Village Creek-Lake Arlington Watershed Protection Plan

developed by

The Village Creek-Lake Arlington Watershed Protection Partnership

May 2019

Village Creek
Lake Arlington
WATERSHED
PROTECTION

Trinity River Authority of Texas

On the cover:
Birdhouse in a green ash tree,
found on an embankment in the
southern extent of Lake Arlington.

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Funded by

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Investigating Entities

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List of Acronyms

AU	Assessment Unit/Animal Unit
AVMA	American Veterinary Medical Association
BMP	best management practice
BOD_5	5-day biological oxygen demand
CCN	Certificate of Convenience and Necessity
CDP	Census-designated place
cfu	colony-forming units
chl-a	chlorophyll-a
CRP	Clean Rivers Program
CWA	Clean Water Act
DO	dissolved oxygen
DFW	Dallas-Fort Worth metropolitan area
DR	Designated Representative
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
ESA	Environmentally-sensitive area
FDC	flow duration curve
FWS	U.S. Fish and Wildlife Service
GIS	geographic information system
IDDE	Illicit Discharge Detection and Elimination
I/I	Inflow and Infiltration
LAMP	Lake Arlington Master Plan
LDC	load duration curve
LULC	land use/land cover
MSL	mean sea level
MS4	Municipal Separate Stormwater Sewer System
MoS	margin of safety
MPN	most probable number
NHD	National Hydrography Dataset
NCTCOG	North Central Texas Council of Governments
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NWS	National Weather Service
OP	orthophosphate-phosphorus
OSSF	on-site sewage facility
pH	potential hydrogen
POR	period of record
ROW	right-of-way
RRC	Texas Railroad Commission
RV	recreational vehicle
§	section of a book or document
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SSO	sanitary sewer overflow
SUD	Special Utility District
SWCD	Soil & Water Conservation District
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TAG	Technical Advisory Group
TCEQ	Texas Commission on Environmental Quality
TCWSP	Tarrant County Water Supply Project
TDS	Total Dissolved Solids
TIAER	Texas Institute for Applied Environmental Research
TKN	total Kjeldahl nitrogen
TP	total phosphorous
TPWD	Texas Parks and Wildlife Service
TRA	Trinity River Authority of Texas
TRWD	Tarrant Regional Water District
TSS	total suspended solids
TSSWCB	Texas State Soil & Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
VCLA	Village Creek-Lake Arlington Watershed
WPP	watershed protection plan
WTP	water treatment plant
WWTF	wastewater treatment facility

Executive Summary

Lake Arlington is a reservoir located in southern Tarrant County, forming part of the boundary between the cities of Arlington and Fort Worth. The lake is fed primarily by Village Creek, a tributary of the West Fork of the Trinity River with a contributing watershed that headwaters in northern Johnson County, flowing northward to feed Lake Arlington. This watershed spans 28 river miles and covers 143 square miles (91,402 acres). Lake Arlington supplies water to the citizens of Arlington, but also to several other cities within Tarrant County (Bedford, Colleyville, and Euless, along with portions of Grapevine and North Richland Hills). Recreation is popular on the lake, and is a popular destination for anglers looking for catfish or largemouth bass in particular.

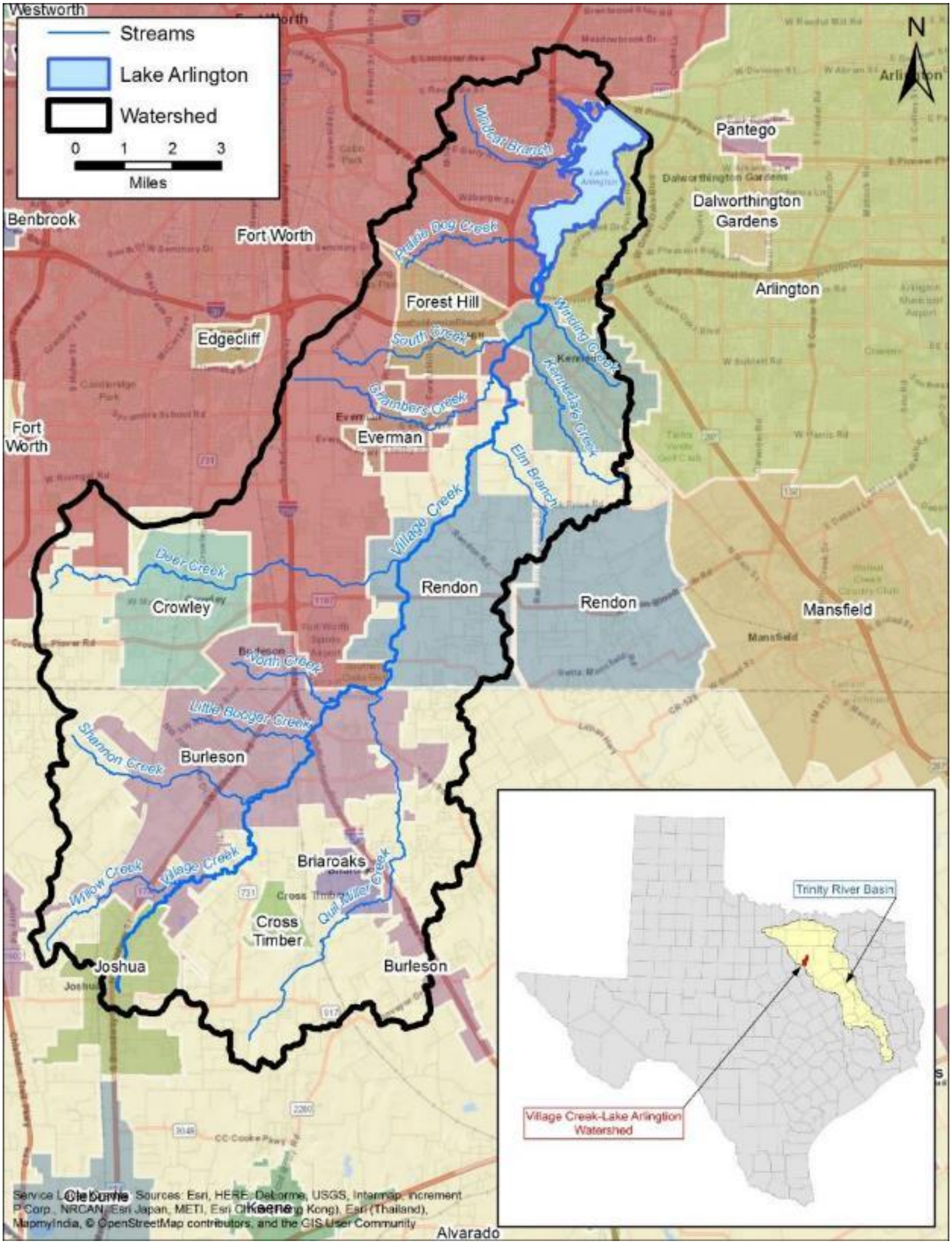
Portions of ten incorporated communities and one census-designated place call the watershed home, varying in population from nearly 400,000 down to less than 300. The majority of the watershed surrounding the lake is urbanized, as is the area around the city of Burleson. Although the majority of the urban areas around the lake are fully built-out, there exists significant potential for urban growth in the southern extent of the watershed around Burleson and Joshua. Currently, these areas consist of mostly undeveloped land, with pasture, grassland, and deciduous forest being prominent both to the south and east of the watershed. In these areas, cattle are the most prominent livestock species, constituting just over half of the estimated livestock population in the watershed. The remainder is composed of nearly equal representation from sheep, goats, and horses. These three species, while well-represented in more rural areas, were also observed with frequency in many lower-density urban areas in the watershed, on small-acreage properties commonly referred to as "hobby farms." Industry appears to be most dense within the stretch of land just south of the lake along the I-20 interstate highway corridor, but examples of larger industrial complexes can be found throughout the watershed.

The Need for a Plan

Village Creek was first listed for a recreational use impairment due to excessive levels of *E. coli* bacteria in the 2010 *Texas Commission on Environmental Quality Integrated Report for Surface Water Quality.* Successive reports published in 2012 and 2014 indicated that the creek was becoming progressively more impaired. At the time this watershed protection plan was being developed, the approved 2016 Integrated Report was not yet available for use. Current data places Village Creek at a geometric mean of 302 MPN/100 mL, more than double the state standard of 126 MPN/100 mL for water bodies designated for primary contact recreation. This impairment applies to the entire waterbody, designated as assessment unit 0828_A. While this impairment does not extend to Lake Arlington, the lake does exhibit levels of nitrate and chlorophyll-a that constitute general use concerns in the lake. Chlorophyll-a is by far the longest-standing concern, first listed in 2006 with appearances in every biennial report since. The latest data from 2014 places three lake assessment units, 0828_02, 0828_05, and 0828_6, at geometric means between 44.96 and 48.99 µg/L, which exceeds the screening level of 26.7 µg/L. Nitrate first appeared on the concerns list in 2012 and again in 2014, but only in an assessment unit 0828_07. In this unit, nitrate reached 0.47 mg/L in the 2014 report, exceeding the screening level of 0.37 mg/L for lakes.

Stakeholders Take Action

Efforts to address these impairments and concerns began well before the conception of this WPP, with the earliest efforts beginning in 2011 as area stakeholders began to meet to discuss the Lake Arlington Master Plan, an initiative sponsored by the City of Arlington. This was followed by a study of ecological sensitivity in the Village Creek-Lake Arlington watershed, led by the North Central Texas Council of Governments, in partnership with the Trust for Public Land. In 2012, Kennedale followed on the heels of these efforts with its own Village Creek Master Plan. Though they vary in scope and intent, these three studies laid the foundations for discussions that would eventually lead to the suggestion of potentially developing a watershed protection plan for the Village Creek-Lake Arlington watershed. Coordination between the City of Arlington, the Texas Commission on Environmental Quality, and the Trinity River Authority ensued, and in 2015, these entities began developing the Village Creek-Lake Arlington Watershed Protection Plan.



Basemap: ESRI World Streetmap; Stream data source: National Hydrography Dataset (NHD).

Location of Village Creek-Lake Arlington Watershed.

Over the course of the next three years, stakeholders gathered to form the Village Creek-Lake Arlington Watershed Partnership, meeting to discuss priorities for water quality improvements and strategies for preventing further degradation. Development of the plan took place over the course of 16 meetings between the general Partnership and its subcommittees. Meetings were open to the public, represented by attendees from watershed residents, businesses, municipal and county staff, other public officials, and state/federal agency staff. From the onset, Partnership members clearly defined their goals of improving water quality in Village Creek and protecting water quality in Lake Arlington, while simultaneously accounting for the socio-economic needs and recreational wants of those that live, work, and play in the VCLA watershed.

Addressing Pollutant Sources

A watershed characterization was initiated during the first year of the project, providing additional water quality data for stakeholders to use in their quest to identify potential pollutant sources. Through the use of several pollutant load calculation techniques, it was determined that pet waste, livestock, feral hogs, and septic systems were significant sources of *E. coli.* However, after much discussion about the relative cost effectiveness of the best management practices associated with reducing loads for each of these pollutant source categories, stakeholders were able to adjust their priorities, focus on managing modeled sources that could be managed more efficiently, and were even able to incorporate management measures to address some important non-modeled sources, including illegal dumping, lawn wastes, and residue. While these two sources are not directly related to significant *E. coli* loads, both still present real threats to water quality if left unchecked, so stakeholders chose to make these additional priorities in addition to the efforts focused on *E. coli* load reductions.

Researchers associated with the WPP used the collected water quality data to determine that a reduction of 72% in *E. coli* concentrations would be needed to meet the state water quality standard for primary contact recreation and maintain a 10% margin of safety to account for uncertainties inherent to the planning, research, and implementation strategies associated with the WPP effort. Data was also used to set interim milestones to guide progress in pursuit of water quality goals. Due to a lack of numeric criteria and available data, numeric goals were not set for other pollutants, but goals and interim milestones using other metrics, such as reductions in the number of sanitary sewer overflow events) were dictated whenever it was appropriate to do so. It was determined that the majority of pollutant sources in the watershed were nonpoint sources and therefore closely related to stormwater runoff. Because of this, it is likely that many of the management measures purposed for *E. coli* reductions will likely also reduce a number of other pollutants, including nutrients (like nitrate), sediments, and other hazardous substances that could become pollutants in the future.

Recommended Actions

Based on their evaluation of the monitoring, modeling, and survey data collected during earlier stages of the WPP, Partnership members recommended several management practices targeted to *E. coli* reductions, with expectations that other known and emerging pollutants would also be attenuated along with *E. coli* when the management measures are applied. Additional recommendations were made to gather more information regarding illegal dumping activities, illicit discharges, and other stormwater-related sources, so that efforts to address these concerns can be mobilized quickly during the implementation stages of the WPP.

Dogs and Cats

Pets are a significant source of *E. coli* in the watershed. Stakeholders immediately recognized that efforts put towards reducing loads from pet waste, specifically from dogs as well as outdoor, feral, or barn cats, would provide significant reductions with high cost-effectiveness. Recommendations made by the stakeholder group include the development and adoption of model pet waste ordinances and by-laws to help combat bad actors that leave pet waste in public areas, installation of additional pet waste stations in high-need areas throughout the watershed, and promotion and installation of pet waste digesters for homeowners to help reduce the incidence of pet waste-borne *E. coli* entering waterways from their backyards.

Illegal Dumping

Illegal dumping was a significant concern for stakeholders in the VCLA watershed, and addressing the problem early in implementation quickly became a priority. To support this effort, early grant funding requests are expected to incorporate support for wider-ranging and more frequent surveys of the watershed to locate popular illegal dumpsites so that the proper enforcement entities have the necessary information to move forward with cleanup efforts. Hazardous household waste pickup days for rural/unincorporated areas were also identified as a need, as was expansion of current lake cleanup events to extend into the Village Creek watershed to be inclusive of communities in the southern extent of the watershed.

Lawn Residue and Waste

Development of model lawn residue and waste ordinances and by-laws to discourage residents and businesses from disposing of organic lawn waste into stormwater drains and/or overuse lawn chemicals was seen as a priority to reduce impacts to aquatic health in the creeks and the lake. Existing landowner resources promoting land management, green infrastructure, proper irrigation, soil health, and herbicide/pesticide application were also seen as valuable resources.

Livestock

Agricultural management measures have been a mainstay of the watershed planning process, and are popular options for incorporation into WPPs due to their flexibility in aggregating a number of smaller land, forage, and animal management practices into cohesive, whole-farm or whole-ranch plans that are developed by local resource technicians to meet the needs of the watershed.

Feral Hogs

While feral hogs did prove to be a significant source of *E. coli* loading in the watershed, stakeholders understood that attempts to manage the population would be costly, resource-intensive, and would likely only provide minimum returns on investment. To that end, management recommendations focus on using existing or voluntary measures such as landowner agreements to construct exclusionary fencing around attractive nuisances (e.g. game feeders), and shoot-on-site tactics. In addition to limited funding identified for creation and management of a framework designed to connect landowners to a network of trappers, trapping programs, and other feral hog-related resources, Partnership members also outlined funding for a municipal trap share program, if the need and desire to move forward with a coordinated trapping program arises in the future.

Sanitary Sewer Overflows

It is understood that the majority of corrective activities associated with sanitary sewer overflows falls outside of the purview of the Clean Water Act Section 319(h) program, but stakeholders still recognized opportunities to assist wastewater infrastructure managers with identification of potential SSOs. The implementation of stormwater infrastructure assessments designed to identify illicit wastewater connections, proper placement and abundance of storm drains, and the identification of other opportunities to improve stormwater conveyance, will help minimize impacts from infiltration and inflow from stormwater systems. This assessment will help identify infiltration into wastewater infrastructure and reduce pollution from sanitary sewer overflows.

Septic Systems

Retrofitting and replacing failing septic systems is a proven method of reducing pollution. However, significant installation costs can quickly exhaust available implementation funding with a lower return on investment when compared with other management activities. Instead, the Partnership focused on incentivizing septic inspections and pumpouts, with system retrofits and complete replacements identified as a secondary component. Neighborhood-wide events to take advantage of cost savings for inspections and pumpouts were also identified as viable management measure. Emphasis was also placed on promotion of “septic to sewer” initiatives available for residents in areas covered by centralized wastewater systems but have yet to make the switch from their existing septic system.

Education and Outreach

In general, education and outreach initiatives will be tied to the physical and programmatic management measures covered in the previous section. Various examples include:

- Implementation of existing resources highlighting the importance of proper pet waste disposal;
- Development of educational materials for novel or under-utilized pet waste management methods;

- Land conservation education for new owners of hobby farms with no prior farming experience;
- Continued development and delivery of feral hog educational workshops;
- Coordination with other entities on existing, successful campaigns for littering and illegal dumping;
- Implementation of "Water Wise" programming for homeowners and lawn care professionals regarding proper stormwater management techniques associated with home and lawn care;
- Implementation of existing septic system maintenance training for homeowners; and
- Development of new training for professionals like real estate agents to reduce the likelihood of system failure and surface water contamination.

Tracking Implementation Progress

To track implementation progress and improvements in water quality, it will be necessary to continue routine water quality monitoring in the watershed. There may also be a need to supplement this broad scoped monitoring effort with more targeted monitoring, which could be catered to a specific source, location, or management measure of interest. As the needs of the watershed progress, flexibility in the monitoring program will be imperative so that researchers can adapt to the monitoring needs as new developments arise. Future changes in water quality, along with implementation updates and other relevant news, will be conveyed to stakeholders in a manner agreed upon by the Partnership. An annual newsletter will be provided over the 10-year implementation period, with meetings held on an as-needed basis.

What's Next?

In the coming years, the Village Creek-Lake Arlington Watershed Protection Partnership will continue to convene, at a frequency and manner that is agreed upon by the Partnership, with an annual meeting as a minimum. These meetings will be designed to provide attendees with updates on implementation progress, covering active and completed projects, along with any water quality or aesthetic improvements these projects exemplified. These meetings will also serve as checkpoints to evaluate implementation progress and to determine whether adaptive management techniques will be needed to ensure projects stay on course in pursuit of water quality goals so that future generations may benefit from the work done in the present to protect the valuable resources in the Village Creek-Lake Arlington Watershed.

Morning dew on a web overlooking Village Creek at the US 287 BUS bridge in Kennedale, TX.

1.0 Watershed Management

1.1 Watersheds and Water Quality

A watershed is the land area that drains water to a common point such as a stream, river, lake, wetland, or ocean. Watersheds can be very small, such as part of a park that drains to the creek in your neighborhood. Many of these small watersheds combine to form much larger watersheds, such as major river basins that drain large portions of states, and in some cases, cover large portions of countries or continents. For example, several sub-watersheds make up the Village Creek watershed, which is itself part of the Trinity River basin (Figure 1-1).

No matter where you are on the Earth, you're in a watershed. As runoff water from storms flows across the landscape, it picks up and carries sediment and various other substances as it flows to a waterway. This means that everything we do on the land affects both water quality and quantity, and the cumulative effects can impact the function and health of the whole watershed.

An effective watershed management strategy will show a measurable effect on the water quality of the receiving waterbody. To accomplish this, the strategy must account for and examine the full scope of human activities and natural processes that occur within the watershed's boundary.

1.2 The Watershed Approach

Watersheds often contain parts of many municipalities and counties, and may even cross state lines. This often makes it difficult for any one entity to approach and solve water quality concerns on their own. To address this constraint, many state resource agencies, in partnership with federal agencies, have adopted a *watershed approach* for managing water quality, which involves assessing the sources and impacts of water quality impairments at the watershed level. That information can be used to develop and implement best management practices (BMPs) that are applicable throughout the entire watershed.

Figure 1-1. Conceptual interpretation of the Village Creek-Lake Arlington watershed system.

Utilizing a watershed approach greatly improves the chances of identifying and evaluating all potential pollution sources to a waterway. A key component of the watershed approach is the input from stakeholders, who may be anyone that has an interest in the watershed. These stakeholders may offer unique insights and experiences gained from either working, living, or engaging in recreation in the watershed. These insights and experiences will supplement water quality monitoring data to help inform management decisions that are put into practice. As users of the watershed, stakeholders have a vested interest in the water quality, and will also be affected by the management decisions used to address water quality issues.

1.3 Watershed Protection Planning

To support stakeholders who wish to utilize this watershed approach, the U.S. Environmental Protection Agency (EPA) has developed a list of *nine key elements* necessary for developing a successful watershed protection plan (WPP) capable of addressing water quality issues. A WPP document outlines the coordinated efforts of all stakeholder groups as they plan to implement a prioritized set of water quality protection and restoration strategies. Details about these elements, as well as the WPP chapters they correspond to, are provided in Appendix A: Key Elements of Successful WPPs.

The intent of the Village Creek-Lake Arlington (VCLA) WPP is to empower stakeholders to implement these strategies through voluntary participation in pursuit of the environmental goals they set themselves. Public participation is a critical component throughout the process, as it is up to stakeholders to select, design, and implement management strategies best suited for the watershed from the standpoints of economic feasibility, social acceptability, and scientific credibility. The success of the VCLA WPP is dependent on the continued commitment of residents, landowners, businesses, and elected officials to act as good stewards of the natural resources of the watershed.

1.4 The Village Creek-Lake Arlington Watershed Protection Partnership

Effective WPPs utilize local knowledge and expertise to guide the planning process, ensuring that the BMPs selected for implementation are relevant to the watershed's issues, applicable to the environmental setting of the watershed, and feasible for the watershed residents, given available resources. If this process is followed, local stakeholders are more likely to modify their behaviors and adopt the BMPs identified in the Plan.

1.4.1 Formation

The VCLA Watershed Protection Partnership (Partnership) effort was initiated to address water quality concerns in both Lake Arlington (segment 0828) and its tributaries. Drinking water from Lake Arlington is utilized by over half a million people in both the city of Arlington and other communities throughout Tarrant County. Although Lake Arlington is currently fully supporting its drinking water use, several assessment units (AUs) of Lake Arlington are listed on the TCEQ 2014 Water Quality Inventory—Water Bodies with Concerns for Use Attainment and Screening Levels for chlorophyll-a (chl-a) and nitrate (TCEQ, 2015a). The lake's main tributary, Village Creek, has been listed on TCEQ's Texas Water Quality Inventory-303(d) List as impaired for bacteria since 2010 (TCEQ, 2015b).

Rapid and often unsustainable development around the lake and within the watershed has and will continue to negatively affect water quality over time, as indicated by previous studies conducted for the watershed, namely the 2011 Lake Arlington Master Plan (LAMP) (Malcolm Pirnie and Arcadis U.S., 2011), the 2011 Greenprint Study conducted by the Trust for Public Land (TPL, 2011), and the Village Creek Master Plan and Flood Study developed for the City of Kennedale (Halff, 2012). To combat this degradation, local stakeholders have elected to take a proactive approach to establish appropriate management measures to ensure that the water quality in the lake is protected.

As part of the process for developing the LAMP, stakeholders were identified and their participation was elicited. Beginning in 2011, bimonthly stakeholder meetings within the Lake Arlington watershed were held to discuss opportunities to collaborate on watershed protection. This activity was instrumental in creating the Clean Water Act (CWA) Section (§) 319(h) grant application. An assessment of the LAMP was undertaken in May 2012 by these stakeholders to identify and prioritize the suggested projects. During the development of the LAMP, the results of the sampling and modeling efforts identified nutrients and chl-a as important parameters of concern. While well-suited to the objectives of the LAMP, the sampling and modeling performed was not of sufficient quantity and specificity to allow for load reductions to be calculated for existing impairments. To address this need and ensure eligibility for federal assistance for water quality protections and improvements through the CWA § 319(h) grant program, the group made the recommendation to pursue a watershed-based plan effort. This, along with support from those parties involved with the Greenprint Study and the Village Creek Master Plan, provided the support base needed to begin orchestrating a concerted stakeholder effort in the watershed.

1.4.2 Structure

The public effort for the Partnership consists of three stakeholder groups, each with its own set of responsibilities and focus areas. To ensure that watershed interests are well-represented, there is a continued effort by the project team to maintain stakeholder representation that is well-distributed, both spatially throughout the watershed, and topically amongst multiple users with varying needs.

General Membership

The Partnership functions as the overall stakeholder group, consisting of all stakeholders, including subgroup members and general members. As such, there are no formal membership requirements, and members may come and go as they please. Partnership meetings serve as a public forum for stakeholder concerns and updates on project progress.

Steering Committee

To facilitate the decision-making process, a core group of stakeholders presently act as the voting body of the Partnership, known as the Steering Committee (Committee). The Committee has and will continue to vote on key watershed decisions and review potential water quality improvement BMPs for applicability in the watershed.

The intent of creating the Committee is to foster a wide representation of varied focus groups, including local landowners, businesses, and government officials. These focus groups represent areas of shared knowledge and interest, capable of providing valuable feedback from a variety of perspectives. A list of members and focus groups is provided in Figure 1-2.

Steering Committee (17 members)

Municipalities (4)

- City #1 (Lake Arlington area)
- City #2 (Village Creek area)
- City #3 (at large)
- City #4 (at large)

Private Landowners (4)

- Rep #1 (Lake Arlington area)
- Rep #2 (Village Creek area)
- Rep #3 (Ag/Rancher)
- Rep #4 (at large)

Counties (1)

- Public Health (Johnson or Tarrant Co.)

Local Resource Agencies (2)

- SWCD Rep (Dalworth or Johnson District)
- Ag Extension Agent (Johnson or Tarrant Co.)

Regional Water Entities (2)

- Rep #1
- Rep #2

Industry (2)

- Food/Beverage
- Energy

Education (2)

- 4-year institution
- 2-year institution

Figure 1-2. Steering Committee membership and focus groups.

Technical Advisory Group

The Partnership also saw a need to create a second stakeholder subgroup capable of providing technical guidance, resource information, and funding opportunities to both the Committee and the Partnership. This technical advisory group (TAG) will serve strictly in an advisory capacity with no formal voting power, making recommendations to the Partnership and Committee as needed. A list of participating entities is provided in Figure 1-3.

Technical Advisory Group (12 members)

- North Central Texas Council of Governments (NCTCOG)
- Natural Resource Conservation Service (NRCS)
- Railroad Commission of Texas (RRC)
- Texas AgriLife Extension & Research (AgriLife)
- Texas Commission on Environmental Quality (TCEQ)
- Texas Institute for Applied Environmental Research (TIAER)
- Texas Parks & Wildlife Department (TPWD)
- Trinity River Authority of Texas (TRA)
- Tarrant Regional Water District (TRWD)
- U.S. Environmental Protection Agency (EPA)
- U.S. Fish & Wildlife Service (FWS)
- U.S. Geological Survey (USGS)

Figure 1-3. Technical Advisory Group membership.

1.4.3 Coordinated Development of the Plan

Development of the Plan was achieved through the combined efforts of the Steering Committee, TAG, and general Partnership over the course of a 29-month period. Partnership members were instrumental in identifying BMPs and strategies that proved useful from their diverse experiences, and the TAG was useful in providing technical information towards these practices' potential benefits. The Committee used information from both groups to recommend which BMPs were the best fit for the VCLA watershed and its residents.

Ultimately, this information was used by the Committee to evaluate the BMPs that need to be implemented to achieve the desired water quality goals. This process involves continued communication between all three groups as they identify measurable milestones for these goals and prioritize specific BMPs. This may require review and revision of the Plan through the use of adaptive management techniques, as well as the effective communication of valuable information about the impacts of the Plan to other interested or affected entities, both within and outside of the watershed.

Achieving improvements in water quality will not be a short-term effort and will continue long after the initial planning period is complete. Even after the Plan's water quality goals are achieved, continued preservation of these goals and long-term protection of the watershed is necessary. As such, the Steering Committee will continue to be a functional group throughout the implementation period of the Plan, as successive components of the Plan are put into practice throughout the VCLA watershed. These programs and practices will require periodic evaluation of their results through the use of continued water quality monitoring, which will be targeted to interim and long-term milestones. Through these evaluations, adaptive management techniques will be used to reassess the recommended strategies used in the watershed.

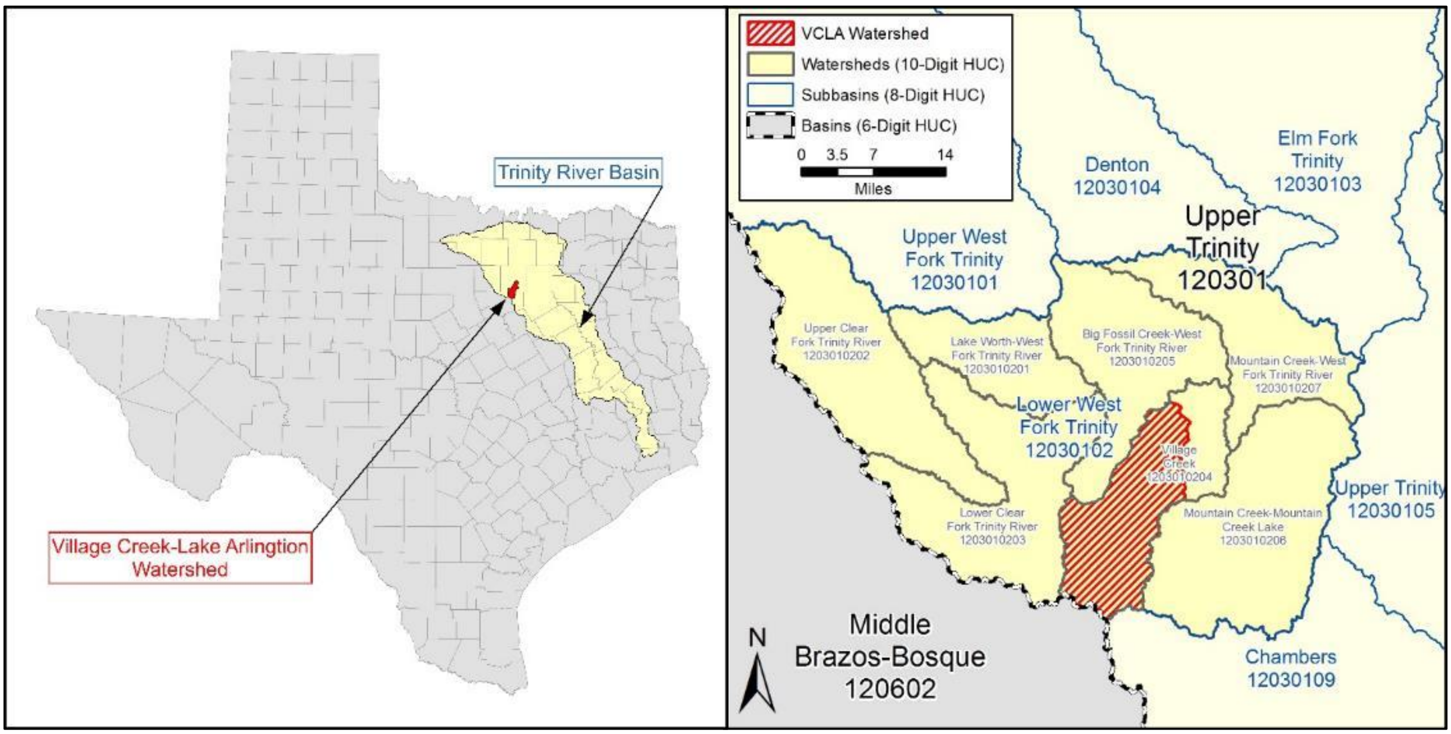
Watershed stakeholders attending the Texas Riparian & Stream Ecosystems Workshop in Arlington, TX.

2.0 Watershed Overview

2.1 Geography

The VCLA watershed extends approximately 28 river miles from its headwaters near the City of Joshua in Johnson County to the Lake Arlington dam in Tarrant County. Elevations in the watershed range from 1,065 ft above mean sea level (MSL) at Caddo Peak in the headwaters of Willow Creek west of Joshua in Johnson County, down to 550 ft above MSL at the normal conservation pool elevation of Lake Arlington.

The watershed contains two TCEQ-designated segments, Lake Arlington (0828), and Village Creek (0828A). The entire drainage area behind the Lake Arlington dam consists of approximately 143 mi^2, or 91,402 ac. The VCLA watershed is composed of a series of smaller watersheds that are defined by 12-digit hydrologic unit codes (HUC). These smaller HUCs then combine to form larger HUCs that are defined by 10, 8, 6, or 4 digits. For example, the VCLA watershed is actually composed of several subunits of the Village Creek watershed (10-digit hydrologic unit code (HUC): 1203010204). This is part of the Lower West Fork Trinity subbasin (HUC 12030102) which is part of the Upper Trinity River basin (HUC 120301) and the Trinity River subregion (HUC 1203) (Figure 2-1).



On the left: The Trinity Basin within the context of the state, with the location of the VCLA watershed in red. On the right: a closer view of the watersheds and nearby subbasins that interact with the VCLA watershed. Data Source: TWDB and TCEQ.

Figure 2-1. Location of the Village Creek-Lake Arlington watershed within the Trinity River Basin in Texas.

While Lake Arlington receives the majority of its flow from Village Creek, it will occasionally receive storm flows from other smaller tributaries along its perimeter. Wildcat Branch and Prairie Dog Creek are the largest tributaries on the west side of the lake, but they and the majority of the other direct lake tributaries are largely ephemeral in nature. There are a few smaller tributaries on the east bank that drain housing subdivisions. Steady baseflow is present in many of these eastern tributaries. Spring flow in Village Creek is rare, but several seeps have been identified midway through the watershed that may constitute some small portion of baseflow as well.

Village Creek itself is fed by several named tributaries, with Winding Creek, Kennedale Creek, and Elm Branch draining the area in the vicinity of Kennedale. Deer Creek drains Crowley and parts of northern Burleson, while Little Booger Creek, Shannon Creek, and Willow Creek drain the western portion of Burleson around IH-35. To the east, Quil Miller Creek drains a large rural area containing eastern Burleson, along with the towns of Briaroaks and Cross Timber. Population centers in the watershed include 10 municipalities and one census-designated place (CDP) (Table 2-1).

2.2 Geology and Soils

The VCLA watershed is largely located within the Grand Prairie physiographic province according to the Physiographic Map of Texas (BEG, 1996). The majority of the watershed is underlain by units from the Washita and Woodbine groups, with some fluviatile terrace deposits and alluvial floodplain deposits in areas underlying Lake Arlington and Village Creek.

Soils in the vicinity of the lake are composed mainly of fine sandy loams with silty clays near the transitional zone within Village Creek. Some of the more common upland soil groups in the watershed include Crosstell fine sandy loams, Sanger clays, Crosstell-Urban land complex, and Ponder clay loam. Several hydric soils occupy the bottom land areas of the watershed, with Frio silty clays, Pulexas fine sandy loam, and Hassee fine sandy loam being most common (USDA, 2015a, 2015b). For a more comprehensive list of soils in the watershed, visit the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) Soils Surveys developed for Johnson and Tarrant counties available online at: https://websoilsurvey.sc.egov.usda.gov/.

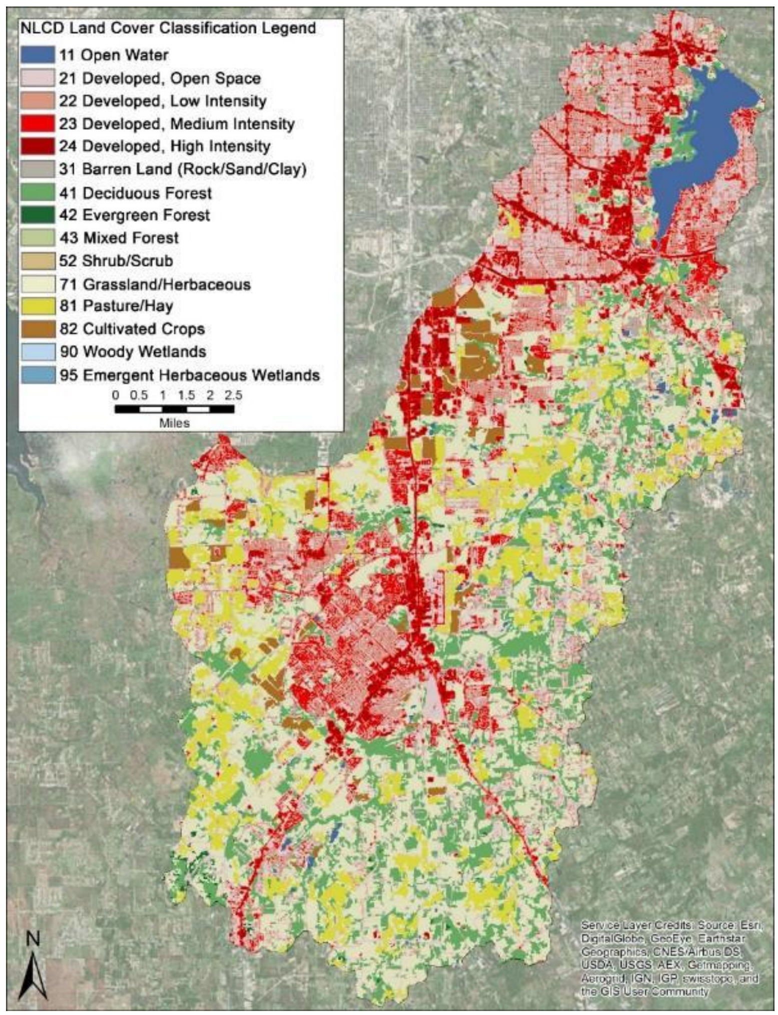
2.3 Land Use and Land Cover

The downstream portions of the watershed surrounding the lake are urbanized, while the upstream portions of the watershed have remained generally rural with some pastureland and row-crop agriculture. Major population centers include the city of Burleson and the communities of the southwest DFW Metroplex, which includes portions of Fort Worth and Arlington. These population centers compose the majority of the developed land in the area, shown in red on Figure 2-2. Land use within the watershed from 2013, based on data collected by the North Central Texas Council of Governments (NCTCOG), is depicted in Figure 2-3, which relates a use category (residential, industrial, undeveloped, etc.) to the land cover information. The urban centers previously mentioned are characterized by a high percentage of single family homes, but a significant percentage of industrial complexes are shown to exist immediately south and west of the lake. Outside of these urbanized areas, ranch land is dominant, with pockets of farm land and undeveloped lots being typical.

Table 2-1. Population centers in the VCLA watershed.

Name	2015 Population Estimate[a]	% of City Limit in Watershed[b]	Population in Watershed
Arlington	388,125	3.61%[c]	14,024
Briaroaks	496	100.00%	496
Burleson	43,625	89.16%	38,894
Cross Timber	275	100.00%	275
Crowley	14,853	100.00%	14,853
Everman	6,352	100.00%	6,352
Forest Hill	12,881	99.95%	12,874
Fort Worth	833,319	10.42%	86,856
Joshua	6,066	49.28%	2,989
Kennedale	7,715	84.08%	6,487
Rendon CDP	13,577[d]	48.29%	6,556

(a) U.S. Census Bureau estimate based on 2010 census projections.
(b) Calculated using TXDOT 2015 municipal boundary dataset.
(c) Excludes part of the city limits that lie within Lake Arlington's footprint.
(d) Based on the 2010 population and average 2010-2015 projected population increases for nearby municipalities.



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

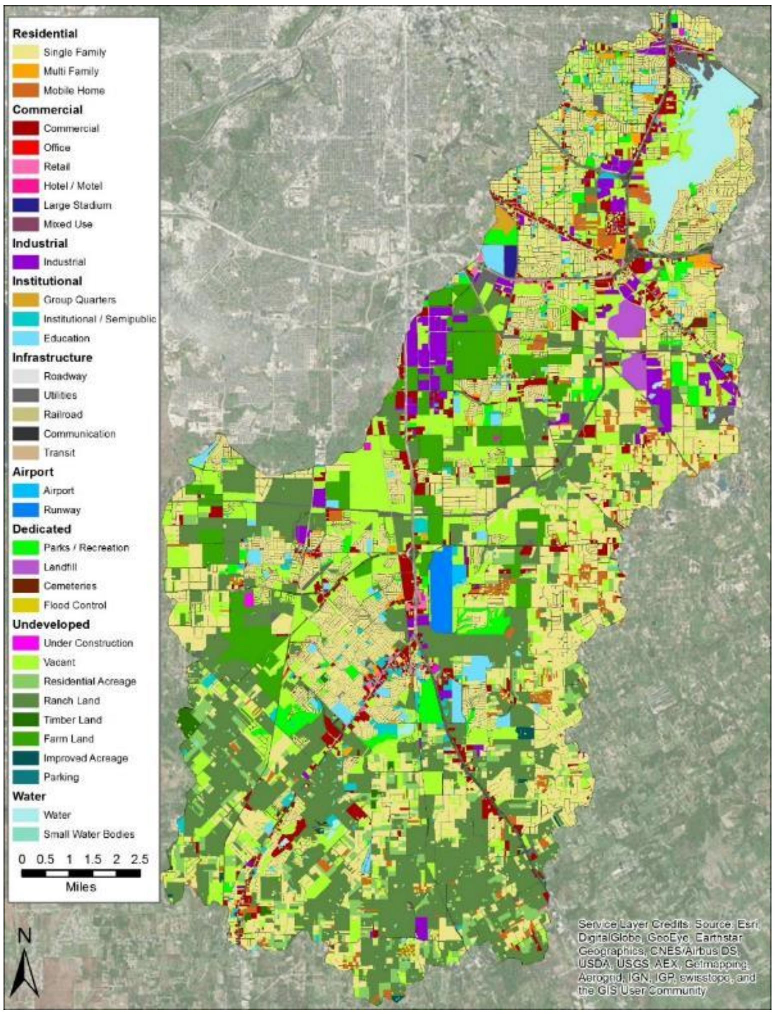
Figure 2-2. 2012 NLCD land cover classes in the watershed.

2.4 Ecology

The watershed is wholly situated within the Cross Timbers ecoregion. All of Lake Arlington is located in the Eastern Cross Timbers ecoregion (29b). Here, oaks are common overstory trees, along with hickory, redcedar, and various sumac species. Native grasses such as bluestem, Indiangrass, and dropseed are represented in the understory and prairie inclusions. The majority of Village Creek also falls within 29b, but the western portion of the watershed, including several smaller tributaries, is encompassed within the Grand Prairie ecoregion (29d). The upland area is dominated by tallgrass prairie species. In undisturbed areas, this includes bluestems, Indiangrass, gramas, and cupgrasses. In riparian bands, woody species such as elm, pecan, and hackberry are common (Griffith et al., 2007).

No critical habitat for any federally-listed threatened and endangered species exists in the watershed, but data from the U.S. Fish and Wildlife Service (FWS) and Texas Parks and Wildlife Department (TPWD) indicated several threatened and endangered species that may occur intermittently throughout the watershed. Of note in the FWS's Federal list were several endangered or threatened avian species, including the Black-capped Vireo (*Vireo atricapilla*), Golden-cheeked Warbler (*Dendroica chrysoparia*), Least Tern (*Sterna antillarum*), and Whooping Crane (*Grus Americana*). The list also included one species of freshwater mussel, the Texas Fawnsfoot (*Truncilla macrodon*), which is currently listed as a Candidate species (USFWS, 2016).

Additional avian and mollusk species appear on the TPWD list. These county-level lists also include several fish, mammal, reptilian, and plant species, which are not present in Federal lists (TPWD, 2016a, 2016b).



Data source: NCTCOG; Basemap: ESRI World Imagery.

Figure 2-3. 2013 NCTCOG land use classifications in the watershed.

2.5 Fish and Macroinvertebrate Communities

2.5.1 Lake Arlington

Due to its relatively urban locale, Lake Arlington has long been a popular venue for sport and recreational fishing for south-central portions of the Metroplex. As such, populations of Largemouth Bass, White Crappie, and Channel Catfish are managed by the Texas Parks & Wildlife Department (TPWD). In particular, Lake Arlington is a popular destination for Channel Catfish, and regularly boasts the highest catch rates amongst all the lakes within its district. Largemouth Bass are also very popular and are stocked frequently.

Prey species include abundant populations of Gizzard and Threadfin Shad, along with sustainable numbers of Bluegill and Longear Sunfish. Channel Catfish are, as previously mentioned, very abundant in the lake, but Flathead Catfish are also present. Largemouth Bass and White Crappie are usually abundant, but the latest population numbers are lower than in past surveys. White Bass, though present, are not common, and Yellow Bass populations are on the rise.

Emergent vegetation within the lake is typically sparse, so fish habitat usually consists of native vegetation such as water willow and buttonbush, although there have been human efforts to enrich habitat through artificial structures constructed from bamboo. Fish also utilize a number of artificial rocky shorelines and riprap for cover.

Recently, two invasive species have posed a threat to the lake. These include zebra mussels and an aquatic plant known as Giant Salvinia. TPWD worked with the City of Arlington to install signage near boat launches and public areas around Lake Arlington to educate anglers and boaters of the threat, and to date no reports of either species have been documented in the lake. (Brock and Hungerford, 2015).

2.5.2 Village Creek Aquatic Life Monitoring

The portion of Village Creek upstream of Lake Arlington is classified as an intermittent stream with perennial pools that are sufficient to support significant aquatic life use. Data collected in the summer and fall of 2016 indicated that the stream exceeded its previously-presumed 'limited' use level.

For fish, events conducted in both the critical summer months and the cooler index period produced 'Exceptional' fish scores for both species diversity and population. Several of the notable species identified include catfish (Yellow Bullhead, Flathead, Channel), sunfish (Bluegill, Longear, Redear, Green), Largemouth bass, white crappie, topminnow (Blackspotted, Blackstripe), Bullhead minnow, shiner (Red, Blacktail), Gambusia, and Bluntnose Darter.

