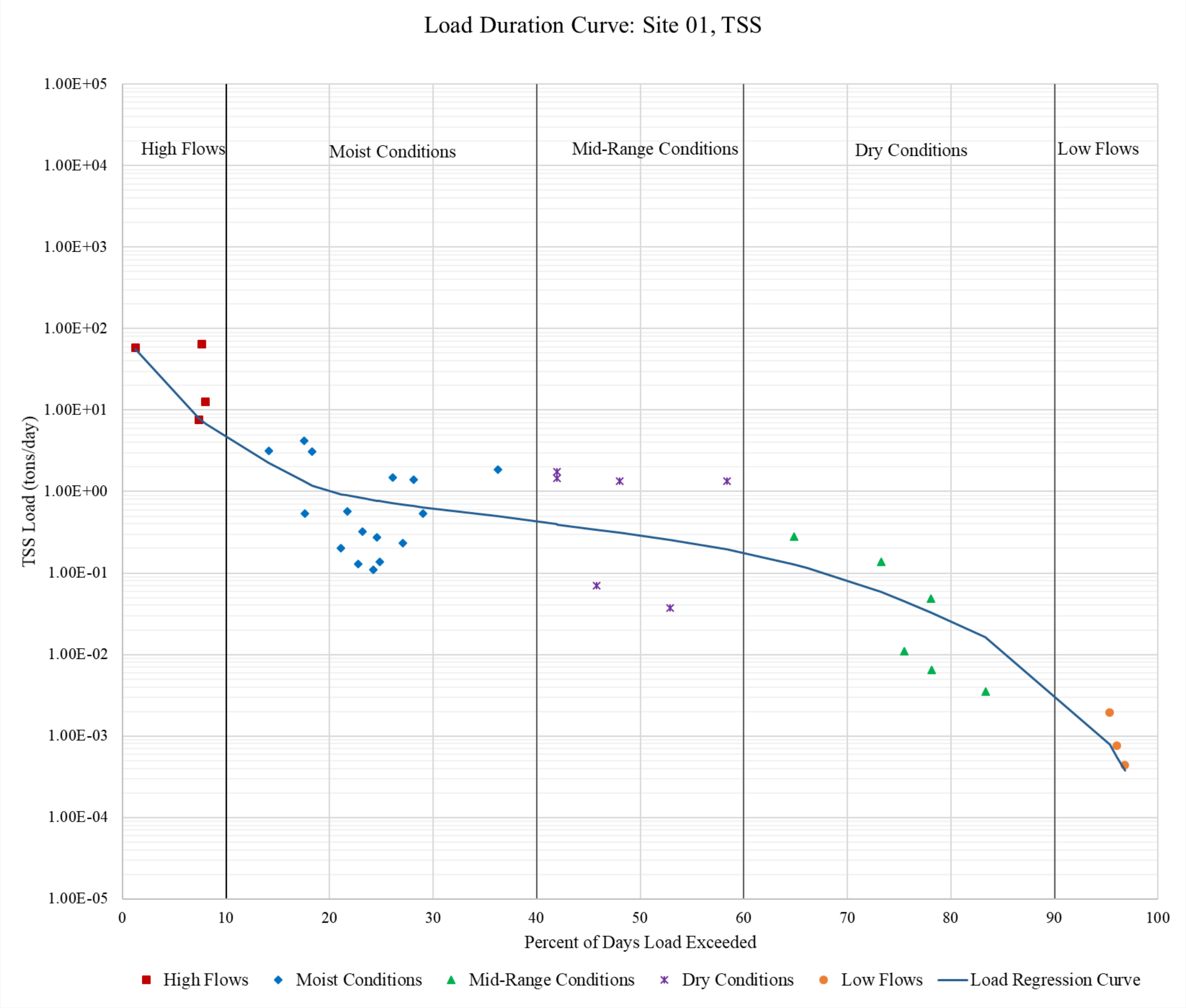

Figure 23 The load reduction curve of TSS at Site 1

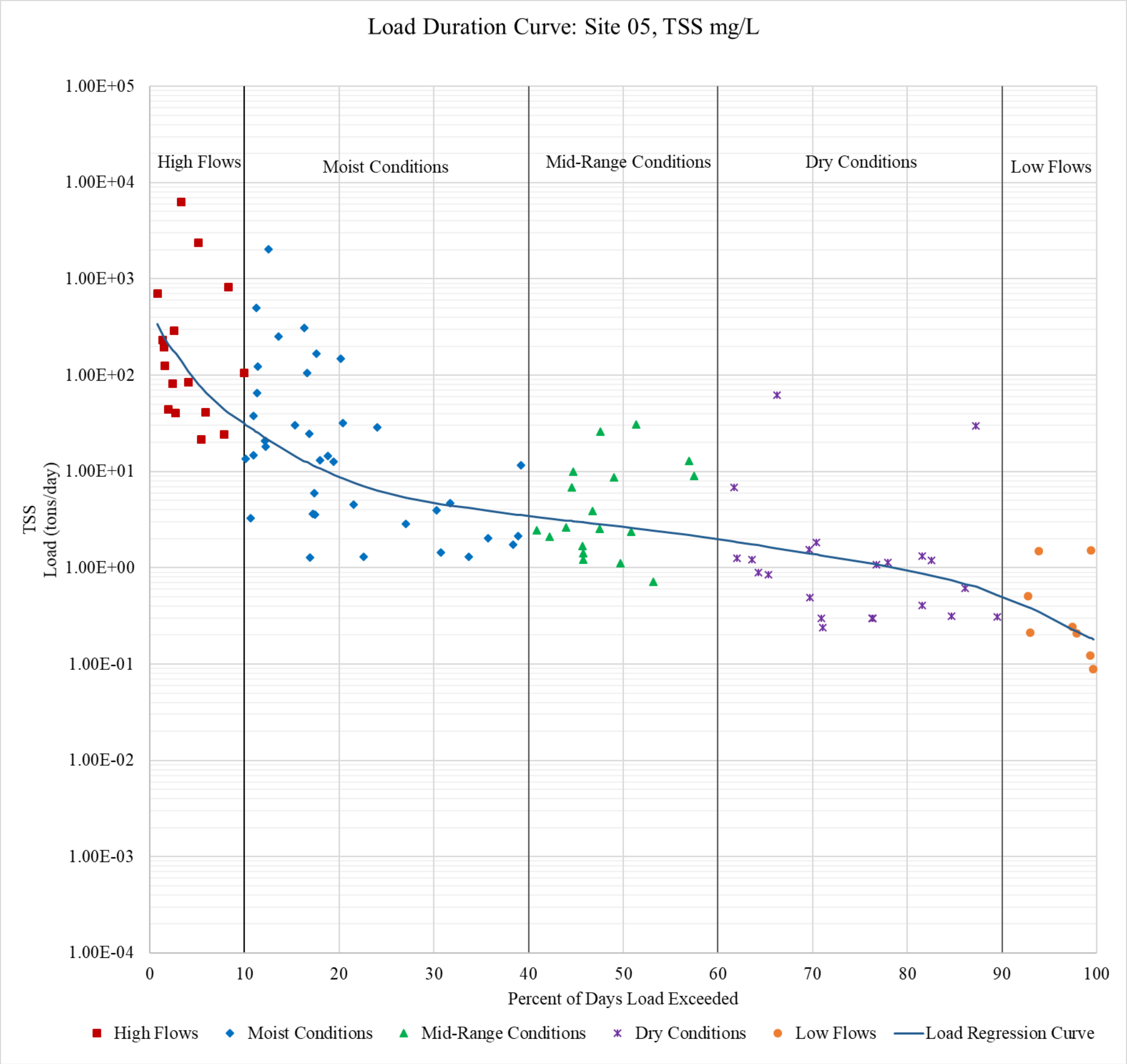

Figure 24 The load reduction curve of TSS at Site 5

### 3.3 Land Cover influence on loading

Table 21 summarizes the pollution loading calculations based on the land cover for high flows, moist conditions, mid-range conditions, dry conditions and low flow conditions at both site 1 and

5 for parameters. In addition, the difference of each parameters including flow, TSS, *E. coli*, ammonia, nitrate+nitrite was calculated between sites 1 and 5 in order to illustrate the correlation of changes of pollution load with the changes of flow. A positive percent difference indicates that Site 5 land cover is a greater influence on pollutant loading in Rowlett Creek compared to Site 1. A negative percent difference indicates that Site 1 land cover is a greater influence on pollutant loading in Rowlett Creek.

