Bacteria Modeling Report for the Spring Creek Watershed

January 2021

This document was prepared by the Houston-Galveston Area Council (H-GAC) for the stakeholders of the Spring Creek Watershed Partnership. It was prepared in cooperation with the Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (EPA).

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SPRING CREEK WATERSHED PARTNERSHIP

Houston-Galveston Area Council

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

EPA United States Environmental Protection Agency

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SECTION 1: INTRODUCTION

The watershed area of Spring Creek includes portions of Grimes, Harris, Montgomery, and Waller Counties. Approximately 440 square miles of land are drained by a network of tributaries into the main stem of Spring Creek before ultimately discharging into the West Fork San Jacinto River and Lake Houston (**Figure 1**). Developed land cover is extensive on the eastern side of the watershed and is expected to extend westward into land currently covered by pasture, grass, forest, and shrubs. A great deal of recreation activity and community focus has been placed on its riparian corridor, including an active greenway.

The most recent version of the Integrated Report of Surface Water Quality[1] produced by the Texas Commission on Environmental Quality (TCEQ) indicated exceedances of state water quality standards for a range of parameters in many of the streams in the Spring Creek Watershed[2]. Concerns for aquatic life and general use due to depressed dissolved oxygen and high nutrient concentrations were noted throughout the watershed. High concentrations of the fecal indicator bacteria *Escherichia coli* (*E. coli*) resulting in impairments to contact recreation use were also prevalent. Because *E. coli* are found in the digestive systems of people and animals, detecting high concentrations of this organism in the surface water indicates potential contamination from sources such as untreated sewage, agricultural runoff, or deposits from wild animals. Especially in cases where human waste pressures are indicated, there is also a likelihood that additional pathogens could be present in waterways. Without taking action to manage sources of contamination, recreation activities such as swimming and wading in streams will not be safe for communities of the watershed. More importantly, these negative effects could extend to the reservoir that Spring Creek and its tributaries drain into, Lake Houston, which serves as a drinking water source for communities throughout the region.

These challenges led to the development of a Watershed Protection Plan (WPP) which will outline the specific goals and action strategies set forth by local stakeholders to achieve water quality improvements. In their roles as facilitators to this stakeholder group, the Houston-Galveston Area Council (H-GAC) conducted a series of modeling efforts to provide stakeholders with a more comprehensive understanding of fecal bacteria sources impacting the Spring Creek Watershed. These modeling efforts include estimations for fecal bacteria load reductions and improvements in dissolved oxygen levels needed to comply with state water quality standards determined with load duration curve (LDC) analyses. Additionally, potential fecal bacteria source load assessments for each of the sub-watersheds in the project area were conducted using the Spatially Explicit Load Enrichment Calculation Tool (SELECT). These assessments will help to determine where and how improvements can be made to reduce negative impacts to water quality.

The following sections of this document will discuss:

- Needs of the project that will be met through modeling analyses,
- Types of models used in this report and how they fit into the design of the overall analysis,
- Results of LDC evaluations,
- Results of SELECT model evaluations, and
- An overview of the outcomes and implications of the findings from this report.

[1] This report references the 2020 version of the Integrated Report of Surface Water Quality. These assessments determine which streams are classified as having impairments (measurements exceeding numerical or other specific state water quality standards) or concerns (exceedances of screening levels or other non-numeric/specific criteria).
[2] A more detailed analysis of water quality is discussed further in the Water Quality Data Analysis Summary Report for the Spring Creek Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the Spring Creek Modeling Quality Assurance Project Plan) are available for review at https://springcreekpartnership.weebly.com/documents.html.