Benthic macroinvertebrate genera represented included caddisflies, damselflies (rubyspot, dancer), riffle beetles, flatworms, dragonflies (amberwing, spinyleg, ringtail), mayflies, water striders, non-biting midge flies, horse flies, and black flies. One species of scud (amphipod) was also identified, *Hyalella azteca.* Sampling for freshwater mussels was not a component of the study, but Tapered pondhorn, Threeridge, Yellow sandshell, Giant floater, and Asian clam specimens were observed in the field.

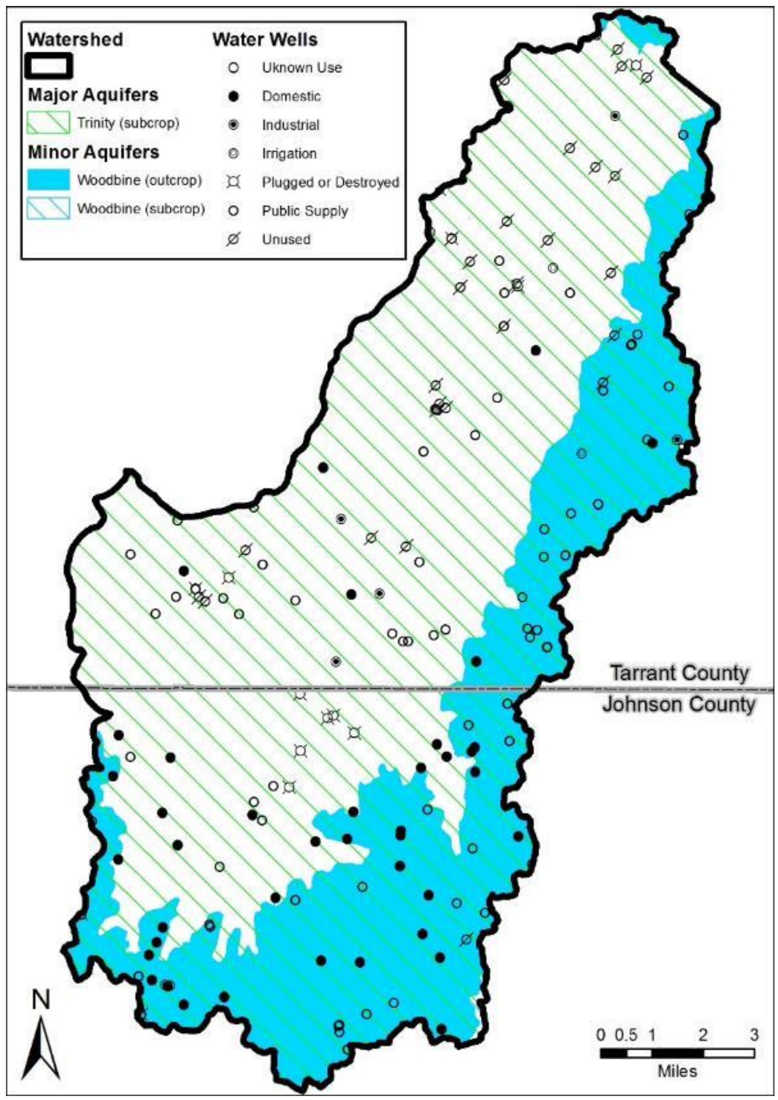
2.6 Climate

County-level data for areas within the watershed characterize the climate as 'humid subtropical,' with hot, humid summers and generally mild to cool winters (Kottek et al., 2012). Mean annual daily temperature from the National Weather Service (NWS) database for the Dallas/Fort Worth (DFW) Metroplex (https://www.weather.gov/fwd/dfwclimo) is 65.9 °F for the entire period of record (POR) between 1899 and 2015. Temperatures are generally lowest in January and highest in July, with POR daily annual averages of 45.5 °F and 85 °F, respectively.

The watershed generally receives between 32 and 36 inches of precipitation annually, while the mean annual precipitation for the entire DFW area is 33.1 inches for the entire POR between 1899 and 2015. The lowest yearly total came in 1921, with only 17.9 inches, with the highest yearly total occurring in 2015, when prolonged storms brought 62.8 inches of rain, along with historic flooding.

2.7 Groundwater

Two major aquifer groups exist within the VCLA watershed: the Trinity group and the Woodbine group. Data provided by the Texas Water Development Board (TWDB) indicate that public water supply wells (86 total) are the most common and widespread water use type (Figure 2-4). Domestic



Data source: TWDB.

Figure 2-4. Aquifers and known water wells in the VCLA watershed.

use wells (41 total) are more frequently found in the southern extent of the watershed, mainly within Johnson County. A few irrigation and industrial use wells also exist throughout the watershed.

2.7.1 Trinity Group

The subcrop region of the Trinity aquifer underlays the entirety of the watershed (Figure 2-4). The ongoing development within the general DFW Metroplex has significantly impacted water availability in this aquifer, with levels in some areas dropping more than 550 ft from historic levels. As a consequence, many public water supply wells have been abandoned since the mid-1970s in favor of surface water supply sources. This has translated to a slight recovery for the aquifer, but areas of Johnson County still remain as much as 100 ft below normal depth (Ashworth and Hopkins, 1995).

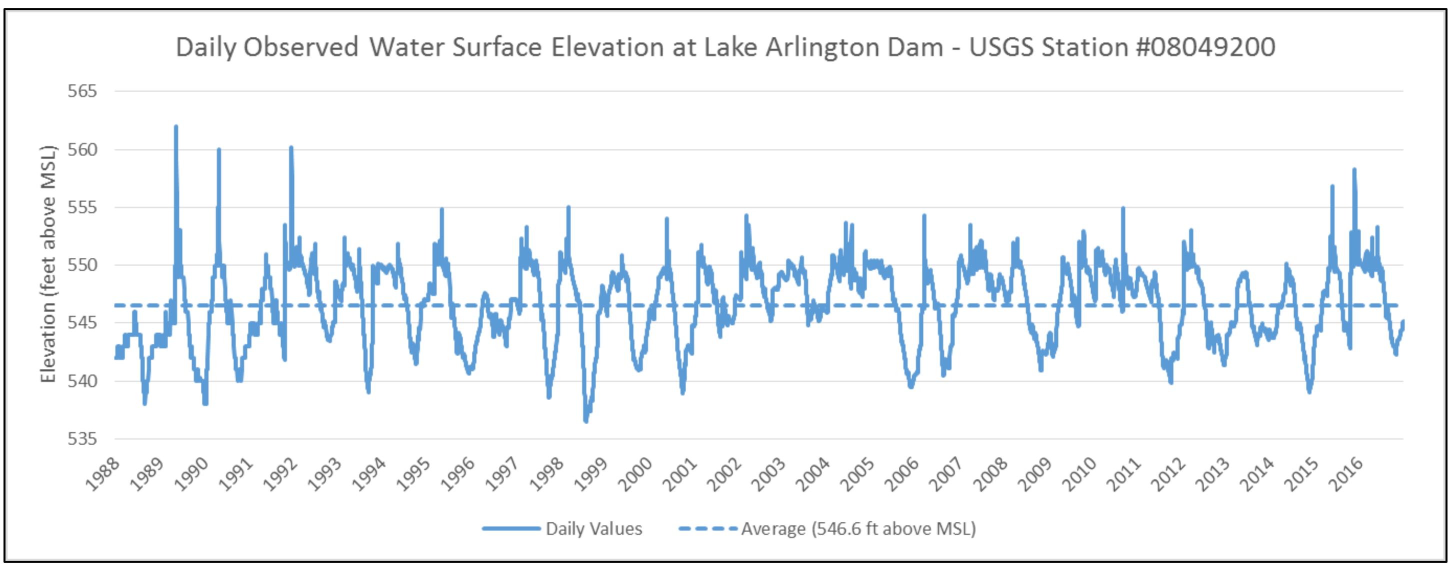
2.7.2 Woodbine Group

The outcrop region of the Woodbine group is represented along the eastern and southern edges of the watershed, along with a small sliver of the subcrop region, which is located in the far southeast corner of the watershed (Figure 2-4). Only the lower two of the three zones of the Woodbine are suitable for public water supply or domestic use. Water within the upper zone, also called the outcrop, often contains excessive levels of iron, and is not recommended for these uses. Although the chemical quality of the water deteriorates quickly in well depths greater than 1,500 ft, the areas above this depth and below the outcrop zone are considered to be of overall good water quality, assuming that steps have been taken to seal off portions of the upper Woodbine that contain excessive amounts of iron (Ashworth and Hopkins, 1995).

2.8 Surface Water

2.8.1 Lake Arlington

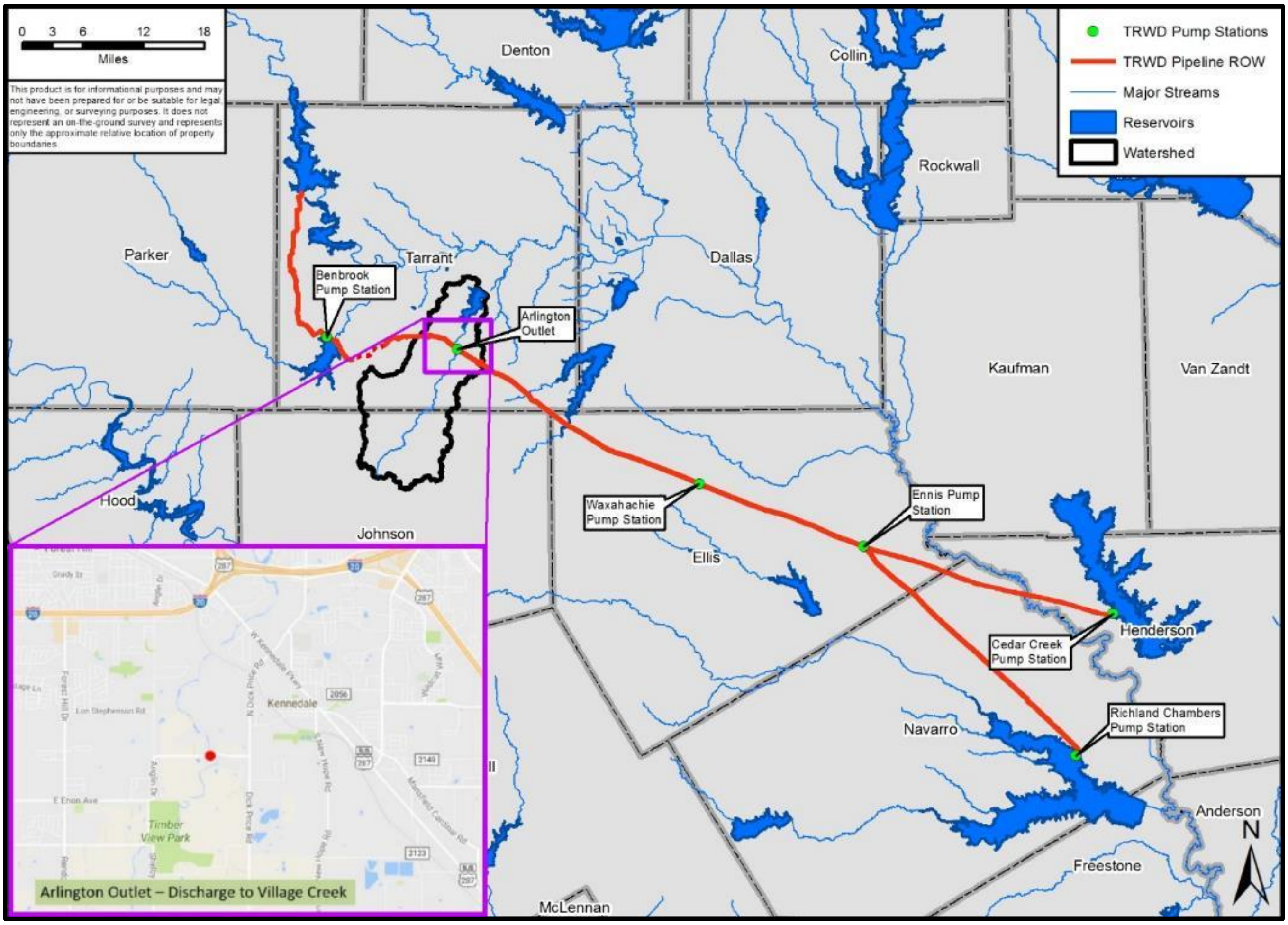
The normal conservation pool elevation for Lake Arlington is 550 ft above MSL, which coincides with the elevation of the drop inlet spillway that drains the lake, located near the east end of the Lake Arlington dam. A flowage easement held by the City of Arlington allows for additional operational flexibility during high flow events up to 560 ft above MSL. During flood events, water may crest the uncontrolled emergency spillway, which has a crest elevation of 559.7 ft above MSL and a width of 882 ft and flow uncontrolled over the spillway (Malcolm Pirnie and Arcadis U.S., 2011). Historical lake elevations from 1988 to 2016 are provided in Figure 2-5.



Data source: USGS.

Figure 2-5.Daily Observed Water Surface Elevation in Lake Arlington, 1988-2016.

The management of the lake's pool elevation relies heavily on the contractual relationships with the Tarrant Regional Water District (TRWD), particularly in the summer months. Under a 1971 agreement, TRWD agreed to maintain a minimum lake elevation of 540 ft MSL during the summer months (from June 1 to September 1) and a minimum of 535 ft MSL during the remainder of the year. Under the agreement, TRWD supplements water from Village Creek with additional water piped in from two other reservoirs in East Texas, Richland-Chambers and Cedar Creek Reservoirs (Figure 2-6). This permits Lake Arlington to be used as a terminal storage reservoir in TRWD's Trinity River Diversion Water Supply Project. The outlet for this pipeline is situated just downstream of the Village Creek bridge on Everman-Kennedale Road, shown on the inset map in (see 'Arlington Outlet') on Figure 2-6. From the Lake Arlington outlet, the pipeline continues on to Lake Benbrook and from there to Eagle Mountain Reservoir. Occasionally, flow in the pipeline is reversed to deliver water from Lake Benbrook to supply Lake Arlington.



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

Figure 2-6. Pipeline ROW for reservoir connectivity within the Trinity River Diversion Water Supply Project.

Water rights permits for Lake Arlington are held by the City of Arlington and TXU Electric/Excelon Power. Prior to the construction of the Lake Arlington Dam, Lake Erie inhabited an area in the northwestern corner of the lake. Although it retains some of Lake Erie's former utility as an industrial cooling water source, Lake Arlington water is presently used primarily for municipal purposes, providing drinking water to over half a million residents in the City of Arlington, as well as some surrounding communities in Tarrant County. Drinking water from the lake is treated at two facilities: the Pierce-Burch Water Treatment Plant (WTP), owned and operated by the City of Arlington, and the Tarrant County Water Supply Project (TCWSP) WTP, owned and operated by the Trinity River Authority (TRA). Water from the Pierce-Burch WTP is supplied to the citizens of Arlington, while water from the TCWSP WTP meets the needs of the citizens of Bedford, Colleyville and Euless, along with portions of Grapevine and North Richland Hills. Withdrawals for these uses are provided in Table 2-2. The lake is also used regularly for public recreation, with several public and privately owned docks allowing for boat entry for fishing and other recreational activities (Malcolm Pirnie and Arcadis U.S., 2011). For additional information regarding the human history and corresponding development that shaped the area and its water supply needs, please see Appendix B.

Table 2-2. Sources of supply and uses of water in Lake Arlington.

Lake Arlington Supplies and Uses	Annual Averages (acre-ft)	
	Inflows	Withdrawals
Natural supply from watershed	50,995[1]	N/A
City of Arlington Pierce-Burch WTP	N/A	32,800[2]
TRA TCWSP WTP	N/A	34,000[2]
Excelon Handley Power Plant	N/A	4,000[3]
TRWD Discharge from Cedar Creek and Richland-Chambers Reservoirs to Village Creek	43,500[4]	N/A

N/A - not applicable

(1) Based on rainfall data from 1992-2009 and PLOAD model projections. Estimated annual inflow includes baseflow from Village Creek (2,735 acre-ft) and estimated surface runoff.

(2) Average annual withdrawal between 2009 and 2010.

(3) Projected 2010 net demand, considering diversion and return flows (TRWD, 1998).

(4) Average monitored discharges between 2005 and 2009.

Adapted from: Lake Arlington Master Plan, Malcolm Pirnie 2011.

Holders of water rights on Lake Arlington are authorized to impound a total of 45,710 acre-feet of water behind the dam. In contrast, TRA diverts water for their TCWSP plant through contractual agreements with TRWD, utilizing the imported water brought in to Village Creek from TRWD's Trinity River Diversion Water Supply pipeline, instead of the yield from Village Creek itself. In a given year, inflows from the pipeline can be expected to contribute approximately 46% of the total average annual inflows to the lake (Table 2-2).

2.8.2 Lake Tributaries

Two named tributaries feed Lake Arlington: Wildcat Branch, along with several other unnamed tributaries, drains areas of Fort Worth to the west of the lake, while Village Creek drains the majority of the watershed, which is to the south. Several small unnamed tributaries drain the thin corridor of the watershed that exists to the east of the lake.

Flow data for Village Creek is tracked continuously by a U.S. Geological Survey (USGS) gaging station at the Village Creek bridge on Rendon Road (USGS Gage #08048970). This station is situated upstream of TRWD's Arlington Outlet, and therefore does not record inputs from the Richland-Chambers and Cedar Creek Reservoirs. This flow dataset only dates back to July 2007, but additional flow data exists within the Surface Water Quality Monitoring Information System (SWQMIS) from previous years.

Looking downstream on the unnamed tributary to Lake Arlington under high flow conditions.

3.0 Water Quality Assessment

The EPA requires states to develop a list (commonly called the 303(d) List) describing all impaired waterbodies that do not conform to established water quality standards (40 CFR § 130.7). In accordance with the CWA (33 USC § 1251.303), States may create and apply their own water quality standards, but these must first be approved by the EPA. In Texas, these water quality standards and the designated uses they are designed to support are defined in the Texas Water Code, in fulfillment of the requirements laid out by the CWA. Addressing waterways impaired by pollution and hazardous substances is at the heart of the CWA, which requires standards that: 1) maintain and restore biological integrity; 2) ensure that all waterbodies remain “swimmable and fishable” by protecting fish, wildlife, and recreational uses, and 3) assess the many uses of a water of the state (public water supply, agricultural, industrial, wildlife, recreation) from both a use and value standpoint.

EPA also requires that states develop acceptable strategies for restoring water quality in its impaired waterbodies (40 CFR § 130.7). One acceptable strategy is the use of a regulatory mechanism for developing total maximum daily loads (TMDLs) that sets budgets for pollutants in a waterbody. These budgets identify the waterbody’s maximum pollutant loading capacity and the reduction required to meet standards for applicable uses. TMDLs accomplish this by allocating the pollutant load budget to a variety of pollutant sources and establishing the maximum allowable loads from those sources. An alternative strategy involves the use of non-regulatory methods, such as a WPP. This allows stakeholders to identify and address water quality impairments, along with other water quality concerns in the watershed, with more autonomy in comparison to a TMDL. Due to the wider scope allowed with WPPs, established water quality goals may also include protections for unimpaired waters in addition to those designed to attain standards in impaired waters.

3.1 Waterbody Assessments

TCEQ conducts biennial assessments of Texas waterbodies, with results provided in the *Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) List* (Integrated Report). These assessments are the drivers for waterbodies being added or removed from the 303(d) List. The TCEQ 2014 Texas Integrated Report for the Trinity River covers a seven-year assessment period from December 1, 2005 to November 30, 2012 (TCEQ, 2015c). This period occurs nearly three years before the WPP efforts began and only contains data from 2 of the 11 stations monitored as part of the watershed characterization component of the WPP project. Further detail about the methods used for this assessment are described in the 2014 Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ, 2015d).

Sample collection on Village Creek at the FM 1187 bridge.

Findings of the Integrated Report assessments are classified as Fully Supporting, No Concern, Use Concern, Screening Level Concern, and Not Supporting. **Use Concerns** are given for assessments against designated use criteria for water quality parameters such as DO and *E. coli*. Use Concerns can apply to datasets with limited data where the threshold number of exceedances are met or to datasets with adequate data where there are less than the threshold number of exceedances required for a Not Supporting finding. **Screening Level Concerns** apply to General Use parameters, such as nutrients and chl-a, as well as a few other parameters for other designated uses. These parameters have screening levels rather than standards.

Waterbodies assessed in Texas are given a segment identification number (ID), which is then subdivided into one or more AUs. Lake Arlington is defined as segment 0828, which is composed of eight AUs, 0828_01 through 0828_08. In contrast, Village Creek, or segment 0828A, has only one AU, 0828A_01, which includes the whole segment (Figure 3-1). The results of the 2014 waterbody assessment for the VCLA watershed are shown in Table 3-1, accompanied by an evaluation of which designated uses had available data for a use assessment. Note that while data was not collected within the lake itself as part of this project, AUs in the lake with contaminants of concern noted in the 2014 assessment are displayed. This is provided so that data collected for these contaminants within its tributaries may potentially inform any correlations or connections between inflow of contaminants from the tributaries and the concentrations and locations of higher pollutants in the lake.

Table 3-1. 2014 Texas Integrated Report information for AUs in the VCLA Watershed.

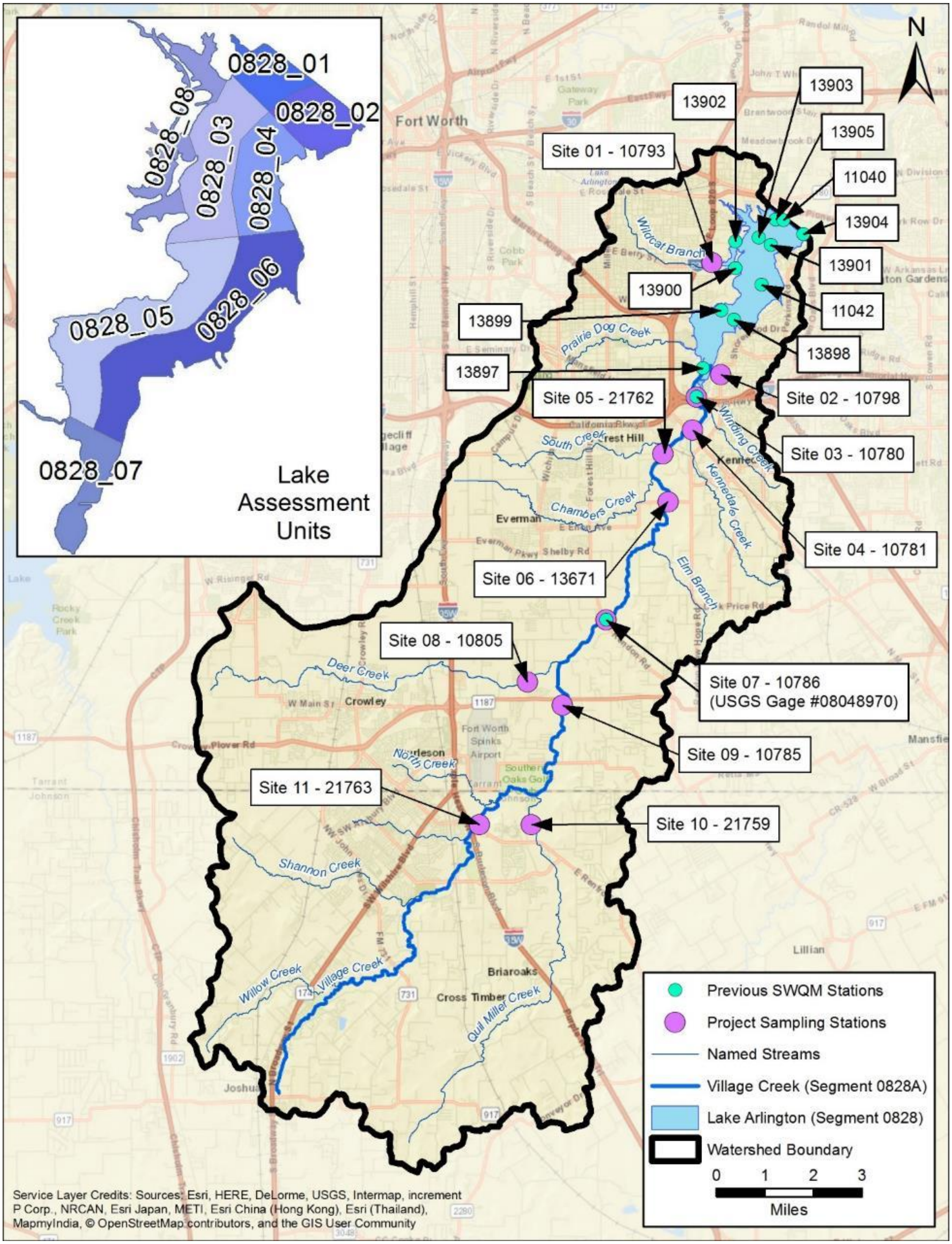
Waterbody	AU	Designated Uses*					2014 TCEQ Report	
		Aquatic Life	Contact Recreation	General Use	Fish Consumption	Public Water Supply	Impairments	Concerns**
Lake Arlington: Lowermost portion of lake along western half of dam	0828_01			•	•	•		
Lake Arlington: Lowermost portion of lake along eastern half of dam	0828_02	•	•	•	•	•		• chlorophyll-a
Lake Arlington: Western half of lower portion of lake	0828_03			•	•	•		
Lake Arlington: Eastern half of lower portion of lake	0828_04	•		•	•	•		
Lake Arlington: Western half of upper portion of lake	0828_05	•	•	•	•	•		• chlorophyll-a
Lake Arlington: Eastern half of upper portion of lake	0828_06	•	•	•	•	•		• chlorophyll-a
Lake Arlington: Uppermost portion of lake	0828_07	•	•	•	•	•		• nitrate
Lake Arlington: Remainder of lake	0828_08			•	•	•		
Village Creek: From Lake Arlington to the headwaters	0828A_01	•	•	•	•		• bacteria	

**Blanks in the "Designated Uses" column indicate that no data was available for a specific designated use in the corresponding segment, or that a specific designated use does not apply for that segment.*

***To simplify data presentation, the "Use Concern" and "Screening Level Concern" classifications were combined into a single "Concern" category.*

3.2 Texas Surface Water Quality Standards

TCEQ is responsible for establishing numeric and narrative criteria for water quality in the state of Texas. These criteria are described in TCEQ's Texas Surface Water Quality Standards (TSWQS) and are approved by the EPA. These standards are codified in the Texas Administrative Code (TAC), Title 30, Chapter 307, hereto referred to as TAC 307 (TCEQ, 2014) and are used by TCEQ regulatory programs to establish reasonable methods of assessing waterbodies of the state with the intent of implementing targeted strategies aimed at specific designated uses. Site-specific water quality criteria for Lake Arlington (Segment 0828) and Village Creek (Segment 0828A), as defined in TAC 307, are presented in Table 3-2, along with designated use associated with each criteria parameter. All parameters must be evaluated with a minimum of 10 samples (excluding *E. coli*, which requires 20) from a seven-year period to determine whether a designated use is being met (TCEQ, 2015d).



Basemap: ESRI World Street Map; Stream data source: NHD.

Figure 3-1. Assessment Units, segments, and monitoring stations in the watershed.

Bacteria

Primary contact recreation uses are evaluated using a bacteria standard of 126 colony-forming units (cfu) per 100 mL sample of water, although newer bacteria enumeration methods use a most probable number of colonies (MPN)/100 mL metric. The two should be considered equivalent for the purposes of this study. This standard, which is applied to all freshwater systems in Texas, is typically applied unless site-specific standards have been developed. This standard is compared to the geometric mean (geomean) of the sample set, which must include a minimum of 20 samples over a seven-year period (TCEQ, 2015d). The risk level associated with this standard is based on epidemiological data (from the Great Lakes and lakes in Oklahoma) which indicates the instance of gastrointestinal illness in 8 individuals out of a population of 1000 engaged in primary contact recreation (swimming, diving, or children wading) (USEPA, 1986).

Total Dissolved Solids

Total dissolved solids (TDS) is a rudimentary measurement of all the dissolved ions within a waterbody, such as chloride, sulfate, and other dissolved salts. While it does provide a very rough indicator of general water quality for evaluating aquatic life and public water supply uses, it cannot reveal the specific source or composition of the ions in the sample. The maximum allowable average concentration for TDS in either Lake Arlington or Village Creek is 300 mg/L (TCEQ, 2014).

Other Measurements

Several additional parameters are often measured routinely to assess general use, support of aquatic life, and for public water supply use. These include dissolved oxygen (DO), water temperature (temp), potential hydrogen (pH), chloride, and sulfate. Chloride and sulfate are components of TDS, with excessive levels of each posing similar concerns for both aquatic life and public water supply uses. Chloride standards for both Lake Arlington and Village Creek are 100 mg/L. The sulfate standard for the lake is likewise 100 mg/L, but no such standard exists for Village Creek (TCEQ, 2014). Due to their close association with TDS and the fact that no issues with either constituent were known prior to the inception of the project, neither parameter was directly measured during the characterization efforts. Water temperature and pH are similarly important for a variety of uses. Healthy aquatic habitats in Texas typically fall within a pH range of 6.5-9.0. The pH values can be heavily dependent on water temperature, with excessively high water temperatures (>95 °F) indicating conditions that are stressful for aquatic organisms. This association is also evident with DO, which is vital to the survival of fish and other aquatic fauna, being affected by both temperature and nutrient concentrations. For Lake Arlington, a 24-hour DO average of 5.0 mg/L and minimum of 3.0 mg/L must be maintained to support its aquatic life use. For Village Creek, these standards are 3.0 mg/L and 2.0 mg/L, respectively (TCEQ, 2015d).

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

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

3.3 Nutrient Screening Levels and Reference Criteria

TCEQ Screening Levels

Currently, no numeric standards exist for nutrients in streams in the state of Texas. Numeric standards for chl-a have been approved by EPA for 75 reservoirs in the state; however, Lake Arlington is not one of these reservoirs. In such situations where no water quality standards exist or are in the process of being developed, controls such as narrative criteria and antidegradation considerations are often used. Despite this lack of numeric criteria, TCEQ continues to screen for parameters such as nitrogen, phosphorus, and chl-a as preliminary indicators for waterbodies of possible concern for 303(d) impairments. To support this effort, nutrient screening levels are often used to compare a waterbody to screening levels that are set at the 85th percentile for those parameters of interest seen in similar waterbodies (Table 3-3). The Texas Nutrient Screening Levels are based on statistical analyses of Surface Water Quality Monitoring (SWQM) data (TCEQ, 2015d).

EPA Reference Criteria and Other Sources

The EPA Reference Criteria are regional values based on data from reservoirs and streams within specific ecoregion units and subunits (USEPA, 2000a, 2000b). It is worth noting that these Reference Criteria differ from the Texas Nutrient Screening Levels in that EPA developed the Reference Criteria using conditions that are indicative of minimally impacted (or in some cases, pristine) waterbodies, attainment of which would result in protection of all designated uses within those specific units and subunits. As such, Reference Criteria thresholds are much lower than those for state screening levels, and surpassing Reference Criteria thresholds may not necessarily indicate a concern, as is the case with the state thresholds (Table 3-3). Where state screening levels or national reference criteria were non-existent, other sources were used, for nitrite in particular (Mesner and Geiger, 2010).

3.4 Segment Impairments and Concerns

When a sufficient number of elevated water quality measurements cause the waterbody to surpass the water quality criteria (min, max, average, or geomean), the waterbody is considered impaired and may not be supportive of one or several of its

Table 3-3. Nutrient Screening Levels and Reference Criteria.

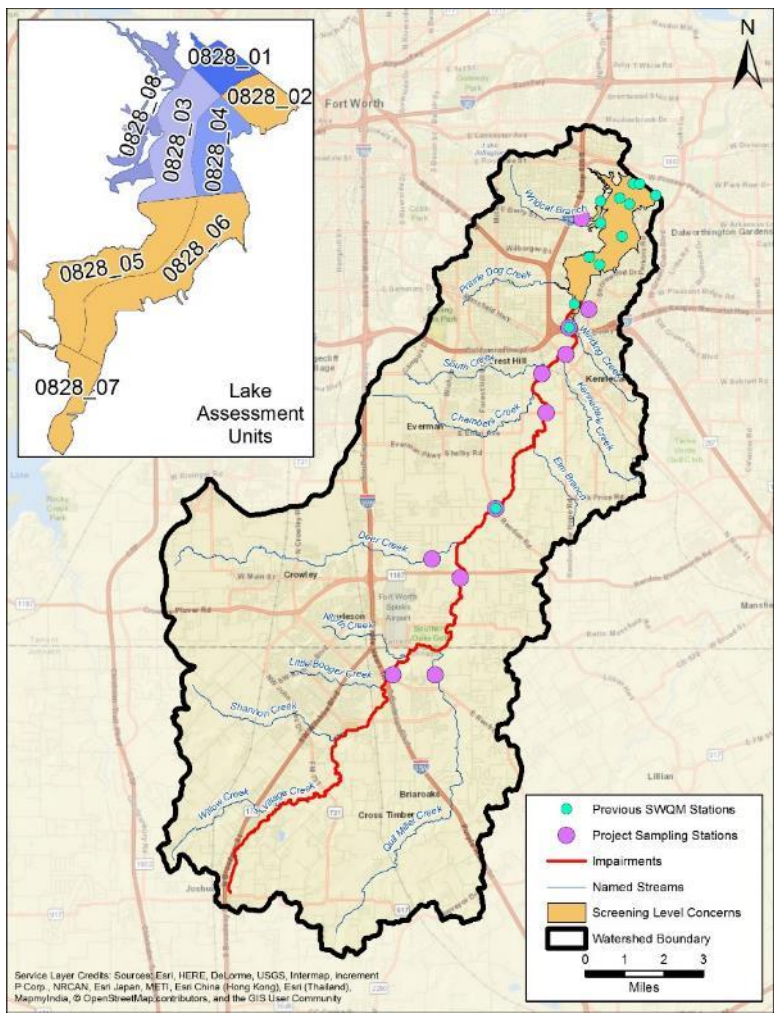
Parameter		Lake/ Reservoir	Stream	Source
TKN	(mg/L)	0.41	0.4	EPA Reference Criteria[a]
NO_2	(mg/L)	0.02	0.02	Other Sources[b]
NO_3	(mg/L)	0.37	1.95	TCEQ Screening Levels
TP	(mg/L)	0.20	0.69	TCEQ Screening Levels
OP	(mg/L)	0.05	0.37	TCEQ Screening Levels[c]
Chl-a[d]	(µg/L)	26.7	14.1	TCEQ Screening Levels

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

(b) For nitrite, concentrations above 0.02 mg/L (ppm) usually indicate polluted waters (Mesner, N., J. Geiger. 2010. Understanding Your Watershed: Nitrogen. Utah State University, Water Quality Extension.

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

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



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

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

designated uses. For the assessment period covered by the *2014 Texas Integrated Report*, Village Creek was the only impairment in the watershed, specifically for bacteria (Table 3-1, Figure 3-2).

If more than 20% of a waterbody's samples from the assessment period exceed a screening level, then on average, it will experience higher pollutant concentrations than 85% of the streams in Texas and thus is considered to have a concern for elevated nutrients. For the same 2014 assessment period, there were three AUs in the lake with screening level concerns for chl-a and one with a concern for nitrate. No screening level concerns were identified in Village Creek, and no use concerns were identified anywhere in the watershed (Table 3-1, Figure 3-2). Historically, *E. coli* geomeans have been on the rise since Village Creek was first listed in 2010. Since then the mean exceedance has more than doubled from 141.54 MPN/100 mL to 302.07 MPN/100 mL in the latest Integrated Report (2014). Exceedances for chl-a also occurred on the 2010 Integrated Report, but further increases have been much less pronounced than those of *E. coli* (Table 3-4).

Table 3-4. Records of impairments and concerns in the watershed.

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

4.0 Potential Pollutant Sources

Pollutants from human activities and natural processes can be grouped into two categories, based on their origin:

Point source pollution is a discharge that can be traced back to a single point of origin. This can be a pipe, drain, or outfall and is typically discharged directly into a waterway. Because point sources are tied to human activity, they regularly contribute flow to a system regardless of the native flow conditions. In fact, point sources may constitute most or all of the baseflow in some systems, particularly in urban watersheds where large or regional wastewater treatment facilities (WWTFs) provide consistent effluent flows.

Point source pollution is regulated through a permitting process; in Texas this is administered through the Texas Commission on Environmental Quality (TCEQ). One example of a permitted discharge is effluent from WWTFs. Here, the treated effluent must remain within specific pollutant limits so that the facility's impact on the receiving waterbody is minimized. Other examples include wastewater infrastructure issues, like a break in a wastewater pipeline, or a sanitary sewer overflow (SSO). These point sources bypass WWTFs, and can have either acute (short-term) or chronic (long-term) effects on water quality depending on when they're identified and how quickly they're addressed.

Nonpoint source pollution, by contrast, tends to be more challenging to manage since it cannot be traced back to a single point of origin. Instead, pollutants that are dispersed over the land (either through human activity or natural processes) are carried into waterways with runoff from storm events. Several factors may influence the types and amounts of pollutants that ultimately end up in a waterway, but they are primarily dependent on land use and land cover (LULC). Sources of pollutants may include excess agricultural or residential fertilizers, fluids from leaking vehicles, pet waste from yards or urban public areas, or waste from wildlife, livestock, and feral hogs.

When considering the impacts of pollutant sources, it is important to account for the source's proximity to waterways. This is accomplished by estimating the percentage of the *E. coli* load that could realistically be transported from source to waterways through surface water or ground water transport. Weighted percentages for each source's location will be applied using the Spatially Explicit Load Enrichment Calculation Tool (SELECT). This approach weights riparian zones more heavily than those in upland zones to illustrate the increased impacts from sources in riparian zones. For additional information on SELECT and how source loads were calculated for both point and nonpoint sources, see Appendix E.

4.1 Prioritizing Pollutant Sources

Likely pollutant sources in the watershed were identified through the historical data review, water quality monitoring, and source identification/load calculation efforts. These results were interpreted and refined with the help of watershed stakeholders, including project partners, the Steering Committee, and the TAG (Figure 4-1, Table 4-1).

As discussions with stakeholders progressed throughout the planning process, it became clear that stakeholder priorities for water quality did not always run parallel with the results of water quality monitoring and modeling efforts. For example, feral hog contributions to *E. coli* loads were ranked 3rd overall in volume, but stakeholders understand the difficulty of controlling wild animals as management measure, and thus chose to focus their efforts where funding would be better spent on more reliable

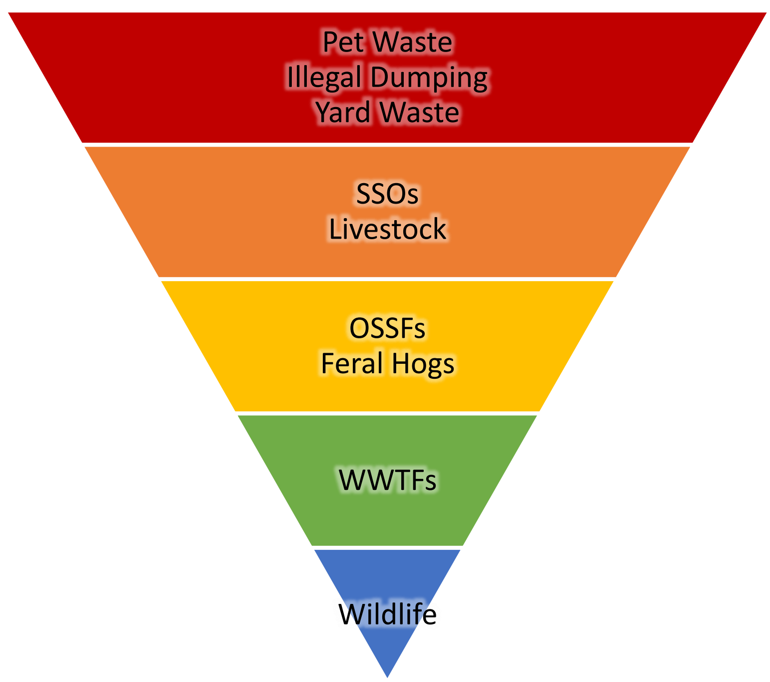


Figure 4-1. Continuum for prioritizing pollutant sources in the watershed, from highest priority (red) to lowest (blue).

results. This leads into a 2nd example, where efforts to reduce illegal dumping are a 1st-level stakeholder priority, but could not even be included in the modeling due to a lack of reliable data on illegal dumping as a source of contamination. Similar allowances were made when considering acute contamination problems of high volume vs. chronic contamination problems of low but consistent volume. Stakeholders spent substantial time and effort considering these situations as they sorted through their collective priorities. They used a tiered approach to group priorities of similar urgency, based on perceived need, probability of success, and economical advantages.

Table 4-1. Summary of potential pollutant sources in the watershed and associated management priority as indicated by stakeholders.

Source	Concerns	Potential Impacts	Rank[1]	Priority[2]
Pets	Improper disposal of pet waste Disease transmission and public safety Lack of education on impacts and proper disposal	(1) Indirect *E. coli* loading to waterbody from yards, public greenspaces, kennels, and shelters; (2) spread of disease amongst/between species	1	1
Illegal Dumping	Household/construction waste disposal in/near waterbody Animal carcass/hunting remains disposal in/near waterbody Disposal of large items (furniture, appliances, vehicles)	(1) Direct/indirect contamination of waterbody from *E. coli*, nutrients, and hazardous materials; (2) localized human health hazards; (3) Flow obstruction/alteration	-	1
Lawn Residue and Waste	Improper disposal of yard clippings Excessive fertilizer, herbicide, or pesticide application	(1) Direct/indirect contamination of waterbody from E. coli, nutrients, and hazardous materials; (2) impacts to aquatic wildlife	-	1
SSOs	Failure due to stormwater I&I issues Failure due to age, land erosion, or construction damage	(1) Direct/indirect *E. coli* loading to waterbody; (2) human health hazards	5	2
Livestock	Increased runoff from overgrazing of upland areas Manure transported to waterbody by runoff Riparian buffer zone degradation Direct manure deposition in waterbody	(1) Direct/indirect *E. coli* loading to waterbody; (2) loss of natural pollutant mitigation capabilities	2	2
OSSFs	"Straight pipes" and other illegal wastewater discharges Failure due to age, improper design, or lack of maintenance Improperly treated aerobic effluent applied to land	(1) Direct/indirect loading of untreated wastewater to waterbody; (2) local groundwater resource degradation	4	3
Feral Hogs	Manure transported to waterbody by runoff Riparian buffer zone degradation Direct manure deposition in waterbody Displacement/predation of native species	(1) Direct/indirect *E. coli* loading to waterbody; (2) loss of natural pollutant mitigation capabilities; (3) loss of natural species diversity	3	3
WWTFs	Failure due to age, stormwater I&I, or lack of maintenance Overloads from population growth or illicit connections	(1) Direct loading of untreated wastewater to waterbody	7	4
Wildlife	Manure transported to waterbody by runoff Riparian buffer zone degradation Direct manure deposition in waterbody	(1) Direct/indirect *E. coli* loading to waterbody; (2) loss of natural pollutant mitigation capabilities	6	5

(1) Relative impact of *E. coli* load on the watershed, as ranked by the SELECT analysis. Sources noted by '-' could not be included in the SELECT analysis.

(2) Water quality restoration priorities, as identified by watershed stakeholders in tiers descending from 1 (highest priority) to 5 (lowest priority).

4.2 Point Source Pollution

4.2.1 Permitted Discharges

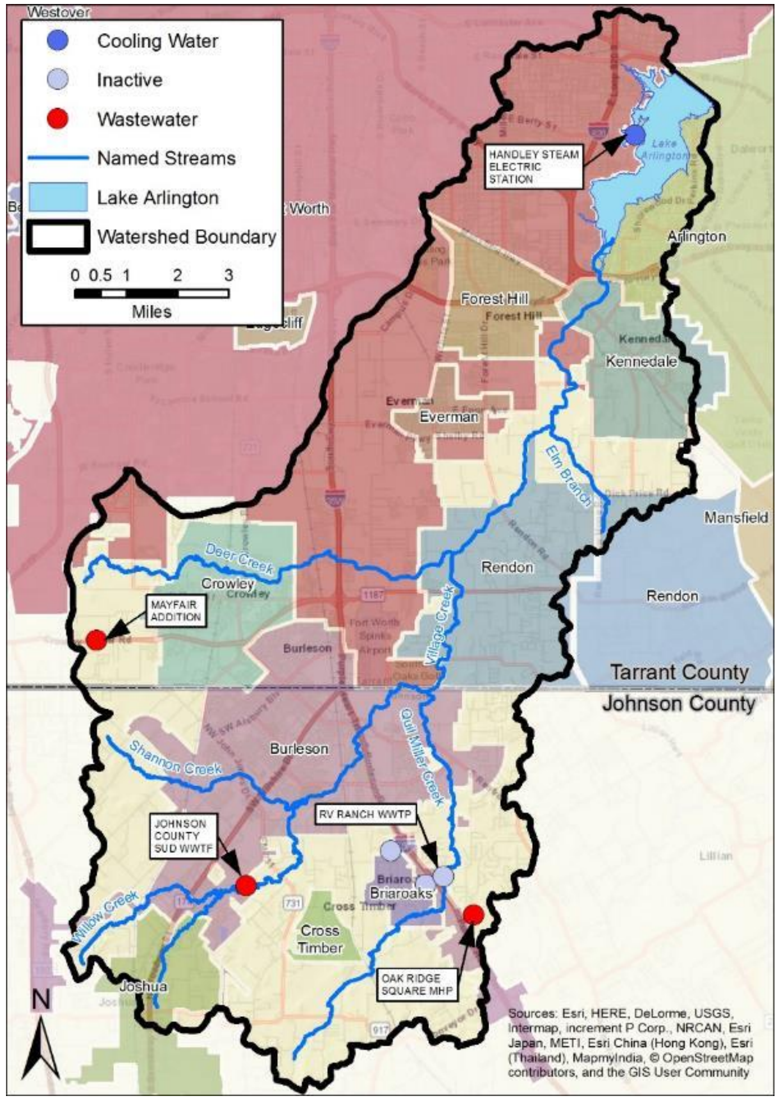
Seven permitted wastewater discharges exist in the VCLA watershed (Figure 4-2). Four are inactive or have had their permit cancelled. The Handley Power Plant is also a discharger, but its effluent is characterized as industrial cooling water used within the plant, and is not expected to be a contributor of *E. coli*.