### *Flow*

During high flows, the percentage difference in runoff per acre between Site 1 and Site 5 is 19%. During moist conditions, the percentage difference in runoff per acre between Site 1 and Site 5 is 68.9%. During mid-range conditions, the percentage difference in runoff per acre between Site 1 and Site 5 is 95%. During dry conditions, the percentage difference in flow is 412%. During low flows, the percentage difference in flow is 7,510%. Site 1 watershed is located within Site 5 watershed and acreage is significantly different, 25,000 acres vs 78,000 acres. The greatest change is seen in dry conditions and low flows. This is most likely due to a WWTP discharging daily flows within the midbasin of Rowlett Creek, downstream of site 1 and upstream of Site 5. High flows do not show a significant percent change most likely because of the intensity of these storms and the subsequent sheet flow. Moist conditions and mid-range conditions show an increasing difference in runoff and this may be in part due to greater density of urban landscape throughout the midbasin between Site 1 and Site 5.

### *E.coli*

During high flows, the percentage difference in concentration increase of *E.coli* in runoff per acre between Site 1 and Site 5 is 60%. During moist conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 2.9%. During mid-range conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is -6.8 %. During dry conditions, the percentage difference in concentration increase is 101.7%. During low flows, the percentage difference in concentration increase is 2,285.6%. The greatest change is seen in dry conditions and low flows. This is most likely due to a WWTP discharging daily flows, the additional tributaries within the midbasin transporting higher concentrations and/or minor stormwater flow over impervious areas. High flows show a significant percent change in concentration per acre, but the increase in concentration does not correlate with the percent change in flow. The pollutant loading in high flows is related to non-point source runoff. There is a greater density of urban landscape throughout the midbasin between Site 1 and 5 as well as an increase in impervious. However during moist conditions and mid-range conditions the increase or decrease in pollutant loading based on land cover is minimal. This *E.coli* behavior as a function of flow is similar in these conditions despite land cover. The pollutant loading is thus a source of non-point runoff . Homeowner education will be key in addressing this impairment. During dry and low flow conditions, WWTP discharges will also need to be further investigated.

### *Total Suspended Solids*

During high flows, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 77%. During moist conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 147.7%. During mid-range conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 185.8 %. During dry conditions, the percentage difference in concentration increase is 656%. During low flows, the percentage difference in concentration increase is 10,481.8%. During high flow storms, sediments are scoured from stream banks and suspended in the stream. TSS loading during high flow conditions is similar at the headwaters of Rowlett and throughout the midbasin. During moist and mid-range conditions, non-point sources contribute TSS into the stream system by runoff picking up sediments and flushing it into streams. During dry and low conditions, there is no storm runoff contributing to TSS increase in loading. This increase in TSS loading can be related to land cover.

*Ammonia*

During high flows, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 39.18%. During moist conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 40.02%. During mid-range conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 45.29 %. During dry conditions, the percentage difference in concentration increase is 214.57%. During low flows, the percentage difference in concentration increase is 2,735.73%. During high flow, moist conditions, and mid-range conditions, ammonia concentration increase is similar and is related to change in land cover from Site 1 to Site 5. During dry and low flow conditions ammonia increases, but in correlation with increase in natural flow conditions that could be based on input from the WWTP upstream. Ammonia is not a concern in this watershed based on the load duration curves.

*Nitrate+nitrite*

During high flows, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 183.4%. During moist conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 438.4%. During mid-range conditions, the percentage difference in concentration increase in runoff per acre between Site 1 and Site 5 is 581.7 %. During dry conditions, the percentage difference in concentration increase is 1,809.9%. During low flows, the percentage difference in concentration increase is 27,824.4%. During high flow, moist conditions, and mid-range conditions, nitrate+nitrite loadings increase is related to change in land cover between Site 1 and Site 5. Non-point sources contribute to runoff during these flow conditions. During dry and low flow conditions nitrate+nitrite substantially increases, but in correlation with increase in natural flow conditions that could be based on input from the WWTP upstream. Nitrate+nitrite is not a concern in upper Rowlett Creek watershed, but a concern in the entire watershed based on the load duration curves. Non-point source concerns and point source concerns should be addressed for nitrate+nitrite concerns.