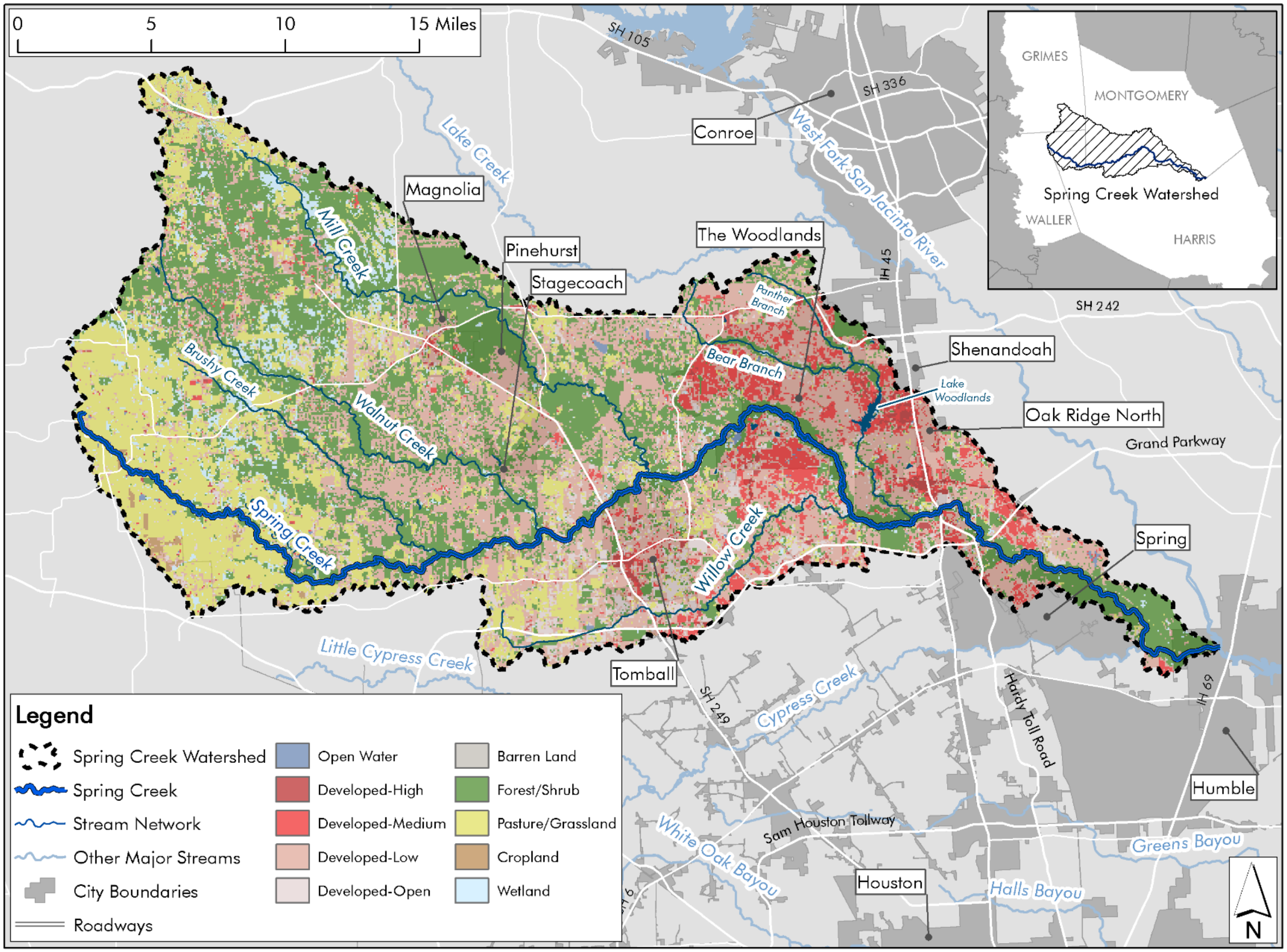

Figure 1. *The Spring Creek Watershed, Land Cover and Regional Context*

Section 2: Project Needs

Model results are an important resource for stakeholders seeking to make watershed planning decisions. By observing modeled data, stakeholders will develop a better understanding of what pollutant sources are impacting the watershed, at what magnitudes pollutants are delivered to the system, where pollutant pressures are spatially distributed, and how to address these concerns most effectively. Beyond this primary need, the combination of modeling results, other data analyses, and stakeholder input is essential to the fulfillment of Element A of the United States Environmental Protection Agency (EPA) 9-element model for watershed-based plans[3].