Details about the three active WWTFs and any associated permit limit exceedances for water quality parameters are provided in Table 4-2. Of these facilities, only one is considered a municipal discharger, the Johnson County Special

Utility District (SUD), with a permitted average daily discharge of 0.7 million gallons per day (MGD). The other two facilities are smaller plants that treat wastewater from a housing subdivision and a mobile home park. Both maintain a permitted average daily discharge of < 0.1 MGD. Recent permit exceedances for these facilities for *E. coli*, total suspended solids (TSS), 5-day biological oxygen demand (BOD_5), and ammonia are provided in Table 4-2.

The significance of the WWTF locations in this watershed is that effectively all monitored reaches of the watershed may contain some portion of wastewater effluent constituting their baseflow throughout the year (Figure 4-2). It is worth noting that until 2017, another WWTF known as RV Ranch WWTP was also operating. This facility serviced a number of businesses, including a recreational vehicle (RV) park, campgrounds, and water theme park. However, an increasing frequency of *E. coli* permit violations over the past decade prompted the city of Burleson to investigate the non-compliant facility. In the summer of 2017, the city was able to successfully tie in all the associated businesses to Burleson's municipal wastewater system and retired the RV Ranch WWTP to inactive status (Figure 4-2).

Stormwater inflow and infiltration (I/I) issues associated with the wastewater infrastructure connected to the WWTF are the most common cause of elevated *E. coli* concentrations leaving the facility above permitted effluent limits. This exceedance of treatment capacity can also be caused by unknown



Basemap: ESRI World Street Map; Stream/WWTF data source: TCEQ.

Figure 4-2. Permitted discharges in the VCLA watershed.

Table 4-2. Compliance history for active WWTFs in the Village Creek-Lake Arlington watershed.

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

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

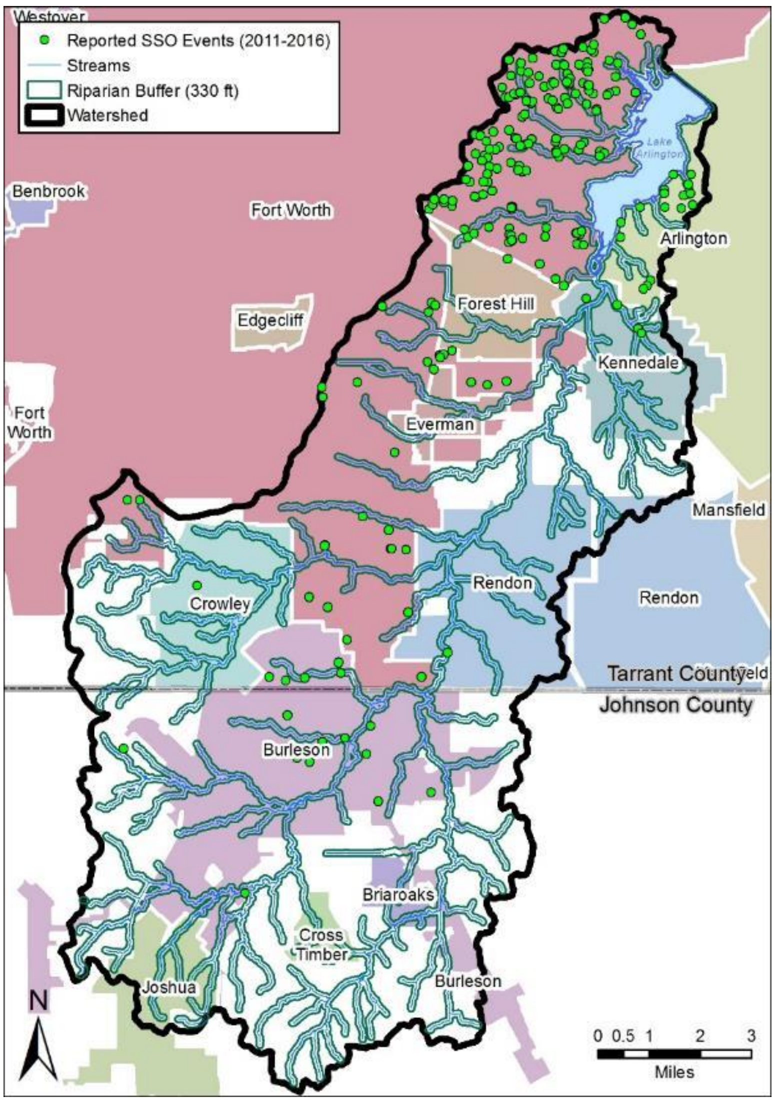
(2) 3-year geomean based on daily measurements from USEPA data, 1/31/2014 - 12/31/2016 .

(3) Reported quarterly rather than monthly.

illicit connections delivering inconsistent additional flows, or from continued urbanization stressing the WWTF beyond its original design capacity. Emerging contaminants in effluent are also a concern, with LAMP stakeholders specifically discussing endocrine-disrupting compounds as a potential risk (Malcolm Pirnie and Arcadis U.S., 2011).

4.2.2 Sanitary Sewer Overflows

Being components of the wastewater conveyance system, many of the same issues encountered at WWTFs are caused by issues with the pipes and other infrastructure carrying wastewater from homes and businesses. SSOs occur when pipes are blocked, broken, or when deteriorating pipes and connections allow stormwater or groundwater infiltration into the wastewater system. These I/I issues often result in combined stormwater/ wastewater volumes that exceed the design capacity of the pipes, causing backups that will eventually find a relief point, often a manhole cover or other surface access. From this relief point, untreated sewage can potentially reach streams and lakes if not contained properly or in a timely manner. For this reason, proximity of the SSO site to a waterbody must be accounted for when analyzing potential impacts. For this project, 90% of the *E. coli* contributions within a 330-ft (100-m) buffer are assumed to reach waterbodies. For upland areas outside of this riparian buffer, the contribution is reduced to 50%. Both the riparian buffer distance and contribution percentages were recommended by the TAG and agreed upon by stakeholders, having seen values similar to these used in other WPPs and TMDLs throughout the state.



SSO data source: NCTCOG; Stream data source: NHD

Figure 4-3. Reported SSO events in the watershed, 2011-2016.

Older neighborhoods tend to be more prone to SSOs, as they tend to be serviced by older infrastructure that may be subject to the deterioration or design capacity issues mentioned previously (Figure 4-3). For the purposes of this project, SSOs, when combined with pet waste nonpoint sources, will be used as surrogates for urban runoff when calculating pollutant loads from urban sources.

4.2.3 Other Point Sources

LAMP stakeholders also expressed interest in identifying threats to groundwater quality throughout the watershed. While important, these additional sources are not specifically tied to *E. coli* concerns, and as such cannot be estimated as part of this analysis due to the technical limitations of the analytical tool used for this project.

Water Wells

Chemical or pollutant spills that occur in or near any water well can provide a direct route for pollutants to reach aquifers, bypassing the soil and rock substrata that usually provide some measure of remediation in natural systems. Plugged or destroyed wells, along with abandoned or otherwise unmaintained wells, are of particular interest. These wells are usually not closely monitored and potential contamination may go unnoticed for long periods of time. A total of 34 unused and 14 plugged or destroyed wells are present in the watershed (Figure 2-4). Well construction standards, along with regulation of abandoned or deteriorated water wells, are under the jurisdiction of the Texas Department of Licensing and Regulation (TDLR). Complaints for such wells can be reported to TDLR through their website.

Underground Storage Tanks

Underground storage tanks (USTs) are often used to store petroleum products and other hazardous liquids, most notably at gas stations. Most USTs are made of common steel, and thus are subject to oxidation and rust over time. Excessive corrosion may lead to cracks or holes in the tank, which can result in groundwater contamination. TCEQ is the regulatory entity and current custodian of records related to leaking USTs in Texas.

Oil & Gas Exploration

Although several traditional oil and gas wells exist in the watershed, continued development of the Barnett Shale natural gas field has resulted in expansion of hydraulic fracturing activities, sometimes in close proximity to the lake. As such, development of additional pad sites and associated pipelines and process water injection wells is anticipated to continue (Malcolm Pirnie and Arcadis U.S., 2011). Along with groundwater concerns, pad site construction may require a deforestation or other clearing of vegetation that can lead to increased runoff, in terms of both volume and frequency. If these pad sites are located near riparian buffer zones, the increased runoff may deliver higher pollutant loads to nearby waterways. The most recent EPA report on hydraulic fracturing (USEPA, 2016) recommended that stakeholders focus on several activities that are more likely than others to result in water supply impacts, including but not limited to:

- Water withdrawals in areas where groundwater is already scarce;
- Surface spills of chemicals or process water that may reach groundwater sources;
- Fluid injection into inadequately designed wells that allow for leakage into groundwater;
- Discharge of inadequately treated process water into surface water; or
- Disposal or storage of process water in unlined or improperly lined pits, allowing for groundwater contamination.

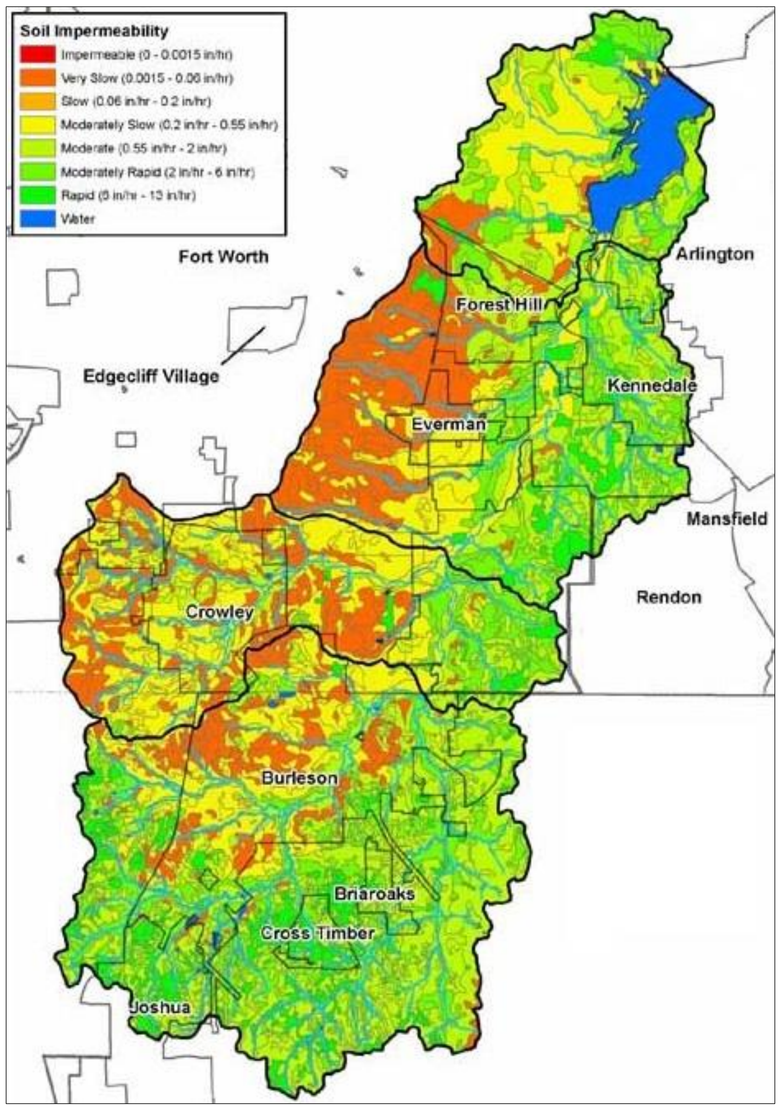
The Texas Railroad Commission (RRC) is the entity responsible for regulation and operation of oil & gas wells in Texas.

4.3 Nonpoint Source Pollution

Unless explicitly stated for each source, the contribution weights for the riparian buffer (90% contribution) and upland areas (50% contribution) mentioned previously are applied to the nonpoint sources analyzed for this project.

4.3.1 On-Site Sewage Facilities

There are several unincorporated and rural areas in the watershed where on-site sewage facilities (OSSFs) are used by residents for wastewater treatment. When not functioning properly, OSSFs can become sources of pollution for *E. coli*, nutrients, and solids, both in groundwater and surface water bodies. A variety of causes can be to blame for reduced performance or malfunctions, including improper design/installation, lack of maintenance, unsuitable soil types (Figure 4-4), age of the system, and proximity to other systems.



Adapted from LAMP (Malcolm Pirnie and Arcadis U.S., 2011).

Figure 4-4. Permeability of soils in the watershed.

Pooled effluent seeping from malfunctioning OSSF (credit: City of Arlington).

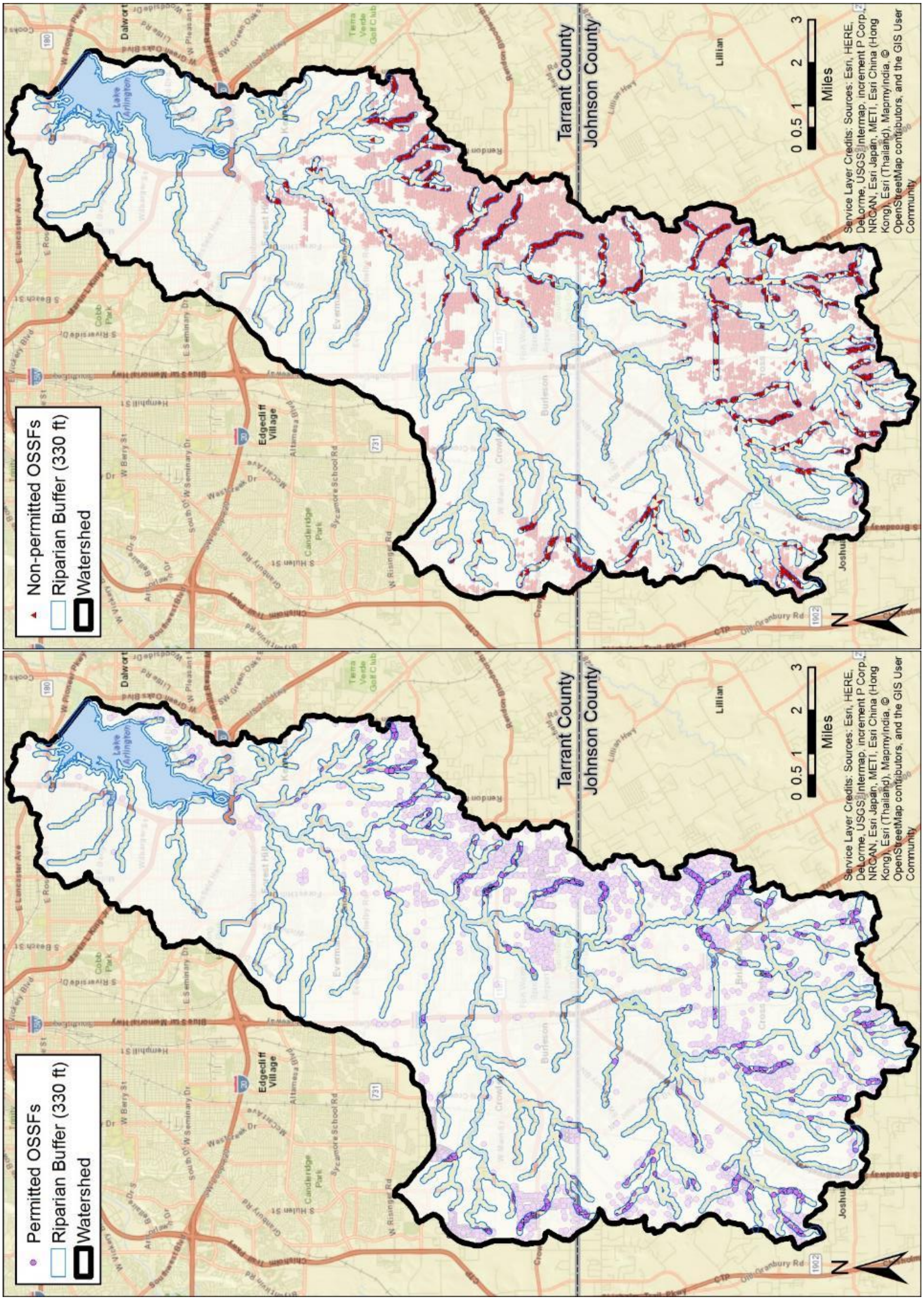
Since 1989, counties are responsible for maintaining records of permitted OSSFs, which must be inspected to ensure compliance with state regulations. Many of the known existing systems in the watershed installed prior to 1989 are not tied to a current permit, indicating that they have not been recently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

Proximity to a waterbody is also a major factor in contamination. OSSFs within the stakeholder-recognized buffer distance (330 ft) are expected to have the greatest impact (Figure 4-5). For this reason, stakeholders chose to focus management efforts specifically on those OSSFs within the buffer for this project, agreeing to a 90% contribution weight from OSSFs within the riparian buffer. OSSFs contributions from upland areas were limited to 10% to account for some additional remediation provided by the soil before reaching the surface. Of the total 10,687 OSSFs estimated to exist in the watershed, only 3,454 have existing permits. Considering only those OSSFs inside the riparian buffer, 457 have associated permits and 1,826 do not. Proximity to other systems can negatively affect OSSF performance, particularly in areas where systems are densely spaced. In these situations, multiple failures are possible if one drain field exceeds its capacity and impacts adjacent fields, increasing the likelihood for drain field contaminants reaching waterbodies.

4.3.2 Pet waste

Feces from pets may also be a source of *E. coli* and nutrient loading to waterbodies via stormwater runoff. This may include dogs as well as cats that defecate outdoors, such as feral and barn cats. As with any nonpoint source, the severity of the contamination from an area is heavily influenced by the presence of impermeable soils (Figure 4-4) and increasing amounts of impervious cover (e.g., buildings, parking lots, Figure 2-2) associated with ongoing development in the watershed. These measurements are derived from human population data, so while there will be some contributions from rural areas, it is expected that urban areas will show the largest contributions. Thus, loading from pet sources will serve to approximate *E. coli* and nutrient contributions from urban runoff, in concert with other yard waste runoff and contributions from SSOs. Additionally, if excessive pet waste is left in yards to accumulate, this increases the chances of gastrointestinal parasite or other disease transmission to other pets or potentially to other species.

Estimates for pets (Table 4-3) were made by extrapolating census data from the watershed and applying nationwide estimates for the number of dogs and cats per household. According to the American Veterinary Medical Association (AVMA), 36.5% of all households own dogs, and 30.4 % own cats. The average number of dogs by those households is 1.6 (AVMA, 2012). That number is slightly higher for cats, but stakeholders recommended using the dog estimate to account for the outdoor cats that do not use litter boxes. This estimate is supported by information from several animal welfare groups, which estimate 350,000 stray cats in the DFW Metroplex, with the majority in the southern extent (Rajwani and Tsiaperas, 2016) The standard contribution weights for riparian (90%) and upland (50%) were then applied.



Basemap: ESRI World Street Map; Data source: Tarrant/Johnson Counties. Upland areas masked to emphasize OSSFs in riparian zones.

Figure 4-5. Permitted and non-permitted OSSFs in the watershed.

4.3.3 Agricultural Activities

Livestock that roam freely to graze can also be a contributor to nonpoint source *E. coli* loads, especially if they have direct access to waterbodies where they can defecate directly into or near a waterbody. However, poor land management practices can also affect the amount of manure *E. coli* that reaches waterbodies from upland areas by stormwater flows. If pastures are overgrazed, improperly tilled, or otherwise mismanaged for runoff potential, runoff will increase, which can deliver larger loads of *E. coli*, nutrients, and pesticides/herbicides to waterbodies.

Initially, populations for cattle, sheep/goats, and horses (Table 4-3), were estimated using data from the 2012 National Agricultural Statistics Survey, or NASS (USDA, 2012). Holding with values used in other WPPs across the state, all livestock animal classes were originally applied to 100% of grassland and 90% of pasture land classes in the watershed. Populations were applied to pasture at a lower percentage on the assumption that some portion will be used for seed or hay crops and not grazed by livestock. These stocking percentages were recommended by the TAG and approved by the Steering Committee. Cattle population estimates were compared to USDA stocking rate recommendations, and stakeholders eventually recommended moving forward with the NASS estimate. However, stakeholders felt the NASS numbers for sheep/goats and horses were too low. This assumption was made given the watershed's location along the metropolitan/rural fringe of the DFW metroplex, where many small-acreage "hobby farms" and youth 4-H/FFA animal projects that do not receive the NASS mail-outs are expected to inflate numbers beyond the NASS estimates. To account for this, stakeholders recommended increasing the population estimates for both horses and sheep/goats. For these two source classes, the applicable land use was expanded to include 5% of low-density developed areas to account for some of the hobby farms/animal projects that exist in the urban/rural mosaic that is typical in the watershed.

Table 4-3. Estimated animal populations in the watershed.

Source		Population[1]	Additional Information
Pets	Dogs	21,903	Estimate from U.S. Census and AVMA data
	Cats	18,243	Stakeholder recommendation adapted from dog estimates
Livestock	Cattle	6,488	NASS estimate
	Sheep/Goats	2,500	Stakeholder adjustment from NASS estimate of 839
	Horses	2,500	Stakeholder adjustment from NASS estimate of 1,037
Wild Animals	Deer	1,461	TPWD annual median density estimate for RMU #22
	Feral Hogs	1,000	Stakeholder adjustment based on several TAMU studies

(1) Estimate includes adjustments made by stakeholders to reflect perceived populations in the watershed.

In addition to *E. coli* and nutrient inputs from grazing livestock, production agriculture may also contribute other types of nonpoint source pollution to waterways, including nutrients from fertilizers, herbicides, and pesticides.

4.3.4 Wildlife and Feral Hogs

Although some areas of denser forest exist in the watershed, it is expected that the majority of wildlife in the watershed inhabit the forested riparian buffers that exist throughout the watershed. Wild animals tend to spend much of their life moving through riparian areas so stakeholders felt it was important to account for them as a pollutant source. Stakeholders agreed that accounting for native wildlife specifically (e.g., not including feral hogs) would be a source of "background" or "baseline" *E. coli* loading rather than a significant opportunity for *E. coli* load management. For this project, wild animal populations were estimated using data for deer and feral hogs, as no data exists for other species.

For deer populations, stakeholders agreed to use the most recent annual median density estimate of one deer per 53.7 acres (53.7 ac/deer) recommended by the TPWD analysis for the resource management unit (RMU) in which the watershed exists (unpublished TPWD data). According to TPWD, this density is spread across all land uses except heavy development and open water. Feral hogs, by contrast, were applied only to riparian zones and upland forested areas. Although data from several studies done by Texas A&M University were originally cited for the estimate, stakeholders agreed that the population density for feral hogs was roughly double that of deer throughout the watershed. Using the stakeholder-provided population estimate (Table 4-3), this amounted to approximately 26.62 ac/hog, in close agreement with the original 2:1 hog-to-deer population density assumption.

4.3.5 Other Nonpoint Sources

There are several other pollutant sources that stakeholders deemed important, but for which we could not account for numerically in the pollutant analysis due to lack of data. Some of the sources include 1) direct depositions of *E. coli* from bridge-nesting birds, 2) *E. coli* contributions from rural "yard birds" and small backyard poultry operations in both rural and urban areas, 3) stormwater runoff from exercise areas for dog kennels/animal shelters if feces are not properly disposed of, as well as washout areas for these facilities where collected feces travels with wash water into nearby waterways, 4) illegal dumping at bridges/secluded areas, 5) exotic animal operations (ranches, sanctuaries, hunting outfitters, etc.), and 6) residential yard waste that is improperly handled, allowing yard clippings, fertilizer, pesticides, herbicides, excess sediments, and other pollutants to reach storm drains and nearby waterbodies.

Other sources of urban runoff were also considered, including stormwater runoff from large industrial/commercial pads, roads, and parking lots. These areas can be sources of polyaromatic hydrocarbons (PAHs), automotive fluids, and other synthetic compounds used by humans (detergents, degreasers, colorants, etc.) (Malcolm Pirnie and Arcadis U.S., 2011). Many of these areas may be subject to regulation under their own stormwater pollution prevention plans (SWPPPs).

Stakeholders agreed that addressing illegal dumping and yard waste were important pollutant sources that should be prioritized. Throughout the monitoring effort, staff observed numerous animal carcasses and discarded animal hunting remains near/under bridges and along roadsides near riparian zones, particularly in secluded areas. These remains can contribute directly to *E. coli* loads in a waterway, especially in places where disposal is recurrent and removal or cleanup is infrequent or non-existent. If improperly managed, organic waste and chemical residues from managed green spaces (e.g., residential lawns, public parks, sports fields, golf courses, etc.), can also be a major contributor of pollutants to waterbodies, even in the absence of pets and their waste. Over-application can lead to an excessive build-up of nutrient fertilizers, pesticides, and herbicides in managed green spaces. Stormwater runoff (or similarly, lawn irrigation) will carry these pollutants to the nearest waterbody, usually via storm drain. In addition to the concerns associated with the herbicides and pesticides, excessive nutrient fertilizer runoff from multiple residential lawns will accumulate in the waterbody, encouraging growth of excessive algae.Extensive algal populations can cause diurnal swings in DO in the water, potentially placing aquatic organisms at risk. Once the algae have exhausted the excess nutrient supply, they will eventually die and begin to decay, removing additional DO, which is a major cause of fish kills. Some algal species also produce toxins that can kill fish and other gill-breathing organisms, especially when in high abundance. If nutrient enrichment is also accompanied by leaf litter and grass clippings being blown into storm drains after mowing, the decay from this plant matter will further exacerbate DO swings and impair water quality even further.

Fish kills due to excessive algal growth (credit: TPWD).

5.0 Pollutant Source Assessment

Flow measurement on Village Creek near Kennedale, TX.

No one method of analysis is sufficiently accurate to provide a clear picture of the water quality impacts in a watershed on its own. To ensure that a thorough characterization of the watershed's status was achieved, pollutant loadings were assessed using a variety of methods utilizing both empirical data and estimations based on literature values from multiple sources. The methods used in this study included routine and flow-biased water quality data analysis, a load duration curve (LDC) analysis based on collected data for multiple pollutants, and spatial analysis of potential *E. coli* sources using SELECT. Additional information about these analyses is provided in Appendix C and Appendix F, respectively.

5.1 Water Quality Monitoring

Additional sampling proposed for this project was intended to further characterize the sources of the nutrient screening level concerns in the lake and the *E. coli* impairment in Village Creek. This supplemental sampling began in June 2016 and concluded in May 2017. Three distinct sampling regimes were conducted as part of this effort:

- Regime #1 - routine sampling at 11 sites (herein after called routine monitoring). This regime consisted of bi-monthly *E. coli*, nitrites or NO_2, nitrates or NO_3, total Kjeldahl nitrogen (TKN), total phosphorus (TP), orthophosphate (OP) samples, and chl-a, as well as field and flow parameters. These routine samples were consistently taken near the beginning of the two-month cycle, regardless of flow conditions. This routine data will be used for biennial integrated water quality assessments conducted by TCEQ.
- Regime #2 - bi-monthly flow-biased monitoring at the same 11 sites (herein after called flow-biased monitoring) and for the same parameters described in Regime #1. The goal of the flow-biased monitoring was to ensure that, to the furthest extent possible, the full range of flows were represented in the resultant data so that functional LDCs could be produced. Therefore, sampling for targeted flows was based on data gaps that developed in the routine monitoring. For example, if routine monitoring did not include high flow events, then higher flows were targeted for monitoring. Conversely, if routine monitoring tended to occur during normal and higher flow events, then low flow events were targeted. Use of data from these samples has been restricted to load calculation, and thus does not qualify for inclusion in future biennial integrated reports composed by TCEQ.
- Regime #3 - optical brightener (OB) testing at various sites in the watershed including, but not necessarily limited to, the 11 sites at which routine and flow-biased monitoring were conducted. This testing consisted of anchoring natural untreated cotton sampling medium in rigid flow-through containers in the stream for a period of time (24 to 48 hours). The sample medium was later collected and checked for fluorescence from detectable OBs. These compounds are found in many laundry detergents and can therefore indicate the presence of sewage leaks or failing septic systems. OB detection results may help identify potential human sources of *E. coli* in the watershed and inform the selection of BMPs to manage these sources.

A variety of sites were selected to encompass different land uses and flow regimes (Figure 3-1). One site characterizes residential and industrial developments on the west side of Lake Arlington (10793), with another characterizing residential developments on the east side (10798). Seven sites are located on the main tributary to the lake, Village

Creek. Two of these sites, which characterize industrial and manufacturing land uses, are periodically under influence of the lake (10780 and 10781). This means that measurements taken at these sites when water levels are at or near the conservation pool elevation may represent pooled water from the lake rather than inflowing water from Village Creek (also called 'backwater' conditions. Further upstream, two sites are located on either side of the TRWD outfall (21762 and 13671), which brings in additional water from two lakes in east Texas and significantly changes water quality when active. Another station (10786) is located at the site of a USGS gage, at the approximate midpoint of the watershed. Two stations located further upstream characterize suburban-rural mosaic land uses (10785 and 21763). Two upstream tributaries were also monitored: Deer Creek (10805) and Quil Miller Creek (21759), representing similar suburban-rural mosaic land uses.

5.1.1 *E. coli*

The additional monitoring conducted in 2016 and 2017 indicates that contact recreational use is not supported in Village Creek or its tributaries due to elevated *E. coli* levels. The data also indicates that the additional two tributaries to Lake Arlington that were sampled (stations 10798 and 10793) may also not support contact recreational uses. Often, evaluations of supported uses employ a 10% margin of safety (MoS) to account for one or several sources of uncertainty related to data collection and analysis, including field collection and laboratory errors. When applied in water quality, the MoS is often observed to provided additional confidence that the noted water quality action level is being met. A boxplot analysis of all stations (Figure 5-1) revealed that only one station (21762) maintained a geomean concentration well below the 10% MoS (113 MPN/100 mL) at 76 MPN/100 mL, with another (10786) just below the water quality standard (126 MPN/100 mL) at 124 MPN/100 mL. With the exception of these two sites and Deer Creek (10805), the boxplots indicate that more than half of the samples collected at each site exhibited *E. coli* concentrations higher than the standard, with geomeans varying from 171 (10805) to 713 MPN/100 mL (10798). As indicated earlier, it is worth reiterating that flow-biased sampling methods were a component of this data collection effort, and several high- and flood-flow events represented in the boxplot were intentionally sought so that a variety of flows would be available to conduct a thorough LDC analysis and load estimations. As such, only a portion of this data will be represented in future biennial integrated reports.

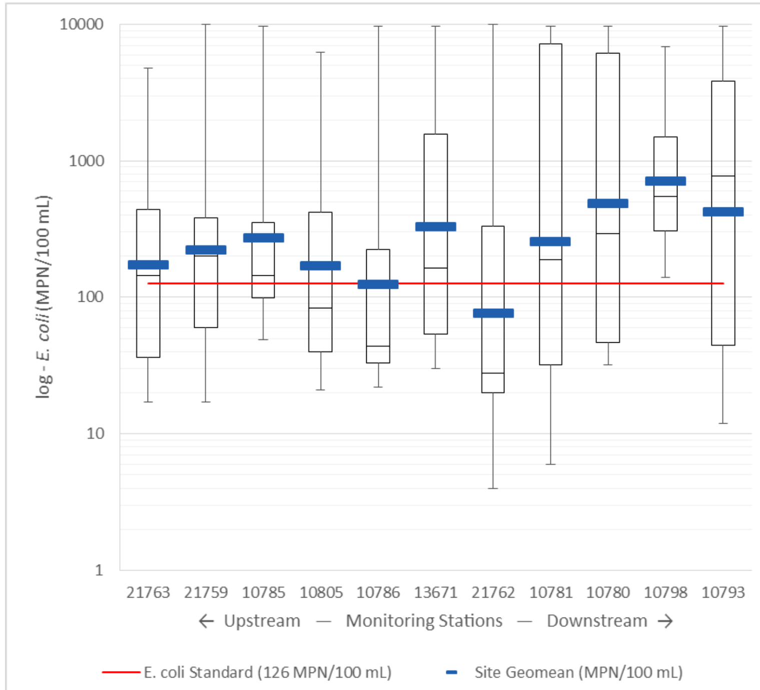


Figure 5-1. Boxplots and geomeans for E. coli samples collected June 2016 – May 2017.

For most of the sites on Village Creek (upstream from station 21762), *E. coli* concentrations appeared to be closely related to precipitation events and thus higher flows, indicating that nonpoint sources and/or resuspension of existing sediment bacterial colonies are likely to be the significant contributors of *E. coli*. Figure 5-2 provides an example of the flow-concentration relationship typical of these stations. Beginning at station 21762, however, dilution from incoming flows from the TRWD outfall significantly reduces *E. coli* concentrations. The relationship between concentration and flow is confounded when this outfall is active. During these release events, flow increased but *E. coli* concentrations tended to remain low, only exceeding the standard when associated with a precipitation event (Figure 5-3). The direct relationship between increasing flow and *E. coli* concentration breaks down even further at sites closer to the lake (10781, 10780, 10793). Here, backwater conditions that result as the lake approaches its capacity further reduce the predictability of the flow-concentration relationship. However, as seen in the example shown in Figure 5-4, high *E. coli* can still reliably be predicted using recent rainfall at these three sites.

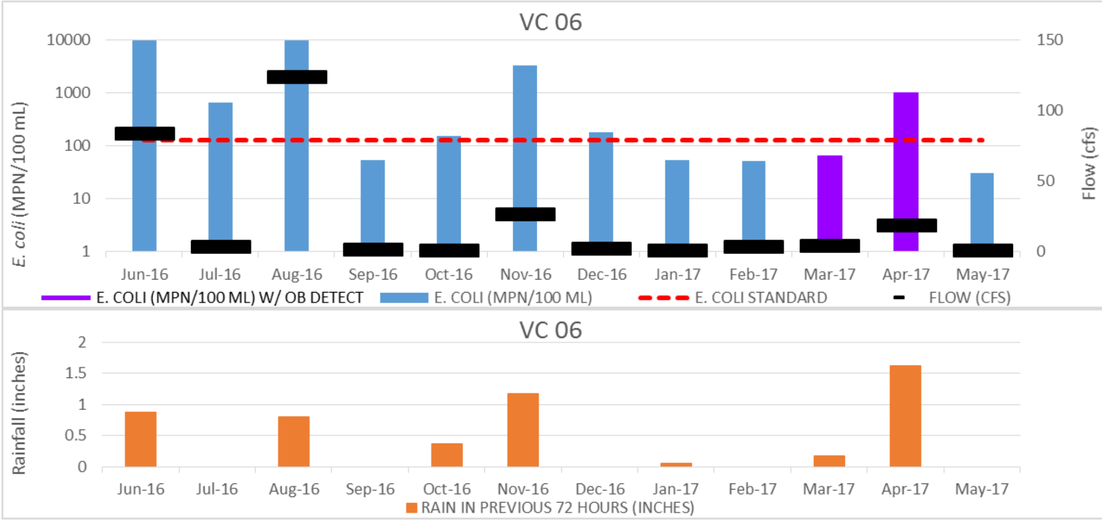


Figure 5-2. Hydrology and E. coli parameters, Village Creek at Everman Drive (13671).

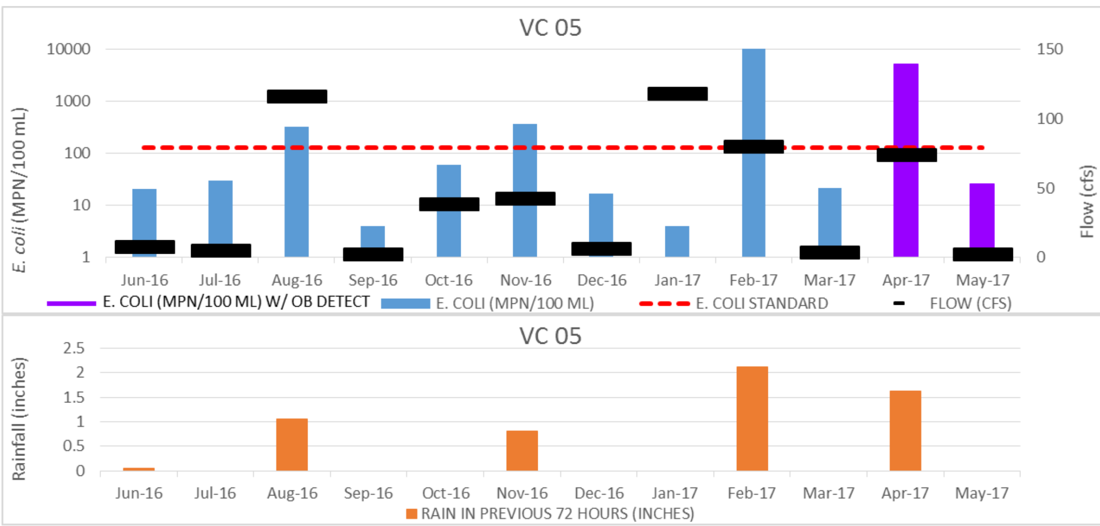


Figure 5-3. Hydrology and E. coli parameters, Village Creek near Freeman Drive (21762).

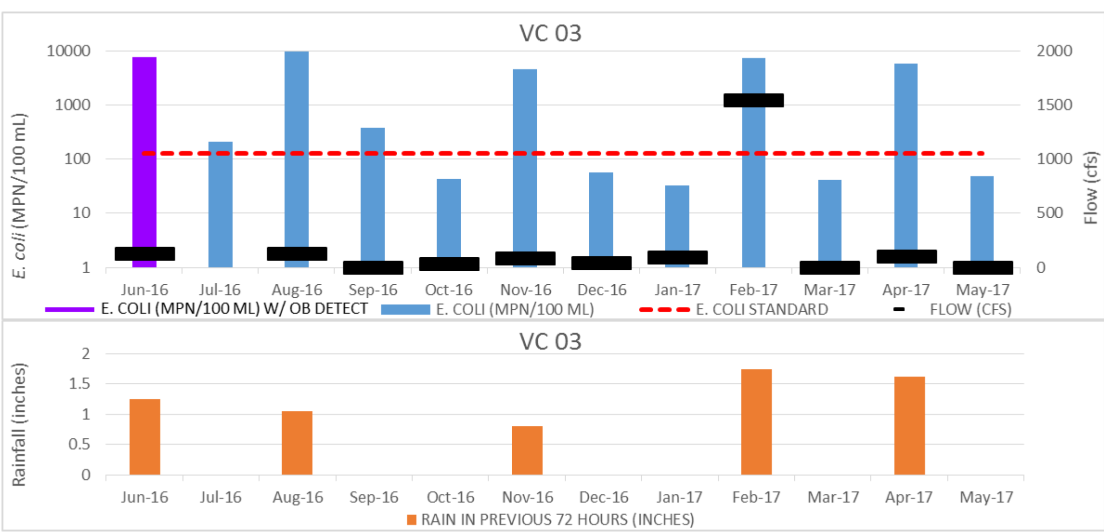


Figure 5-4. Hydrology and E. coli parameters, Village Creek at IH-20 (10780).

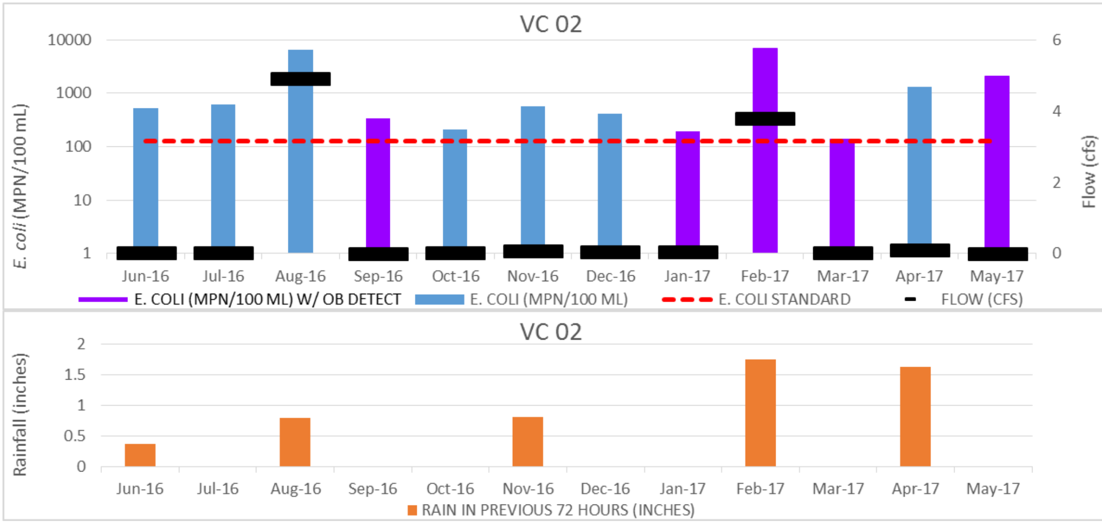


Figure 5-5. Hydrology and E. coli parameters, Tributary of Lake Arlington (10798).

Rainfall data for each station was estimated using area-interpolated daily precipitation values from the NWS's Advanced Hydrologic Prediction Service (https://water.weather.gov/precip/). This provides a more accurate estimate of recent rainfall compared with using precipitation values from the nearest weather station.

Despite being collected at relatively the same time frame as the other monitoring stations, the station on the unnamed tributary to the lake (10798) displayed distinct flow-concentration relationships that were unlike any of the other sites. For instance, 10798 was the only site that displayed *E. coli* concentrations that were consistently elevated above the water quality standard, despite regularly being the site with the lowest flow (Figure 5-5). It was also the only monitored site that appeared to maintain consistent flow throughout the project, even during the "flash drought" conditions encountered in the summer of 2015 when even the main stem of Village Creek exhibited disconnected pools and zero recorded flow at the Rendon USGS gage (site 10786). This continuous flow condition is supported by the anoxic substrate conditions encountered in several portions of the reach, particular in concrete-lined portions where black substrate is often indicative of continuously-wet conditions in the bed and banks. Upon hearing of the potential issue, City of Arlington staff promptly responded to investigate. Further analysis of the site revealed that point source issues may play a part in the consistently elevated values and continuous flow, but definitive conclusions have yet to be made, as follow-up tests done at wastewater infrastructure bisects with the tributary have yet to show leakage occurring.

5.1.2 Solids

Typically, discussions of solids, and TDS in particular, are not major components of watershed plans. Most of the BMPs aimed at curbing TDS are applicable to reducing *E. coli* and nutrient inflows, so they can easily be grouped in with those contaminants for simplicity. However, given the potential point source influence encountered at site 10798, along with several elevated geomeans in upper reaches of the watershed (Figure 5-7), TDS became a prominent parameter of interest from a water supply perspective.

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

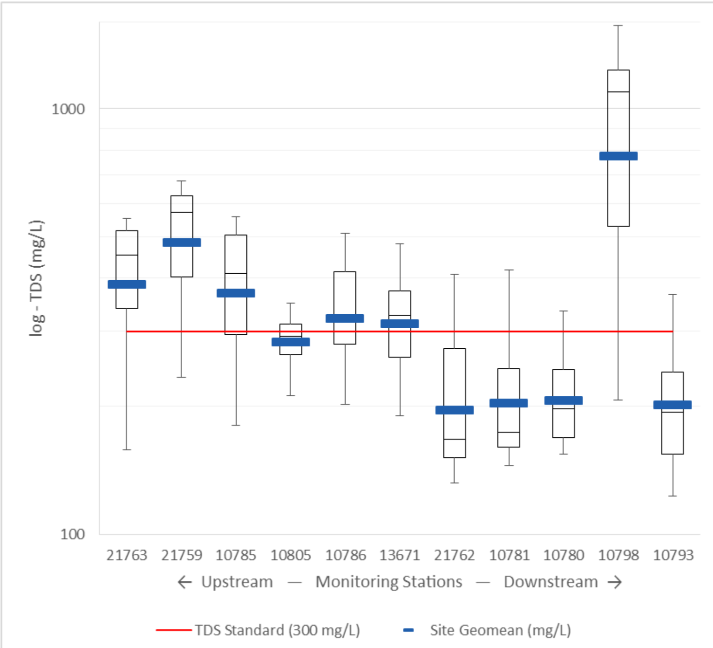


Figure 5-6. Boxplots and geomeans for TDS samples collected June 2016 – May 2017.