The Rowlett Creek watershed land cover and land use is mixed use where upstream is characterized as  open field/agriculture/residential and downstream is highly urbanized with golf courses, a WWTP, high density housing, industrial and commercial properties. Based on the Table 21, Site 5 land cover contributes higher flows and a higher concentration of pollutants during all flow conditions. Green infrastructure is one category of BMPs that could be implemented to address small rainfall events to reduce stormwater flow in order to reduce the concentration of pollutants from entering the stream system. It would be in the best interest of the municipalities to examine all dog parks, livestock/cattle grazing areas, horse pastures, swine lots, etc. for potential areas to install green infrastructure such as rain gardens and bioretention ponds to slow stormwater runoff  laden with pollutants from entering creek systems or agricultural BMPs  such as vegetation buffers to prevent access to creeks. Further, homeowner education on the who, what, when, where, why in regards to pollutants and the health of waterbodies should be implemented.

Table 21 Loading based on Land Cover acreage per site per parameter per flow conditions

| | Site 1 | Site 5 | Flow | | Site 1 | Site 5 | Concentration | Percentage Difference |
|---|---|---|---|---|---|---|---|---|
| | Flow | | Difference | Percentage Difference | TSS Tons/Day | | Difference | |
| 5% High Flows | 0.0092962 | 0.0110662 | 0.0017700 | 19.04 | 0.000586469 | 0.0010383 | 0.00045182 | 77.04 |
| 25% Moist Conditions | 0.0006268 | 0.0010589 | 0.0004321 | 68.94 | 0.000030426 | 0.0000754 | 0.00004495 | 147.73 |
| 50% Mid-Range Conditions | 0.0002629 | 0.0005127 | 0.0002498 | 95.01 | 0.000011722 | 0.0000335 | 0.00002179 | 185.88 |
| 75% Dry Conditions | 0.0000479 | 0.0002452 | 0.0001973 | 412.06 | 0.000001944 | 0.0000147 | 0.00001275 | 656.07 |
| 95% Low Flows | 0.0000010 | 0.0000757 | 0.0000747 | 7,510.39 | 0.000000037 | 0.0000039 | 0.00000391 | 10,481.79 |

| | Site 1 | Site 5 | Concentration | | Site 1 | Site 5 | Concentration | Percentage Difference |
|---|---|---|---|---|---|---|---|---|
| | Ammonia as Nitrogen Tons/Day | | Difference | Percentage Difference | Nitrate+ Nitrite as Nitrogen Tons/Day | | Difference | |
| 5% High Flows | 0.00000261748 | 0.000003643 | 0.0000010255 | 39.18 | 0.0000257539 | 0.00007300 | 0.00004724 | 183.43 |
| 25% Moist Conditions | 0.00000018869 | 0.000000264 | 0.0000000755 | 40.02 | 0.0000015232 | 0.00000820 | 0.00000668 | 438.39 |
| 50% Mid-Range Conditions | 0.00000008083 | 0.000000117 | 0.0000000366 | 45.29 | 0.0000006122 | 0.00000417 | 0.00000356 | 581.67 |
| 75% Dry Conditions | 0.00000001636 | 0.000000051 | 0.0000000351 | 214.57 | 0.0000001099 | 0.00000210 | 0.00000199 | 1,809.87 |
| 95% Low Flows | 0.00000000049 | 0.000000014 | 0.0000000133 | 2,735.73 | 0.0000000025 | 0.00000070 | 0.00000070 | 27,824.37 |

| | Site 1 | Site 5 | Concentration Difference | Percentage Difference |
|---|---|---|---|---|
| | E.coli Load MPN/Day | | | |
| 5% High Flows | 179,860,482.52 | 288,796,509.21 | 108,936,026.70 | 60.57 |
| 25% Moist Conditions | 10,119,669.36 | 10,415,531.84 | 295,862.48 | 2.92 |
| 50% Mid-Range Conditions | 4,004,449.51 | 3,730,378.58 | -274,070.94 | -6.84 |
| 75% Dry Conditions | 650,619.25 | 1,312,872.05 | 662,252.79 | 101.79 |
| 95% Low Flows | 10,418.07 | 248,534.04 | 238,115.97 | 2,285.60 |

Calculation procedure: From each parameters regression analysis, the linear trendline equation was used to determine the specific loading concentration at each flow condition. The concentration was then divided by the acreage of the specific watershed. The percentage difference between watersheds was calculated by dividing Site 1 results by the difference between Site 1 and Site 5, then multiplying by 100.