Needs specific to the development of a WPP for Spring Creek include:

- Relating streamflow to pollutant loads to identify at which flow conditions exceedances of water quality standards are observed using LDC models,
- Establishing goals (fecal bacteria load reduction and dissolved oxygen improvement benchmarks) necessary for compliance with state water quality standards using LDC models,
- Using fecal indicator bacteria data as proxy for estimating spatial relationships and source analysis of fecal waste loading in area subwatersheds using SELECT models, and
- Using the LDC and SELECT model results to relate load reductions to source load data and estimate specific source load reductions.

As an additional consideration, both current and future source loading conditions will be assessed to account for the expansion of developed area and other land changes forecasted to take place in the watershed in the next 25 years.

Section 3: Model Selection and Analysis Design

3.1 Model Selection

To best suit the project needs described in Section 2, H-GAC staff selected LDC and SELECT models to represent pollutant loading data in the Spring Creek Watershed. These models strike the balance between efficiency and complexity, and have been used widely on other WPP projects throughout the region.

After discussions between H-GAC and TCEQ regarding this project as well as similar watershed planning efforts, relating LDC reduction percentages linearly to SELECT source load estimation models was determined to be appropriate for decision-making needs related to WPP development. Fate and transport of pollutants are not captured by these models between source loads and could be more precisely represented by complex modes such as SWAT. However, the level of detail rendered from these intensive analyses ultimately does not provide more meaningful support for stakeholder decision-making, and requires additional cost and time to develop. As part of the WPP, long-term monitoring and assessments of efficacy will be carried out which will help to offset the need for complex, predictive modeling.

Additionally, H-GAC staff incorporated modifications to the standard SELECT modeling process to counteract spatial generalization of results. By utilizing buffers—zones within a set distance of another feature—models can assign more weight to certain sets of results based on spatial relationships. In the case of watershed planning, potential pollutant loads from sources within buffers immediately surrounding waterways can be given more weight than sources distributed outside the buffer according to higher

[3] https://www.epa.gov/nps/handbook-developing-watershed-plans-restore-and-protect-our-waters

likelihood of impact. Another modification to the SELECT models used in this report involved the utilization of a base assumption for wildlife impacts throughout the watershed. This helps to bridge the gap that the SELECT model can sometimes face when limited by sparse or insufficient wildlife data.

3.2 Analysis Design

According to findings from the most recent version of the Integrated Report of Surface Water Quality produced by TCEQ, the most widespread and frequently occurring impairment in the Spring Creek Watershed is caused by high levels of the bacteria *E. coli*, which can indicate the presence of fecal waste and pathogens in surface water. Water quality and spatial data used in this report were collected from quality assured sources including the Surface Water Quality Monitoring Information System and the National Hydrography Dataset. While fecal bacteria assessments are the principal component of this report, additional analyses on dissolved oxygen data were conducted. Using LDCs and SELECT models, the following analyses were designed to consider:

- Whether adequate water quality and flow data exist for the study area,
- Which of the major flow categories are of the highest concern in this watershed,
- Which locations throughout the watershed could act as benchmarks for monitoring progress toward water quality goals,
- What pollutant sources need to be incorporated into the models and where to acquire data to represent these sources,
- How to determine the best source estimations,
- At which points in the future to forecast projected loading values and how to develop them,
- How to incorporate the buffer method into a modified SELECT output, and
- How stakeholder input could be used to refine these assessments.

Model results from LDCs and SELECT evaluations were combined to link reduction goals to specific source loads and develop effective water quality improvement strategies for the WPP. Future reduction targets derived from this assessment represent 5-year benchmarks through the year 2045.

SECTION 4: LDC EVALUATIONS

4.1 Overview

LDCs were used to characterize the relationship between pollutant loads and stream flow. By determining the difference between modeled loads and the maximum loads permitted by state water quality standards, reduction targets can be estimated. Because high levels of fecal indicator bacteria and low levels of dissolved oxygen were indicated as major pressures in the Spring Creek watershed, this process was carried out on both datasets.

4.2 Load Estimation

Origins of fecal waste indicated by *E. coli* in waterways are informed by the stream flow conditions observed at the time of sample collection. This information is also helpful in determining the strategies that will be most effective in reducing contamination. For example, if fecal bacteria levels are highest in periods of high flows seen during flooding events, stormwater flows and other nonpoint sources are likely to be the major contributors to impairment. If fecal bacteria levels are highest when flows are limited, point sources or sources known to steadily contribute contaminants into waterways are indicated as the greater concern.