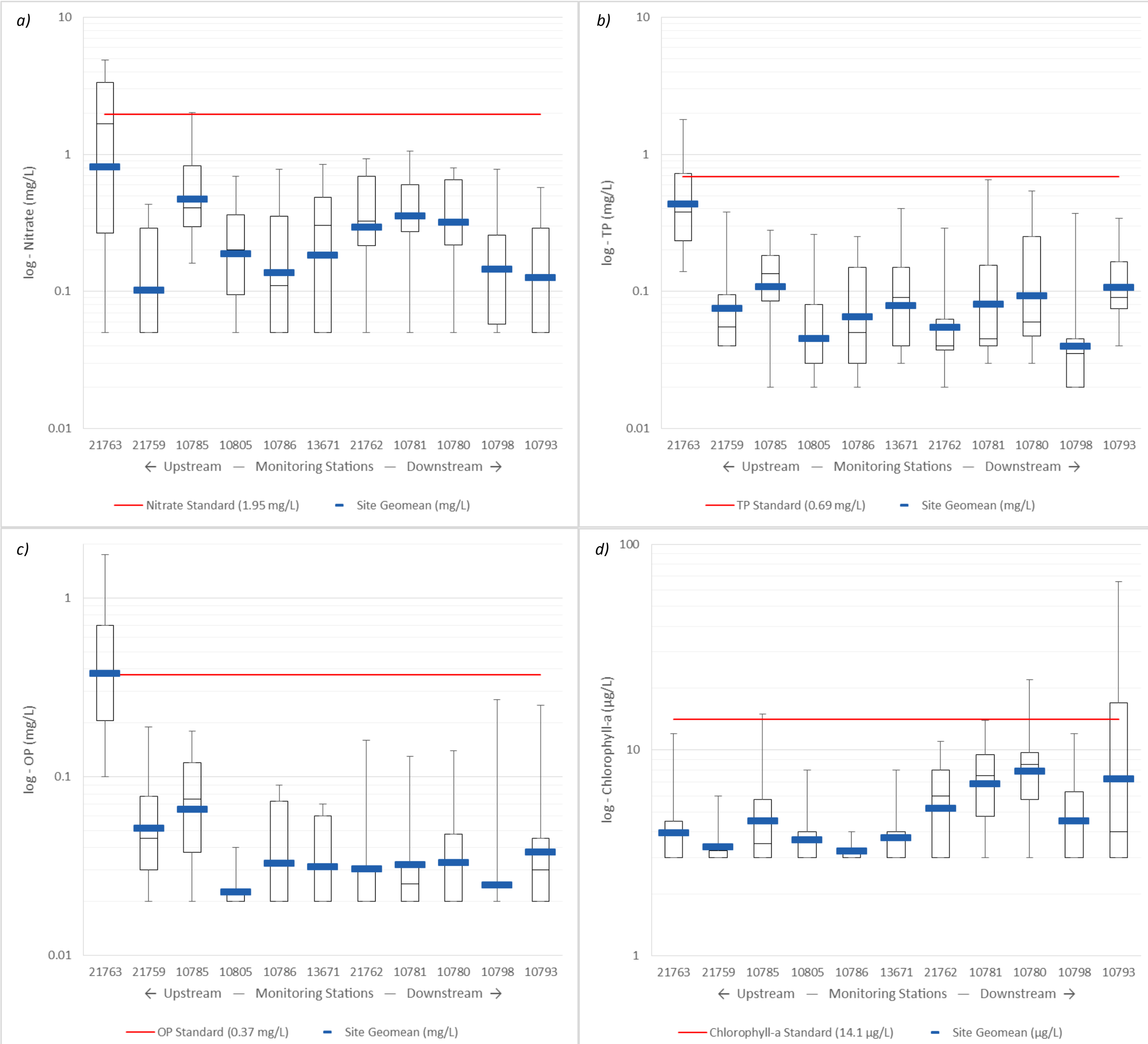
With the exception of the Deer Creek tributary (10805), high TDS values were also apparent in all monitoring sites above the TRWD outfall, with geomeans for the five sites exceeding the water quality standard (300 mg/L) (Figure 5-6). The Quil Miller Creek tributary (21759) exhibited the 2nd highest geomean in the dataset, but in general, both the site geomeans and overall TDS ranges tended to decrease on Village Creek with downstream progression, indicating that additions of flow from other tributaries (dilution) played a role in the TDS reduction.

5.1.3 Nutrients

Although several nutrients exhibited occasionally high levels within the lake, no one nutrient was elevated within any of the lake's tributaries. However, values for nitrogen and phosphorus species at the at the most upstream Village Creek site (21763) were slightly elevated when compared to other sites (Figure 5-7). In contrast to the TDS trend, it would appear that the two tributaries, Quil Miller and Deer Creeks, are now providing the dilution, this time for nutrients. This indicates that the primary source of nitrogen and phosphorus in the watershed originates in the headwaters of Village Creek's main branch. Initial assumptions on sources focused on the agricultural land use near the headwaters. However, greater agricultural land use in the Quil Miller Creek subwatershed prompted re-evaluation of potential sources. After further review of aerial imagery, it became apparent that there were two golf courses upstream of site 21763, one which bordered the west bank of Village Creek, and another through which Village Creek bisected. Golf courses can be a prominent source of nutrients from extensive fertilizer use. Proposed supplemental monitoring will further explore this possibility in the future. Effluent from the nearby WWTF may also be a contributor to the elevated values within this reach of the main stem, with wastewater discharges (and thus nutrient enrichment) being more significant here than in either of the tributaries providing dilution.

This trend reversed direction with respect to chl-a, where the three highest geomeans were exhibited by the three sites (10781, 10780, and 10793) that were under influence of the lake for at least a portion of the project's duration (Figure 5-7). Higher chl-a concentrations here are likely due to decreased flow velocity, which allows for free-floating algal species to populate an area more easily.

Despite the lack of distinct nutrient-related water quality concerns in the tributaries, caution should be exerted when drawing conclusions on how tributary inputs impact the lake. Nutrients are transient in a flowing system such as a creek or river, but once those nutrients are delivered to a dammed waterbody like a lake or reservoir, flow rates decrease significantly, and will likely even be difficult to accurately measure during reservoir releases at the dam. This increased residence time leads to accumulation of nutrients, sediment, and other solids. Nutrients will continue to accumulate in both the water column and bed sediments, until they are used by organisms, removed by human means (typically through dredging), or resuspended and flushed downstream over the dam. If excessive nutrients begin to accumulate in a lake, this reduces the growth limitations on algae, and algal blooms will often result, a phenomenon commonly referred to as lake eutrophication. In many cases, eutrophication is a natural process in lakes, but can be intensified with the proliferation of urban environments. In addition to the potentially harmful environmental effects, algal blooms may also cause taste and odor problems in municipal water taken from the lake, and may impact recreational opportunities.



Boxplots for parameters of interest include a) nitrate, b) TP, c) OP, and d) chl-a.

Figure 5-7. Boxplots and geomeans for nutrients in samples collected June 2016 – May 2017.

5.2 Load Duration Curve Analysis

In watersheds where nonpoint sources are the likely primary source of pollutant loading, LDCs are useful tools for illustrating the relationship between stream flow, pollutant concentration, and the resulting pollutant loads. The pollutant loads during each monitoring event can be compared to the maximum allowable load at that particular flow rate; this data can then be used to calculate the reduction needed to meet the water quality goal for each pollutant. Although LDCs cannot be used to differentiate between specific sources (e.g., livestock, pets, OSSFs), they can be used to determine whether point sources or nonpoint sources are the primary concern by identifying whether exceedances occur within a specific flow regime. If exceedances are only observed during periods of high flow or moist conditions associated with storm events, then nonpoint sources are the likely contributor. However, if allowable load exceedances are also present during dry conditions or periods of low flow, then it is likely that point sources are also contributing to the overall load, becoming more prominent as flows decrease (Figure 5-8). Both stakeholders and regulatory entities recognize that exceedances at high flows are usually attributed to flooding, and thus inherently unmanageable. Therefore, stakeholders agreed that reductions demonstrated in the mid-range conditions flow regime would be most appropriate for representing the water quality reduction goal at each site. Additional information regarding LDC development is provided in Appendix D.

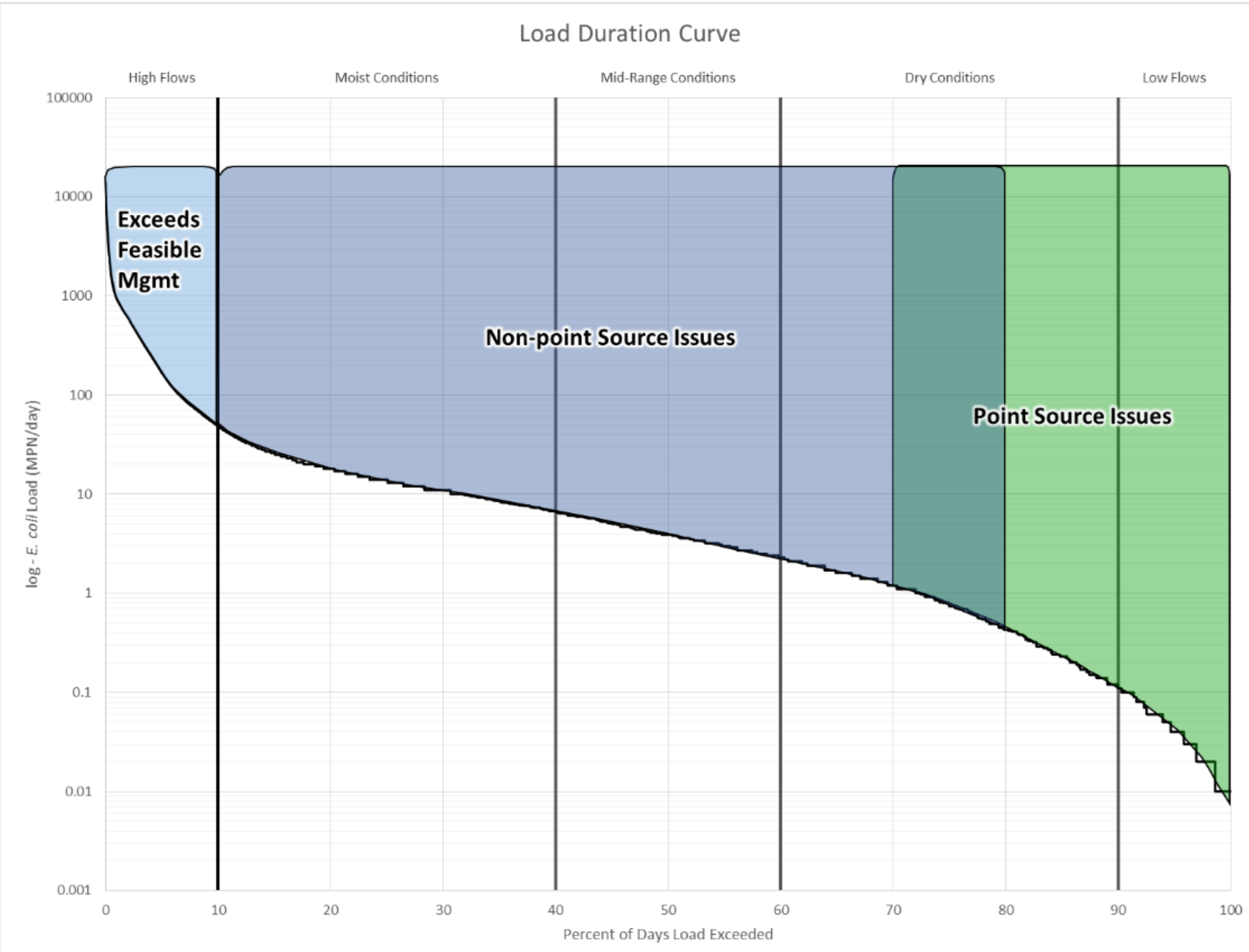


Figure 5-8. Flow categories and regions of likely pollutant sources along an example load duration curve.

A minimum of 12 paired stream flow-pollutant concentration data points are required to properly execute the LDC analysis tool. During the monitoring effort, 12 paired samples were successfully collected for all sites except 10793, which experienced several periods of no flow during the monitoring effort. LDCs were developed at each of the 11 stations for five key constituents, *E. coli*, TDS, nitrate, TP, and chl-a, so that any trends between stations could be analyzed. Although the LDCs for all sites were instrumental in developing an understanding of pollutant load dynamics throughout the watershed, stakeholders chose to focus on two sites to determine several short-term and long-term water quality goals.

Site 10781

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

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

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

Site 10798

As discussed in Section 5.1.1, it is suspected that the unnamed tributary monitored at site 10798 may be impacted by point sources to a much greater extent than the rest of the watershed. For this reason, this tributary was analyzed with additional short-term goals in mind when compared to the long-term water quality goals identified for the whole watershed. LDC analysis for this site will help to further identify the source type (point vs. nonpoint) by comparing the required load reductions between the various flow categories.

5.2.1 *E. coli*

As represented by the data collected at site 10781, the LDC analysis indicates that elevated *E. coli* concentrations are primarily associated with high flow, moist conditions, and mid-range conditions flow categories, indicating that nonpoint source inputs and in-stream resuspension of *E. coli* from bed sediments are primarily responsible for the exceedances (Figure 5-9). Similar conditions are represented at other stations along Village Creek. To ensure that water quality goals are achieved, an annual reduction of 1.61E+14 MPN/yr during mid-range conditions is needed at this site (Table 5-1).

In contrast to all other monitored sites, the LDC analysis for site 10798 revealed that reductions were required at all flow conditions, including low flows (Table 5-1). This was also exemplified in the graphical interpretation, as it was the only site where the regression trend for the calculated loads (in blue) never intersected the trend for the maximum allowable load (in red) (Figure 5-9). Here, reductions during mid-range conditions are expected to be 1.83E+11 MPN/yr.

Table 5-1. *E. coli* load reduction goals at a) site 10781 and b) site 10798.

a) Flow Condition at Site 04 (10781)	% of Time Flow Exceeds	Daily Loading (MPN/day)	% Daily Reduction Needed for Goal	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)	b) Flow Condition at Site 04 (10793)	% of Time Flow Exceeds	Daily Loading (MPN/day)	% Daily Reduction Needed for Goal	Annual Loading (MPN/yr)	Annual Reduction Needed (MPN/yr)
High Flows	0-10%	8.90E+13	96	3.25E+16	3.10E+16	High Flows	0-10%	6.36E+11	98	2.32E+14	2.27E+14
Moist Conditions	10-40%	1.71E+12	81	6.23E+14	5.14E+14	Moist Conditions	10-40%	1.47E+11	90	5.36E+13	5.23E+13
Mid-Range Conditions	40-60%	5.89E+11	72	2.15E+14	1.61E+14	Mid-Range Conditions	40-60%	6.22E+08	80	2.27E+11	1.83E+11
Dry Conditions	60-90%	2.49E+10	12	9.08E+12	2.13E+12	Dry Conditions	60-90%	2.36E+08	73	8.60E+10	6.34E+10
Low Flows	90-100%	3.78E+09	-	1.38E+12	-	Low Flows	90-100%	7.09E+07	61	2.59E+10	1.57E+10

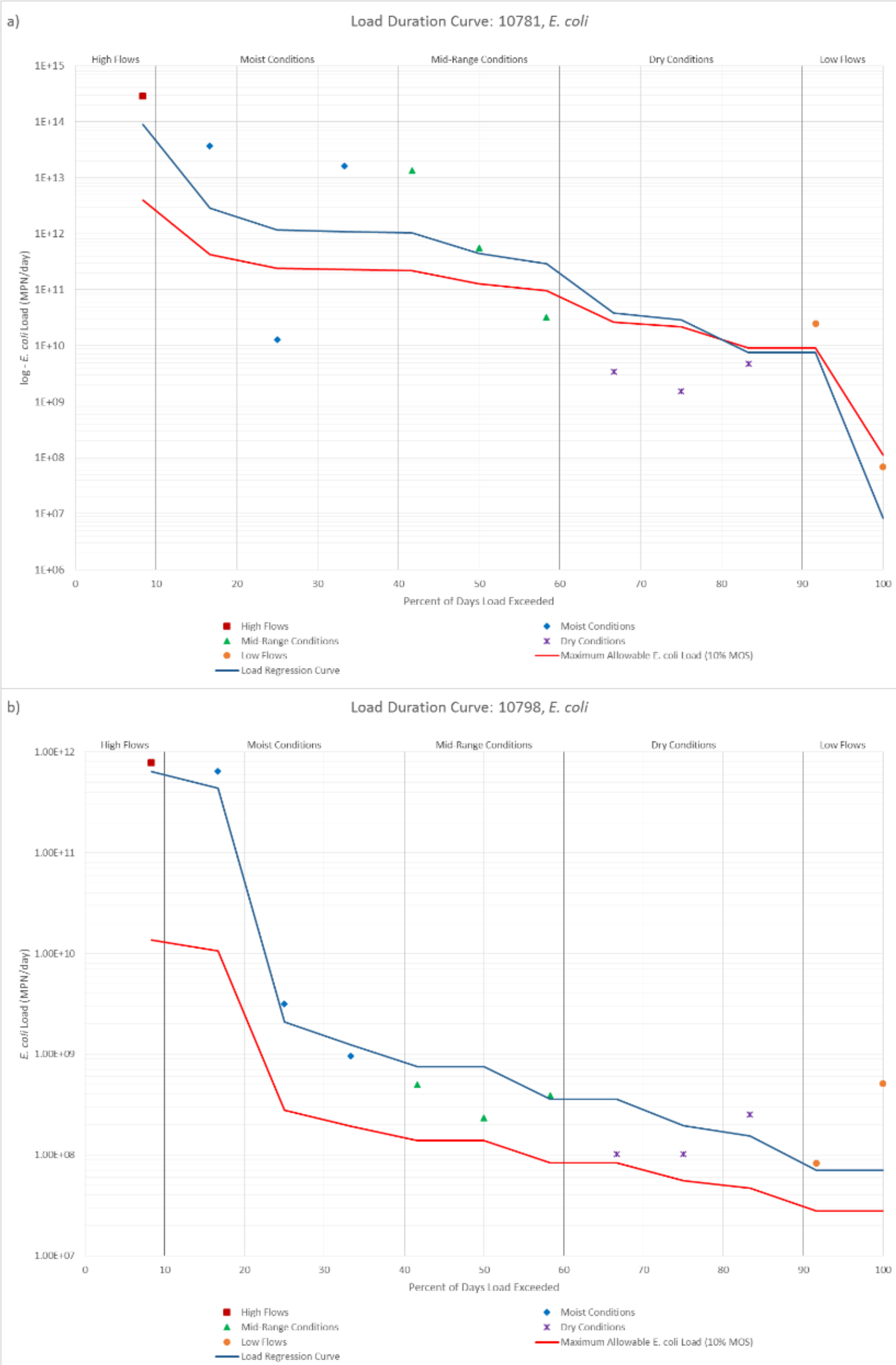


Figure 5-9. LDCs for E. coli at a) site 10781 and b) site 10798.

5.2.2 Solids

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

For the unnamed tributary, exceedances were prevalent at all flow conditions except high flows. However, TDS is primarily used in this study as a supplemental source of information to further identify potential sources of *E. coli* and nutrient pollution. Therefore, no load reduction goals were identified for inclusion by the stakeholders.

5.2.3 Nutrients

As indicated in Section 5.1.3, Lake Arlington is listed for both nitrate and chl-a concerns. Although several collected samples surpass nutrient screening levels for nitrate and TP in the two most upstream sites (21762 and 21759), no overall nutrient concerns currently exist in any of the lake's tributaries. However, it should be noted that the screening level thresholds for nitrate and TP are higher in streams than in lakes (Table 3-3). This means that a nutrient concentration in a stream may meet the screening level there, but would likely surpass the lake's screening level if a sample was taken near the stream-lake confluence where dilution effects were not yet significant. Therefore, while stakeholders did not specifically outline water quality goals in terms of a reduction, several protective measures to mitigate future increases will be recommended. These protective measures are expected to minimize increases to chl-a by limiting the nutrients available to algal species, thus limiting eutrophic potential.

5.3 Spatial Analysis of *E. coli* Sources Using SELECT

Watershed prioritization and BMP recommendations were further refined with the use of the SELECT analysis, which further partitions potential *E. coli* loads into 55 modeled catchments, or subwatersheds (Figure 5-10), based on likely *E. coli* sources as identified by watershed stakeholders. Using a combination of geographic information system (GIS) and spreadsheet tools, estimated populations of various warm-blooded animal species (humans, pets, livestock, wildlife) were distributed spatially throughout the watershed based on each population's applicability to different land use/land cover characteristics, and then sub-categorized into riparian and upland zones. Once distributed, species-specific *E. coli* load production values published in scientific literature were applied to each population (Table 5-2), producing the *E. coli* loads that may eventually find their way to waterways (Figure 5-11, Figure 5-12, Figure 5-13). To account for the variety in

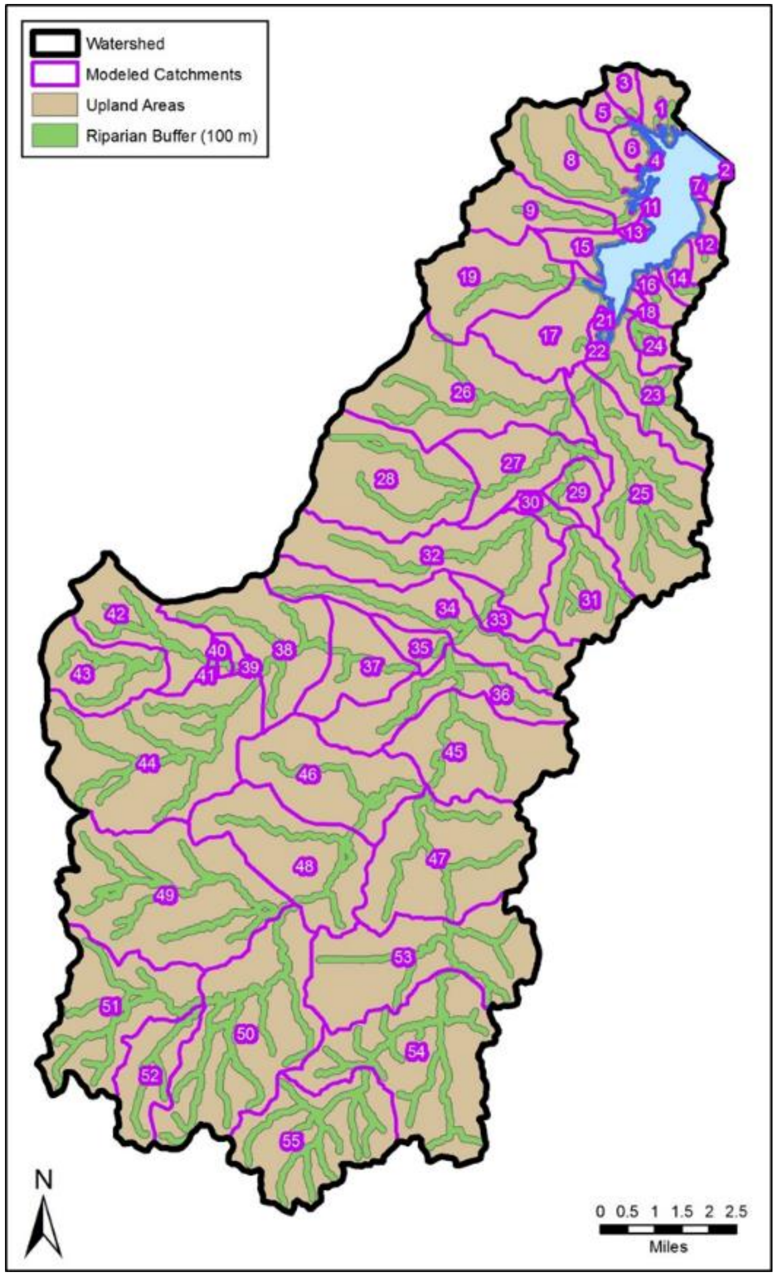


Figure 5-10. Subwatersheds and riparian buffer zones in the watershed for use in the SELECT analysis.

Table 5-2. *E. coli* loading factors for calculating *E. coli* loads from various sources.

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

the sizes of the subwatersheds, these loads were then normalized to a per-acre basis to ensure that contributions from larger subwatersheds did not overshadow those from several smaller ones. Finally, the separate, normalized sources are then aggregated to produce an overall normalized *E. coli* load for each subwatershed. For an in-depth look at the SELECT analysis, please refer to Appendix E. Please note that SELECT was designed specifically for calculating loads from *E. coli* sources, and thus cannot be used to calculate loads from other pollutants of interest to stakeholders, despite their relative importance.

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

Raw SELECT output is often seen as a "worst case scenario" for estimating *E. coli* loads, as the tool does not contain any built-in functionality that automatically adjusts for *E. coli* die-off, predation, soil entrainment, or other forms of mitigation between the time of deposition up to its introduction to a waterway. However, these processes can be partially accounted for by applying weights to the loads based on their distance to a waterway. For example, manure deposition within riparian buffer areas (< 100 m from a stream), carry more weight than would deposition in an upland area further away (Figure 5-10). Use of this tactic will allow for further refinement of critical areas for BMP implementation.

E. coli loads were similar for all livestock species (cattle, sheep, goats, and horses), being generally more prevalent in the more rural areas just south of the lake near Everman and Rendon, and further south in Johnson County, with minimal impacts in the urban areas east and west of the lake and in the vicinity of Burleson and Crowley. In particular, per-acre loads were most concentrated in subwatersheds 29, 50, 27, 54, and 32 (Figure 5-11).

Impacts from deer *E. coli* loads were not as widespread, with noticeably less impacts near urban centers, with rare exception. The greatest impacts for deer occurred in the same subwatersheds impacted by livestock, with subwatersheds 29, 54, 50, and 30 bearing the highest per-acre loads (Figure 5-12). The highest *E. coli* loads for feral hogs were exhibited in subwatersheds 13, 54, 29, 30, and 50, but impacts were slightly higher in several urban subwatersheds closer to the lake when compared to other sources. In contrast, *E. coli* loads from pets tended to be highest in these smaller, urban watersheds, with the highest loads encountered in subwatersheds 10, 7, 20, 11, and 22, all occurring along the rim of the lake.

As expected, *E. coli* loads from OSSFs were most significant in the rural areas to the south and east, with the highest loads coming from subwatersheds 36, 31, 53, 45, and 55. Impacts from SSOs were more scattered, with the highest *E. coli* loads borne by subwatersheds 17, 46, 35, 23, and 8. For WWTFs, the three subwatersheds containing active facilities, 50, 44, and 54, were the only ones with measurable loads (Figure 5-13).

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

Stakeholders must be prepared for the unexpected when it comes to pollutant source management (credit: City of Fort Worth).

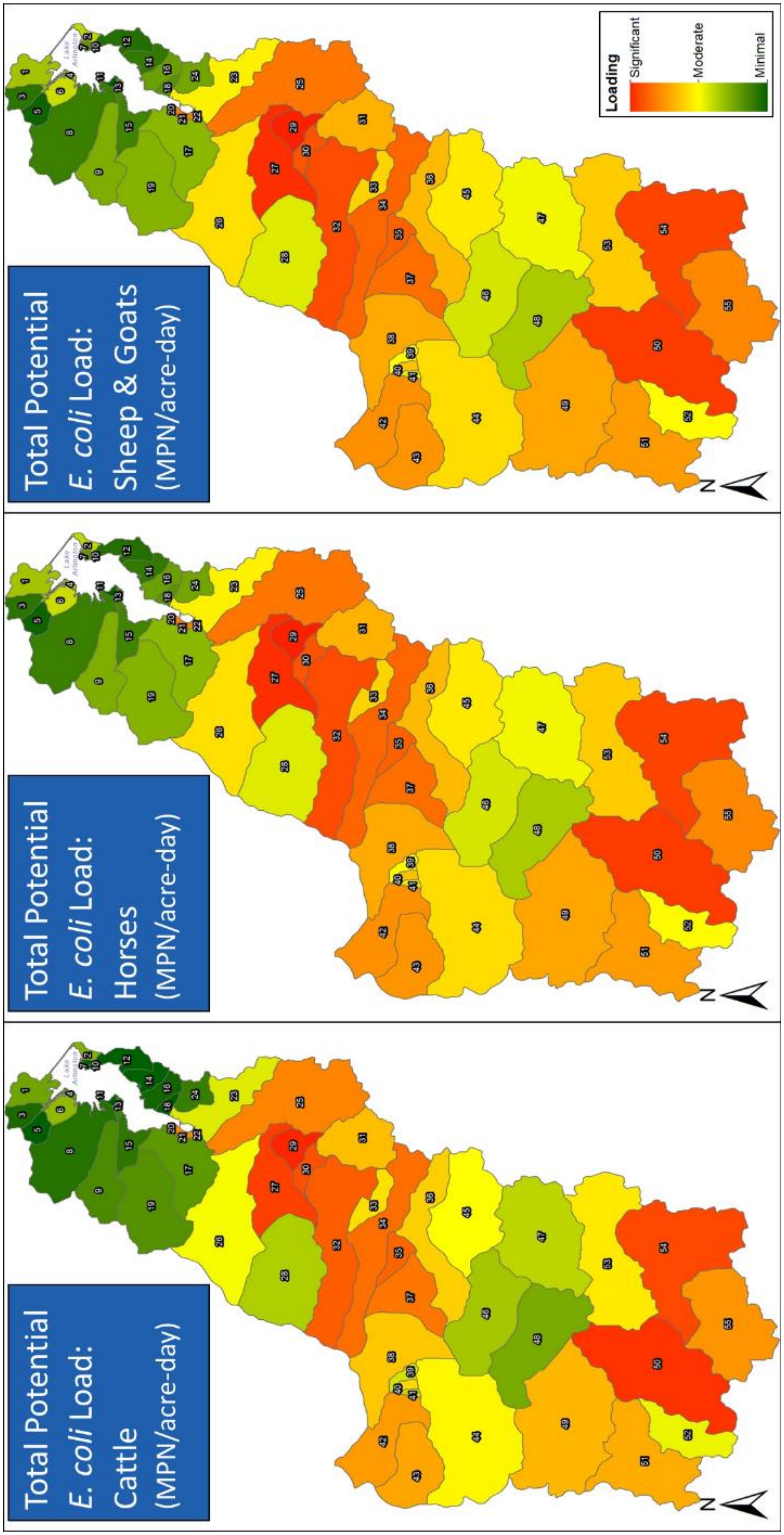


Figure 5-11. Relative severity of E. coli loads from livestock, by subwatershed.

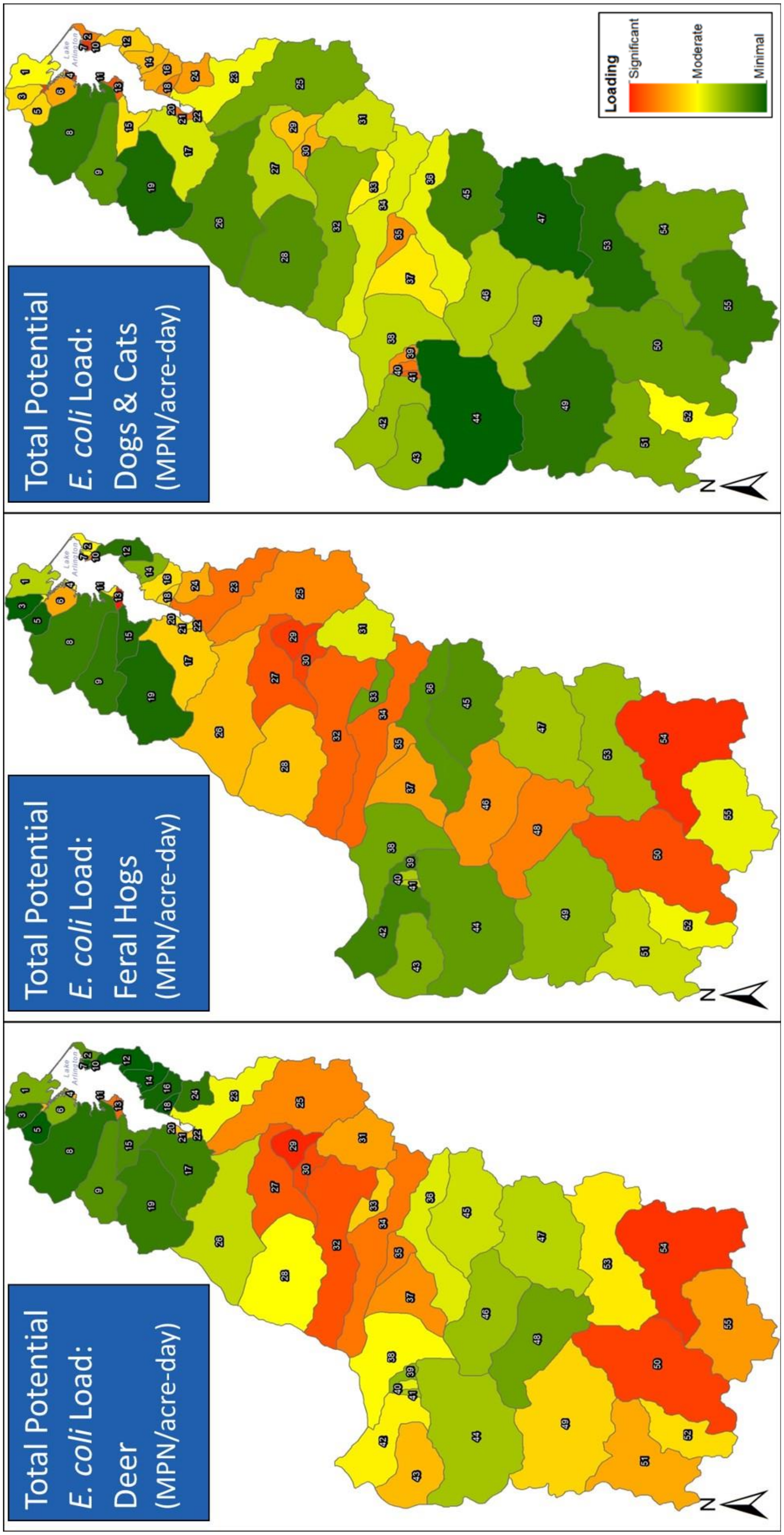


Figure 5-12. Relative severity of E. coli loads from deer, feral hogs, dogs, and cats, by subwatershed.

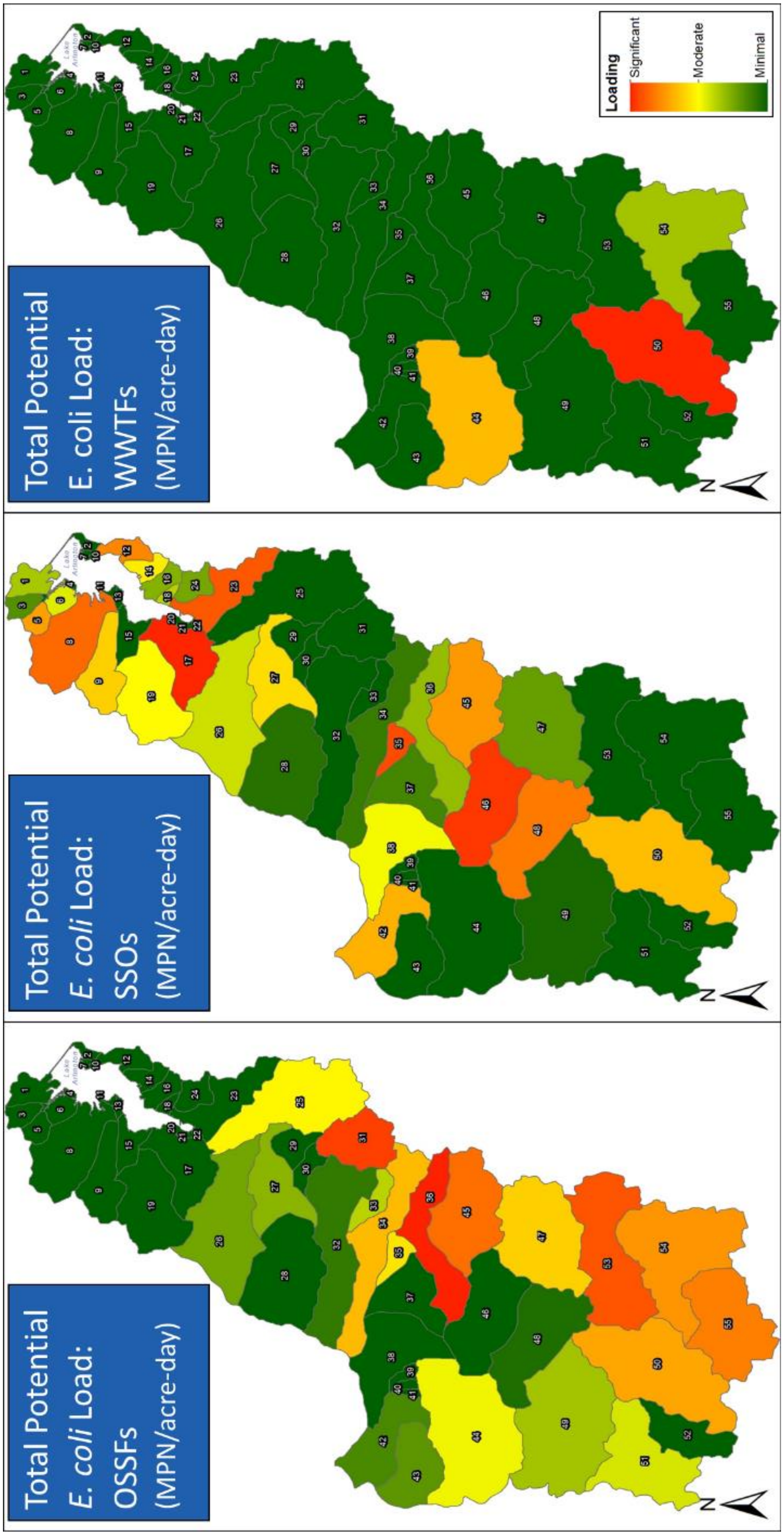


Figure 5-13. Relative severity of E. coli loads from human waste sources, by subwatershed.

Overall, impacts from all combined *E. coli* sources appeared to be most prevalent in three collective categories: 1) in smaller subwatersheds surrounding the lake, 2) near the center of the watershed downstream of the Deer Creek-Village Creek confluence, and 3) in subwatersheds near the headwaters with a relatively high percentage of riparian-to-upland area. Of these, 8 of the 10 subwatersheds with the highest per-acre *E. coli* loads were located on the lake rim (Figure 5-14). On the west side of the lake, these contributions are likely from wildlife in large forested areas that compose a significant portion of the coastline. However, several large oil extraction pads exists within these forested areas. The increased runoff generated by these open areas may carry a disproportionate amount of *E. coli* from the forested areas into the lake. In the more urbanized areas around the lake, much of this influence likely comes from dog/cat populations. Pets were by far the most prominent source, with all watersheds contributing at least some amount of *E. coli*. The pets category exhibited both the highest maximum and minimum contributions, highlighting the importance for management of this *E. coli* source. *E. coli* contributions from sheep and goats followed in prominence, with loads from cattle being very similar. OSSFs also supplied significant loads. Figure 5-15 provides a visual comparison of the minimum and maximum loading values for all evaluated *E. coli* sources for the watershed, while Table 5-3 provides an in-depth analysis of all evaluated sources in all 55 subwatersheds. Please note that Figure 5-15 uses units of MPN/ac-day for comparison between pollutant source classes, while Table 5-3 uses units of MPN/day to establish the scope of the reductions needed to meet water quality goals.

As mentioned previously, there exist several potential *E. coli* sources that could not be modeled reliably, but that stakeholders still recognize as viable pollutant management opportunities. These un-modeled sources, as listed in Section 4.3.5, will also be considered in the overall management strategy covered in future chapters.

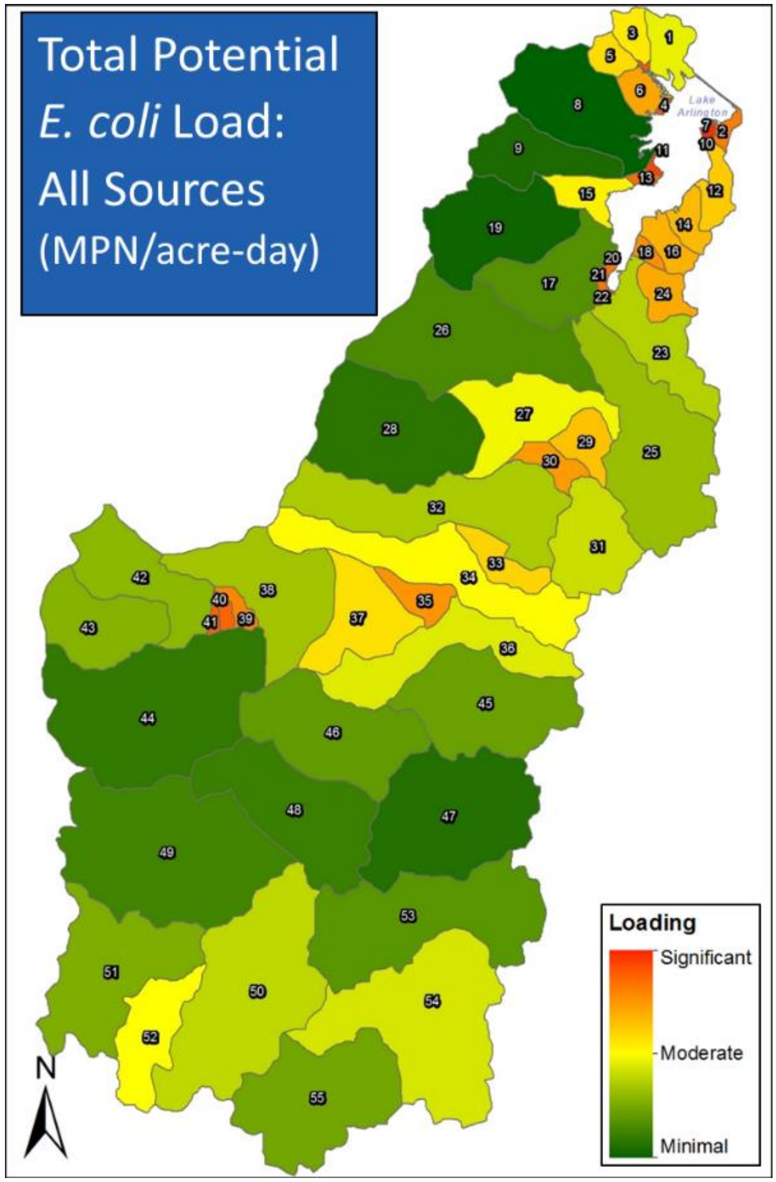


Figure 5-14. Relative severity of E. coli loads for all sources by subwatershed.

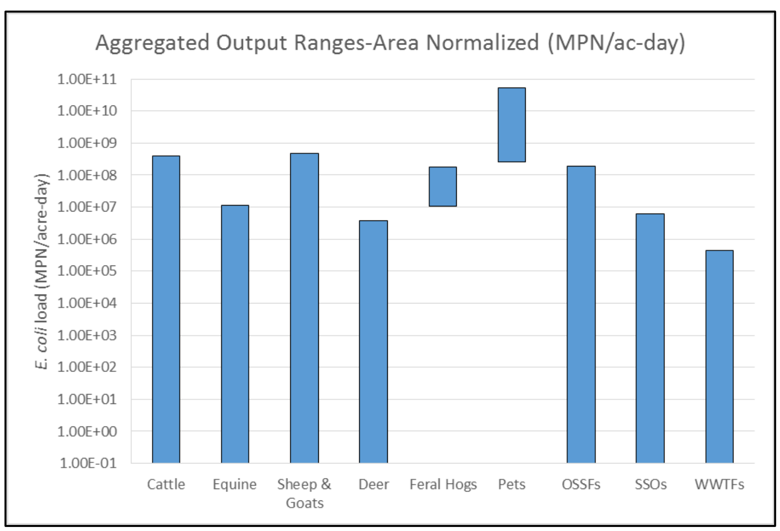


Figure 5-15. Daily Potential E. coli load ranges for all source categories.

Table 5-3. Potential *E. coli* loads for all subwatersheds and evaluated sources (MPN/day).