### 3.4 Watershed management plan recommendation

Best management practices (BMPs) are the primary method to control pollutant runoff. Depending on the concerns identified, certain BMPS can be implemented to combat the pollutants. *E. coli* and nutrient impairments or threats can stem from pet waste, livestock, wildlife, sanitary sewer overflows, OSSF failures for example. Ways to combat these require a multi-faceted approach.

Rowlett Creek is impaired for *E.coli* and the impairment is associated with flow or storm event runoff that is classified as non-point source pollution. The land cover in this watershed is heavily developed and includes highly dense residential developments, multiple golf course, plethora of parks and greenspaces, as well as forested riparian areas. Pets and wildlife are the most likely cause of bacteria in Rowlett Creek. Next steps would be to conduct bacterial source tracking in order to determine the exact bacteria source. Best management practices consisting of homeowner education on impacts and proper disposal and pet waste initiatives such as installation of pet waste stations should be explored. TRA Clean Rivers Program produced a 2020 Basin Summary Report. Within that report they analyze Rowlett Creek. The report supports our analysis, findings and BMP suggestions (TRA, 2020).

Nitrate is of concern in this watershed. The increase in nitrate concentration is correlated with flow and most importantly lower flows. A wastewater treatment facility is upstream and it is known that effluent-dominated streams exhibit higher nitrate values in low flows. Non-point source pollution can also be a factor for increased nitrate in the watershed. This can be related to over-irrigation of the multiple fertilized golf courses, parks and homes scattered throughout the watershed. Best management practices consisting of educating land and homeowners on proper irrigation, proper yard clipping disposal, herbicide/pesticide application and green infrastructure should be pursued. The report supports our analysis, findings and BMP suggestions (TRA, 2020). In addition, a research project targeting wet weather events through the Regional Stormwater Monitoring Program commissioned by NCTCOG found that total nitrogen and total phosphorus contributions via stormwater runoff are not significantly different than concentrations found during dry weather. This supports our findings that nitrogen is a non-point and point source concern. A comparison was also made with TSS to the National Stormwater Quality Database and it was found that TSS and total nitrogen was higher than 75% of the data (Atkins, 2016).

# CHAPTER 4

# CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

## 4.1 Conclusions

Monitoring activities were conducted weekly from March 2020 to December 2020 in order to insure a variety of weather conditions, most importantly dry flow and wet weather conditions. 65 samples were collected which were analyzed by NTMWD and SMU for *E.coli*, total nitrogen, ammonia as Nitrogen, total phosphorus, and TSS. Additional parameters analyzed in the field were pH, conductivity, DO, and temperature. Historical data (pollutants and flow) spanning 1980 to December 2020 were compiled from various sources, including TCEQ SWQM program, City of Plano monitoring data, and NCTCOG monitoring data. The water quality monitoring data was compared to TCEQ surface water quality standards, TCEQ screening levels, and EPA screening levels. Modeling was completed by AgriLife to support development of LDC's and FDCs in order to determine impairments or exceedances as well as analyze the impact of land cover between Site 1 and Site 5.

*E.coli*

The site 1 and site 5 *E.coli* geomean is 627.45 MPN/100mL of water and 423.67 MPN/100 ml of water respectively. The load regression curve for both sites is greater than the allowable *E.coli* load at geomean criterion of 126 MPN/day. *E.coli* loading exceeds the limit established by TCEQ. A large percentage in reduction is needed at all flow conditions: High Flow, Moist Conditions, Mid-Range Conditions, Dry Conditions, and Low Flows. High flow conditions are considered not feasible to manage. However, moist conditions and mid-range conditions indicate non-point source issues. Dry conditions and low flows can be attributed to point source issues. An additional analysis was completed to further compare Site 1 and Site 5 land cover conditions with flow and pollutant loading that supported these findings and also identified that *E.coli* is a watershed wide issue.