To calculate LDCs for Spring Creek and its tributaries, stream flow data from the United States Geological Survey (USGS) and Clean Rivers Program (CRP) water quality data from the Surface Water Quality Monitoring Information System were used. USGS gage data is ideal to produce flow duration curves used in LDC analyses due to the long-term, continuous measurements recorded by the gages. Based on the percentage of days during the study period flows of a known magnitude are observed, a flow duration curve is developed and plotted. To this plot, curves resulting from the multiplication of state water quality standards and values of the flow duration curve are added to represent the maximum allowable contaminant loads during each flow condition. Finally, individual observed pollutant levels collected during the study period and a curve modeled from these observations (load regression curve) are plotted. For areas where the load regression curve exceeds the maximum allowable contaminant load curve, reductions are needed.

4.3 Site Selection

Locations of monitoring data used for LDC analyses were selected based on their periods of record, water quality conditions, availability of corresponding stream flow data, and representativeness of smaller drainage areas within the greater watershed known as subwatersheds. Subwatershed delineation is useful as a means of yielding more spatially specific information that can be used to target source load reductions with greater precision. This analysis references the eight subwatersheds described below and shown in **Figure 2**.

1) **Mill Creek (SW1)** – the drainage area of Mill Creek which runs southeast from its headwaters in Grimes County to a confluence with Spring Creek near Tomball. While there is an active monitoring station located on Mill Creek, its location near the mid-point of the stream indicates that data collected there does not capture water quality dynamics closer to the confluence with Spring Creek. Further, there is no available stream flow data at this tributary. For these reasons, no LDC analysis was performed for this subwatershed. Because there is less development in this subwatershed compared to those to its east, water quality data[4] from Mill Creek most closely resembles data collected in other tributaries forming the headwaters of Spring Creek. Assumptions about the Mill Creek Subwatershed were made based on data from its western neighbors.
2) **Walnut Creek (SW2)** – the drainage area between Mill Creek and Brushy Creek on the western side of the Spring Creek Watershed characterized by low development. This area is represented by Station 20642 (Walnut Creek at Decker Prairie Rosehl Road) near Walnut Creek's confluence with Spring Creek. No gaged stream flow data is available on this tributary; however, stream flow was estimated by linear regression. Continuous stream flow values from a nearby USGS gage on Spring Creek (08068275) was plotted against one-time flow recordings logged during sampling events for ambient data. The linear relationship between these values was used to estimate continuous stream flow values.
3) **Brushy Creek (SW3)** – the drainage area between Walnut Creek and the headwaters of Spring Creek on the western side of the Spring Creek Watershed which is also characterized by more natural land cover types. This area is represented by Station 20643 (Brushy Creek at Glenmont Estates Boulevard) near Brushy Creek's confluence with Spring Creek. As with Walnut Creek, no gaged stream flow data is available on this tributary, however, stream flow was estimated by linear regression as described in the process used for Walnut Creek.

[4] A more detailed analysis of water quality is discussed further in the Water Quality Data Analysis Summary Report for the Spring Creek Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the Spring Creek Modeling Quality Assurance Project Plan) are available for review at https://springcreekpartnership.weebly.com/documents.html.