Sub-watershed	Cattle	Horses	Sheep & Goats	Deer	Feral Hogs	Dogs & Cats	OSSFs	SSOs	WWTFs	Total E. coli
1	3.67E+10	1.18E+09	5.08E+10	4.49E+08	2.93E+10	7.57E+11	—	2.18E+06	—	**8.76E+11**
2	8.77E+09	3.04E+08	1.30E+10	8.57E+07	1.73E+10	1.18E+12	—	—	—	**1.22E+12**
3	1.24E+09	8.27E+07	3.54E+09	8.12E+06	3.28E+09	6.07E+11	—	3.24E+05	—	**6.15E+11**
4	3.04E+09	9.50E+07	4.07E+09	9.65E+07	6.76E+09	1.19E+12	—	—	—	**1.20E+12**
5	—	5.42E+07	2.32E+09	—	3.38E+09	6.01E+11	—	2.18E+07	—	**6.06E+11**
6	2.26E+10	8.11E+08	3.47E+10	3.04E+08	4.70E+10	1.03E+12	—	1.46E+06	—	**1.14E+12**
7	—	1.61E+07	6.91E+08	—	3.71E+09	1.14E+12	—	—	—	**1.14E+12**
8	1.66E+10	7.94E+08	3.40E+10	5.74E+08	7.65E+10	6.94E+11	—	4.43E+08	—	**8.23E+11**
9	1.63E+10	8.53E+08	3.66E+10	5.55E+08	4.16E+10	6.30E+11	—	3.43E+07	—	**7.26E+11**
10	—	1.19E+07	5.11E+08	—	4.22E+09	1.39E+12	—	—	—	**1.40E+12**
11	—	—	—	1.23E+08	5.88E+09	1.05E+12	—	—	—	**1.05E+12**
12	—	9.10E+07	3.90E+09	—	1.10E+10	8.98E+11	—	3.97E+07	—	**9.13E+11**
13	9.29E+08	2.90E+07	1.24E+09	2.29E+08	1.27E+10	1.19E+12	—	—	—	**1.21E+12**
14	—	9.54E+07	4.09E+09	—	1.58E+10	1.02E+12	—	4.84E+06	—	**1.04E+12**
15	4.59E+09	1.92E+08	8.23E+09	1.77E+08	1.12E+10	8.93E+11	—	—	—	**9.18E+11**
16	5.97E+08	2.27E+08	9.71E+09	3.91E+06	5.75E+10	1.15E+12	—	7.85E+05	—	**1.21E+12**
17	5.70E+10	2.24E+09	9.61E+10	5.41E+08	2.53E+11	1.01E+12	4.45E+09	1.01E+10	—	**1.43E+12**
18	—	5.51E+07	2.36E+09	—	1.75E+10	1.01E+12	—	4.60E+05	—	**1.03E+12**
19	6.48E+10	2.20E+09	9.45E+10	6.28E+08	4.65E+10	6.79E+11	2.60E+09	2.43E+07	—	**8.90E+11**
20	1.49E+09	4.60E+07	1.97E+09	1.34E+07	1.26E+09	5.57E+11	—	—	—	**5.62E+11**
21	2.01E+10	5.76E+08	2.47E+10	1.38E+08	1.12E+10	1.15E+12	—	—	—	**1.21E+12**
22	—	6.06E+06	2.60E+08	—	4.88E+09	7.86E+11	—	—	—	**7.91E+11**
23	2.09E+11	6.53E+09	2.80E+11	2.28E+09	2.37E+11	1.40E+12	3.71E+08	4.79E+08	—	**2.13E+12**
24	5.27E+09	2.94E+08	1.26E+10	1.12E+08	6.81E+10	1.50E+12	—	8.33E+05	—	**1.58E+12**
25	1.01E+12	3.02E+10	1.29E+12	9.19E+09	5.69E+11	1.26E+12	2.26E+11	—	—	**4.40E+12**
26	5.23E+11	1.65E+10	7.06E+11	5.40E+09	5.54E+11	1.07E+12	7.38E+10	1.52E+07	—	**2.95E+12**
27	6.67E+11	1.98E+10	8.48E+11	5.57E+09	2.85E+11	9.49E+11	3.30E+10	2.56E+07	—	**2.81E+12**
28	3.32E+11	1.07E+10	4.58E+11	5.17E+09	4.95E+11	9.69E+11	3.71E+08	2.54E+06	—	**2.27E+12**
29	2.15E+11	6.27E+09	2.69E+11	2.11E+09	9.02E+10	9.87E+11	1.08E+10	—	—	**1.58E+12**
30	1.35E+11	3.85E+09	1.65E+11	1.25E+09	5.93E+10	1.03E+12	5.19E+09	—	—	**1.40E+12**
31	2.85E+11	8.45E+09	3.62E+11	3.25E+09	1.08E+11	1.20E+12	3.07E+11	—	—	**2.28E+12**
32	1.25E+12	3.72E+10	1.59E+12	1.15E+10	5.38E+11	1.25E+12	3.93E+10	—	—	**4.72E+12**
33	8.93E+10	2.56E+09	1.10E+11	1.00E+09	2.38E+10	8.93E+11	3.71E+10	—	—	**1.16E+12**
34	9.60E+11	2.80E+10	1.20E+12	8.08E+09	4.29E+11	1.63E+12	2.79E+11	2.20E+06	—	**4.53E+12**
35	1.60E+11	4.64E+09	1.99E+11	1.18E+09	6.73E+10	1.99E+12	2.97E+10	1.48E+08	—	**2.45E+12**
36	3.73E+11	1.09E+10	4.69E+11	3.21E+09	8.60E+10	1.88E+12	3.94E+11	5.01E+06	—	**3.22E+12**
37	5.12E+11	1.53E+10	6.58E+11	3.81E+09	2.34E+11	1.72E+12	1.71E+10	1.30E+06	—	**3.16E+12**
38	4.46E+11	1.33E+10	5.71E+11	4.00E+09	1.07E+11	1.85E+12	1.08E+10	1.32E+07	—	**3.00E+12**
39	2.05E+10	6.33E+08	2.71E+10	1.85E+08	6.15E+09	1.53E+12	—	—	—	**1.58E+12**
40	1.61E+10	4.60E+08	1.97E+10	1.42E+08	4.95E+09	1.58E+12	—	—	—	**1.63E+12**
41	8.00E+09	2.36E+08	1.01E+10	9.40E+07	3.64E+09	1.63E+12	—	—	—	**1.65E+12**
42	4.12E+11	1.22E+10	5.23E+11	2.99E+09	6.27E+10	1.04E+12	1.00E+10	8.67E+07	—	**2.06E+12**
43	3.69E+11	1.07E+10	4.60E+11	3.26E+09	7.37E+10	8.62E+11	2.11E+10	—	—	**1.80E+12**
44	7.93E+11	2.36E+10	1.01E+12	6.58E+09	2.09E+11	1.31E+12	2.47E+11	—	2.25E+08	**3.60E+12**
45	4.37E+11	1.28E+10	5.48E+11	4.31E+09	1.06E+11	1.26E+12	4.74E+11	2.27E+08	—	**2.85E+12**
46	2.71E+11	8.87E+09	3.80E+11	3.28E+09	4.40E+11	1.42E+12	7.42E+08	2.19E+09	—	**2.53E+12**
47	4.31E+11	1.30E+10	5.58E+11	5.53E+09	1.93E+11	9.95E+11	2.69E+11	4.53E+06	—	**2.46E+12**
48	2.13E+11	7.50E+09	3.21E+11	2.42E+09	4.73E+11	1.35E+12	6.68E+09	4.05E+08	—	**2.37E+12**
49	9.98E+11	2.93E+10	1.25E+12	9.31E+09	2.47E+11	1.54E+12	1.31E+11	2.16E+05	—	**4.21E+12**
50	1.78E+12	5.27E+10	2.26E+12	1.64E+10	7.64E+11	1.43E+12	4.07E+11	2.16E+08	2.14E+09	**6.71E+12**
51	6.20E+11	1.82E+10	7.82E+11	6.14E+09	1.88E+11	1.38E+12	1.42E+11	—	—	**3.13E+12**
52	1.92E+11	5.83E+09	2.50E+11	2.42E+09	1.27E+11	1.62E+12	2.23E+09	—	—	**2.20E+12**
53	6.13E+11	1.84E+10	7.87E+11	6.67E+09	1.92E+11	1.09E+12	6.26E+11	—	—	**3.33E+12**
54	1.68E+12	4.96E+10	2.12E+12	1.60E+10	7.45E+11	1.50E+12	4.13E+11	—	8.16E+07	**6.52E+12**
55	7.46E+11	2.21E+10	9.49E+11	7.36E+09	2.20E+11	1.07E+12	3.01E+11	—	—	**3.31E+12**
Totals										
Daily	1.70E+13	5.11E+11	2.19E+13	1.64E+11	8.69E+12	6.48E+13	4.52E+12	1.45E+10	2.45E+09	**1.18E+14**
Annual	*6.21E+15*	*1.86E+14*	*7.99E+15*	*5.99E+13*	*3.17E+15*	*2.36E+16*	*1.65E+15*	*5.29E+12*	*8.94E+11*	***4.29E+16***

5.4 Documentation of Illegal Dumping Using Photograph Repository

Significant quantities of refuse and potentially hazardous materials were found in and near tributaries by TRA field scientists at many of the sampling locations. Therefore, further reconnaissance in the watershed was conducted at rural/urban bridge crossings and cul-de-sacs with known or expected uses as illegal dumping sites.

Prior to conducting the reconnaissance, 22 sites were selected using aerial imagery, based on roadway access and proximity to Lake Arlington. A standard field data sheet was created that included parameters such as waste type, streambank erosion, homeless occupation, stream flow, and waste quantity. These parameters were further broken down into sub-categories with assigned point values based on potential water quality impacts. Hazardous waste was assigned the highest value of 5, whereas common litter items (cans, cups, fast food containers, bags, bottles, etc.), were assigned the lowest value of 1. Each site's cumulative point value was multiplied by a factor of 1-2 if the refuse was purposely dumped and then multiplied by 1-2 again based on the quantity. This created a standard grading rubric for each site where higher severity scores indicated more severe potential negative impacts on water quality. During the survey, field scientists completed data sheets, recorded GPS points, and took photographs to support their findings.

Field data were entered into a spreadsheet and used to create a mapping geodatabase. Using the total severity score, sites were distributed into four categories: 1) *minimal impact*, 2) *some impact, 3) significant impact, and* 4) *critical impact.* Of the 22 sites, five were classified as *critical impact*, three were *significant impact*, four had *some impact*, and nine had *minimal impact* on water quality.

Example of a site with minimal impacts from illegal dumping.

Example of a site with some impacts from illegal dumping.

Example of a site with significant impacts from illegal dumping.

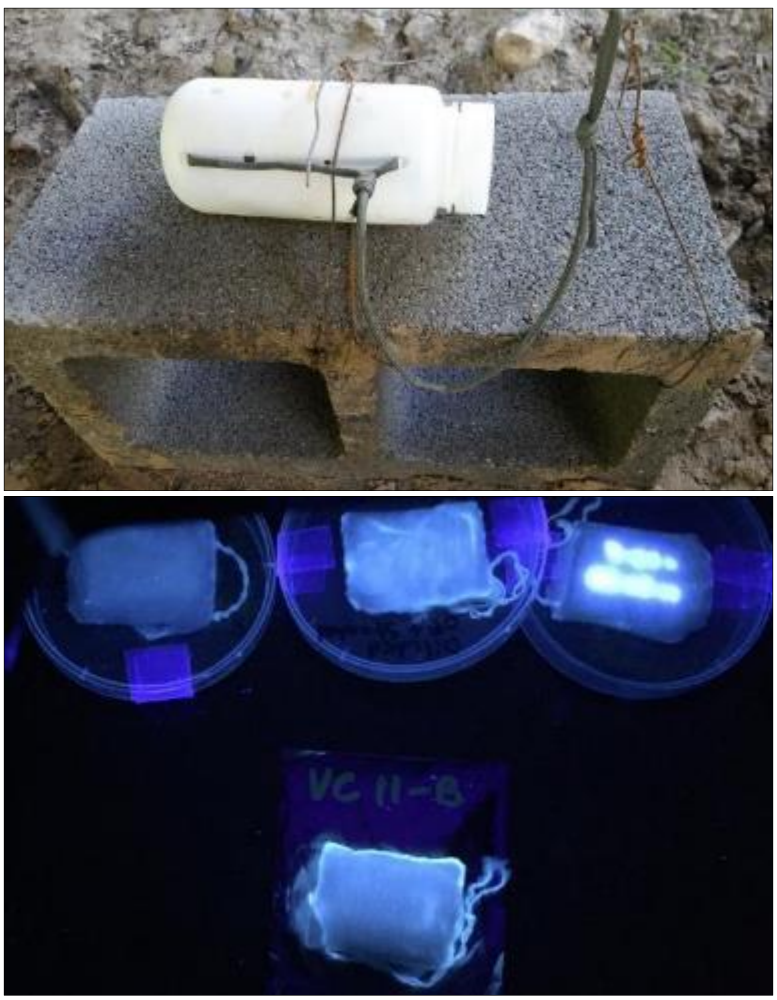
Example of a site with critical impacts from illegal dumping.

Based on preliminary observations, sites with significant or critical impacts from illegal dumping usually have evidence of repeated dumping events. Stakeholders agreed that further monitoring is required to have more conclusive information on illegal dumping behavior at these sites, and recommend expansion of both the scope and frequency of the survey.

To support this recommendation, a story map has been created using ArcGIS Online software that can be shared with interested individuals and enforcement authorities. This application is capable of spatially cataloging potential dumping sites, allowing users to include pictures depicting the extent of the impacts. Previous interactions between TRA and several municipalities in the watershed demonstrated that there was indeed a willingness to cooperatively address the illegal dumping issue at the municipal level. This might provide an opportunity to improve communication between the departments involved in enforcement and other departments engaged in routine or frequent field operations that may be able to provide information about illegal dumping activity and dumping sites. Through the development, expansion, and use of this or some similar online spatial/visual reporting tool, it is the stakeholder's intent that inter-departmental and inter-municipal communication will improve, resulting in quicker response times and potentially even improving the odds of identifying offenders engaged in dumping activities.

5.5 Optical Brighteners Analysis

Optical brighteners (OBs) are dye compounds that are added to laundry detergent to make clothing seem whiter or brighter in color after washing. Although not a direct measurement of bacterial contamination, the presence or absence of OBs in the water found at the monitoring site may be an indicator of human sewage contamination, which is a potential source of *E. coli* in the watershed. In most cases, "greywater" from laundry washing, sinks, and dishwashers is combined with "blackwater" from toilets and urinals in the waste stream leaving a residence and travels to either an OSSF or centralized municipal WWTF. While it is true that very little OB biodegradation occurs in these two facilities, it has been shown that as much as 85% of OBs are removed from the water by adsorbtion to sludge particles that settle out of the effluent water before it is released (Poiger et al., 1998). This allows for the OBs to be used as a reliable indicator for human sewage contamination. Common sources of OBs include 1) malfunctioning OSSFs, 2) non-permitted "straight pipes" that offer no treatment, and 3) leaking, damaged, or otherwise malfunctioning WWTF infrastructure, either within the conveyance lines to the facility, or within the facility's treatment train itself. However, other household, personal care, and industrial products can contain similar dyes, which can present 'false positives' in the test. These include, but are not limited to, antifreeze, car wash detergents, lawn grass dyes, and some viral-vector pesticides.



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

The method used in this project was adapted from similar ones employed within municipal stormwater conveyance systems by various municipalities in the DFW area. Positive results are reflected above for selected sites in Figure 5-2 through Figure 5-5. Results for all sites are provided in Appendix C. The method itself, while providing some insight into what are believed to be several false positives, did not necessarily provide any solid evidence of human waste contamination at any point in the watershed, either as a consistent load or as a periodic occurrence. It may be that there are simply too many variables to account for in natural waterways that do not exist in heavily channelized municipal stormwater conveyance systems. However, due to the cost-effectiveness and simplicity of the analysis, TRA will continue to conduct OB studies in the event that the analysis does, in fact, provide early detection of human waste contamination during future field sampling operations.

5.6 Conclusions

Based on these analyses, it is clear that there are several significant sources of *E. coli*, nutrients, and other contaminants distributed throughout the watershed, and that focusing on one particular land use or location will not provide a viable solution. Soil permeability also appears to play a significant role in the sharp increases in *E. coli* loading seen downstream of the site near Enon Rd (21763), where any water quality improvements afforded by the addition of water from the TRWD outfall are quickly masked by runoff inputs from other tributaries from areas with highly impermeable soils off to the west (Figure 4-4). In many cases, wildlife tend to be the primary contributor of *E. coli* in Texas watersheds. Stakeholders have few management options in these cases, and VCLA stakeholders even expressed interest in avoiding management of wildlife contributions altogether, instead preferring to account for wildlife *E. coli* loads as background or baseline contributions. However, due to the significant amount of urbanized area in the VCLA watershed, several sources that are inherently more manageable outranked wildlife sources. For this reason, *E. coli* contributions from dogs and cats are likely the primary source of pollution in the watershed, followed closely by agricultural livestock. These sources prove to be advantageous for *E. coli* management in the watershed, as several well-known and proven management strategies exist for both source categories, whether it be for *E. coli* or nutrients. Additional BMPs put in place for several of the other source categories will provide additional flexibility for achieving the 1.61E+14 MPN/yr reduction on Village Creek and the 1.83E+11 MPN/yr reduction needed for the unnamed tributary.

Survey site on Wildcat Branch impacted by both floatable trash and significant erosion.

6.0 Management Strategies and Associated Load Reductions

The WPP planning process operates on a continuum, beginning with the identification of the watershed's issues and recognition of the data gaps that need to be addressed before decisions can be made to remedy those issues. Several analyses are then conducted to spatially and quantitatively characterize the pollutant loads. This information can then be used by stakeholders to make informed decisions about the management methods most appropriate for remedying the issues with the highest stakeholder priorities.

6.1 Meeting Water Quality Goals

The primary water quality goals for the watershed, as defined in Section 5.2.1, are specifically for *E. coli* loads, in terms of MPN/day. However, these loads are expected to fluctuate, with reductions from BMP implementation offset by increases from land use/land cover changes with continued development. To meet this challenge, load reduction goals will always refer back to the primary contact recreation quality standard for *E. coli* of 126 MPN/100 mL, which is measured as a concentration rather than a load. A 10% MoS on the water quality standard will be observed for load calculation, so the water quality target for the waterbodies of interest will effectively be 113 MPN/100 mL for calculating the *E. coli* loads.

Typically, only one index site is chosen for establishing water quality goals in a WPP. However, as described in Section 5.2, conditions in an unnamed tributary of Lake Arlington do not resemble those throughout the rest of the watershed, and thus stakeholders have recommended that separate goals be established for that small watershed. For Village Creek, site 10781 (US 287-BUS) was chosen. Likewise, the monitoring site on the unnamed tributary, 10793 (@ Bowman Springs) will be used as its index site. Stakeholders selected the mid-range conditions flow regime as the basis for calculating the load reductions needed to reach the water quality goal. With reductions for both systems already in excess of 70% within this regime, stakeholders sought to set a realistic goal for water quality improvement that could be revisited in the future if merited. The required annual reductions, under mid-range conditions, are 1.61E+14 MPN/yr for Village Creek and 1.83E+11 MPN/yr for the unnamed tributary.

Conducting flow measurement at the watershed index site, downstream of US 287-BUS in Kennedale, TX.

Construction BMPs for stormwater pollution (silt fences, green curlex mat, sod replacement) near a development's retention pond (credit: City of Fort Worth).

Although the *E. coli* reductions are the primary regulatory goal for the WPP, stakeholders agreed that bacteria issues were not necessarily the primary concern in the watershed. Concerns related to the amount of nutrients reaching the lake and their relationship to eutrophication, and more specifically algal growth, were of primary interest due in part to the lake's uses as a popular recreational area and as the sole drinking water supply for many residents throughout Tarrant County. While it is true that LDC analysis did not reveal any explicit nutrient load reductions for any of the sites, stakeholders understand that nutrient storage can occur in lakes even if monitoring does not indicate nutrient concerns in the tributaries. For this reason, nutrient reductions will be tied to management recommendations for *E. coli*, since many *E. coli* BMPs, (specifically those for water retention/detention and treatment) are also expected to curb both nutrient and sediment loads as well. Stakeholders also expressed interest in addressing more visible forms of pollution, including floatable trash, illegal dumping, and yard residues. Due to the sporadic and often transient nature of these sources, no quantitative reduction goals were recommended. However, stakeholders did recommend goals related to improving homeowner education and communication between various field investigators and regulatory entities (municipalities) to improve response time and cleanup.

With many examples of active oil and gas production around the lake and throughout the watershed, it is also possible that contamination from petroleum products or production by-products may endanger the lake or its tributaries. Due again to the sporadic and transient nature of these occurrences (similar to SSOs), no explicit load reduction goals were identified within the scope of the WPP towards these areas specifically; they will instead be considered within the overall scope of loads considered for greenspaces and open areas in general. There is also the possibility that stakeholders may choose to re-evaluate the need to address these areas separately in the future.

6.2 The Whole Watershed Approach

Stakeholders understand that focusing all of the group's efforts on a single source will likely result in diminishing returns in the form of load reductions with successive incremental funding increases. Instead, stakeholders have chosen to offset these diminishing returns by selecting appropriate BMPs for a variety of pollutant source categories. While the overall loads from each source were certainly taken into account, the stakeholder BMP recommendation process also incorporated elements of feasibility, cost-effectiveness, and community visibility. It is for this reason that several un-modeled sources (e.g., illegal dumping, yard waste) received a higher stakeholder priority rating than did more significant *E. coli* sources (e.g., livestock, OSSFs), as illustrated in Table 4-1. Conversely, these selection criteria also serve as justification for why stakeholders chose not to prioritize BMPs for native wildlife *E. coli* contributions, even recommending to avoid them outright to avoid creating perceived attractive nuisance issues near alternative watering facilities. This approach has been used in other WPPs, as management of wildlife in any capacity (for *E. coli* deposition or otherwise) is impractical, costly, and thus unlikely to yield meaningful load reductions within the watershed.

Prioritization by source was then followed by spatial prioritization. Stakeholders agreed that while placement of physical/environmental BMPs should follow the results of the SELECT analysis, education-based BMPs should be focused on areas that impose the most direct impacts to Lake Arlington and expand outward and upstream as appropriate. Following the expectations of adaptive management, it is anticipated that these priority areas will fluctuate in size, shape, and location as needs arise or are resolved. These adjustments will rely heavily on stakeholder input, and only those BMP recommendations approved by stakeholders (at present or in the future) will be considered. Stakeholders themselves are responsible for implementing these voluntary recommendations, and their willingness to do so will ultimately define the speed and efficacy with which water quality goals are achieved.

6.3 Synergies with the Lake Arlington Master Plan

Being the initial inspiration for this WPP, readers will find numerous references to the LAMP throughout this document. While the two plans share a geographical setting and common goal of protecting water quality within Lake Arlington, they differ slightly in scope. In addition to water quality protection measures, the LAMP also contained recommendations for aspects of lake aesthetics and future development alternatives. Conversely, the WPP focuses only on improvements to water quality, effectively magnifying and addressing various components of the LAMP related to nonpoint source pollution management, with heavy emphasis placed on pollutant loading due to *E. coli*. However, as previously stated, both LAMP and WPP stakeholders have identified water quality improvement and protection priorities beyond the *E. coli* impairment. Many of these priorities were conveyed in Section 7 of the LAMP, *Source Water Protection and Watershed Management* (Malcolm Pirnie and Arcadis U.S., 2011). Management recommendations relevant to the WPP, will be summarized in the following subsections; please refer to Section 7 of the LAMP for additional details.

6.3.1 Stormwater Runoff Volume Reduction and Pollution Control Measures

Runoff Reduction Requirements for Subdivision/Development Regulations

The LAMP recommends the establishment/enforcement and periodic review of multiple ordinances related to reducing the amount of impervious surfaces in new construction and redevelopment projects. These ordinances, which are utilized more prominently within 100-year floodplains, require developers to include stormwater BMPs and green infrastructure in their designs to remain as close to the pre-development hydrologic (runoff) condition as possible.

Citizen attempting to curtail erosion issues on their property on Lake Arlington using green curlex mats and terracing (credit: City of Arlington).

BMPs for Reducing Runoff Volume

To support the implementation of both voluntary and compulsory (via ordinance) stormwater runoff reduction and pollution control measures, the LAMP recommends several BMPs aimed at either runoff reduction or stormwater detention/remediation. Please reference page 110 of the LAMP for additional details about the recommended BMPs (Malcolm Pirnie and Arcadis U.S., 2011).

Establishment of Environmentally Sensitive Areas and Floodplain Corridors

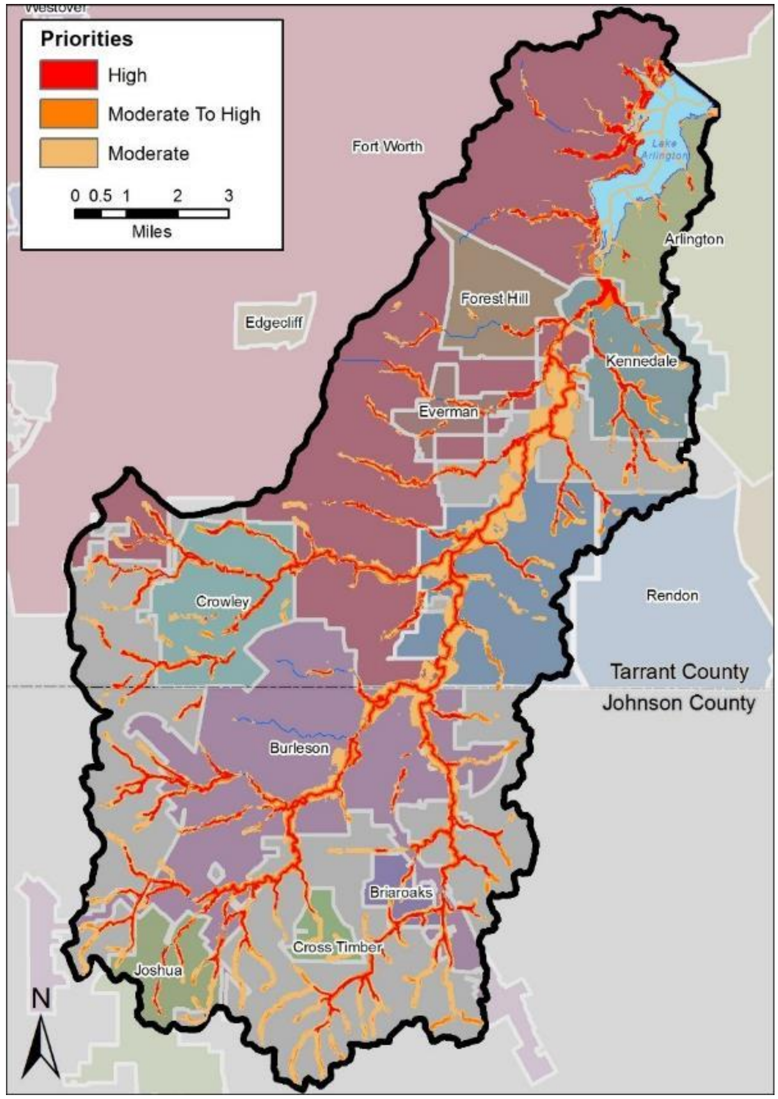
Perhaps the most important opportunity for improving and protecting water quality lies in the ability to preserve existing riparian buffer zones or rehabilitate those that have been degraded. Protection of these environmentally sensitive areas (ESAs) around waterbodies ensures that there exists a last line of defense between pollutant sources and waterways. The intent behind establishing ESAs is not to restrict or discourage development, but rather to provide stakeholders and decision-makers with spatial prioritization for several of the proposed “first strike” initiatives for pollutant reductions in the watershed. This concept was further developed in the TPL Greenprint study, which further classified ESAs into three priority levels (Figure 6-1). A similar Greenprint study was also conducted for parts of Lake Lewisville, and has since been developed even further into Denton County’s Greenbelt Plan (UTCT, 2017). The Greenbelt Plan takes the ESA concept a step further, seeking to permanently protect these areas through a land trust. No such plans have been made for the VCLA watershed, but should stakeholders determine this is a viable option, it could be addressed in the future.

6.3.2 Runoff Control from Disturbed Areas

The land disturbance that is inherent to any land development/construction project was a significant focal point for the LAMP. These sites can result in both short-term and long-term watershed contamination from a variety of sources. Section 7 in the LAMP provides an extensive list of runoff control BMPs for both circumstances.

Construction Sites

The LAMP briefly discusses National Pollutant Discharge Elimination System (NPDES) requirements for Phase I- and Phase II-regulated entities. CWA § 319(h) grant funding cannot be used for activities already required by an entity's municipal separate stormwater sewer system (MS4) permit, but may be used (with caution) to fund similar activities "above and beyond" what is required by the MS4. Therefore, construction site BMPs won't compose a significant portion of grant funding requests through the CWA § 319 process. Instead, 319 funds would be used for establishing post-construction pollution controls above and beyond what is required by MS4 permits, where the landowner voluntarily proposes to limit or reverse chronic erosion or significantly reduce pollutants in runoff from the property by installing appropriate green infrastructure components to better mimic pre-construction runoff conditions.



Data Source: TPL, NCTCOG

Figure 6-1. Prioritized areas for BMP implementation in the watershed.

Oil and Gas Exploration Sites

With typical construction sites, the majority of water quality impacts are acute in nature, with erosion and pollutant concerns diminishing as the site recovers ecologically. However, when areas are cleared for oil and gas exploration pad sites, these same pollutant inputs can potentially become chronic concerns. Local studies revealed that while petroleum hydrocarbons were not any more prevalent in stormwater runoff when compared to other sites, concentrations of metals and TSS were significantly higher, often comparable to runoff concentration values from active construction sites (Banks and Wachal, 2017). The study concluded that installation of typical stormwater BMPs would result in sediment yield reductions of 50-90%. Pad sites for oil and gas extraction are regulated through the Texas RRC, and thus the opportunity for management through the WPP is limited. Regardless, TRA will coordinate with local RRC staff and municipalities to inventory existing stormwater run-on/runoff BMP requirements for pad sites to uncover any opportunities for improvement.

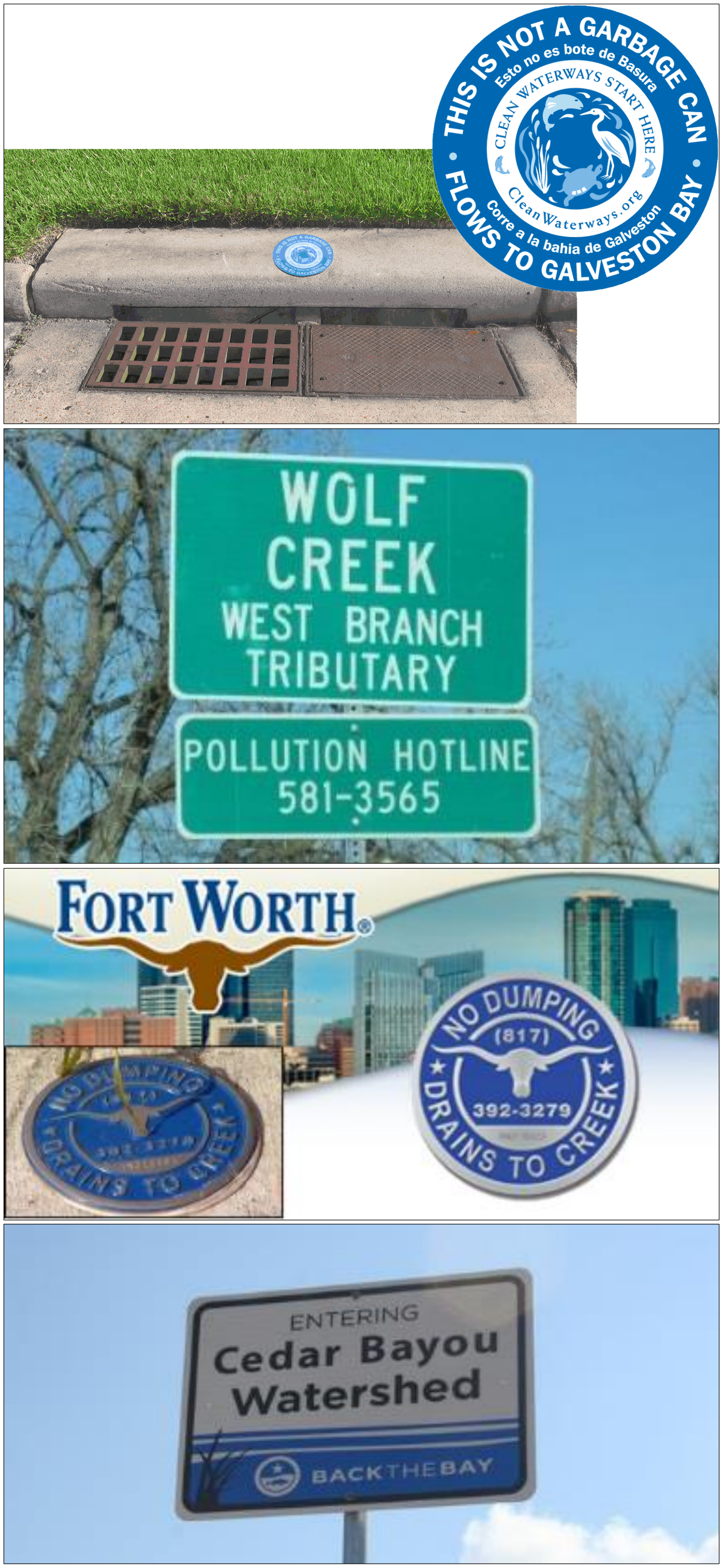


Figure 6-2. Examples of watershed boundary signage and storm drain signage.

6.3.3 Trash and Litter Control

Trash Control and Anti Littering Campaigns

The LAMP recommends mass media advertising as a means of public education for littering concerns, instead of flyers and handouts that will likely become litter themselves. The LAMP also recommends static options such as road signage for watershed boundaries and storm drain signage to remind people that waste from littering and illegal dumping remains untreated and can harm aquatic life or even end up in their drinking water (Figure 6-2).

Municipal Operations

Thorough review of several source control measures at the municipal level was also a recommendation of the LAMP. Source controls like litter bin operations, street sweeping, site management plan enforcement, and industrial/high risk commercial inspections were recommended for routine evaluation.

Inter-departmental coordination to reduce the amount of illegal dumping - as well as the response time for addressing such activities - was also proposed. Much of this recommendation focused on interdepartmental cooperation at the municipal level, ensuring that field staff from all departments relayed valuable information back to those capable of enforcement. WPP stakeholders see illegal dumping as a significant issue in the watershed, and plan to address this issue specifically in later sections.

In-stream and Municipal Infrastructure Trash Reduction Methods

Several in-stream and infrastructure-based litter collection BMPs were also reviewed, including end-of-pipe nets, boom-style litter collectors, bar screens, baffles, and hydrodynamic separators. These components, their applications, and advantages/disadvantages are described in detail in Section 7 of the LAMP.

6.3.4 Other Stormwater Management Measures

Illicit Discharge Detection and Elimination (IDDE) Programs

The LAMP recommends that municipalities in the watershed develop their own IDDE programs and accompanying ordinances, to include identification, mapping, and periodic inspection of a certain percentage of their stormwater outfalls annually. This would include dry-weather sampling for suspected contamination at outfalls, as well as establishment of higher-priority sites (industrial/high risk commercial sites, landfills) for more frequent analysis.

Public Education and Outreach Programs for Lawn Additives Use

Programs aimed at use/disposal of pesticides, herbicides, and fertilizers were also proposed for creation or expansion. The LAMP proposed a combination of mass media campaigns and targeted training through workshops as the most effective method of achieving significant improvement in water quality.

6.4 Animal Sources

6.4.1 Pet Waste

Although certainly more of a concern in higher-density urban areas, pet waste was determined to not only be the largest potential *E. coli* source throughout the entire watershed, but also the most pervasive, with no subwatersheds exhibiting “zero loads” for pet waste (Figure 5-15). Stakeholders also recognized that many of the public areas frequented by residents and their dogs occur in or near riparian areas and flood zones (greenbelt parks, dog parks), where the potential for contamination is greater. Efforts will begin with a focus on the critical areas described in the SELECT analysis, which include the subwatersheds adjacent to the lake and those in more urbanized areas. As human populations in the watershed rise, so will those for dogs and cats. BMPs selected for reduction of *E. coli* loads from pet waste will primarily focus on dogs, as it is assumed that most domestic cats use litter boxes and have their waste deposited in the landfill. However, it is expected that some portion of domestic felines are indoor/outdoor cats, barn cats, or other feral cats that do defecate outdoors. It is also likely that some cat owners continue to dump soiled cat litter into the environment after cleaning.

Management practices recommended to reduce pet waste *E. coli* loads seek to remove pet waste from known pathways by either a) confining the waste to a landfill, or b) treating the waste on-site in the ground through infiltration. This includes capitalizing on several educational opportunities that are already being promoted through various entities in the DFW metropolitan area, in addition to new resources currently being developed as part of this WPP effort and several others in the North Central Texas area. This includes relevant print media (utility bill inserts, info pamphlets, public signage) as well as mass media campaigns (websites, videos). This also includes promotion of both proven waste management methods and pilot projects. By providing additional opportunities for pet waste pickup and removal, such as supplementary pet waste stations for public areas that are currently lacking or have stations in need of repair. Installation of newer yet potentially even more effective pet waste treatments called in-ground pet waste digesters is also planned. A summary of stakeholder recommendations and the associated load reductions for pet waste are provided in Table 6-1.

Above: Installation of DIY pet waste digester (Zach Ogilvie, www.instructables.com).
Below: Installation of prefabricated pet waste digester near Lake Arlington.

Table 6-1. Recommended BMPs for pet waste.

<table>
<tr><th colspan="4">Pollutant Source: Pet Waste</th></tr>
<tr><td colspan="4">Concerns: (1) Improper disposal of pet waste, (2) lack of education on impacts and proper disposal, (3) disease transmission and public safety</td></tr>
<tr><td colspan="4">Potential Impacts: (1) Indirect E. coli loading to waterbody from yards, public greenspaces, kennels, and shelters; (2) spread of disease amongst/between species</td></tr>
<tr><td colspan="4">Critical Areas: (1) Subwatersheds adjacent to the lake, (2) urbanized areas</td></tr>
<tr><td colspan="4">Goal: Reduce the E. coli load from pet waste delivered to waterbodies through stormwater and irrigation runoff through management of E. coli loads representing 20% of the present pet population (8,029 pets).</td></tr>
<tr><td colspan="4">Objectives: (1) Increase education and outreach efforts pertaining to proper disposal of pet waste, (2) Provide opportunities for proper waste disposal/abatement</td></tr>
<tr><th colspan="4">Recommendations</th></tr>
<tr><th>Responsible Party</th><th>Management Practice</th><th>Timeframe</th><th>Costs</th></tr>
<tr><td>Cities, counties, NCTCOG, regional entities</td><td>Expand delivery of existing pet waste education resources, develop/implement new educational resources (e.g., utility bill inserts, websites, info pamphlets, videos, signage in public greenspaces/trails)</td><td>2021-2030</td><td>$170,000</td></tr>
<tr><td rowspan="4">Cities, counties, HOAs, NAs</td><td>Development/adoption of model pet waste pickup/ disposal ordinances (municipalities) and by-laws (HOAs/NAs)</td><td>2021</td><td>Unknown</td></tr>
<tr><td>Reconaissance of critical areas for pet waste station placement in municipal or community greenspaces</td><td>2021</td><td>$3,000</td></tr>
<tr><td>Install 25 new pet waste stations (@$300/station) and fund supplies (collection bags, wastebin bags) for 9 years (@ $85/yr)</td><td>2022-2030</td><td>$27,000</td></tr>
<tr><td>Install bioswales/rain gardens in parks for onsite treatment of pet waste in stormwater/irrigation runoff ($12,500/site @ 4 sites)</td><td>2022-2030</td><td>$50,000</td></tr>
<tr><td>Residents</td><td>Install 5 pet waste digesters (@ $1000/install) per year on residential properties</td><td>2021-2030</td><td>$50,000</td></tr>
<tr><th colspan="4">Estimated Load Reductions</th></tr>
<tr><td colspan="4">BMPs recommended for pet waste seek to a) confine the waste to a landfill, or b) treat waste on-site in the ground. In doing so, the amount of E. coli from pet waste sources entering waterways via runoff from rainfall or irrigation will be reduced. It is reasonable to assume that not all of the deposited waste can be removed via bagging/burial, so a 75% removal efficiency will be applied to the load reduction. Similarly, it is expected that the recommendations will likely only capture loads from only 20% of the present pet population (8,029 pets). With the 75% removal efficiency, a 15% reduction is expected. The expectation that only 25% of the E. coli deposited by pets actually reaches the stream is then generally applied as an attenuation factor to realistically estimate the actual reduction. This results in a reasonable estimate of the total annual pet waste reduction of 1.37E+15 MPN/yr for the managed pet population.</td></tr>
<tr><td>Effectiveness</td><td colspan="3">With several dense population centers in the watershed, pet populations are estimated to be similarly dense. Treatment in this case is by direct removal of the pollutant source and internment elsewhere, exhibiting a high removal efficiency. Therefore, noticeable reductions are likely even by managing a limited population.</td></tr>
<tr><td>Certainty</td><td colspan="3">Improving opportunities for proper pet waste disposal for those aware of the contamination concern will provide most of the reductions.It is assumed that those who have other reasons for not properly disposing of waste will be difficult to convince to modify their behavior.</td></tr>
<tr><td>Commitment</td><td colspan="3">Most greenspaces already have some level of pet waste stations on-site, although bag stocking and bin cleanout could be improved. Signage for ordinances/by-laws are less visible, and enforcement thereof is limited or non-existent. Many homeowners are interested in installing pet waste digesters due to the low cost and convenience, but may be uncomfortable with the amount of digging required for proper function in north Texas soils.</td></tr>
<tr><td>Needs</td><td colspan="3">Funds for increasing the number and continued maintenance of pet waste stations, enactment of pet waste disposal ordinances/by-laws or enforcement of those existing, willing homeowners for expansion of pet waste digester installation program, with funding support.</td></tr>
</table>

6.4.2 Livestock

Production Agriculture

Livestock species (cattle, horses, sheep, and goats) ranked 2nd with respect to daily potential *E. coli* loading, according to the SELECT analysis. However, stakeholders placed livestock inputs lower within the list of priorities for several reasons. It is understood that while the livestock *E. coli* load is large when compared to other modeled sources, there are several other threats to overall water quality in closer proximity to the lake that could also prove to be more cost-effective for long-term management. It is also understood that while the watershed's listing for *E. coli* impairment only began in 2010, production agriculture within the watershed has been steady, and in some areas has decreased, with the growth of urban areas in Tarrant and Johnson Counties.

As a source, waste from livestock may sometimes be deposited directly into a waterbody if the animals are allowed access for drinking or wading to cool off during hotter seasons. In addition to direct water quality impacts from *E. coli*, direct access may significantly impact bank stability and sedimentation near the access area. However, livestock waste is typically deposited in upland areas and washed into waterways via stormwater runoff. As such, a significant amount of the *E. coli* deposited by livestock as waste dies before it can reach a stream or lake.

In production agriculture, BMPs for water quality improvement typically involve strategic placement and utilization of resources to manage population density/distribution, thereby improving vegetative cover, and in turn reducing *E. coli* in runoff. Using exclusionary fencing is a simple method for reducing/eliminating livestock access to streams, but requires the construction of alternative watering facilities and shade to accommodate livestock needs. Exclusionary fencing, however, continues to be somewhat unpopular among producers. Even if fencing is not used, additional water troughs conveniently placed closer to animal grazing areas can still reduce traffic to streams. Typically, these additional water sources are supplied with a well, but can be fed by municipal supply if well drilling is not feasible. To reduce stormwater runoff of *E. coli* in upland areas, BMPs focused on improving soil infiltration and reducing runoff velocity are most effective. Prescribed grazing, when combined with herbaceous weed control, brush management, and strategic plantings of forage species will improve the vegetative cover quality of grazing areas. Responsible pest and nutrient management will further improve forage health and reduce the potential for excess additives being washed into waterbodies.

These practices are most effective when applied simultaneously across an entire property using a comprehensive management plan. To assist producers, technical and financial assistance is available through NRCS as conservation plans (CPs) and the Texas State Soil & Water Conservation Board (TSSWCB) as water quality management plans (WQMPs). These plans, usually administered through local soil & water conservation districts (SWCDs) are developed with input from district-level technicians familiar with the management methods best suited for the local area. A summary of priority project areas, stakeholder recommendations and the associated load reductions for livestock are provided in Table 6-2.

Small-acreage Farms

As noted earlier, a number of small-acreage hobby farms exist within the watershed, which stakeholders recognized as a potentially significant contributor to growing water quality concerns. In contrast to area trends in production agriculture, there is significant anecdotal evidence that the number of hobby farms is increasing. It is likely that many of these hobby farm operators are new to agriculture, and more likely to be uneducated about proper land management practices. This, combined with a tendency for higher stocking rates on the smaller plots, increase the likelihood for *E. coli* contamination to nearby waterbodies in comparison to full-scale production agriculture operations.

It is likely that most, if not all of these hobby farms do not qualify for WQMP or CP funding, since these plans usually require a minimum income from agricultural production to qualify for financial assistance. However, educational opportunities are still planned for hobby farm owners looking to improve their knowledge about land management and how their decisions can impact local water quality for themselves and their neighbors.

Table 6-2. Recommended BMPs for livestock.