### *Nitrate+Nitrite*

The site 1 nitrate+nitrite average grab sample concentration is 1.24 mg/L. The load regression curve is lower and does not exceed the screening limit of 1.95 mg/L. No reductions are needed at site 1. The correlation coefficient between flow and grab sample was -0.02 indicating that the relationship is weak. This supports the findings of the LDC that non-point source runoff of nitrate+nitrite does not impact Rowlett creek headwaters. For Site 5, the nitrate+nitrite average is 3.92 mg/L and exceeds the TCEQ screening level concern of 1.95 mg/L. The load regression curve exceeds the allowable Nitrate in all conditions, albeit by 1% in High flows. Percentage reduction is needed at all flow conditions: High Flow, Moist Conditions, Mid-Range Conditions, Dry Conditions, and Low Flows. High flow conditions are considered not feasible to manage. However, moist conditions and mid-range conditions indicate non-point source issues. Dry conditions and low flows are point source issues. An additional analysis was completed to further compare Site 1 and Site 5 land cover land cover conditions with flow and pollutant loading that identified nitrate+nitrite is not of concern in upper Rowlett Creek subwatershed based on land cover, but is a concern based on land cover in the midbasin and outlet to Lake Ray Hubbard.

### *Ammonia*

The site 1 ammonia as Nitrogen average is 0.15 mg/L. The load regression curve is lower and does not exceed the screening limit of 0.33 mg/L. No reductions are needed at site 1. The site 5 ammonia as Nitrogen average is 0.510 mg/L and exceeds the TCEQ screening level concern of 0.33mg/L. However, only 12 of 73 grab samples exceeded the screening level. The load regression curve is lower and does not exceed the screening limit of 0.33 mg/L. No reductions are needed at site 5. An additional analysis was completed to further compare Site 1 and Site 5 land cover conditions with flow and pollutant loading that identified that land cover does impact ammonia loading in the stream systems during high, moist, and mid-range conditions. Further, a WWTP upstream may be contributing to increased ammonia loading during dry and low flow conditions.

### *Total Suspended Solids*

The Trinity River basin is naturally turbid and there is no screening limit or standard for TSS in Rowlett Creek. If waters are highly turbid or have high suspended sediment loads, it will decrease light penetration and thus limit productivity. Figure 23 and Figure 24 displays the computation of load duration of TSS in tons/day spanning high flows to low flows from dates ranging March 2020 to December 2020 at site 1 and 5. An additional analysis was completed to further compare Site 1 and Site 5 land cover conditions with flow and pollutant loading that identified that land cover does impact TSS loading in the stream systems during all conditions. High, moist, and mid-range conditions carry non-point source pollutants. Based on land use analysis from SWAT modeling provided by AgriLife, 92% of the watershed has impervious surfaces. This further supports the finding that TSS loading from non-point source runoff during storm events significantly increases throughout the midbasin.

### *Total Kjeldahl Nitrogen*

There was no historical data that analyzed or detected for TKN near site 1. In addition, only 4 out of the 28 samples analyzed from March to December 2020 detected TKN, 3 out of 4 values were greater than the detection limit of 0.4 mg/L. Therefore, it is impossible to make any conclusive statement whether the TKN is of concern or not, since the limited data set did not allow for a quantitative analysis. As for TKN at site 5, the average concentration was 1.63 mg/L and thus exceeds the EPA screening level concern. Based on historical and current data analysis the load regression curve is greater than and does not intersect with allowable or maximum allowable pollutant load, thus indicating load reduction is required. The correlation coefficient between flow and grab sample was 0.56 indicating a strong correlation which is consistent with the findings in the Load Duration Curve. Therefore, TKN is a non-point source runoff concern and potentially a point source concern. A land cover analysis could not be completed due to insufficient data.

### *Total Phosphorus*

Total phosphorus screening limit for streams regulated by TCEQ is 0.69 mg/L. There was no historical data that analyzed or detected for total phosphorous near Site 1. In addition, only five out of the 28 samples analyzed from March 2020 to December 2020 detected total phosphorus at site 1, which were under the limit of 0.69 mg/L. Therefore, total phosphorus is not of concern at site 1, although the limited data set cannot allow for a quantitative analysis.