4) **Spring Creek, Upper (SW4)** – the drainage area of the headwaters of Spring Creek running east from Waller County. The delineation for this area stops just north of Tomball near the confluence with Mill Creek. Though this area is characterized by a majority of natural land cover types, it is also the subwatershed with the highest concentration of agricultural land cover. Ambient data for this area is represented by Station 11314 (Spring Creek at SH 249) and stream flow was assessed from USGS gage 08068275.
5) **Willow Creek (SW5)** – the drainage area of Willow Creek south of the main stem of Spring Creek. This area is covered by a variety of land types including areas of high intensity development. Ambient data were collected from Station 11185 (Willow Creek at Gosling Road) near the confluence with Spring Creek. Stream flow data were collected from USGS gage 08068325. As the USGS gage is located upstream from the location of the station, a drainage area ratio was used to convert continuous stream flow observed at the USGS gage to an estimation of flows further downstream.
6) **Spring Creek, Middle (SW6)** – the drainage area of Spring Creek between its headwaters west of SH 249 and the downstream section of the watershed starting to the east of I-45. This subwatershed is overlapped by the Woodlands Township which is one of the most heavily developed areas in the watershed, although a variety of natural and developed land types cover this area. Ambient data were collected from Station 11313 (Spring Creek Bridge at I-45) and stream flow data were assessed from USGS gage 08068500.
7) **Panther Branch (SW7)** – the drainage area of Upper and Lower Panther Branch, Bear Branch, and Lake Woodlands north of Spring Creek. This subwatershed is at the heart of the Woodlands Township and is the most heavily developed. Ambient data were collected from Station 16627 (Lower Panther Branch at Footbridge 265 M Upstream of Sawdust Road) and stream flow data were assessed from USGS gage 08068450.
8) **Spring Creek, Lower (SW8)** – the drainage area of Spring Creek running east of I-45 to a confluence with the West Fork of the San Jacinto River. This area overlaps with the city of Spring and is heavily developed outside of the greenway area east of the Hardy Toll Road. Unfortunately, no gage data is available for this subwatershed. It is represented by proxy by Station 11313 immediately west of its delineation boundary.