<table>
<tr><th colspan="4">Pollutant Source: Livestock</th></tr>
<tr><td colspan="4">Concerns: Overstocking of animals that results in overgrazing, degradation of riparian buffers, stream bank destabilization, and disturbance of aquatic habitat</td></tr>
<tr><td colspan="4">Potential Impacts: (1) Indirect E. coli loading to waterbody from rangeland, ag fields, and small acreage operations (hobby farms), (2) threats to aquatic life health/diversity, (3) property damage from stream bank failures</td></tr>
<tr><td colspan="4">Critical Areas: Production agriculture operations and hobby farms near riparian zones</td></tr>
<tr><td colspan="4">Goal: Reduce E. coli loading from livestock through education and by encouraging participation in WQMP/CP programs, with projects focused on minimizing the amount of time animals spend in riparian zones by improving resources across the property</td></tr>
<tr><td colspan="4">Objectives: (1) Promote use of WQMPs/CPs in the watershed, with emphasis on operations near riparian zones, (2) provide educational opportunities for hobby farm owners to improve management of their property</td></tr>
<tr><th colspan="4">Recommendations</th></tr>
<tr><th>Responsible Party</th><th>Management Practice</th><th>Timeframe</th><th>Costs</th></tr>
<tr><td>Production agriculture in riparian zones</td><td>Development and implementation of WQMPs and CPs for 15 properties (@$15K/plan)</td><td>2021-2030</td><td>$225,000</td></tr>
<tr><td>Production agriculture in upland zones</td><td>Development and implementation of WQMPs and CPs for 25 properties (@$15K/plan)</td><td>2021-2030</td><td>$375,000</td></tr>
<tr><td>Hobby farm operators</td><td>Provide educational opportunities and informational resources focused on new small acreage landowners who plan to stock animals on-site</td><td>2021-2030</td><td>$10,000</td></tr>
<tr><th colspan="4">Estimated Load Reductions</th></tr>
<tr><td colspan="4">Adherence to precscribed whole-farm management plans like WQMPs and CPs is expected to reduce E. coli loading to streams through indirect (fecal contamination in stormwater runoff) and direct (direct fecal deposition in streams) inputs. Improving landcover management and limiting the time spent by animals in riparian zones are expected to provide a total annual E. coli load reduction of 5.09E+13 MPN/yr, in addition to reductions to both nutrient and sediment loads. For simplicity, this calculation was made using only the cattle population, as they were by far the most numerous livestock species (56% of the total estimated livestock population). The standard 25% attenuation factor was again applied to realistically characterize the reduction (for rotational grazing and exclusionary fencing only). Additional detail regarding this estimate is provided in Appendix F.</td></tr>
<tr><td>Effectiveness</td><td colspan="3">Reducing the time spent by livestock within riparian zones, coupled with proper management of vegetative cover in upland areas, are expected to provide significant direct and indirect reductions to E. coli loads, reaching waterbodies, with those used directly within riparian zones being the most effective.</td></tr>
<tr><td>Certainty</td><td colspan="3">Locating willing landowners may be difficult without the assistance of local natural resource representatives, and there is no guarantee that future owners will continue to utilize the BMPs identified in the site plans if the property changes ownership.</td></tr>
<tr><td>Commitment</td><td colspan="3">Agricultural landowners are typically willing to engage in land conservation practices once they're made aware of the benefits, especially if those pratices relate to cost savings in the form of reduced erosion and more efficient use of pesticides, herbicides, and fertilizers. However, initial costs may limit adoption of such practices.</td></tr>
<tr><td>Needs</td><td colspan="3">Significant financial support, as directed through the WQMP and CP programs, is essential for the success of this component, which is capable of providing significant load reductions if utilized across all ag species. Therefore, education pertaining to participation and benefits of these programs is also imperative, as is funding for education targeted to new small-acreage landowners.</td></tr>
</table>

6.4.3 Feral Hogs

The potential *E. coli* load from feral hogs ranked 3rd overall, but feral hog control as a means of load reduction was given a much lower priority ranking by stakeholders. It was understood that feral hogs are indeed a persistent and growing threat to water quality that needs to be addressed, even in metropolitan areas. However, in contrast to domesticated livestock, population management with feral hogs is difficult, due in no small part to the species' prolific reproductive capacity. Feral hogs also prefer dense habitat, are opportunistic feeders, and can quickly adapt to trapping tactics and pass this knowledge on to their offspring if care is not taken to capture entire groups at one time.

Despite these obstacles, stakeholders still recognize that feral hogs' preference for riparian habitat places them at the epicenter of water quality impacts, and proposed several BMPs aimed at either continuation/expansion of current educational/outreach activities, or encouragement of low-cost voluntary measures that can be employed by landowners impacted by feral hog activity. TRA, along with several other local and regional entities, will continue development and delivery of feral hog education catered to a variety of stakeholder groups across the watershed. To complement these education and outreach activities, stakeholders also expressed interest in establishing a framework making information available to the public for local hog trappers, trap wholesalers/distributors, trapping programs and other feral hog related resources in a centralized location.

Although education/outreach activities can be practical, low-cost approaches to control, stakeholders understand that support of control methods intent on physical removal of feral hogs remain the most effective method that will lead to water quality improvements. TRA and its partners will continue to promote several voluntary activities for private landowners targeted to either removal of hogs or associated attractive nuisances, like 1) constructing exclusionary fencing around deer feeders and other food sources to prevent feral hog use, and 2) trapping and/or shooting all hogs on-site, cooperating with their managers and lessees to do the same. Stakeholders also indicated their support for a "trap share" program, where 2-3 state-of-the-art, wirelessly operated traps would be purchased by a regional entity, to be loaned out to municipalities or the counties for use in public greenspaces currently besieged by feral hogs. A summary of priority project areas, stakeholder recommendations and the associated load reductions for feral hog control are provided in Table 6-3.

Evidence of feral hog damage in urban areas (credit: City of Fort Worth).

Table 6-3. Recommended BMPs for feral hog control.

<table>
<tr><th colspan="4">Pollutant Source: Feral Hogs</th></tr>
<tr><td colspan="4">Concerns: Uncontrolled proliferation of feral hogs in watershed</td></tr>
<tr><td colspan="4">Potential Impacts: (1) Direct/indirect E. coli loading in riparian zones, (2) destruction of riparian buffers, crops, pastures, (3) resource competition with and predation of native species</td></tr>
<tr><td colspan="4">Critical Areas: Riparian buffer zones throughout entire watershed</td></tr>
<tr><td colspan="4">Goal: Reduce the feral hog population by 5% in the watershed (50 hogs) and prevent further population increases</td></tr>
<tr><td colspan="4">Objectives: (1) Increase education and outreach efforts pertaining to feral hog control, (2) reduce and maintain population through direct removal of hogs and removal of/exclusion of hogs from attractive nuisances</td></tr>
<tr><th colspan="4">Recommendations</th></tr>
<tr><th>Responsible Party</th><th>Management Practice</th><th>Timeframe</th><th>Costs</th></tr>
<tr><td>Cities, counties, NCTCOG, regional entities</td><td>Fund and field a "trap share" program that will allow for three corral traps to be shared amongst cooperating entities for placement in public greenspaces (@$15K per system, +$5000 for support/maintenance for 10 yrs)</td><td>2021-2030</td><td>$50,000</td></tr>
<tr><td rowspan="4">Any public/private landowners, land managers</td><td>Voluntarily construct exclusionary fencing around deer feeders and other food sources to prevent feral hog use</td><td>2021-2030</td><td>Unknown</td></tr>
<tr><td>Voluntarily shoot all hogs on-site, cooperating with managers and lessees to do the same</td><td>2021-2030</td><td>Unknown</td></tr>
<tr><td>Provide framework to landowners for easy access to trappers, trap wholesalers, trapping programs, and feral hog-related other resources, in cooperation w/ local and regional partners</td><td>2021-2030</td><td>$5,000</td></tr>
<tr><td>Restoration/extension of riparian buffers to repair feral hog damage and/or improve water quality resilience in stressed areas</td><td>2021-2030</td><td>Unknown</td></tr>
<tr><td>All stakeholders</td><td>Continue development and delivery of general/specific feral hog educational workshops (yearly, @$7500/event)</td><td>2021-2030</td><td>$75,000</td></tr>
<tr><th colspan="4">Estimated Load Reductions</th></tr>
<tr><td colspan="4">Due to their physiological need to live in close proximity to water sources, removal of feral hogs can provide significant reductions to E. coli loads, with reductions through both direct fecal deposition and via stormwater runoff from riparian zones, many of which may have been already disturbed by hog use. Through the removal of 5% of the population (50 hogs) and prevention of further increases, a reduction of 2.03E+13 MPN/yr is expected, after applying the 25% standard attentuation factor.</td></tr>
<tr><td>Effectiveness</td><td colspan="3">Provided the rural/urban mosaic land use of the watershed, it is expected that some feral hog control will take place on agricultural lands, but the most effective control will occur within the riparian corridors hogs use to travel between known food supplies. Population control will decrease loading primarily through direct fecal deposition, but also through stormwater runoff contributions.</td></tr>
<tr><td>Certainty</td><td colspan="3">Feral hogs are an adaptable and mobile species, and even minimal population reductions may be difficult to obtain and even more difficult to maintain, especially if large groups (sounders) become wary of tactics employed as recommended BMPs.</td></tr>
<tr><td>Commitment</td><td colspan="3">Although most landowners affected by feral hogs are willing to implement population control tactics, the effectiveness and certainty of success depend heavily on the diligence and commitment of landowners to not deviate from the recommended methods of hog removal, as well as the continued existence of financial/technical assistance.</td></tr>
<tr><td>Needs</td><td colspan="3">Funds to support education/outreach activities are needed, as well as continued technical assistance for improving the effectiveness of hog removal tactics.</td></tr>
</table>

6.5 Human Activities

6.5.1 Illegal Dumping and Litter Accumulation

As previously indicated, no reliable data currently exists with which to estimate *E. coli* loads that may arise from both illegally dumped materials and passively accumulated floatable litter in waterways. *E. coli* loads comprise only a fraction of the potentially hazardous substances that may arise from illegal dumpsites, which commonly occur in easily accessible areas, constituting a public health hazard. Many also voiced concerns related to the prevalence of the dumping activity in such close proximity to Lake Arlington, which provides drinking water to over half a million residents. For these reasons, stakeholders consider illegal dumping to be a 1st-tier priority for water quality improvement.

Above: Floatable litter accumulation in Lake Arlington (credit: City of Arlington).
Middle: Illegal dumping activity on Village Creek.
Below: Homeless occupation is a significant source of refuse accumulation under bridges in several watershed locations.

Several regional campaigns for littering currently exist, which can be administered in the watershed. This was reiterated for any existing illegal dumping-related content, if such programs currently exist. Expansion of the Lake Arlington cleanup events further into the Village Creek was also identified as a viable method of both direct removal of garbage and, illegal dump site discovery. Stakeholders also had an interest in the proliferation of home hazardous waste pickup/dropoff events into rural/unincorporated areas, as those efforts are currently only available to residents of participating cities.

Finally, stakeholders expressed interest in continued development of the proposed illegal dumping/refuse accumulation surveys, both by frequently revisiting established sites and adding new sites as more impacted areas become apparent through watershed reconnaissance and receipt of information from other watershed stakeholders. This also includes significant efforts to improve and promote interdepartmental communication at the municipal level to ensure that valuable information about potential illegal dumping sites discovered by any other municipal employee reaches code enforcement staff. Likewise, communication between neighboring cities, local agency staff, residents and the appropriate city staff will also help to ensure the success of this effort. Continued monitoring of illegal dumping sites may also reveal the need for long-term surveillance and/or posting of relevant signage to improve the efficacy of enforcement efforts. A summary of priority project areas, stakeholder recommendations and associated load reductions for illegal dumping and litter accumulation are provided in Table 6-4.

Table 6-4. Recommended BMPs for illegal dumping.

Pollutant Source: Illegal Dumping and Litter Accumulation			
Concerns: (1) Multiple pollutants from illegally dumped materials leaching into local water resources, (2) large dumped items restricting/redirecting flow in waterways			
Potential Impacts: (1) Direct/indirect contamination of waterbodies from *E. coli*, nutrients, and hazardous materials, (2) localized human health hazards, (3) Flow obstruction/alteration resulting in impoundment or erosion			
Critical Areas: (1) Small urban tributaries around the lake, (2) riparian buffers			
Goal: Reduce waste to a degree resulting in 15% of the total baseline survey sites shifting to lower-impact categories			
Objectives: (1) Work with municipalities to monitor sites and provide evidence for enforcement actions, (2) Increase education and outreach efforts pertaining to litter and illegal dumping through existing mass media campaigns, (3) Coordinate with other stakeholder entities to set up creek cleanup events in their vicinity			
Recommendations			
Responsible Party	**Management Practice**	**Timeframe**	**Costs**
Cities, counties, NCTCOG, HOAs, NAs	Continuation and expansion of survey to identify illegal dumping/refuse accumulation "hot spots" throughout watershed for 10 years (@$5800/yr); Use results of survey to coordinate with other entities to provided evidence for enforcement actions and to identify critical areas for signage/surveillance in urban and rural areas	2021-2030	$58,000
Counties, CDPs, NCTCOG	Work with county representatives and local leaders in unincoroporated areas to institute hazardous waste pickup days for 10 years (2/yr @$10k/yr)	2021-2030	$100,000
Cities, counties, NCTCOG, HOAs, NAs, nonprofits, regional entities, resource agencies	Coordinate w/ other watershed entities on public outreach/education opportunities via existing litter/illegal dumping mass media campaigns	2021-2030	Unknown
	Work w/ other watershed entities (Keep "____" Beautiful groups) to coordinate cleanups on Village Creek or its tributaries for 10 years (1/yr @ $3500/event)	2021-2030	$35,000
Estimated Load Reductions			
BMPs recommended for illegal dumping and litter accumulation are not tied to a specific *E. coli* reduction, but it is likely that reductions in the incidence of *E. coli* will occur to some degree, as dumping of whole animal carcasses and hunting remains are commonly found at site survey locations, occasionally deposited directly in the waterbody. Although this group of BMPs may not necessarily be tied to a load reduction, its visual nature will allow for documentation of progress as individual management measures are put into place.			
Effectiveness	The "patchwork" urban/rural landscape indicative of the watershed provides prime opportunities for illegal dumping activity, and several chronically affected sites appear to be well-known and frequently used by nearby residents/businesses. Treatment in this case is by direct removal of the pollutant source and internment elsewhere, exhibiting a high removal efficiency. Due to the highly visible nature of the pollutant source, identification takes minimal effort.		
Certainty	Improving opportunities for proper waste disposal for those aware of the contamination concern is expected to yield little, if any, improvement, as illegal dumping typically takes place as a matter of convenience for perpetrators, and thus it will be difficult to convince them to modify their behavior. Therefore, it is assumed that the bulk of illegal dumping concerns will be addressed through enforcement of city ordinances and criminal investigations, which can be improved through the use of proposed photo/video surveillance techniques.		
Commitment	Several municipalities have code enforcement staff currently available to handle illegal dumping activities, but lack the staff to actively patrol for violations. Providing these staff with the evidence they need will improve their efficiency and response time.		
Needs	Fund support of HHW pickup/dropoff and creek cleanup events; fund routine watershed reconnaisance to identify/characterize dump sites and track site recovery or movement; enforcement of existing illegal dumping codes once evidence has been provided.		

6.5.2 Lawn Residue and Waste

Stakeholders evaluated concerns related to residue and waste from managed green spaces in a manner similar to that previously used for illegal dumping and litter accumulation concerns. This came from the understanding that both sets of concerns arose from direct human influence on the landscape, either from ignorance of the environmental impacts, lack of proper education/training, or potentially from willful disregard of existing laws and ordinances. Similarly, a lack of solid information required to make pollutant load estimates was recognized here as well, meaning that lawn residue and waste could not be quantitatively compared to other pollutant sources. Despite this lack of information, stakeholders saw the benefits of emphasizing BMPs for this widespread water quality concern, identifying it as a 1st –tier priority to be addressed, due chiefly to its importance for managing eutrophication and overall water quality in Lake Arlington.

As is the case with many other pollutant sources, education and outreach initiatives are a vital first step. In this case, that entails ensuring that both staff and citizens have the knowledge to recognize behaviors that produce nutrient and DO concerns, which can consequently lead to fish kills, taste/odor problems in drinking water, or other impacts from eutrophication. Stakeholders have also proposed the use of illicit discharge studies for municipal stormwater infrastructure, chiefly to identify violations, but to also provide information to complement other pollutant site tracking efforts mentioned elsewhere within this WPP framework (see Section 6.5.1). EPA defines an illicit discharge as "...any discharge to an MS4 that is not composed entirely of stormwater..." with few notable exceptions like water from emergency response events (water from firefighters) or discharges specifically allowed through NPDES permitting (USEPA, 2005). Put simply, this means anything other than "rain down the storm drain" is considered an illicit discharge, whether put there willfully, accidentally, or while unaware of the environmental consequences. Successful identification of these illicit discharges involve a survey of either all or a subset of a municipalities' storm drain inlets, looking for evidence of everything from hazardous wastes like automotive fluids or other liquids poured directly into drain inlets to yard waste forced in with a leaf blower. Encouraging neighboring municipalities to enforce existing or adopt new model lawn waste handling/disposal ordinances to manage these activities is a high priority for stakeholders. A summary of priority project areas, stakeholder recommendations, and associated load reductions for lawn residue/waste are provided in Table 6-5.

Move organic debris back onto lawns or into compost piles to avoid storm drain clogs and impacts to aquatic health in local streams (credit: www.mygreenmontgomery.com).

Table 6-5. Recommended BMPs for lawn residue and waste.

Pollutant Source: Lawn Residue and Waste

Concerns: (1) Improper disposal of organic lawn waste, (2) excessive fertilizer, herbicide, pesticide, or other chemical application on lawns and other open areas

Potential Impacts: (1) Direct/indirect contamination of waterbody from *E. coli*, nutrients, and hazardous materials; (2) impacts to aquatic wildlife

Critical Areas: (1) Lake-adjacent subwatersheds, (2) managed open spaces (sports fields, golf courses, oil/gas pad sites)

Goal: Reduction of nutrients sufficient to remove nitrate and chlorophyll-a concerns in Lake Arlington

Objectives: (1) Increase education and outreach efforts pertaining to proper handling of organic yard waste, (2) Promote use of residential/commercial lawn management, (3) conduct illicit discharge surveys

Recommendations

Responsible Party	Management Practice	Timeframe	Costs
Cities, counties, NCTCOG, regional entities, resource agencies	Expand delivery of existing lawn waste education resources, develop/implement new educational resources (utility bill inserts, websites, pamphlets, videos, signage in public greenspaces/trails)	2021-2030	$170,000
	Deliver "water wise" education program to residents/landscapers for proper lawn care, landscaping, and stormwater management, w/ soil nutrient testing opportunity (3 events @$3500/event)	2022, 2025, 2028	$10,500
Cities, counties	Conduct illicit discharge surveys	2021-2030	Unknown
Residents, businesses, cities, counties	Incentivize install of permeable paver driveways/sidewalks and rain barrels (10 events @ $5500/event)	2022-2030	$55,000
	Encourage planting of low-water use (native and adapted) species in yards and greenspaces	2021-2030	Unknown
Schools, HOAs/NAs, golf courses, oil & gas pad operators, airports, real estate	Connect landowners w/ existing resources for proper land management, green infrastructure, irrigation, soil testing/fertilization, herbicide/pesticide application	2021-2030	Unknown
	Development and adoption of model lawn waste pickup/disposal ordinances for municipalities and by-laws for HOAs/NAs	2021	Unknown

Estimated Load Reductions

BMPs recommended for lawn residue/waste seek to reduce the amount of organic matter, nutrients, and chemicals reaching waterbodies via stormwater runoff and irrigation. Although the LDC analysis revealed that load reductions were not needed within any of the monitored tributaries, both nitrate and chlorophyll-a concerns exist within the lake. It is expected that several of the BMPs recommended for *E. coli* reductions will also reduce nutrient loading, by either a) confining the organic matter to a landfill, b) on-site retention and composting, or c) more efficent applications of lawn additives. In doing so, the amount of organic matter, nutrients, and other chemicals from lawn waste and residue entering waterways via runoff from rainfall or irrigation will be reduced at values proportional to those of *E. coli*.

Effectiveness	Effectiveness varies depending on the BMP of interest, with direct removal/reductions possible with respect to proper lawn waste management, but less direct benefits from lawn chemical application training/management. Again, given thedense population centers in the watershed, noticeable reductions are likely even if participation is limited.
Certainty	Education on properly managing lawn waste is a low-cost solution that most individuals can adopt easily. Enforcement of current lawn waste ordinances within municipalities is typically limited, with few cities having enough to properly address the issue. Unclear if on-site soil testing made available at workshops will improve participation.
Commitment	Homeowner adherence to lawn waste management protocols can be fleeting, dependent on perceptions of convenience, aesthetics, and understanding of negative impacts. City staff devoted to code enforcement will be as committed as their funding and schedules permit. Most homeowners understand the impacts of over-application of lawn additives, but may be uncomfortable with customizing their lawn care regimens even after receiving training to do so.
Needs	Funding for development and delivery of educational resources, development and/or enforcement of lawn waste ordinances with funding for staff.

6.6 Wastewater

6.6.1 Centralized Wastewater

For incorporated areas where onsite wastewater treatment is unfeasible due to higher population densities, centralized systems are the most common method of wastewater treatment. These systems use a network of pipelines connecting several homes and businesses to a centralized processing facility where it is treated before being released into a nearby waterway. It was determined that WWTFs within the VCLA watershed generally function as intended, with few instances of effluent violations.

In contrast, several vulnerabilities within the conveyance system, which includes above-ground and underground pipelines, pump stations, and manholes, were identified. These include both I/I issues that cause the majority of wet-weather SSOs, as well as blockages and physical damage that tend to result in dry-weather SSOs. Of these, I/I issues tend to cause the majority of large-volume SSOs most likely to reach waterbodies before being contained. Dry-weather SSOs tend to be the result of human activity, specifically improper disposal of non-flushable items in toilets. Stakeholders agreed that with violations at area WWTFs being infrequent, it was best to focus efforts on identifying and correcting SSOs. While SSOs ranked 5th in potential volume as an *E. coli* loading source in the watershed, stakeholders recognized that the instance of many large-volume SSOs near the lake were indeed in need of attention, and proposed that SSOs constitute a 2nd-tier priority for water quality improvement.

Above: Active SSO with flow from sewer access (credit: City of Arlington).
Middle: Evidence of recent wet-weather SSO – note debris around rim (credit: City of Fort Worth).
Below: Underground SSO, emerging at a culvert (credit: City of Fort Worth).

Education and outreach efforts will tend to focus on preventing blockages and damage by educating citizens about the consequences of indiscriminately using toilets as means of waste disposal, and how it costs them more in the long run to do so. SSOs from I/I issues will focus on training and education for municipal staff and other wastewater infrastructure operators, with emphasis on establishing and/or improving interdepartmental and inter-entity communication to ensure that I/I issues are quickly identified and addressed, including use of citizen reporting for improved coverage and function. Some funding was identified to assist municipalities with additional stormwater infrastructure assessments used to locate infrastructure in need of redesign or refurbishment, but the majority of construction for SSO-related water quality improvement rests with municipal capital improvement program (CIP) funding, as infrastructure projects are typically outside of the purview of CWA 319(h) funding mechanisms. A summary of priority project areas, stakeholder recommendations and the associated load reductions for centralized wastewater are provided in Table 6-6.

Table 6-6. Recommended BMPs for centralized wastewater treatment infrastructure.

<table>
<tr><th colspan="4">Pollutant Source: SSOs</th></tr>
<tr><td colspan="4">Concerns: (1) Overloaded wastewater infrastructure from inflow/infiltration, illicit discharges, or conveyance blockages from improperly disposed waste items, (2) failure of deteriorated, aging, or undersized wastewater infrastructure</td></tr>
<tr><td colspan="4">Potential Impacts: Direct/indirect loading to waterbodies from failing infrastructure/overloaded systems, (2) localized human health hazards</td></tr>
<tr><td colspan="4">Critical Areas: (1) Subwatersheds adjacent to the lake, (2) older neighborhoods w/ aging infrastructure</td></tr>
<tr><td colspan="4">Goal: Reduce the E. coli load from human sewage delivered to waterbodies through failing or overloaded wastewater conveyance infrastructure by reducing the instance of SSOs by 10%</td></tr>
<tr><td colspan="4">Objectives: (1) Identify high-priority SSOs, their causes, and available remedies, (2) Increase public education and outreach efforts pertaining to protection of wastewater infrastructure</td></tr>
<tr><th colspan="4">Recommendations</th></tr>
<tr><th>Responsible Party</th><th>Management Practice</th><th>Timeframe</th><th>Costs</th></tr>
<tr><td>Wastewater infrastructure operators</td><td>Use interdepartmental communication mechanisms to identify recurring/high-volume SSOs to target for rehab/ replacement through capital improvement programs</td><td>2021-2030</td><td>Unknown</td></tr>
<tr><td>Cities</td><td>Conduct stormwater infrastructure assessments for identification of illegal wastewater connections, proper placement and abundance of storm drains, other opportunities to improve conveyance/reduce pollution</td><td>2021-2030</td><td>$12,000</td></tr>
<tr><td>Large parking lot owner/operators</td><td>Incentivize install of permeable paver or other "green" parking lot alternatives to reduce stormwater runoff and decrease likelihood of I/I - related SSOs (4 events @ $35,000/event)</td><td>2022-2030</td><td>$150,000</td></tr>
<tr><td>Residents</td><td>Coordinate with other entities on established public outreach campaigns related to wastewater infrastructure protection/SSO prevention</td><td>2021-2030</td><td>Unknown</td></tr>
<tr><th colspan="4">Estimated Load Reductions</th></tr>
<tr><td colspan="4">Effects from SSOs are highly localized and acute in nature, and in many cases, discharges are contained before reaching a waterway. Therefore, making accurate predictions for load reductions based on these BMPs may be difficult. Much of the wastewater produced within the watershed is conveyed to WWTFs elsewhere, and E. coli violiations at WWTFs in the watershed are extremely rare. Therefore, reducing the instance of SSOs on a numeric basis was deemed as the appropriate metric for tracking progress. Recommended BMPs are expected to provide a decrease in the instance of SSOs over a 6-year period by 10% (30 events), using the 2011-2016 estimate (295 events) as the basis.</td></tr>
<tr><td>Effectiveness</td><td colspan="3">Identification and correction of SSOs will provide a direct reduction to E. coli loads reaching waterbodies. Reductions in the amount of improperly flushed items will significantly reduce the instance of pipeline blockages that lead to many of the smaller, dry-weather SSOs.</td></tr>
<tr><td>Certainty</td><td colspan="3">SSOs can usually be identified easily by both trained staff and concerned citizens, but an entity's ability to address SSO issues is often limited by available funding, with many entities opting for 5-10 year capital improvement plans (CIPs). Improving awareness of what is safe to flush among uninformed individuals may produce some benefit , but it is assumed that those who do so out of convenience will be difficult to convince to modify their behavior.</td></tr>
<tr><td>Commitment</td><td colspan="3">Most cities already employ some level of interdepartmental communication for alerts about stormwater/sewer issues. Regular messaging through education/outreach may be necessary to ensure that the public remains aware of how their actions affect wastewater infrastructure.</td></tr>
<tr><td>Needs</td><td colspan="3">Significant funding is needed to correct even the smallest SSO issue, and many municipalities lack sufficient funding to address them all in a timely fashion. Identifying supplemental funds for CIP projects will be of utmost importance. Existing outreach campaigns like "Defend Your Drains" and "Cease the Grease" are well-known and are low-cost message delivery mechanisms for public messaging.</td></tr>
</table>

6.6.2 OSSFs

OSSFs are still prevalent in the VCLA watershed, which use onsite treatment of human waste into a soil drain field as opposed to routing waste to a centralized WWTF. With normal maintenance, these systems are an effective method of sequestering and mitigating various pollutants within the soil, away from human and animal contact that could result in disease transmission. Should the system fail due to neglect or use beyond its capacity, pathogens, nutrients, and other BOD-related substances could reach the surface, endangering human health and contaminating local surface water sources. In general, the majority of the OSSFs in the watershed exist in the more rural areas further upstream from Lake Arlington. As a source, contamination from OSSFs ranked 4th overall in terms of load volume, but stakeholders recognize that addressing OSSF issues are costly, and there are several other more immediate threats to water quality closer to the lake that present opportunities to impact water quality with significantly less capital costs. With that understanding, BMPs related to OSSF contamination concerns were given a 3rd-tier priority. Given the low volume of the potential releases, proximity is a key consideration for BMP selection. Stakeholders agreed that emphasis again be placed on those OSSFs that exist within the riparian buffer, as these are the most likely to be pollutant sources.

OSSF malfunctions can occur due to lack of maintenance, improper construction in unsuitable soils, or overloading the drain field, resulting in overflows at the surface (City of Arlington).

It is understood that repair or replacement of failing OSSFs is the most straightforward method of contaminant reduction, but that funding such activities would be cost-prohibitive and quickly exhaust available grant funding. It would appear that the majority of both known and supposed OSSF locations in the watershed exist in areas with suitable soil types (Figure 4-4, Figure 4-5), so it is expected that most failures are due to design and maintenance issues. For that reason, it was recommended to consider providing incentives to landowners by offsetting the cost of both inspection and pumpout. Along with the requisite homeowner-focused OSSF maintenance training, it was also brought to attention that training for real estate professionals would also be beneficial. Many stakeholders noted that either during the purchase of their new homes or through the experience of acquaintances, it was clear that OSSF maintenance was clearly an afterthought in most transactions. Many new rural homeowners are likely unaware that they even have an OSSF on their property, a scenario that can quickly lead to system failure. Providing this training, along with providing support to counties and municipalities to draft and enforce ordinances requiring OSSFs to be inspected (and potentially even pumped out) before the property even changes hands would be the preference of the stakeholder group. Support for municipal "septic to sewer" programs, designed to bring older properties within municipal jurisdictions that still use OSSFs onto the centralized WWTF, will also be considered, along with encouraging homeowner associations to coordinate w/ private OSSF contractors to develop neighborhood-wide inspection/pumpout events in an attempt to reduce costs for residents. A summary of priority project areas, stakeholder recommendations and the associated load reductions for centralized wastewater are provided in Table 6-7.

Table 6-7. Recommended BMPs for OSSFs.

Pollutant Source: OSSFs			
Concerns: (1) Direct/indirect pollutant loading from failing/non-existent OSSFs, (2) disease transmission/public safety			
Potential Impacts: (1) Indirect E. coli loading to waterbody from failing/non-existent OSSFs, (2) spread of disease amongst/between species			
Critical Areas: Riparian buffer zones in rural/unincorporated areas			
Goal: Reduce the *E. coli* load from OSSFs delivered to waterbodies directly or indirectly through education, outreach, and incentivized inspections to yield a 15% reduction in the number of deficient systems.			
Objectives: (1) Increase education and outreach efforts pertaining to proper maintenance of OSSFs, (2) Provide access to affordable inspections/pumpouts for at-risk OSSFs in the watershed			
Recommendations			
Responsible Party	**Management Practice**	**Timeframe**	**Costs**
Residents, HOAs, NAs, NCTCOG	Provide homeowner-focused OSSF care/maintenance training (yearly, @$7500/event)	2021-2030	$75,000
Residents, HOAs, NAs	Incentivize OSSF inspections (with pumpout) for property owners with at-risks systems that have not been recently inspected (½ cost for 50 inspections/yr @$325/event, 10 yrs), with priority for OSSFs within riparian buffer zones	2021-2030	$162,500
	Replace failing septic systems (10 systems @ $10,000/system)	2023-2030	$100,000
	Encourage HOAs/NAs to coordinate w/ contractors to develop neighborhood-wide inspection/pumpout days to cut costs	2021-2030	Unknown
Real estate agents, OSSF professionals, NCTCOG	Provide practice-focused OSSF training for awareness of pollution potential, local ordinances, and importance of routine maintenance/cleanouts (yearly, @$7500/event)	2021-2030	$75,000
Cities, Counties	Work with municipalities to create/expand "septic to sewer" programs to transition eligible properties with OSSFs over to the centralized wastewater collection system	2021-2030	Unknown
	Conduct OSSF inventories, draft and enforce ordinances that require OSSFs to be inspected before property changes hands	2021-2030	Unknown
Estimated Load Reductions			
Efforts involve BMPs focused on OSSF owner education and incentivized inspections targeting at-risk OSSFs, with priority given to those located in riparian buffer zones. By applying these recommended BMPs, a 10% decrease in the reduction of failing systems is expected, resulting in an *E. coli* load reduction 2.99E+13 MPN/yr, applying the same 25% attenuation factor used in other reduction calculations to realistically represent the expected load reduction. Reductions for nutrients are also expected, with ranges of 10-40% for nitrogen, and 85-95% for phosphorus species (USEPA 2002).			
Effectiveness	Incompatible soils are a common cause of OSSF malfunction, with many such soils identified in the western half of the watershed. Thankfully, subwatersheds with the highest OSSF densities fall outside of these areas. Lack of awareness and proper maintenance are therefore inferred to be the main causes of malfunction; these are more easily corrected than geologic factors. Repair or replacement of faulty OSSFs will provide direct reductions to *E. coli* loading to nearby waterways.		
Certainty	Workshops targeted to residents/homeowners are subject to wide ranges of variance in attendance, but those targeted to trade professionals are usually well-attended, especially for those with education requirements. If a malfunction is identified during an inspection, most authorized agencies require reporting and remedy to the OSSF. This may motivate some owners to not be proactive and eschew the inspection incentives.		
Commitment	It is unclear if homeowners will put what they learn into practice, but professionals are likely to adopt curriculum into their long-term business practices. It is also unclear whether OSSF owners will continue with proactive inspections after receiving initial incentives.		
Needs	Significant funding is required for the incentivized inspection/pumpout program, along with identification of several local private contractors willing to conduct the work in cooperation with authorized agencies. Funding for administering training programs will also be necessary.		

6.7 Summary of Expected Load Reductions

While reductions to watershed-wide *E. coli* loads are the primary goal of this WPP, stakeholders also chose to incorporate other water quality-related goals for the watershed, along with some potentially unconventional methods of measuring success. In many recent WPPs, education and outreach have become prominent components. While these can be effective means of achieving pollutant reductions, they cannot often be quantitatively measured due to the reticent response time inherent to many BMPs that rely on behavioral change. The use of before/after surveys for these activities can be used to test knowledge gained, but cannot predict what attendees will actually put into practice. Furthermore, any water quality improvements from education/outreach initiatives often run parallel to other recommended BMPs, particularly those targeted to reducing animal waste volumes through population control, which provide direct, and often the most significant, reductions to *E. coli* loads. While less prominent, activities targeted to correction/removal of SSOs, as well as malfunctioning OSSFs, will provide some additional relief for systems stressed by excessive *E. coli* loads. A summary of all anticipated *E. coli* load reductions is provided in Table 6-8.The overall anticipated load reduction provided by the management measures is 1.47E+15 MPN/yr, which exceeds the required reductions of 1.61E+14 MPN/yr for Village Creek and 1.83E+11 MPN/yr for the unnamed tributary.

While no numeric load reductions were explicitly identified for nutrient reductions, there is an expectation that steps taken to physically reduce *E. coli* loads would inherently reduce both nutrient and sediment loads as well. Additionally, measures related to illegal dumping and lawn waste and residues will help provide reductions such that the existing water quality concerns for nitrate and chl-a are not only removed, but water quality overall is improved through reductions in other pollutants as well. As indicated earlier, reductions of these nature are dependent on the level of participation, which cannot always be predicted or differentiated from the load reduction as a whole.

Table 6-8. Summary of recommended management measures and water quality goals.

Management Measures[1]	Anticipated *E. coli* Load Reduction	Other Management Goals
Pet Waste		
Pet waste disposal ordinances Supplemental pet waste stations Bioswale/rain garden projects Back yard pet waste digesters	1.37E+15 MPN/yr	-
Illegal Dumping and Litter Accumulation		
Illegal dumping surveys Rural home hazardous waste pickup/dropoff days VCLA cleanup events	-	15% of sites shift to lower impact category
Lawn Residue and Waste		
Illicit discharge surveys Lawn waste management ordinances Permeable paver sidewalks/driveways, rain barrels, low-water plantings	-	Nutrient reduction to remove existing concerns
SSOs		
Support for interdepartmental reporting network for SSO locations Stormwater infrastructure assessments Permeable paver parking lots	-	Reduce instance of SSOs in watershed by 10%
Livestock		
WQMPs and CPs	5.09E+13 MPN/yr	-
OSSFs		
Incentivized OSSF inspections, pumpouts, replacements, and retrofits HOA/NA coordinated OSSF cleanout events Septic-to-sewer initiatives OSSF inspection ordinances for property transfers	2.99E+13 MPN/yr	-
Feral Hogs		
Trap share program Establish regional feral hog resource and support network Feral hog removal and/or exclusion from attractive nuisances Riparian buffer restoration/extension	2.03E+13 MPN/yr	-
Total Anticipated *E. coli* Load Reduction	**1.47E+15 MPN/yr**	

(1) Note that all management measures categories include education and outreach components.

7.0 Plan Implementation

The management recommendations described in previous chapters are likely to involve multiple entities actively participating in several overlapping efforts at any given time over a structured period for implementation. This complex structure requires a flexible schedule, employing the use of interim milestones to track progress and make changes as necessary. While it is likely that project costs will ultimately fluctuate from now until they are actually implemented, it is still important to provide estimated costs during the planning stage to provide a gross overall estimate as a guide during the early stages of development.

Access to variety of technical and financial resources will be necessary to fully implement the broad scope of projects recommended by stakeholders for this WPP. Matching these resources to each project's needs will be critical during both the development and implementation of this WPP. As time progresses and needs change, the list of available resources may also need to be updated to ensure that stakeholders are made aware of both new assistance sources as well as those that are no longer accessible. The amount and type of resources required for successful implementation will inevitably depend on the size, scope, location, and complexity of each project. Assistance needs will also vary depending on the pollutant source categories the project is intended to manage.

7.1 Schedule, Interim Milestones, and Estimated Costs

Implementation of the VCLA WPP is intended to occur within a 10-year timeframe. However, it is expected that several challenges will be encountered during this period, and will need to be addressed through adaptive management. Some situations that may be encountered include staff turnover within stakeholder entities, lack of funds for project implementation or delayed access to those funds, or even delayed project initiation. As these challenges are encountered, modifications to the schedule and/or list of feasible BMPs may be necessary. Whenever possible, interim milestones should be used by stakeholders to help them make informed judgments about necessary adjustments to the implementation schedule. An initial list of recommended management strategies is provided in Table 7-1, which includes each BMP's intended focus group, expected implementation timeframe with milestones, and anticipated costs, as applicable. Information about the funding sources referenced in the last column in Table 7-1 is provided later in Section 7.5.

Early emphasis for implementation will be on projects that have lower management needs, favorable cost-to-benefit ratios, and the ability to yield significant reductions to loadings for *E. coli* and other contaminants. These "low-hanging fruit" are often projects that have been widely utilized across the state or nation with documented and significant positive influence on water quality and recreational potential. If further reductions are required after implementation and exhaustion of these projects, stakeholders may choose to proceed with incrementally less favorable, more cumbersome, or more costly methods of load reduction as the need arises.

7.2 Synergies with Existing and Ongoing Water Quality Initiatives

It is expected that implementation efforts within the VCLA watershed will experience overlap with several ongoing water quality and environmental initiatives led by other entities within the watershed. Participants in the VCLA WPP should do their best to identify these other entities and become educated about their programming, in an effort to reduce duplication of efforts, avoid division of resources, or to potentially even uncover opportunities for collaboration. Stakeholders should also be aware of the MS4-related activities currently being required of all the Phase I and Phase II entities in the watershed. This should be done to ensure that no grant funding is being used to conduct activities already required by an entity's MS4 permit. Instead, stakeholders should focus on projects that supplement MS4 activities or expand efforts beyond their current scope.

Table 7-1. Summary of BMP recommendations, implementation schedule, and associated costs.

Management Measure	Responsible Party	Unit Cost	Units Implemented (by year)										Total Cost	Funding Source
			1	2	3	4	5	6	7	8	9	10		
Pet Waste														
Pet waste disposal ordinances/bylaws	Cities, counties, HOAs, NAs	N/A	As early as feasible										N/A	L, F3
Supplemental pet waste station recon		$3,000	1										$3,000	F6,S5,S7,N1,N3
Supplemental pet waste station install		$300		25									$7,500	
Pet waste station maintenance/supplies		$85		25	25	25	25	25	25	25	25	25	$19,125	
Bioswales and rain gardens		$12,500		1		1		1		1			$50,000	F6,S5,S7,N1,N2,N3
Backyard pet waste digesters	Residents	$1,000	5	5	5	5	5	5	5	5	5	5	$50,000	F6,S7,N1,N3
Education & outreach - bill inserts	Cities, counties, regional entities	$17,000		1	1	1	1	1	1	1	1	1	$153,000	F8,N1,N3
Education & outreach - general		$17,000	Assitance/input as needed										$17,000	
Livestock														
WQMPs and CPs	Production agriculture	$15,000		2	5	5	5	5	5	5	5	3	$600,000	F1,F4,F5,F7,S1, S4,S10,S11,N2,N4
WQMP Technician (1/2 time)		$40,000		1	1	1	1	1	1	1	1	1	$360,000	
Education & outreach	Hobby farmers	$1,000	1	1	1	1	1	1	1	1	1	1	$10,000	F8,N1,N2,N3
Feral Hogs														
Trap share program - trap purchase	Cities, counties, regional entities	$15,000	3										$45,000	F6,S7
Trap share program - maintenance		$500	1	1	1	1	1	1	1	1	1	1	$5,000	
Establish regional feral hog resource and support network	Any public/private landowners, land managers	$500	1	1	1	1	1	1	1	1	1	1	$5,000	F6,F8
Feral hog removal		N/A	As many as possible										N/A	Unknown
Hog exclusion from attractive nuisances		N/A	As many as possible										N/A	Unknown
Riparian buffer restoration/extension		N/A	Assitance/input as needed										N/A	F6,S5,S7,N1,N2,N3
Education & outreach	All stakeholders	$7,500	1	1	1	1	1	1	1	1	1	1	$75,000	F8
Illegal Dumping and Litter Accumulation														
Illegal dumping surveys	Cities, counties, HOAs, NAs	$5,800	1	1	1	1	1	1	1	1	1	1	$58,000	F6,S7,S8,N1,N3
Rural home hazardous waste pickup/dropoff days	Counties, CDPs	$5,000	2	2	2	2	2	2	2	2	2	2	$100,000	F6,S7,N1,N3
VCLA cleanup events	All stakeholders	$3,500	1	1	1	1	1	1	1	1	1	1	$35,000	F6,S7,N1,N3
Education & outreach		N/A	Assitance/input as needed										N/A	Unknown
Lawn Residue and Waste														
Illicit discharge surveys	Cities, counties	N/A	As needed										N/A	F6,S2,S7,S8,N1,N3
Permeable paver driveways, rain barrels	Residents, businesses, cities, counties	$5,500	1	1	1	1	1	1	1	1	1	1	$55,000	F6,S5,S7,N1,N2,N3
Low-water use plantings in greenspaces		N/A	Assitance/input as needed										N/A	F6,S5,S7,N1,N2,N3
Lawn waste management ordinances/bylaws	Cities, counties, HOAs, NAs	N/A	As early as feasible										N/A	L, F3
"Water Wise" lawn care training	Residents, landscapers	$3,500		1			1			1			$10,500	F8,N1,N3
Education & outreach - bill inserts	Cities, counties, regional entities	$17,000		1	1	1	1	1	1	1	1	1	$153,000	F8,N1,N3
Education & outreach - general		$17,000	Assitance/input as needed										$17,000	F8,N1,N3
SSOs														
Support for interdepartmental reporting network for SSO locations	Wastewater infrastructure operators	N/A	As needed										N/A	L, F3
Stormwater infrastructure assessments	Cities	$800	1	1	2	2	2	2	2	1	1	1	$12,000	F6,S2,S7,S8,N1,N3
Permeable pavers for parking lots	Lot owners/operators	$37,500		1		1		1		1			$150,000	F6,S5,S7,N1,N2,N3
Education & outreach	Residents	N/A	Assitance/input as needed										N/A	N/A
OSSFs														
Incentivized OSSF inspections/pumpouts	Residents, HOAs, NAs	$325	50	50	50	50	50	50	50	50	50	50	$162,500	F9,S2,S7
Replace failing systems		$10,000			1	1	1	2	2	2	1		$100,000	F6,S5,S7,N1,N2,N3
HOA/NA coordinated OSSF cleanout events		N/A	Assitance/input as needed										N/A	S7
Homeowner OSSF training		$7,500	1	1	1	1	1	1	1	1	1	1	$75,000	F8
Practice-focused OSSF training	Real estate agents, OSSF professionals	$7,500	1	1	1	1	1	1	1	1	1	1	$75,000	F8
OSSF inventory, septic-to-sewer initiatives	Cities, counties	N/A	Assitance/input as needed										N/A	F9,S2,S6,S8
OSSF inspection ordinances for property transfers		N/A	As early as feasible										N/A	L
Monitoring Projects														
VCLA Long-term Monitoring (bimonthly)	TRA	$72,000	1			1			1			1	$288,000	F3,S9
Lake Arlington Profile Study	City of Arlington	$150,000	As early as feasible										$150,000	F6,S6,N1,N3
Bacterial Source Tracking - Unnamed trib to Lake Arlington (monthly)	TRA/City of Arlington	$4,000	12	6									$72,000	F3, F6,S6,N1,N3

7.3 Education and Public Outreach

The implementation efforts of WPPs rely heavily on education and outreach activities to increase the knowledge and acceptance of the physical BMPs used to mitigate pollutant loads in a watershed. For meaningful success to be achieved in a watershed, it is critical that stakeholders be provided information and training that is ongoing, clearly organized, and relevant to the watershed and its specific challenges. Using the resources and connections within multiple entities, educational programs will pull from local entity staff, known topical experts, and practiced industry specialists to provide meaningful content in a variety of subject areas. Many existing programs relevant to pollutant source categories identified in this WPP can be utilized. In cases where present regional programming was found to be lacking, additional funding was identified to develop new programs. It is likely that additional programming needs will arise in the future. In these cases, several options will be considered before seeking supplementary funding to develop and administer new content. Due to the nature of the grant and its primary goal of eliminating the water quality impairment, education and outreach programming will primarily focus on affecting behaviors to drive *E. coli* reductions. However, it is expected that topics such as nutrient reductions, eutrophication, industrial/petrochemical contamination, illegal dumping, floatable trash, green infrastructure, and water conservation will also be discussed. Details about general and specific education and outreach efforts identified for this WPP are provided in Table 7-1.