As for total phosphorus at site 5, the average concentration was 0.54 mg/L and thus does not exceed a screening level concern. Based on historical and current data analysis the load regression curve never intersected with allowable or maximum allowable pollutant load, thus suggesting no load reduction is required. The correlation coefficient between flow and grab sample was -0.05 indicating a weak correlation which is consistent with the findings in the Load Duration Curve. Therefore, Total phosphorus is not a non-point source runoff concern.

*Best Management Practices*

Green infrastructure and homeowner education may be the best management implementation strategies to remediate impairments and concerns. Further, the composition of livestock in the area ranges from 137 chickens, 2,283 cows, 588 horses, 65 pigs/hogs/swine, 818 sheep, and 17 turkeys based on USDA assessment from Model My Watershed, 2021. Livestock can be associated with *E.coli* and nutrient concerns. Bacterial Source Tracing was unable to be conducted in this study, but should be part of future research in order to determine where the source of *E.coli* stems from. Nitrogen was found to only be of concern at the outlet to Lake Ray Hubbard which leads to the conclusion that runoff from residential and landowner fertilizers, as well as WWTP discharge should be the main points addressed. Further, it could be that there has been significant scouring within the stream system itself that plant growth is inhibited or impaired preventing the normal uptake of nitrogen to be significantly reduced.

One objective of the study was to determine if in fact land cover does have an impact on the concentration of pollutants that runoff washes into stream. As stated prior, 92% of the watershed has impervious surfaces. It was found that in some cases land cover does impact runoff and the water quality of the urban watershed, as flow increased over higher density land cover, some pollutants did not increase similarly, they increased exponentially. In Dry conditions, no runoff is expected 75% of the time and flow increased 412% from the Rowlett creek headwaters to the outlet to Lake Ray Hubbard. For pollutants of concern – E.coli and Nitrogen, they increased 101% and 1800% respectively. This would lead one to assume that point source is the concern, however, the consistent irrigation on private property and misuse of fertilizers as well as disregard for sanitation (not picking up pet waste) could result in this increase. This concludes that homeowner education as well as green infrastructure is needed.

The implications of this data are crucial for highlighting the need for green infrastructure, but more importantly adequately addressing standard operating procedures for green infrastructure implementation in local codes, state legislation, and even federal law, for example, making a national building code standard. This also includes outlining adequate inspection requirements/post-construction inspection. Further, there is a need for increased land conservation in order to preserve the remaining open land and riparian zones.

*Lessons learned –Limitations*

The installation of water quality sampling devices (ISCOs) proved to be a consistent problem. They required consistent maintenance, trouble shooting, and relocating. Next steps include developing an innovative way to keep the equipment in place in the clay substrate. The original objective of this study was to analyze 5 sites throughout the watershed, targeting multiple tributaries with the confluence with Rowlett Creek with routine sampling as well as stormwater sampling. The research was significantly reduced to analyze only the headwaters of Rowlett creek and the effluent of Rowlett creek to Lake Ray Hubbard due to site challenges, equipment challenges and technical challenges. A back up sampling plan, site locations, and equipment is suggested. In addition, analyses of instantaneous flow was unavailable due to lack of access to a flow meter. It is in the best interest of future studies to insure a flow meter is used to insure flow data can be analyzed simultaneously with grab samples instead of relying on modeled flow and thus reducing assumptions of flow.

## 4.2 Recommendations for future work

One recommendation for future work includes conducting targeted flow research as well as bacteria source tracking in order to determine what species are in fact contributing to the *E.coli* impairment.  A second recommendation would be to include more sample sites within the midbasin of Rowlett Creek watershed since there are multiple tributaries including a higher order stream, Spring Creek, that is heavily urbanized. Extensive ground truthing should be used when trying to identify sources, this can include an extensive land cover and land use survey and infrastructure assessments. Load Duration Curves should be performed for each subwatershed within Rowlett Creek in order to refine non-point or point source impairment. Further, use of SELECT or SWAT to model subwatersheds for a more refined analysis of where the impairment may be stemming from. The input from stakeholders in the watershed should also be taken into account in order to determine specific pollutant sources for development of a watershed protection plan.

Further research is needed on disturbed urban soils that leads to compaction and reduces infiltration capabilities of the natural soil as well as linear regression analysis on land use versus water quality. Green infrastructure strategies and their expected pollutant removals should be outlined and compared to the need in Rowlett Creek Watershed. WWTP data should be compared to loadings found during dry and low flows.

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