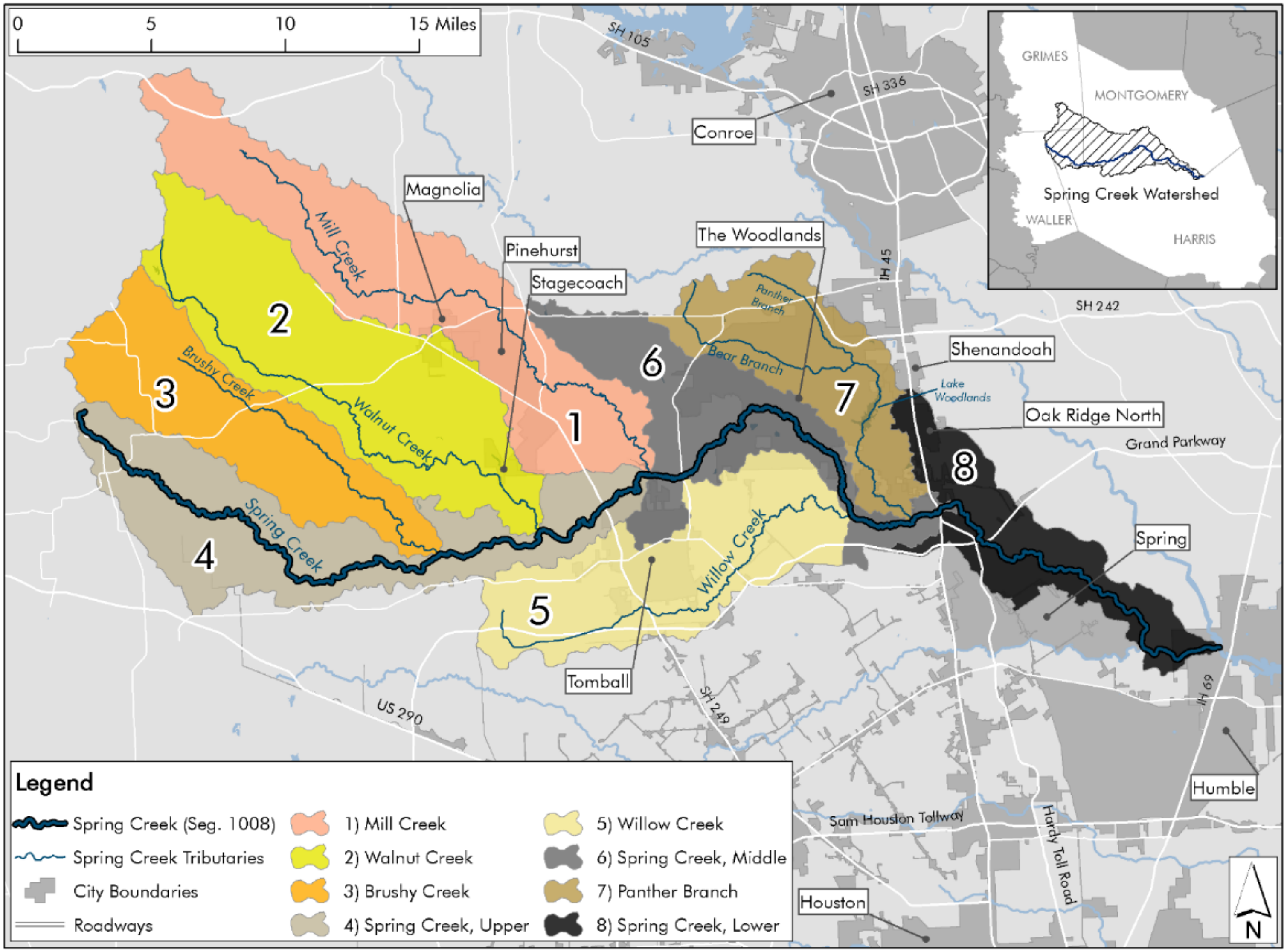

Figure 2. *Subwatersheds of the Spring Creek Watershed*

Ambient water quality data are collected at over 400 sites in the 13-county Houston-Galveston region by H-GAC, local partners, and the TCEQ as part of the CRP. In general, most monitoring stations are sampled by CRP partners on a quarterly frequency for a suite of field, bacteriological, and conventional parameters. The final determination of the regulatory status of each segment is based primarily on these ambient data. The impetus for development of the WPP was formed largely in response to the current regulatory status of Spring Creek and its tributaries, therefore ambient data is a relevant source of information for informing stakeholder decisions. Ambient data used for LDC analyses were collected in the Spring Creek Watershed between 2009 and 2019 at the locations indicated in **Figure 3** and described in **Table 1**.

Table 1. *LDC Locations*

LDC Site	CRP Station	USGS Gage	Assessed Area
Brushy Creek at Glenmont Estates Boulevard	20463	No Gage	Subwatershed 2
Walnut Creek at Decker Prairie Rosehl Road	20462	No Gage	Subwatershed 3
Spring Creek at SH 249	11314	08068275	Subwatershed 4 (and 1 by proxy)
Willow Creek at Gosling Road	11185	08068325	Subwatershed 5
Lower Panther Branch at Footbridge 265 M Upstream of Sawdust Road	16627	08068450	Subwatershed 6
Spring Creek Bridge at I-45	11313	08068500	Subwatershed 7 (and 8 by proxy)