7.4 Technical Assistance

Some of the management measures recommended for this WPP will require specialized technical expertise to adequately and safely navigate the planning, design, and implementation phases on a project-specific basis. Identifying and securing such expertise will be initiated as soon as is feasible for individual projects. For those projects where focused, long-term expertise is needed to guided implementation, creation of and funding for either full-time or split-time positions for watershed projects may be necessary to adequately address the watershed's needs.

7.4.1 Pet Waste Management

Many municipalities already have considerable experience dealing with pet waste concerns as part of their MS4 permitting requirements. This expertise also exists at the regional level, with staff at NCTCOG and the regional water entities (TRA, TRWD) already engaged in delivery of education/outreach programming focused on pet waste as a pollutant source. Although no structural projects are proposed, installation of prefabricated pet waste stations is recommended, which will require some reconnaissance beforehand by either/or TRA and municipal personnel. For pet waste digesters, basic knowledge of soil types is useful, which is readily accessible to homeowners. Before digging occurs, homeowners will also be encouraged to call the statewide 8-1-1 number to ensure that their proposed dig zone is safe to install the pet waste digester.

7.4.2 Livestock Management

Several agencies across the state have significant and documented expertise in the development and implementation of BMPs related to managing livestock and farmland. Agents and technicians from the TSSWCB, NRCS, local SWCDs, and local Texas AgriLife Extension staff are all conveniently officed in the DFW metroplex, and are familiar with the specific needs of the area. A wealth of technical assistance is available to both large-scale agricultural producers and hobby farm operators operating locally. While many whole-property management programs currently exist only for production agriculture, these agencies see the need to develop similar programs for hobby farms and other smaller-scale operations as their exposure has increased, along with their perceived water quality impacts.

Due to its proximity to several urban centers, it is likely that the VCLA watershed possesses a lower percentage of eligible agricultural operations eligible for WQMPs and CPs. Therefore, it is likely that any dedicated technicians hired to develop WQMPs/CPs for the watershed will likely need to be split-time with another watershed, project, or encompass a larger area beyond that of the VCLA watershed. This technician would need to work with knowledgeable personnel from NRCS, TSSWCB, or Texas AgriLife Extension to begin the process of identifying and engaging potential plan candidates.

7.4.3 Feral Hog Management

Although feral hog control as a pollutant load control measure is expected to be a lower priority, several forms of technical assistance will still be made available, chiefly through the proposed development of a feral hog control assistance framework. This is intended to provide landowners with information related to various aspects of feral hog control. This framework will be developed with input from Texas Wildlife Services, Texas AgriLife Extension, and TPWD staff, who provide the bulk of the educational programming currently available to Texas landowners contending with feral hog impacts.

7.4.4 Illegal Dumping and Litter Accumulation

As is the case with pet waste, many municipalities and county officials already have considerable experience with illegal dumping and litter accumulation as part of their MS4 permitting requirements, which is again reflected at the regional level. Their assistance will be vital as TRA expands its illegal dumping survey efforts, providing both historical accounts of any prevalent dumping/accumulation sites and available remedies at their entity's disposal for site cleanup and/or prevention of future dumping activities. The expertise of non-profit organizations, particularly those focused on community beautification and public health, may also prove to be a valuable asset during the development and execution of volunteer watershed cleanup efforts.

7.4.5 Lawn Residue and Waste

Being primarily a stormwater-related issue, there will be considerable reliance on municipal, county, and regional entity personnel who may already be contending with illicit discharge issues as part of their MS4 permits. Their expertise will prove beneficial during the development of the recommended model lawn waste pickup/disposal ordinances. Additional assistance from industry professionals and other outside sources may also be needed to successfully administer the education and outreach initiatives planned for this WPP.

7.4.6 SSOs

Technical assistance for issues tied to SSOs will also rely heavily on municipal and regional entity staff, particularly those in departments related to the management of wastewater infrastructure owned or operated by that entity. Since the majority of the funding identified to address SSOs will come from CIPs initiated by these wastewater infrastructure entities, the expertise of these staff will be instrumental in determining how reconnaissance and interdepartmental communication initiatives identified in the WPP can best be implemented to better inform CIP efforts.

7.4.7 OSSFs

Any efforts to counteract the negative impacts of failing OSSFs are likely to benefit from the continued support and input from county DRs tasked with OSSF initiatives. These individuals will be instrumental in identifying staff from municipalities that are currently engaged in septic-to-sewer initiatives and will be a crucial resource to those elsewhere wishing to implement their own similar efforts as part of the program outlined in the WPP. It is likely that some of these same staff will also be involved with the drafting and enforcement of model ordinances requiring OSSF inspections when real estate property changes hands. Others will be instrumental in coordinating both the incentivized OSSF inspection/pumpout program and the neighborhood-wide pumpout days. DRs will be the lead on any OSSF inventories conducted in the watershed to locate properties with OSSFs most in need of these programs .Input from experienced OSSF inspectors, as well as from real estate professionals who have dealt with rural properties using OSSFs, will also be sought when planning for their respective practice-focused training opportunities which were identified as needs by stakeholders.

7.5 Financial Assistance

While some of the BMPs recommended by stakeholders may be able to take advantage of programs covered through existing funding sources, it is expected that the majority will require financial support in some capacity. In other cases, grant funding may be used for initial reconnaissance or other preliminary assessments, with funding for construction, reconstruction, or retrofitting coming chiefly from other sources (e.g., illegal dumping reconnaissance, illicit discharge surveys). Whenever possible, existing programs in the watershed will be leveraged with new funding to expand scope and/or frequency to further improve the chances of implementation success. For the WPP to be truly successful, it is imperative to identify funding opportunities from a variety of sources that could potentially be used to support one or several projects. Several of the identified sources are frequently utilized by water quality-related projects such as WPPs, and therefore can be easily navigated. In cases where these traditional sources aren't applicable or are otherwise unsuited for a project, it may become necessary to either seek out new sources or creatively apply known resources in fresh new ways to achieve results. The funding sources described below are referenced in the last column in Table 7-1 using the letter/number system accompanying each description. It should be noted that CWA § 319(h) funding (F3 below) could be used to fund some portion of each of the recommended management measures. However, identifying other sources of funding provides additional means of achieving success for the WPP's goals to improve and protect water quality.

7.5.1 Federal Funding Sources

Agricultural Water Enhancement Program

F1 Designed to promote water enhancement projects on agricultural land, this program provides both financial and technical assistance to agricultural producers and rural landowners interested in developing resource conservation plans to protect the quality of the surface and groundwater on their property. This is a voluntary conservation initiative overseen by NRCS, which aims to improve water quality through the implementation of ideas.

Clean Water Act § 106 – State Water Pollution Control Grants

F2 States, eligible tribes, and interstate agencies are able to use § 106 grants to establish, expand, and implement long-term, large-scale water quality monitoring programs. These include statewide water quality monitoring and assessment programs, TMDL development, creation of water quality standards, point source permitting, and training.

Clean Water Act § 319(h) – Nonpoint Source Grant Program

F3 In Texas, the EPA distributes these grant funds evenly between the TSSWCB and TCEQ to implement nonpoint source pollution projects. TSSWCB projects typically focus on nonpoint source pollution from predominantly agricultural and silvicultural watersheds, while TCEQ projects tend to concentrate more on urban sources and other forms of pollution. To be eligible for 319(h) funding, applicants must have a written plan that satisfies the nine key elements of successful watershed-based plans (Appendix A). Applicants may apply for multiple projects, and are usually encouraged to cater their application to either agency based on project goals: projects funding WQMP/CP projects, feral hog control, or stock pond management would therefore be directed to TSSWCB, whereas urban stormwater assessments, illicit discharge surveys, and illegal dumping reconnaissance would be better suited for TCEQ funding. Some projects, such as overall BMP effectiveness monitoring, OSSF-related projects, or pet waste management, could be sought from either agency.

Conservation Reserve Program

F4 Agricultural producers participating in this program are eligible to receive annual rental payments for land where they voluntarily establish vegetative/woody plant cover in ESAs. The NRCS-Farm Service Agency can offset up to 50% of the costs associated with establishing these approved conservation practices, with the ultimate goal of the program being to protect lakes, rivers, streams, and ponds by reducing runoff and therefore sedimentation that can reduce storage capacity and introduce nonpoint source pollutants.

Conservation Stewardship Program

F5 This is another USDA program, administered through NRCS, which encourages producers to implement conservation activities on private cropland, grassland, prairies, improved pasture, and rangeland in a comprehensive manner. Producers are encouraged to combine several practices like prescribed grazing, precision nutrient application and budgeting, manure application, and integrated pest management.

Cooperative Watershed Management Program

F6 The U.S. Bureau of Reclamation provides funding through this two-phased program to 1) develop watershed stakeholder groups (Phase I), and 2) implement watershed management projects. Like the 319(h) grant program, these funds can be used for nonpoint source pollution control and watershed monitoring, modeling, and mapping, but may also be used to fund other watershed restoration activities.

Environmental Quality Incentives Program

F7 This is another USDA-NRCS program that promotes agricultural production and environmental quality as compatible goals that can operate simultaneously on agricultural lands. These are typically 10-year contracts with voluntary participation from agricultural producers seeking to address natural resource concerns on their property through the use of a variety of structural controls and management practices. Plans must be developed in concert with NRCS technicians, who will design the plan for local conditions using NRCS technical standards. Applicants must be engaged in production agriculture to be eligible for technical and financial assistance, and these plans must be approved by local SWCDs before being implemented.

Environmental Education Grants

F8 The EPA's Environmental Education Division, Office of Children's Health Protection and Environmental Education sponsors grants for environmental education intended to promote public awareness, knowledge, and skills to help citizens recognize how their behaviors impact the environment around them. Available funding is dependent on Congressional appropriations, but grant requests that are accepted are typically funded for $15,000 to $25,000.

Rural Development Program – Water & Environmental

F9 USDA's Rural Development Programs offers grants and low-interest loans to rural communities seeking funding to develop water supply and wastewater infrastructure through repair, rehabilitation, or new construction projects.

Rural Repair and Rehabilitation Loans or Grants - Funding is intended to improve/repair low-income housing, or remove health and safety hazards.

Technical Assistance and Training Grants for Rural Waste Systems - Offers grants to non-profit organizations which focus on training and technical assistance relevant to rural water delivery and waste disposal.

Water and Waste Disposal Direct Loans and Grants - This program assists rural communities with populations of less than 10,000 individuals with development of water and waste disposal systems.

Water Resources Development Act – Environmental Restoration Program

F10 Through § 1135 of the Water Resources Development Act, the U.S. Army Corps of Engineers is authorized to plan, design, and construct modifications to existing Corps projects that restore aquatic habitats for fish and wildlife use. This also applies to areas that are subsequently affected by the construction of a Corps project. Funding for individual projects is limited to $10 million in total Federal costs, which can be further leveraged with non-federal funds.

7.5.2 State Funding Sources

Agricultural Water Conservation Program

S1 TWDB assists political subdivisions and private individuals by providing grants and low-interest loans for agricultural water conservation/improvement projects.

Clean Water State Revolving Fund

S2 TWDB also assists political subdivisions and private individuals with authority to own and operate WWTFs by providing grants and loans below market rates for the planning, design, and construction of wastewater, stormwater, reuse, and other pollution control projects. Funds can be used for construction of facilities, collection systems, stormwater/nonpoint source pollution control project, or may even be used to acquire and retrofit existing systems. Loans through the fund have flexible terms and qualifying parties may be eligible for principal forgiveness.

Economically Distressed Area Program

S3 This is another TWDB program that provides grants and loans to communities in economically distressed areas where existing facilities do not adequately meet the minimum needs of residents. Representatives from these areas may request funding for projects to improve their wastewater infrastructure. Although the likelihood is low that funding from this program could be utilized in the watershed, there may be smaller communities or subdivisions in both the rural and urban areas that potentially qualify for assistance based on economic criteria.

Landowner Incentive Program

S4 This program, administered through TPWD, encourages private landowners to implement conservation practices that create, restore, protect, and enhance aquatic and/or terrestrial habitat for at-risk or rare species. A list of eligible species are provided in the Texas State Wildlife Action Plan and Landowner Incentive Plan Priority Plant Species List. The program is somewhat unique in its approach, in that landowners are required to actively contribute through labor, materials, or other means to be eligible for financial assistance.

Outdoor Recreation Grants

S5 Another TPWD program, designed to assist communities of less than 500,000 acquire and develop park land or renovate existing public recreational areas. Grants provide up to 50% matching funds, with a maximum award of $500,000, with two funding cycles per year. Available applicants include municipalities, counties, municipal utility districts, river authorities, and other special districts.

Regional Water Supply and Wastewater Facility Planning Program

S6 This TWDB grant program is designed to help various entities plan for future regional water supply and wastewater facility needs in their region. Funding can be used to determine the most feasible alternatives for facility size/locations needed to meet regional needs under different population scenarios, as well as for identifying functional institutional arrangements to provide adequate services throughout the region.

Supplemental Environmental Projects Program

S7 This TCEQ program redirects the fines, fees, and penalties collected from environmental violations into funding for environmental pollution reduction projects. Instead of contributing to the Texas General Revenue fund, entities subject to enforcement may choose to direct their penalty dollars to other environmental improvement activities like wildlife habitat improvement, pollutant clean-ups, and OSSF repair initiatives. Common project types include illegal dumping site cleanups and household hazardous waste collection events.

Texas Capital Fund

S8 TDA administers this fund as part of its Community Development Block Grant, which is a competitive process providing funding to eligible municipalities and counties in rural areas to construct new or replace old failing public infrastructure. Funds can be used for water supply and waste water lines, as well as stormwater drainage improvements. Typical grant awards range from $100,000 to $1.5 million per project.

Texas Clean Rivers Program

S9 The Texas Clean Rivers Program (CRP) is a state-fee funded program principally providing water quality monitoring throughout the state. Funds are allocated to 15 partner agencies, typically river authorities, to fund routine monitoring, special projects, and public outreach, with funding allocated on a biannual basis. The TRA is the designated CRP partner for the VCLA watershed, which applies the bulk of the allocated funds to water quality monitoring and development of annual water quality assessments. Based on data for the 2018-2019 term, funding identified for special projects was approximately $25,000. A portion of these funds may be available to stakeholders if they are able to identify a monitoring need in the watershed that aligns with the intent of CRP’s special projects program. An additional $15,000 is allotted for education and outreach activities, which fund existing programs that could be utilized within the watershed.

Texas Farm & Ranch Lands Conservation Program

S10 This TPWD program provides grants to landowners for the sale of conservation easements on high-value working lands to protect fish, wildlife, water quality, and agricultural production from the threats of land fragmentation, impervious cover encroachment, and loss of agricultural production. The intent of the program is to educate landowners about the importance of natural resource stewardship by providing a voluntary, free-market alternative for landowners averse to selling and fragmenting their land for development.

Water Quality Management Plans

S11 The WQMP program, administered through the TSSWCB, is another voluntary mechanism for agricultural and silvicultural producers that combines components of several other conservation-based BMPs on a “whole farm” scale to effectively reduce nonpoint source pollution. Utilizing technical guidance from local SWCDs, these plans are developed with the goals of both the producer and the state in mind and provide several financial incentives for participants once the plans are adopted.

7.5.3 Local Funding Sources

L Most grants require some form of matching funds to be eligible for application. In many cases, existing expenses for personnel time, equipment used, ongoing environmental programs, or from other sources are sufficient to offset match funding requirements, but at times other sources of funding may be required. Many municipalities across the state are beginning to embrace creative new ways of funding their environmental projects, including the use of stormwater or environmental services fees as part of their utility billing outlays. Many municipalities in the VCLA watershed already employ the use of such fees. As the watershed becomes increasingly more developed, the need for other entities to implement their own supplemental fee systems may become an increasingly viable option for offsetting the costs of protecting water quality as both runoff and nonpoint source pollution increase along with the amount of impervious cover throughout the watershed.

7.5.4 Other Sources

Non-profit organizations, private foundations, land trusts, and even individual donors may also prove to be useful funding sources.

Cynthia and George Mitchell Foundation

N1 Grants are offered for several programs, including land conservation, water, and sustainability education, with a focus on maintaining sustainability and providing protection and conservation of the state’s land and water resources.

Dixon Water Foundation

N2 Grants are provided to non-profit organizations for projects related to improving or maintaining watershed health through the use of proper land management techniques. Emphasis is on production agriculture, grazing management, and long-term research to monitor the environmental responses to various land conservation and stewardship practices.

Meadows Foundation

N3 Grants are provided to agencies, research universities, and non-profit organizations, with initiatives in several areas, including environmental stewardship. Potential projects for funding include those for water quality, land and habitat conservation, and public education and advocacy.

Texas Agricultural Land Trust

N4 Funding is provided with the intention of preserving Texas’ heritage by protecting farmlands, wildlife habitat, and other natural resources. This is accomplished through the use of conservation easements to curtail land fragmentation and maintain large tracts of land that will remain economically sustainable.

8.0 Measuring Success

The VCLA Watershed Protection effort and the subsequent WPP document that was produced are the products of over three years of coordination between dedicated watershed stakeholders from all walks of life that have come together to protect the water quality and recreational capacity of both Village Creek and Lake Arlington. Continued stakeholder support and input is vital for effective implementation of this WPP. The current core stakeholder group has demonstrated their knowledge of the watershed and passion for protecting the environmental, recreational, and aesthetic aspects of the watershed. However, efforts required for successfully implementing the WPP will far exceed the limitations of a single stakeholder. Therefore, it is imperative that the planning process incorporate several long-term support mechanics for planning implementation timelines, organizing projects, and securing funding for those projects. Additional support will also be needed to track progress, both through demonstration of project completion and through effectiveness monitoring.

8.1 Implementation Oversight

Due to the intensive needs for long-term implementation oversight, a full-time watershed coordinator position will likely be needed for full WPP implementation support. The watershed coordinator will be responsible for shepherding various implementation projects through from inception to completion, beginning with solicitation of project ideas from engaged stakeholders. Along with further project development, funding opportunities must also be identified and approval paperwork must be filed to progress projects. Planning and promotion of educational programming and materials, along with tracking all forms of implementation progress, will also fall to the watershed coordinator to organize. To fully support this position, $110,000 for annual salary, benefits, travel, and other necessities to perform their duties.

8.2 Effectiveness Monitoring

From the onset of the WPP planning process, stakeholders made it clear that they had aspirations well beyond addressing the existing water quality impairments and concerns in Village Creek and Lake Arlington. To that end, a variety of techniques is expected to be utilized to monitor overall WPP effectiveness as projects are implemented. These techniques are intended to be quantitative in nature whenever feasible, but may involve qualitative elements when appropriate. These techniques will also incorporate appropriate interim milestones so that stakeholders can evaluate progress and adapt as necessary to meet the needs of the watershed (see 'Units implemented,' Table 7-1).

Continued long-term and project-specific monitoring will be vital for recording changes in water quality and documenting project success

8.2.1 Water Quality Monitoring

Some form of long-term water quality monitoring is a mainstay of most WPP implementation programs to support ongoing efforts and gauge overall program effectiveness. Typically, these monitoring regimes closely resemble the monitoring site distribution, monitoring frequency, and parameters of interest used during the watershed characterization phase. Stakeholders may choose to employ the use of one or several targeted water quality sampling efforts to supplement an ongoing, low-intensity routine effort, adapting to needs as project demands fluctuate.

Routine Water Quality Monitoring

The routine monitoring regime used for characterization of this watershed is covered in detail in Section 5.1, and will be applied as described there, with allowances for flexibility based on funding availability. At a minimum, parameters for *E. coli*, the nutrients of interest, solids, and sonde measurements (as described in Section 5.1) will be collected at the Site 07 (10786) with quarterly frequency, although there is significant interest and benefit to include Site 04 (10781) on a quarterly basis as well. Site 07 is a priority due to its concurrent use as both a CRP and USGS site before watershed characterization began for the WPP. The majority of the data used in previous biennial assessments (as described in the *Texas Integrated Report*) comes from this site, highlighting its use as a long-term benchmark for denoting water quality improvements in the watershed from a historical perspective. Site 04 (10781) is also identified as a priority, due to its preference for use in modeling and monitoring as the most downstream site outside of significant lake influence. Dedicated monitoring at this site only began in 2016, as part of the watershed characterization project. This may limit its uses as a benchmark in comparison to Site 07, but data from this site will be useful not only for water quality monitoring, but also for estimating watershed pollutant loads, as an endpoint for any future water quality, hydraulic, or hydrologic modeling projects, or for a number of other potential projects expecting to use as site that best represents the majority of the VCLA watershed's inputs to the lake. Ongoing quarterly water quality monitoring at several lake sites (13904, 11042, 13899, and 13897) will also be instrumental in monitoring progress with respect to the nutrient concerns in the lake.

Targeted Water Quality Monitoring

Although useful for tracking overall water quality progress, the regime identified for long-term monitoring at Site 07 and potentially Site 04 will likely be insufficient in both spatial distribution and frequency to adequately describe loadings from specific subwatersheds, or at certain times of the day or year. This inadequacy also precludes efforts to pinpoint the effectiveness of specific BMPs. To meet these needs, it will be necessary to supplement the routine water quality monitoring regime with one or several targeted monitoring regimes, specific to a particular management practice, pollutant source, location, or set of conditions.

The monitoring approach chosen will vary depending on a project's needs. When funding allows, there will be a preference for all routine parameters to be collected, but the suite of parameters chosen will likely be based on a specific project's goals, for efficiency considerations. Given the nature of the impairments and concerns in the watershed priority will be given to flow, *E. coli*, and nutrient parameters, so that implementation progress can be tracked, but additional parameters may be added as appropriate.

Non-numerical Monitoring

In some cases, demonstrating progress through numerical methods (e.g., water quality sampling) may be not be feasible, either due to a lack of data or potentially due to the pollutant's existence as both a qualitative – and quantitative – entity. This will necessitate the use of other metrics to indicate progress. One such example is that of illegal dumping, where the qualitative aspect of large illegal dumpsites in clear public view may constitute public health concerns or unfavorably reflect on the aesthetic conditions of a location.

In other cases, while the source in question may have direct, measurable impacts to water quality, there may still be other considerations associated with the source that require improvements beyond that of an *E. coli* load reduction. One such case is that of SSOs, where there is a higher possibility of human contact with raw sewage, constituting a public health hazard. To illustrate this, goals for this source group are tied to a reduction in the incidence of SSO events and not just to the overall *E. coli* reduction.

Periodic reconnaissance of storm drain inlets and likely illegal dumping sites are other examples of non-numerical monitoring.

8.2.2 Progress Indicators

By definition, adaptive management is the ability to use information as it is collected to modify management approaches and reduce uncertainty over time. To assist stakeholders during the initial 10-year implementation period, several indicator criteria have been developed to check overall progress

(Section 6.0, Table 7-1). When working with a decade-long timeframe, the likelihood of unforeseen circumstances appearing to delay implementation progress is high, highlighting the need for continuous application of adaptive management techniques. Lapses in funding, lack of stakeholder support, and social/political resistance are examples of such situations that may delay implementation. In these situations, stakeholders will use the progress indicators built into each recommended management activity to determine whether delays are significant enough to warrant adjustments to the implementation schedule.

In addition to project-specific progress indicators (see 'Units implemented,' Table 7-1), continued load reductions in pursuit of water quality goals will be used to gauge overall implementation progress. These include attainment of the 126 MPN/100 mL geometric mean goal for *E. coli* and removal from the *303(d) List* for Village Creek, and attainment of nutrient reductions (for nitrate, 0.37 mg/L and chl-a, 26.7 µg/L, as geometric means) so that removal from the list of water bodies with concerns is possible.

By extension, a biannual, iterative application of the *E. coli* standard and nutrient screening criteria within the *Texas Integrated Report* will also be used to monitoring implementation effectiveness. This will become more important as more and more data taken within the implementation period falls within the seven-year moving window utilized for report analysis. If implementation begins on schedule in 2021, the first *Integrated Report* that will use post-implementation data will be 2029. This biennial review, while useful as the statewide benchmark for measuring implementation success, may not be a feasible means of measuring project- specific water quality improvements due to its coarse nature, especially in the short-term. Instead, targeted or project-specific monitoring should be used as the primary indicators for individual BMP success, with the primary indicator of program-wide success measured through periodic review of long-term monitoring results. In this regard, *Integrated Report* results will be used as a helpful secondary indicator of progress.

It is widely understood that load reductions in pursuit of both *E. coli* and nutrient goals will be a long-term endeavor. Changes in water quality are a compound response to a diffuse and complex collection of factors, with positive influences on water quality afforded by implementation efforts often taking months or years to become obvious and measurable. Here again, stakeholders must use their best judgment when considering the need to apply adaptive management techniques is warranted. As the 10-year implementation window draws to a conclusion, progress towards the WPP's goals will again be evaluated using the performance metrics described throughout Chapters 7 and 8. Stakeholders will need to use adaptive management techniques to evaluate whether the water quality goals have been achieved, or if additional or expanded efforts are necessary for success.

Disconnected pools like this example upstream of the FM 1187 bridge near Rendon are a common occurrence during dry periods.

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Appendix A. Key Elements of Successful WPPs

USEPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (USEPA, 2008) describes the 'Element of Successful Watershed Plans' that must be sufficiently included in the WPP for it to be eligible for implementation funding through the CWA § 319(h) grant funding program.

Element	Report Section(s)
Element A: Identification of Causes and Sources	
1. Sources identified, described, and mapped	4.2, 4.3, 5.1, 5.2, 5.3, 5.4, 5.5, Appendix C
2. Subwatershed sources	4.2, 4.3, 5.1, 5.2, 5.3, 5.4, 5.5, Appendix C
3. Data Sources are accurate and verifiable	Figure 4-2, Table 4-2, Figure 4-3, Figure 4-5, 4.3.2, 4.3.3, 4.3.4, 5.1.2, Table 5-2
4. Data gaps	4.2.1, 4.2.3, 4.3, 5.1, 5.3, 5.4, 5.5
Element B: Expected Load Reductions	
1. Load reductions achieve environmental goal	5.2.1, 5.6, 6.1, Appendix F
2. Load reductions linked to sources	6.4, 6.5, 6.6, 6.7, Appendix F
3. Model complexity appropriate	5.2, 5.3, Appendix D, Appendix E
4. Basis of effectiveness estimates explained	6.4, 6.5, 6.6, 6.7, Appendix F
5. Methods and data cited and verifiable	Appendix D, Appendix E, Appendix F
Element C: Management Measures Identified	
1. Specific management measures are identified	6.4, 6.5, 6.6, 6.7, 7.1, 7.2, 0
2. Priority areas	6.4, 6.5, 6.6, 6.7
3. Measure selection rationale documented	6.1, 6.2
4. Technically sound	7.4
Element D: Technical and Financial Assistance	
1. Estimate of technical assistance	7.4
2.Estimate of financial assistance	7.5
Element E: Education/Outreach	
1. Public education/information	0
2. All relevant stakeholders are identified in outreach process	1.4.2, 6.4, 6.5, 6.6, 0
3. Stakeholder outreach	6.4, 6.5, 6.6, 6.7, Table 7-1, 0
4. Public participation in plan development	1.4, 4.1, 4.2, 4.3, 5.2, 5.3, 5.4, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 0
5. Emphasis on achieving water quality standards	3.2, 3.4, 5.1.1, 6.1, 8.2.2, Appendix C, Appendix D
6. Operation & maintenance of BMPs	6.4, 6.5, 6.6, Table 7-1
Element F: Implementation Schedule	
1. Includes completion dates	7.1, Table 7-1
2. Schedule is appropriate	7.1, Table 7-1
Element G: Milestones	
1. Milestones are measurable and attainable	7.1, Table 7-1
2. Milestones include completion dates	7.1, Table 7-1
3. Progress evaluation and course correction	7.1, Table 7-1, 8.2.2
4. Milestones linked to schedule	7.1, Table 7-1
Element H: Load Reduction Criteria	
1. Criteria are measurable and quantifiable	8.2.2
2. Criteria measure progress toward load reduction goal	8.2.2
3. Data and models identified	5.2, 5.3, Appendix D, Appendix E
4. Target achievement dates for reduction	8.2.2
5. Review of progress toward goals	8.2
6. Criteria for revision	8.2.2
7. Adaptive management	8.2.2

Element	Report Section(s)
Element I: Monitoring	
1. Description of how monitoring used to evaluate implementation	8.2
2. Monitoring measures evaluation criteria	8.2
3. Routine reporting of progress and methods	8.2
4. Parameters are appropriate	5.1, 8.2
5. Number of sites is adequate	5.1, 8.2
6. Frequency of sampling is adequate	5.1, 8.2
7. Monitoring tied to QAPP	5.1, 8.2
8. Can link implementation to improved water quality	8.2

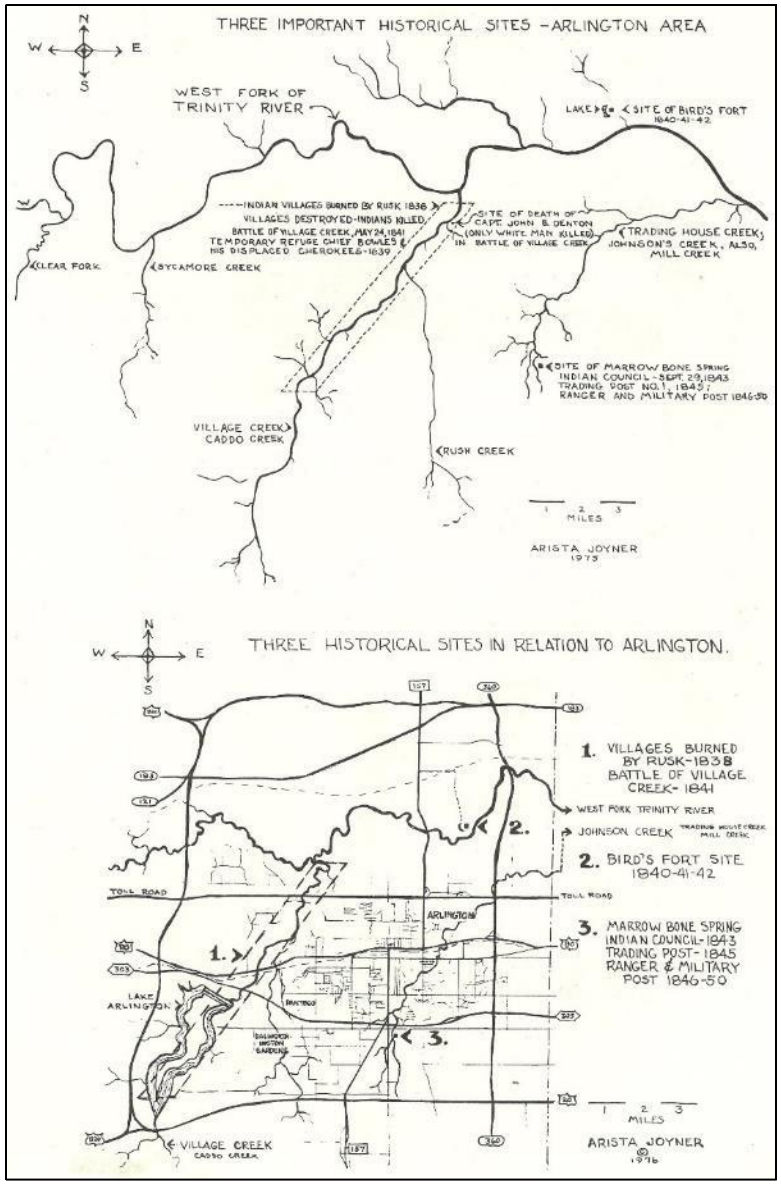
Appendix B. Regional History

Early Settlers

One of the earliest known records of human civilization in Texas, and perhaps the entire continental U.S., comes from a site in the nearby community of Lewisville, in Denton County, which was found during excavation during the construction of the Lewisville Lake dam. Relics from the site, consisting of several hearths and spear points, are often associated with other cultural relics from what is known as the Llano complex, which has been dated to about 12,000 years ago. More recent records from written accounts cite the Wichita subgroup of the Caddo culture as the most notable inhabitants of much of the North Texas area between the Red River and the headwaters of the Trinity. Originating somewhere in Kansas, the Wichita were driven south by the Osage and the Comanche during the 17th century. By the mid-1700s, they had garnered an alliance with local Comanches and established several substantial villages and a trading center on the Red River. Unlike many of their counterparts that became more nomadic after the introduction of the horse, the Wichita remained more sedentary and were known for their gardening. They harvested beans, maize, plums and pumpkins, which were regularly stored in appreciable quantities. They were often known to raise substantial cattle herds as well. (Newcomb Jr., 1961).

Western Expansion

As early European exploration gave way to Western expansion throughout Texas, the present DFW Metroplex became a hotbed for conflict. This was spurred by settlers and military detachments traveling down from the Red River in search of new territory in the Trinity headwaters as they crossed paths with the indigenous peoples of the Village Creek area as early as the 1830s. In 1838, General Thomas J. Rusk took 450 men into what is present day Lake Arlington, only to find a deserted Kickapoo village, which was promptly burned (Figure 8-1). In early May of 1841, in response to several accounts of attacks by natives on settler families in his district, General Edward H. Tarrant returned to the area with nearly 70 volunteers from the Red River counties and gathered at Fort Johnson, near present-day Bonham. On May 24, working on information from one captured native, Tarrant and his men overtook a small outskirt village. A string of other villages was in immediate sight, with the largest close by. The large camp offered no resistance, and it was later learned that the men from this and other nearby camps had departed for a buffalo hunt. Tarrant's men decided to use this to their advantage, and sent out scouting parties to several other villages. Captain John B. Denton led one such party, which was ambushed by an armed group from a nearby native encampment. Several men were wounded, Captain Denton was killed, and the scouting party retreated to Tarrant's main expedition force.



Source: Joyner 1976.

Figure 8-1. Maps of important historical sites and events in the Arlington area.

With his men demoralized, and with the prospect of 70 volunteers facing as many as 1000 warriors from the combined encampments, Tarrant thought it best to retreat. He returned with a larger force in July, only to find that the encampments had been largely abandoned. With his men starving due to a loss of their beef stock from disease, Tarrant decided it best to return to the Red River. At the time, Tarrant and his men viewed the skirmish as little more than the plundering of several villages, but in truth the minor skirmish proved to be a decisive victory for the settlers, as it convinced the tribes present in the Village Creek area to abandon their villages and move further south and west, into the lower Trinity and Brazos River basins (Joyner, 1976; Moore, 2007; Sanders, 1973). This proved to be the major event that opened up the area for large-scale occupation by settlers. Bird's Fort, first erected in 1840, was the site of the first planned trading post. Several deaths and denial of military relief soon forced Bird's party to abandon the post and return to their homes further north. Marrow Bone Spring came later in 1843 after Tarrant's expedition, and became a successful trading post and meeting grounds (Figure 8-1). By 1876, several stores had been erected around Johnson Station, the local post office. However, when the train line connecting Dallas to Fort Worth was erected to the north, both the Station and its associated stores migrated to the area near the rail lines. To avoid confusion, the new location was named Hayter Station, but in 1877 it was renamed Arlington, after Robert E. Lee's hometown in Virginia. (Joyner, 1976).

Due to Tarrant's efforts, settlements in the southern extent of the watershed also began to grow. European settlers began to farm near the Deer Creek area around 1848, near present-day Crowley. A local post office was established in 1882, and the first railroad depot appeared soon after in 1885 (Burke Jr., 1879; Massengill, 1936). Around the same time in 1881, the settlement of Burleson began as a rail depot, which soon brought several stores, churches, and eventually schools (Burleson History Committee, 1981). Ranching, dairy farming, the railroad, and associated ancillary businesses were the prominent economic drivers in the area (Burke Jr., 1879).

By 1884, Arlington had officially become a town and had an estimated population of 800 with a handful of established churches. By 1890, there were 18 recorded businesses, several of which were stores. At its beginnings, Arlington was reported to have had as many as five cotton gins, which proved to be the major source of agricultural revenue early on. Hay, oats, corn, peanuts, potatoes, sorghum, and other produce items were also prevalent, as were dairy cattle and other livestock. From this production grew a distribution center, and thus Arlington became a functional link in shipment to neighboring towns. Another popular export was the mineral water from a well near the town's center that was dug in 1891. The mineral water it yielded was bottled and sold, while the crystals it produced were sold for medicinal purposes. A sanitarium was also built nearby that utilized the water for treating various illnesses. (Joyner, 1976; Sanders, 1973; Schmlelzer, 1984).

From: Collections of the Arlington Historical Society, located at the Historic Fielder House in Arlington, Texas.

Figure 8-2. Postcard from the early 20th century depicting the entrance to Lake Erie.

Into the 20th Century

By 1910, the citizens of Arlington had an electric plant, a water system, natural gas lines, telephones, and a public school system. The electric plant, located in the footprint of the historic Handley neighborhood, began generating power in 1902. Successive iterations of power supply plants were constructed at this same site, continuing with the natural gas plant of present-day operated by Excelon. To cool this early plant, a small creek was dammed to create Lake Erie. This became a popular tourist attraction for residents of the area after a trolley park was built, where many other attractions quickly sprang up. In addition to a holiday resort (Figure 8-2), the area was home to several restaurants, an amusement ride, a roller skate rink, and a dance hall. In 1925 the number of residents was estimated at 3,031. Arlington Downs, a greyhound racetrack built in 1933, drew thousands of gamblers from all across Texas, until pari-mutuel betting was declared illegal in Texas in 1937. This, coupled with a fire that severely damaged the main pavilion of the resort and the eventual closing of the trolley line in 1934, led to an economic downturn in the immediate area.

By World War II, the population of Arlington had grown to 4,240. Post-war expansion in the area included a General Motors assembly plant that opened in 1951, along with the creation of the Great Southwest Industrial District in 1956. This business boom attracted many new residents, and by 1961 the population was estimated at around 45,000, with 1978 figures pegging the estimate closer to 122,200. (Joyner, 1976; Sanders, 1973; Schmlelzer, 1984).

To meet the drinking water needs of the growing population, construction on Lake Arlington began in 1956, near the end of the most severe drought of record to hit Texas from 1946 to 1957 (Malcolm Pirnie and Arcadis U.S., 2011). Luckily, construction of the reservoir was completed in time to catch heavy spring rains that totaled nearly 25 inches and filled the lake almost instantly. Completion of the lake attracted all manner of new development for residential and recreational purposes in the late 1950s and 1960s. Several new subdivisions were built, along with a boat and country club that included a golf course, Olympic pools, tennis courts, picnic areas, and boat launches (Figure 8-3).

From: Hometown by Handlebar (http://hometownbyhandlebar.com/?p=22125).

Figure 8-3. Advertisement for Lake Arlington's first country club in 1961.

Burleson did not experience the same population boom in the first half of the century, even briefly going into a decline before rebounding in the 1940s. Only then did the population boom finally hit, until Burleson sustained such growth that it eventually became a suburb of Fort Worth. As the community began to rely less on agriculture, the 30 businesses present in the 1930s grew to 62 by the 60s, including seven manufacturers, three feed companies, and a brass manufacturer. (Burleson History Committee, 1981).

Modern Development

By 1988, Arlington had an estimated 213,832 residents and 4,105 businesses. By 1990, the former Arlington College had evolved into the present-day University of Texas at Arlington (UTA). UTA is accompanied by nearby Arlington Baptist College as Arlington's two schools of higher learning. Additional recreational, social, and cultural facilities have been constructed around the lake, including many public parks, several public swimming pools, public and private golf courses, tennis courts, auditoriums, libraries, theaters, youth centers, seniors' facilities, and a community center. The lake's importance as a drinking water source was further validated with the opening of several recreational attractions from the 1960s onward, including two amusement parks and stadiums for major and minor league sports teams. Restaurants, hotels, motels, and many retail businesses have since moved to the area to take advantage of these tourist attractions that exist in close proximity and constitute a recreational hub for the Metroplex (Shannon, 2010). Latest estimates place the population at nearly 396,394 as of 2017.

Southern population centers also experienced immense growth during this time, which tracked with the expansion of business and trade in the area. By the 2000s, Burleson had grown to 20,976 residents, with Crowley reporting 7,467, and Joshua reporting 4,250. Manufacturing in the area includes glass production, aluminum products, and leather goods, as well as boat trailer, mobile home, camper top, and metal building fabrication (Maxwell, 2010a, 2010b; Yockstick and Futch, 2010).

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

Figure 8-4 through Figure 8-14 correlate flow, *E. coli* measurements, and OB test results to rainfall events. Flow is represented by black horizontal bars. *E. coli* is represented by the horizontal bars, with light blue representing measurements with negative OB detection, and purple bars representing positive OB detection. The red dotted line represents the water quality criteria for *E. coli* (126 MPN/100 mL), which is technically only appropriate for geomean measurements, but is shown here for a rough comparison.

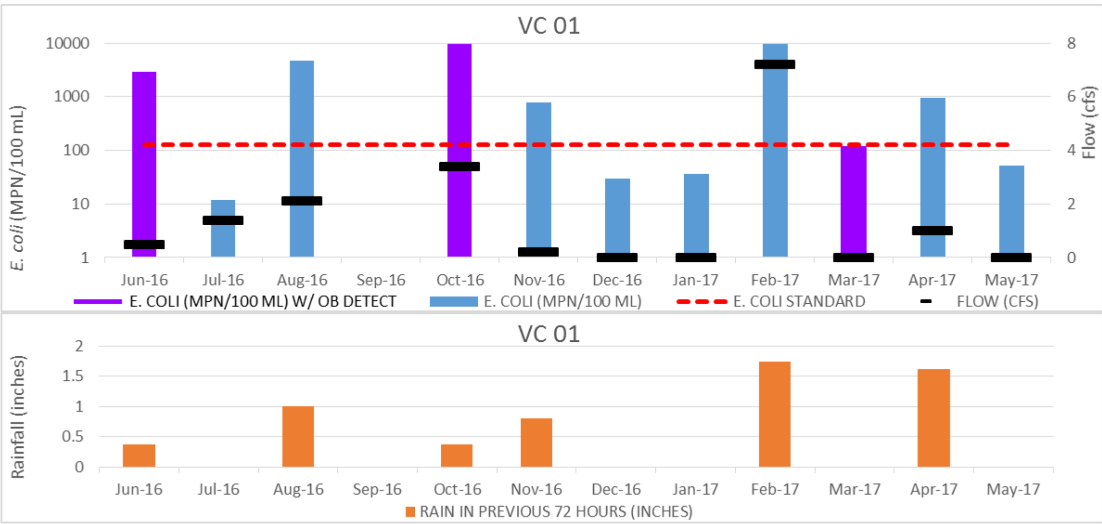


Figure 8-4. Hydrology and E. coli parameters, Wildcat Branch at Cravens Road (10793).

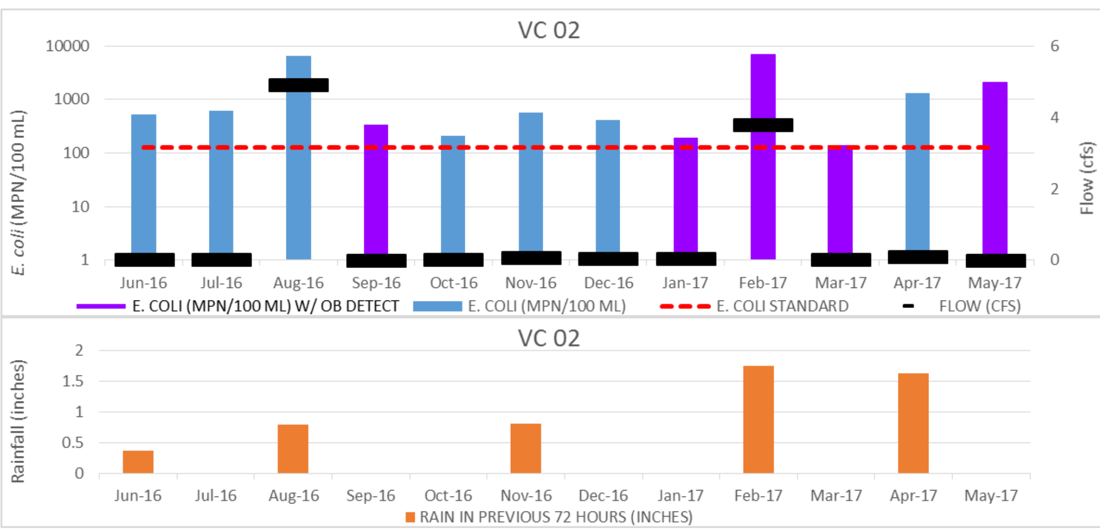


Figure 8-5. Hydrology and E. coli parameters, Tributary of Lake Arlington (10798).

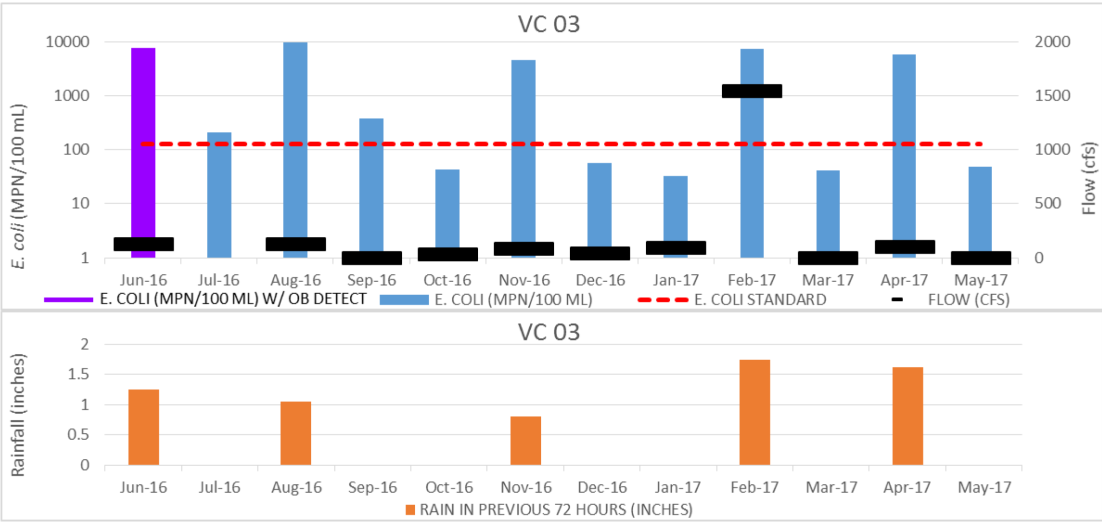


Figure 8-6. Hydrology and E. coli parameters, Village Creek at IH-20 (10780).

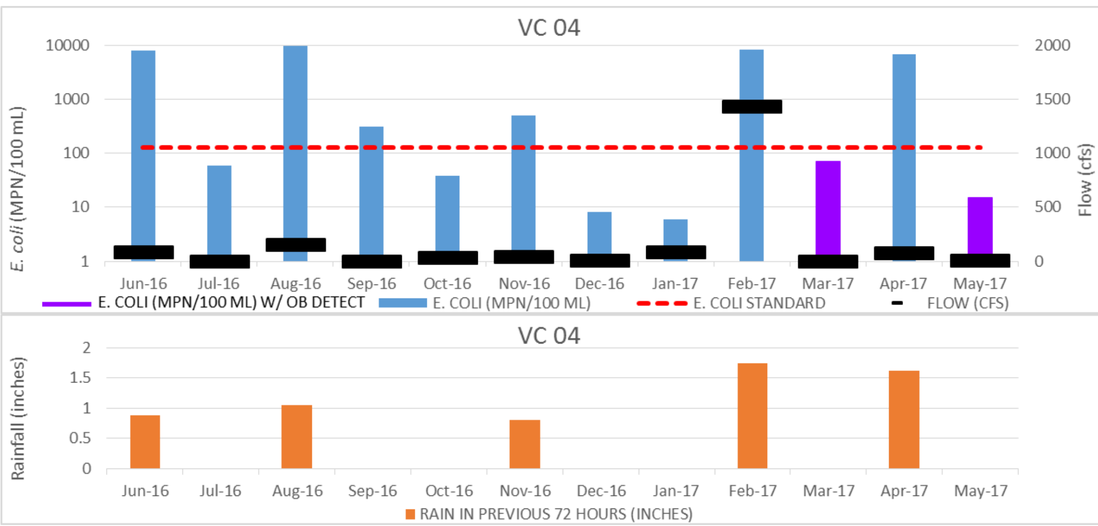


Figure 8-7. Hydrology and E. coli parameters, Village Creek Downstream of US BUS 287 (10781).

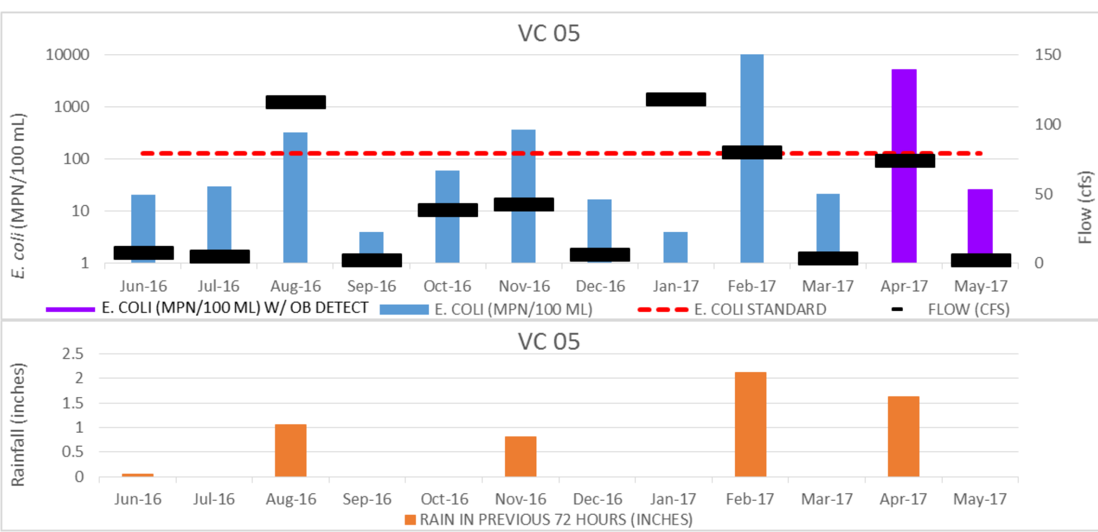


Figure 8-8. Hydrology and E. coli parameters, Village Creek near Freeman Drive (21762).

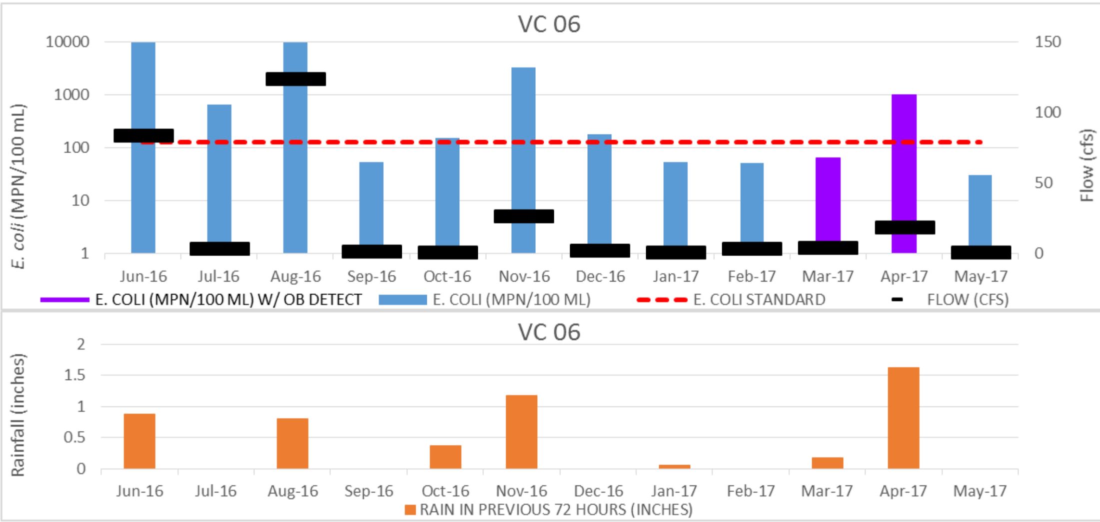


Figure 8-9. Hydrology and E. coli parameters, Village Creek at Everman Drive (13671).

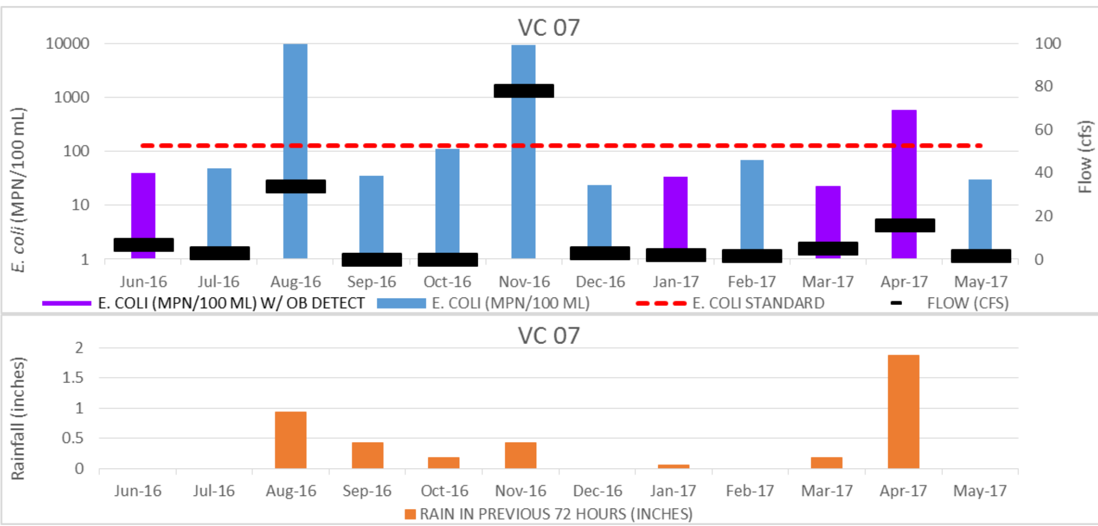


Figure 8-10. Hydrology and E. coli parameters, Village Creek at Rendon Road (10786).

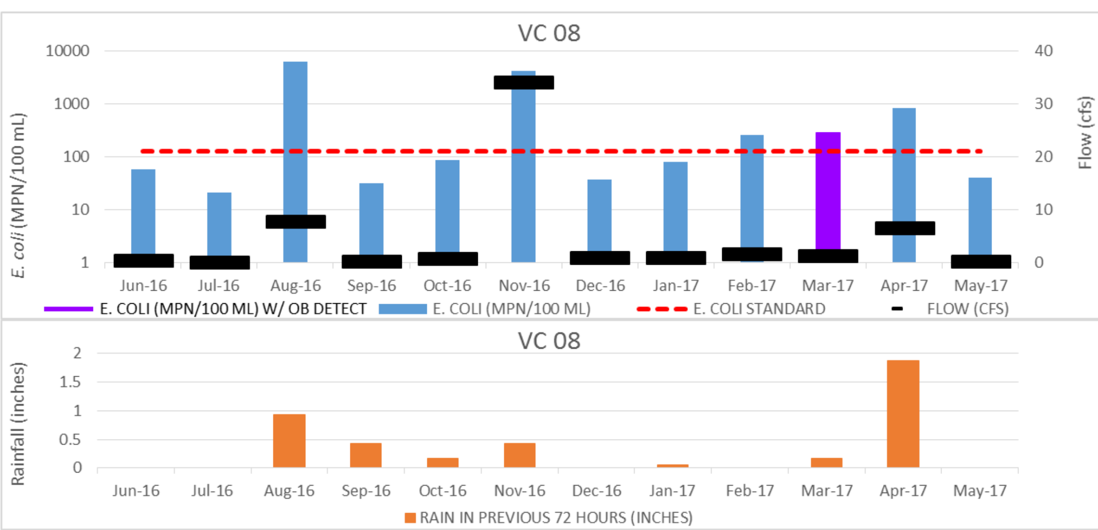


Figure 8-11. Hydrology and E. coli parameters, Deer Creek at Oak Grove Road (10805).

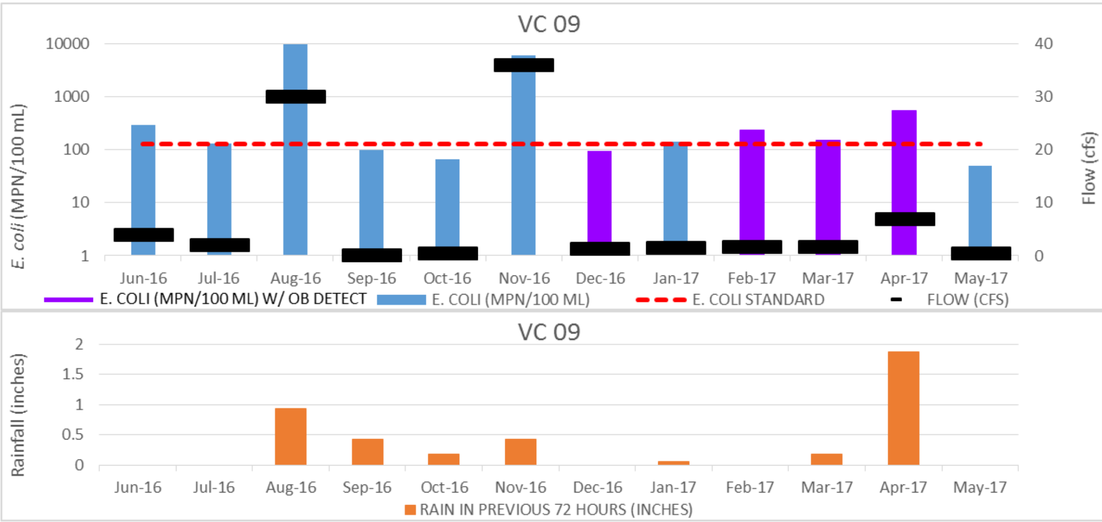


Figure 8-12. Hydrology and E. coli parameters, Village Creek upstream of Oak Grove (10785).

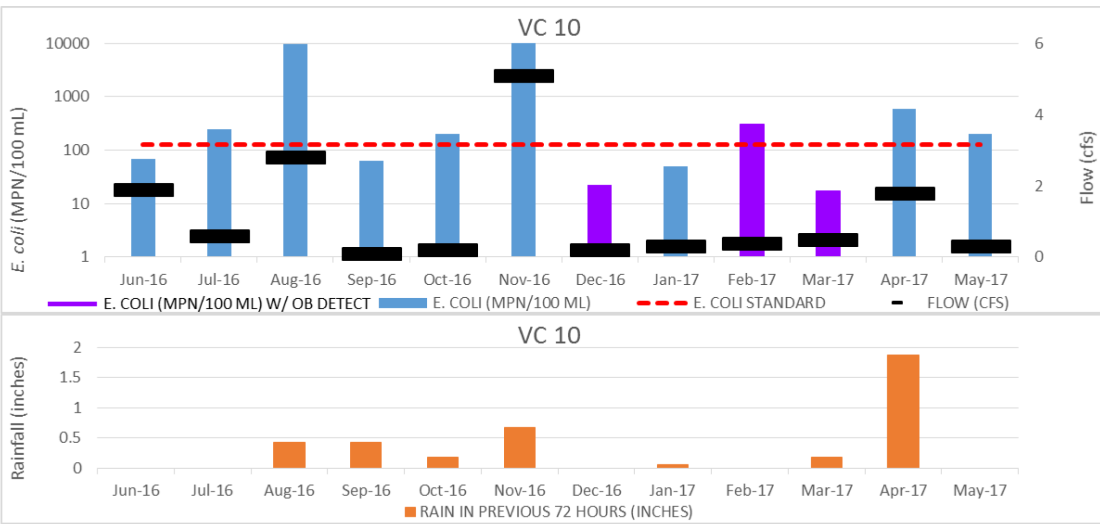


Figure 8-13. Hydrology and E. coli parameters, Quil Miller Creek at County Road 532 in Burleson (21759).

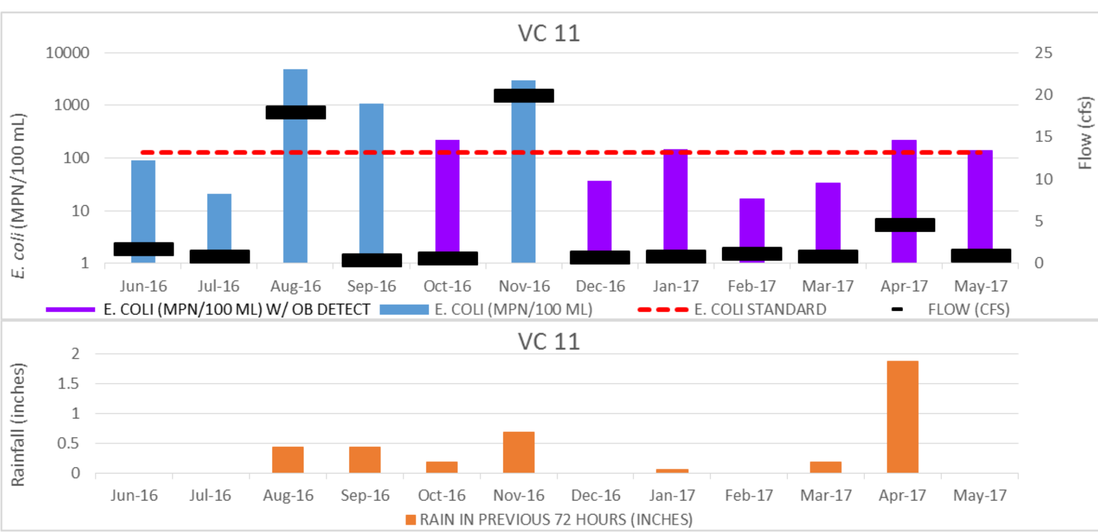
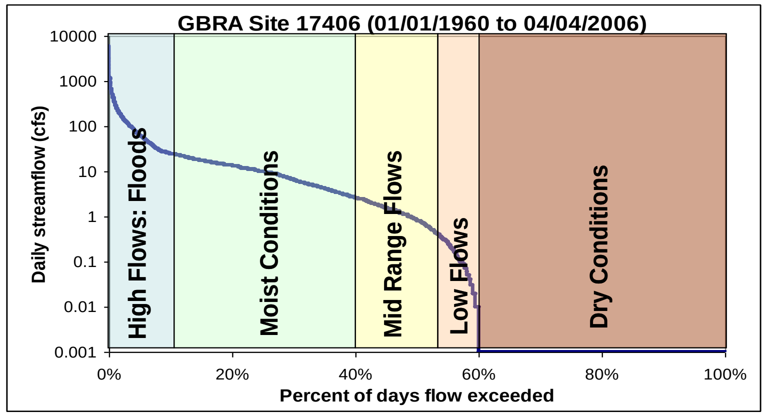


Figure 8-14. Hydrology and E. coli parameters, Village Creek at FM 3391 (21763).

Appendix D. Load Duration Curve Explanation

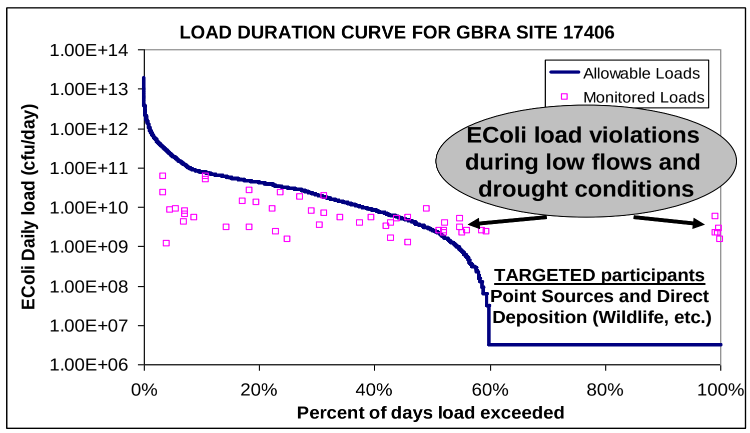
LDCs allow for a visual interpretation of load exceedances in comparison to the allowable load at specific flow conditions. Using flow and *E. coli* data collected from a specific monitoring campaign, flow duration curves (FDCs) and LDCs can be built to further evaluate the contaminant sources. First, all flow values are aggregated and ranked from lowest to highest. This data is then graphically depicted to show the general flow regime, complete with the percentage of time that the water body is expected to be dry, as well as its response to storm flows (Figure C-1).



Source: Flow Duration Curve (FDC) for streamflow conditions at GBRA monitoring station 17406 on Plum Creek, near Uhland, TX.

Figure C-1. Flow duration curve example from Plum Creek watershed (log scale Y-axis).

The FDC can then be used to develop a LDC for a specific pollutant of interest, given that there is pollutant concentration data that complements the flow data. C-2 depicts an example LDC based on the FDC shown in Figure C-1. The first step in the process is to apply the pollutant's allowable limit concentration to all available flow values to produce the allowable load limit curve. In the case of bacteria, this value is 126 MPN/100 mL (blue line in Figure C-2). Then, the baseline monitoring data values for *E. coli* (also in MPN/100 mL) are also multiplied by their associated flow values to get loads for each data point (pink squares in Figure C-2). This can be developed further by performing regression analysis on the monitored data points, as depicted in Figure C-3. Here, the allowable load limit is depicted in red, while the regression line for the data points is depicted in blue. Regression analysis can be completed using one of many techniques. In this case, a USGS program known as Load Estimator (LOADEST) is utilized. For each of the different flow regimes (High Flows, Moist Conditions, Mid-range Flows, etc.), a load reduction estimate can be calculated. Achieving these reductions will become the one of the primary targets for success once the WPP moves into the implementation stage.



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

Figure C-2. Load duration curve example from Plum Creek watershed (log scale Y-axis).

However, it is worth noting that some of these reductions, specifically those within the "High Flows" range, may not be achievable due to feasibility of applying management measures to storm flows that fall within the extreme range. It is therefore customary to focus efforts on the load reductions identified at the lower flow conditions, where it becomes easier to separate potential point source contributors from nonpoint source contributors. In

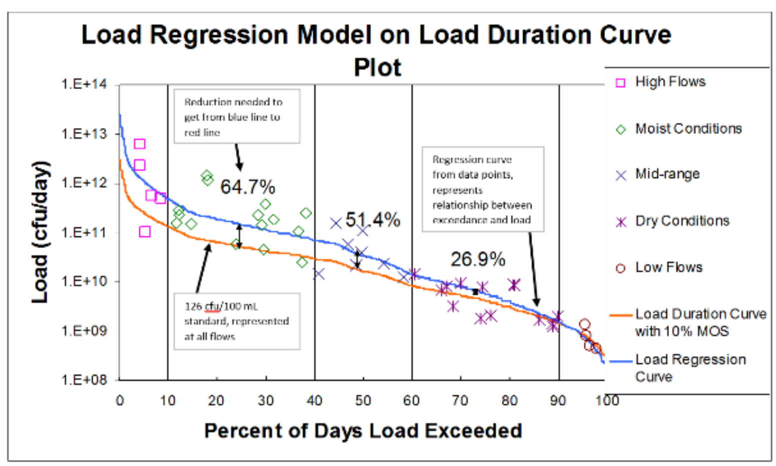


Figure C-3. Load duration curve example for E. coli, with flow condition breakdowns and load reduction estimates (log scale Y-axis).

most cases, if a water body exhibits high pollutant loads on the extreme right of the graph where low flows are represented (Figure C-4), it is highly likely that this may be attributable to a point source, such as a malfunctioning WWTF or leaking/failing wastewater infrastructure somewhere in the watershed. These types of contributions can typically be easily addressed, and are worth investigating early on in the process. Conversely, if pollutant loads tend towards the middle of the graph, it is likely that they are attributed to stormwater runoff during periods of normal or moderate rainfall. While typically not as easily addressed as point sources, load reductions in these areas may also be targeted for watershed pollutant load reductions through BMP recommendations.

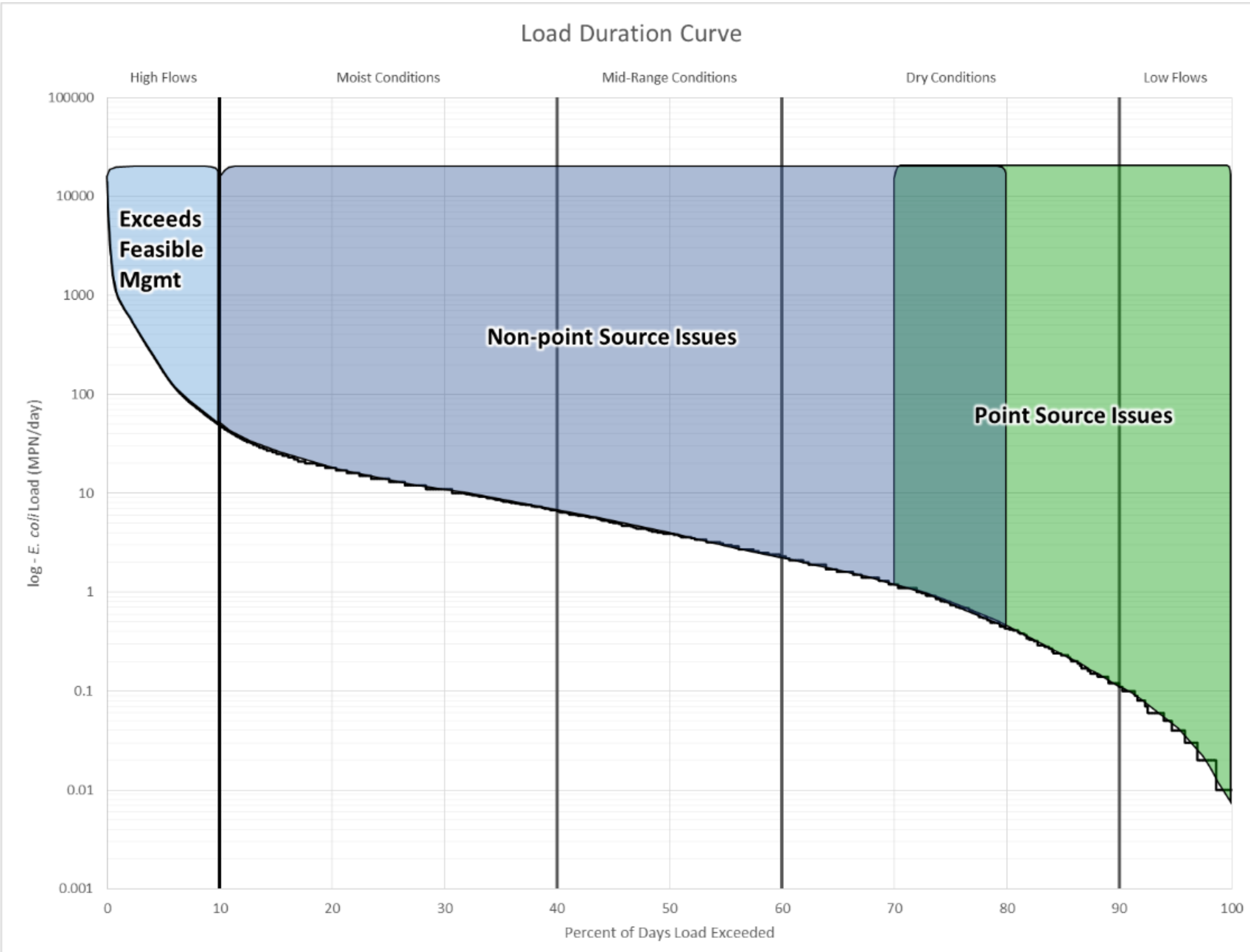


Figure C-4. Flow categories and regions of likely pollutant sources along an example load duration curve.

Appendix E. SELECT Analysis Explanation

General Approach

To further identify the extent of a certain source type's likely contribution to the bacteria load in a specific subwatershed, the SELECT analysis can be conducted for any number of potential bacteria source types, including urban/municipal runoff, agricultural runoff, failing septic systems, wildlife, and even invasive species. For this project, instead of the standard SELECT program, an equivalent employing the use of data entered by hand and calculated in Excel spreadsheets to drive visual output in ArcGIS was used.

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

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

Dogs & Cats

Households Analysis

- Dogs/cats calculations based on # of households (HHs): All the HHs that are within and outside of the riparian buffer zone
- Percent of households owning dogs - 36.5%; owning cats: 30.4%(AVMA 2012)
- Dog density considered as 1.6 dogs per HH (AVMA 2012)
- Cat density considered as 1.6 cats per HH, intended to provide coverage for feral cats, barn cats, and house cats that defecate outdoors
- # HHs calculated using U.S. Census Block group (BG) data:
- Used 2015 "Cartographic Boundary Shapefiles - Block Groups" shapefile to delineate BGs in watershed (USCB 2015a)
- Used 2015 American Community Survey (ACS) 2015 estimates for number of HHs in each census BG (USCB 2015b).
- Performed join operation in ArcMap using BG shapefile and ACS HH table to spatially distribute the ACS HH estimates to their BG
- Clipped BGs to watershed boundary
- Calculated average HH/ac for each BG
- Identified which BGs overlapped with each subwatershed (SW)
- Averaged HH/ac estimates for BG in each SW
- Applied averaged HH/ac value to each SW's acreage to calculate #HH/SW for both upland and riparian zones

Load Calculation

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

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

- *E. coli* loading of 2.5E+9 comes from Horsley and Witten (1996) fecal coliform estimate of 5.0E+9 with 50% fecal coliform (FC) to *E. coli* "rule of thumb" conversion applied
- Assumed 90% contribution in 330-ft (100-m) riparian buffers, 50% from uplands
- Total *E. coli* calculations for each SW are then normalized across the watershed by dividing by the SW's area.

References

U.S Census Bureau. 2015a. Cartographic Boundaries Shapefiles - Block Groups. Available at : <source: https://www.census.gov/geo/maps-data/data/cbf/cbf_blkgrp.html>.

U.S Census Bureau. 2015b. Housing Units: 2011-2015 American Community Survey 5-Year Estimates. American Fact Finder Report B25001. Available at: <https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_15_5YR_B25001&prodType=table)>. Accessed 29 November 2017.

American Veterinary Medical Association. 2012. U.S. Pet Ownership & Demographics Sourcebook, 2012 Edition. Schaumburg, IL : American Veterinary Medical Association. Available at: <https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx>. Accessed 23 December 2017.

Livestock & Feral Hogs

General Assumptions

- Total watershed acreage of land uses relevant to large mammal populations calculated based on NCLD 2011 database (Table D-1).
- County-wide NASS population estimates were extrapolated to the watershed using a percent-area basis (Table D-2).
- Animal populations that were originally based on extrapolated NASS/TPWD/TAMU data were modified based on SC recommendations (Table D-3).
- Used proposed population density adjustments based on % of each land use type used by each animal classification across watershed (Table D-4).
- Land use-based density adjustments (based on those found in other WPPs) applied to animal populations (Table D-5, Table D-6).

Load Calculation

- Adjusted animal populations then used to calculate the *E. coli* for various livestock and feral hogs with the following equations (from Teague 2007):

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

- Total *E. coli* calculations for each SW are then normalized across the watershed by dividing by the SW's area.

References:

Teague, A. E., 2007. Spatially Explicit Load Enrichment Calculation Tool and Cluster Analyses for Identification of *E. coli* Sources in Plum Creek Watershed, Texas. Unpublished MS thesis. Texas A&M University, Department of Biological and Agricultural Engineering, College Station, Texas.

Table D-1. Total land cover acreages for relevant land uses in VCLA watershed.

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

*acreage in watershed, per NLCD database, 2011

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

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

TableD-3. Assumed populations of various large mammals in watershed based on Steering Committee (SC) recommendations.

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

* includes beef, dairy

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

Table D-4. Proposed population density adjustments based on % of each land use type used by each animal classification across watershed.

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

Table D-5. Estimated animal densities, animals/acre and acres/animal basis.

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

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

** per TPWD's density analysis criteria and application

Table D-6. Acreages used in calculation of feral hog population (in green).

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

SSOs

The following procedures were used to prepare regional-level data for DFW from NCTCOG for spatial analysis within SELECT.

General Assumptions

- The compendium of past reports of SSO occurrences will be used to calculate the average daily instance of an SSO occurring, which will be used as a surrogate for any one watershed's likelihood to encounter an SSO.

Raw SSO Data Processing

- NCTCOG aquired SSO data from TCEQ for the region for the period 2011-2016
- Digitized spreadsheet records, clipped to VCLA watershed
- Subdivided SSOs amongst the 55 modeled subwatersheds (SWs)
- Further subdivided between 330-ft (100-m) riparian buffer and upland areas in each SW
- Retrieved spatial data for a) # of SSOs and b) total gallons discharged in riparian/upland zones of each SW
- Divided total discharge for each SW by # of days in 2011-2016 period (2192) to get average daily discharge for each SW's riparian and upland zone

Load Calculation

- The equation to calculate the EC for SSOs (borrowed from CSO and septic equations in USEPA 2001) is:

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

- *E. coli* Load assigned to raw sewage: 5.0E+5 cfu/100 mL (USEPA 2001)
- Convert gal/day to mL/day: 3785.41 mL/gal
- Assumed 90% of overflow reached waterbodies within 330-ft (100-m) riparian buffer and 50% contribution from upland areas
- Total *E. coli* calculations for each SW are then normalized across the watershed by dividing by the SW's area

References:

U.S. Environmental Protection Agency. 2001. Protocol for Developing Pathogen TMDLs. EPA 841-R-00-002. Office of Water (4503F), United States Environmental Protection Agency, Washington, DC. 132 pp.

WWTFs

The following procedures were used to prepare data from the national ECHO database provided through EPA for spatial analysis within SELECT.

General Assumptions

- Outfall data was obtained from the Discharge Monitoring Report (DMR) database via EPA's Enforcement and Compliance History Online (ECHO) website
- Used discharge data reported for calendar year 2015 at all three active WWTFs currently treating human sewage in the watershed
- If the reported flow is 0.00, it is assumed that 60% of the permitted flow is discharged and considered for calculations; however no recorded occurrences of this have been found at present for facilities of interest
- Effluent associated to each WWTF was assumed to be the self-reported flow

Load Calculation

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

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

- Total *E. coli* calculations for each SW are then normalized across the watershed by dividing by the SW's area

References:

Teague, A. E., 2007. Spatially Explicit Load Enrichment Calculation Tool and Cluster Analyses for Identification of *E. coli* Sources in Plum Creek Watershed, Texas. Unpublished MS thesis. Texas A&M University, Department of Biological and Agricultural Engineering, College Station, Texas.

OSSFs

The following procedures were used to prepare county-level data from a variety of sources for spatial analysis within SELECT.

Tarrant County

Permitted OSSFs

- NCTCOG has data for Arlington, Grand Prairie, and for general Tarrant County data for systems installed both pre- and post-2000
- Some overlap into Johnson County and beyond, verified point locations with address analysis
- Checked suspected misplaced points for validity - included those in road centerlines and clustered at interstections - typically result of new road construction not recognized by address locator

Unpermitted OSSFs

- Neither Tarrant County nor Burleson are participants in NCTCOG's 911 System – they use their own system and wouldn't share their data, citing privacy issues
- As an alternative, acquired property parcel information from Tarrant County Tax Assessor's website
- Converted parcel polygons to centerpoints
- Removed points that fell within municipal sewer certificates of convenience and necessity (CCNs), acquired from Public Utility Commission's website
- Additional QA with aerial imagery to remove address points on open lots (no associated buildings w/potentially associated OSSFs), using a numbered 3000 x 3000-ft "fishnet" grid to track progress
- Removed points that overlapped with "Permitted OSSFs" layer above, using address data to verify and fishnet grid to track progress
- Retained points if there was any uncertainty as to whether or not an overlap was a match

Johnson County

Permitted OSSFs

- OSSFs pulled directly from County's hard copy records of permits using addresses
- Applied quality control for obvious errors (duplicate permits, repeating block numbers, inconsistent street names)
- Geocoded using Google Sheets, "Awesome Table" add-in for Google Sheets, and ArcMap
- Applied quality control for produced points, spot-checked some obvious errors and spot-checked several presumably correct points for accuracy using fishnet grid to track progress
- Checked for overlap with Tarrant County records by comparing points from both datasets that fell within close proximity

Unpermitted OSSFs

- Collected geocoded 9-1-1 address points from Johnson County and the City of Burleson and uploaded files to ArcMap
- Removed points that fell within municipal sewer CCNs
- Cross-referenced with sewer line information furnished by municipalities, removed addresses on sewer lines outside of CCNs
- Additional QA with aerial imagery to remove address points on open lots (no associated buildings w/potentially associated OSSFs), using fishnet grid to track progress
- Removed points that overlapped with "Permitted OSSFs" layer above, using address data to verify and fishnet grid to track progress
- Retained points if there was any uncertainty as to whether or not an overlapped point was a match

Load Calculation

- Did not differentiate between businesses and residences
- The equation to calculate the EC for OSSFs is:

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

- *E. coli* load assigned to OSSFs: 5.0E+5 cfu/100 mL (Teague 2007)
- Discharge estimated at 70gal/person-day (2.65E+5 mL) (Teague 2007)
- Average size of household is considered as 2.8 persons (2010 U.S. Census data)
- Assumed failure rates of 50% for unpermitted systems and 12% for permitted systems (Reed et. al 2001)
- Assumed 90% contribution to stream within 330-ft (100-m) riparian buffer and 10% contribution from upland sources – this is lower than the standard 50% used to account for the additional soil remediation that likely occurs before the effluent reaches the surface compared to surface-originating sources
- Total *E. coli* calculations for each SW are then normalized across the watershed by dividing by the SW's area

References:

Teague, A. E., 2007. Spatially Explicit Load Enrichment Calculation Tool and Cluster Analyses for Identification of *E. coli* Sources in Plum Creek Watershed, Texas. Unpublished MS thesis. Texas A&M University, Department of Biological and Agricultural Engineering, College Station, Texas.

Reed, Stowe, and Yanke LLC. 2001. Study to determine the magnitude of, and reasons for chronically malfunctioning on-site sewage facility systems in Texas, pp. vi and x. Austin, Tex.: Texas On-Site Wastewater Treatment Research Council.

Appendix F. Load Reduction Calculations

When calculating *E. coli* load reductions, it is imperative that planners understand that there are many factors at work in the watershed that reduce BMP efficiency, whether they be physical limitations of the BMP itself, barriers to information flow that prohibit full proliferation and use of the BMP amongst all stakeholders, or societal/fiscal limitations that prevent full proliferation of BMP application even when benefits of the BMP are well-know. If planners are not careful in accounting for these factors that limit BMP efficiency, they run the risk of over-estimating load reductions, inflating expectations, and producing erroneous results that could potentially delay and significantly side-track implementation effectiveness. All efforts have been made to account for reduced BMP efficiency when calculating load reductions for this project.

Dogs & Cats

When considering *E. coli* loads for pet waste, it can be assumed that not all people pick up after their pets, and even with a modest improvement in awareness and BMP use, stakeholders were only comfortable with the assumption that 20% of the pet waste load would be managed. With an estimated 40,146 dogs and feral, outdoor, or barn cats in the watershed, the managed population of 20% amounts to 8,029 animals. This population is then multiplied by the per-animal load factor (2.50E+09 MPN/AU-day), and the 75% removal effectiveness factor associated with picking up and bagging pet waste to get a total daily load reduction. This is then extrapolated over a year to arrive at a daily load, and then multiplied by a 25% attenuation factor to account for environmental processes that may deactivate or otherwise remove *E. coli* before it has a chance to reach a waterbody. As mentioned previously, this attenuation factor is yet another attempt to make load reduction calculations realistic, and not account for load reductions that are not associated with the BMP in question. After attenuation, a realistic estimate of 1.37E+15 MPN/yr can be expected from application of pet-waste related BMPs.

Table E-1. Attenuated *E. coli* load reduction for Pet Waste Management.

Load Reduction Calculation - Dogs & Cats	
Total Number of Dogs & Cats in Watershed	40,146
20% of Population to be Managed	8029
E. coli Load for Dogs & Cats (MPN/AU-day)	2.50E+09
Bagged Waste Removal Effectiveness Factor	0.75
Total Daily Load Reduction (MPN/100 mL)	1.51E+13
Total Annual Load Reduction (MPN/100 mL)	5.49E+15
with 25% Attenuation Factor (MPN/100 mL)	**1.37E+15**

Table E-2. *E. coli* removal efficiencies for selected livestock BMPs.

BMP	Removal Efficiency*
Rotational grazing	69%
Exclusionary fencing	42%
Alternative water sources	85%

**median E. coli removal efficiency, based on survey of multiple studies.*

Livestock

When considering load reductions for animal agriculture, it is important to note that multiple species, BMPs, and operation sizes may complicate matters. For the purposes of this study, analysis will be limited to reductions for cattle, as they represent 56% of the wetland's total livestock population. Using NASS estimates, an average farm size was determined for the watershed (128 acres), along with an average number of animal units onsite based on the size of the operation (23 AUs). For each of the three agriculture BMPs discussed in this appendix, several barriers to progress will be discussed. All of the agricultural BMPs suggested here fall under the umbrella of WQMPs, so progress with each may be able to be tracked concurrently. Stakeholders chose to differentiate between BMP performance within riparian and upland areas, using variable values for the pollutant connectivity factor (0.5 for riparian, 0.1 for upland areas)and time spent by animals in either location (20% for riparian, 80% for upland). When comparing between BMPs, accounting for that BMP's specific mean effectiveness (Table E-2) is also necessary. From there, the process is similar to others from this chapter, where the per-animal *E. coli* production (2.70E+09 MPN/AU-day) is multiplied by the farm's population and then reduced using the factors discussed above. Once the loads for each BMP have been calculated and aggregated to the annual time scale, they will be added together as one overall load reduction, but not before application of the flat, 25% attenuation factor used in other BMP analyses throughout this chapter. Once attenuated, this overall *E. coli* reduction will total 5.09E+13 MPN/yr.

Table E-3. Attenuated *E. coli* load reduction for Livestock BMPs.

Rotational Grazing	
Average Farm/Ranch size (ac)	128
# animal units/ farm	23
# Riparian WQMPs	15
Pollutant connectivity factor (riparian)	0.5
% of year animals in riparian pasture	20%
Upland WQMPs	25
Pollutant connectivity factor (upland)	0.1
% of year animals in upland pasture	80%
BMP effectiveness (mean, from table)	0.69
E. coli production (cattle, MPN/AU-day)	2.70E+09
Total reduction from riparian pastures (MPN/yr)	2.35E+13
Total reduction from upland pastures (MPN/yr)	3.13E+13
Total reduction from prescribed grazing (MPN/yr)	5.47E+13
with 25% attenuation (MPN/yr)	1.37E+13
Exclusionary Fencing	
Average Farm/Ranch size (ac)	128
# animal units/ farm	23
# Riparian WQMPs	15
Pollutant connectivity factor (riparian)	0.5
% of year animals in riparian pasture	20%
Upland WQMPs	25
Pollutant connectivity factor (upland)	0.1
% of year animals in upland pasture	80%
BMP effectiveness (mean, from table)	42%
E. coli production (cattle, MPN/AU-day)	2.70E+09
Total reduction from riparian pastures (MPN/yr)	1.43E+13
Total reduction from upland pastures (MPN/yr)	1.9E+13
Total reduction from prescribed grazing (MPN/yr)	3.33E+13
with 25% attenuation (MPN/yr)	8.33E+12
Alternative Water Sources (riparian only)	
Average Farm/Ranch size (ac)	128
# animal units/ farm	23
# Riparian WQMPs	15
Pollutant connectivity factor (riparian)	0.5
% of year animals in riparian pasture	20%
BMP effectiveness (mean, from table)	85%
E. coli production (cattle, MPN/AU-day)	2.70E+09
Total reduction from riparian pastures (MPN/yr)	2.89E+13
Total overall reduction from all BMPs	**5.09E+13**

Feral Hogs

Arguably one of the most direct methods of *E. coli* load reductions due the primary focus on removal by exclusion, capture and transport, or lethal means, feral hog control is particularly effective due to feral hogs' preference for riparian habitat, meaning that there are fewer inefficiencies to account for. Given an initial estimated watershed population of 1000 hogs, a goal of 5% removal was chosen, equaling 50 hogs. When the per-animal *E. coli* loading factor of 4.45E+09 MPN/AU-day is applied and then aggregated over the year, the total load reduction afforded by feral hog population control totals to 8.12E+13 MPN/yr. For consistency, the 25% attenuation factor was again applied, bringing the total attenuated reduction to 2.03E+13 MPN/yr.

SSOs

Due to the high volume, sporadic nature of SSOs, implementation success for the SSO source group will be reflected as the number of SSOs reduced instead of as a load reduction.

OSSFs

An estimated 966 failing OSSFs exist in the watershed. If approximately 10% of those systems are repaired, retrofitted, or replaced, (98 systems), this would yield a total daily reduction of 3.27E+11 MPN/100 mL. When aggregated for the year with the standard 25% attenuation factor applied, the attenuated annual reduction is expected to be 2.99E+13 MPN/100 mL.

WWTFs

No reductions necessary or proposed by stakeholders.

Table E-4. Attenuated *E. coli* load reduction for Feral Hog Population Control.

Feral Hogs	
Total estimated # hogs in watershed	1000
5% of population that will be removed	50
E. coli production (hogs, MPN/AU-day)	4.45E+09
Total reduction from population control (MPN/yr)	8.12E+13
with 25% attenuation (MPN/yr)	**2.03E+13**

Table E-5. Attenuated *E. coli* load reduction for OSSF Management.

Load Reduction Calculation	# of Failing Systems	
	Permitted	No Permit
Total Number of Failing Systems	53	913
10% of Failing Systems Repaired	6	92
Daily Load to be Removed (MPN/100 mL)	2.00E+10	3.07E+11
Total Daily Reduction (MPN/100 mL)	3.27E+11	
Total Annual Reduction (MPN/100 mL)	1.19E+14	
with 25% Attenuation Factor (MPN/100 mL)	**2.99E+13**	

On the back cover:

Looking downstream on Village Creek
under the bridge at Rendon Road
near the town of Everman, TX.

Developed by the Village Creek-Lake Arlington Watershed Partnership

May 2019

Funding provided by the Texas Commission on Environmental Quality through a Clean Water Act § 319(h) grant from the U.S. Environmental Protection Agency, with match funding from the City of Arlington and in-kind contributions from the Trinity River Authority of Texas