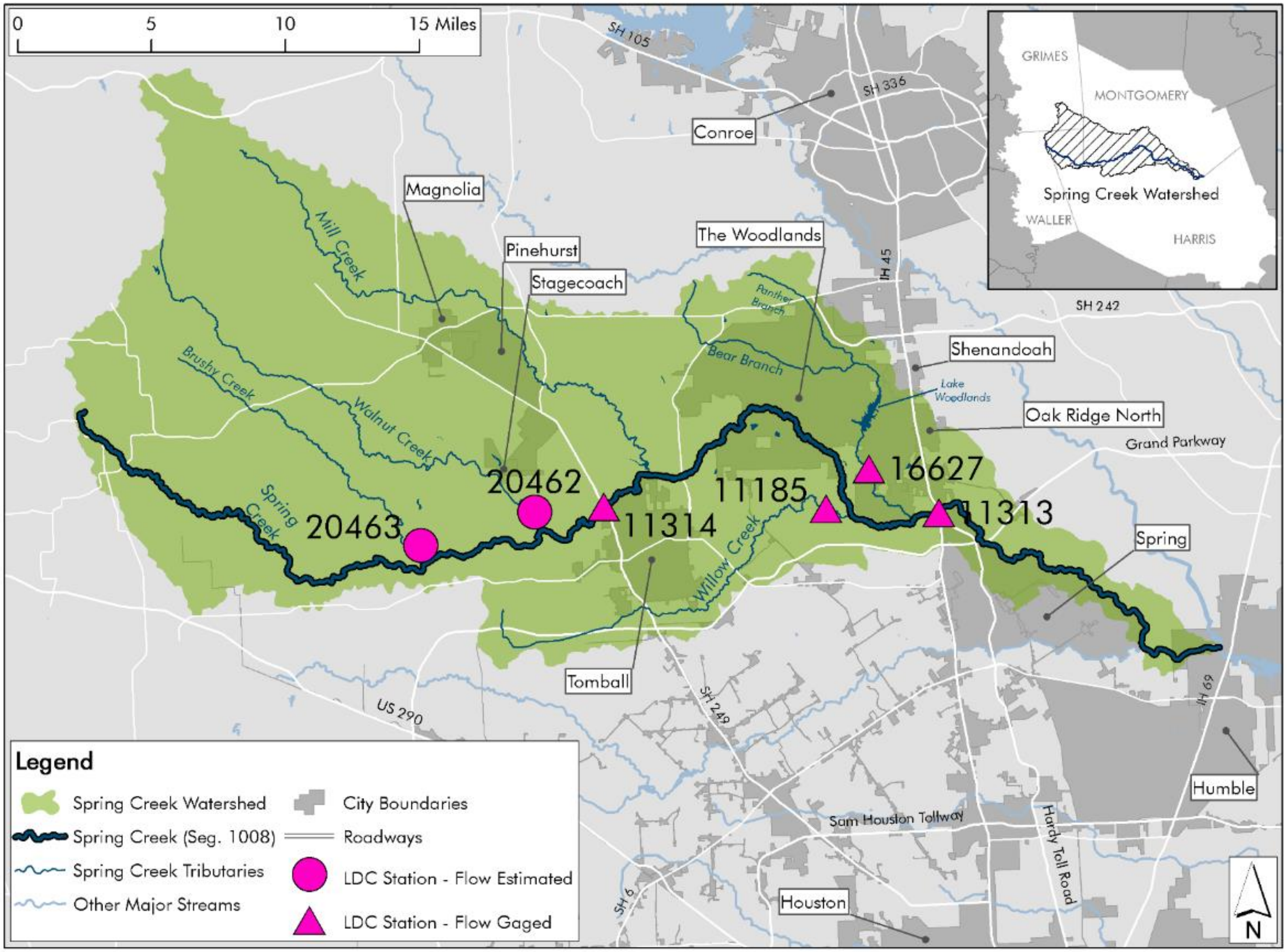

Figure 3. *LDC Locations in the Spring Creek Watershed*

4.4 Data Development

In addition to location and availability of stream flow data, sufficiency and consistency of ambient data collection were important factors leading to the selection of the six CRP stations used for LDC analysis. The number of quality assured data values for both *E. coli* and dissolved oxygen are expressed in **Table 2**. All stations have at least 10 years of data available and range from 33 to 90 samples for *E. coli* and 37 to 98 samples for dissolved oxygen. This is within the acceptable range for LDC development as stated in the quality assurance objectives for the project.

Table 2. *Number of Samples by Station*

LDC Location	Station	# of *E. coli* Samples	# of Dissolved Oxygen Samples
Brushy Creek at Glenmont Estates Boulevard	20463	38	37
Walnut Creek at Decker Prairie Rosehl Road	20462	39	37
Spring Creek at SH 249	11314	79	83
Willow Creek at Gosling Road	11185	90	90
Lower Panther Branch at Footbridge 265 M Upstream of Sawdust Road	16627	33	98
Spring Creek Bridge at I-45	11313	50	66

Figure 4. *Aerial View of Spring Creek*

4.5 LDC Implementation

Project staff used the data referenced above to generate flow curves and LDCs. No appreciable issues were identified in LDC development based on quality assured internal review. Further, results of these analyses were discussed in greater detail with project stakeholders who supported their accuracy and representativeness.

Station 20463 – Brushy Creek at Glenmont Estates Boulevard

Station 20463 is located on Brushy Creek just north of its confluence with Spring Creek. The cumulative drainage of the subwatershed area of Brushy Creek flows to this point. This area includes some residential development but is largely covered by natural land types such as forest, shrubland, grassland and wetland. Development is expected to increase in this area in the coming years with expansion of residential areas. Daily average rates of stream flow in cubic feet per second (cfs) on Brushy Creek are estimated to be between 0 and 1000 cfs. During extreme events such as flooding or hurricanes (*e.g*. floods in 2015 and 2016, Hurricane Harvey in 2017), these estimated rates increased but did not exceed 10,000 cfs. Also of note, the period of record included a statewide drought which resulted in low or no flows between late 2010 and 2012. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 5** and **Figure 6** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 3**. While both geomean and single sample data for fecal bacteria were assessed, at each station observed in this report, only the geomean results were used for determining reduction targets. Values labeled "Geometric Mean Load" (blue squares) are the mean value of "Observed Data" (red circles) within a specific flow condition. The distance between this point and the standard curve represents the reduction needed (represented as percentages on corresponding table). Negative values in **Table 3** indicate that no reductions or improvements are needed in associated stream flow conditions. This is also true of negative results presented in LDC summary tables for subsequent stations.

The results of LDC analyses for Station 20463 indicate a need for moderate reductions in fecal bacteria loading at high flow, moist conditions and mid-range conditions. *E. coli* geomean loads expressed in colony forming units per day (cfu/day) were higher at higher levels of flow and implicate nonpoint sources as the greater pressure in this subwatershed area. An assessment of dissolved oxygen loads expressed in milligrams per day (mg/day) showed that Brushy Creek demonstrated a greater assimilative capacity at higher rates of flow but this ability was limited as flows diminish.

Table 3. *Flow Specific Values for LDC 20463*

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample	Dissolved Oxygen Percent Improvement Needed
High Flows	0-10%	58%	-32%	-154%
Moist Conditions	10-40%	47%	-67%	-116%
Mid-Range Conditions	40-60%	36%	-102%	-90%
Dry Conditions	60-90%	-21%	-285%	-37%
Low Flows	90-100%	-21%	-285%	-37%

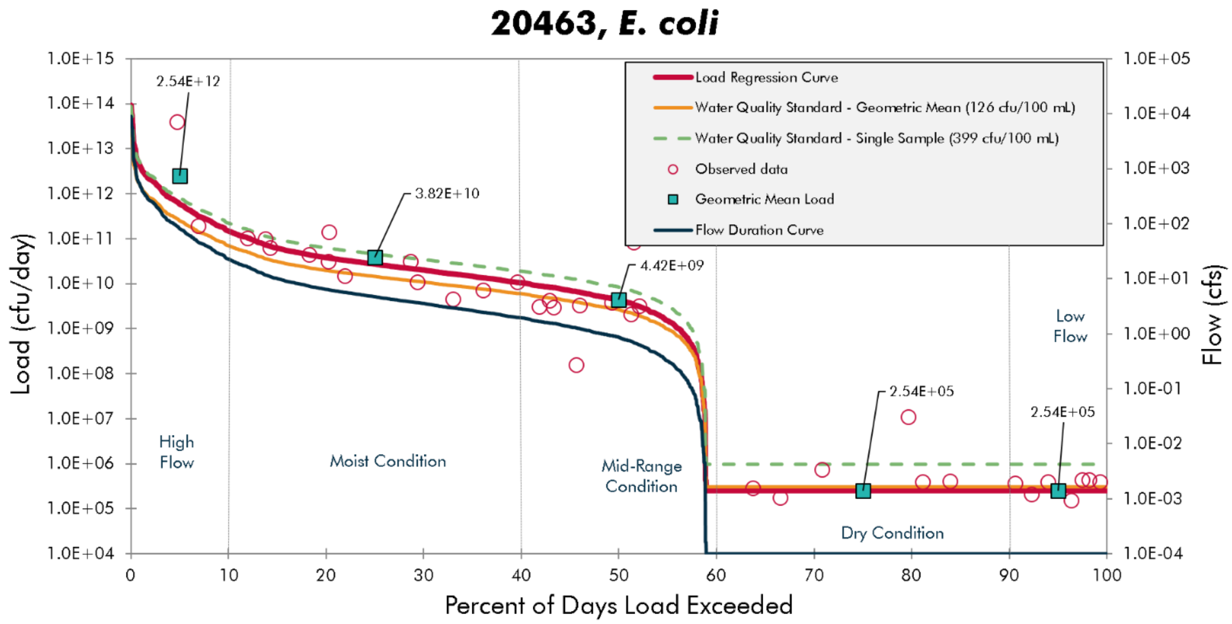

Figure 5. E. coli *LDC for Station 20463*

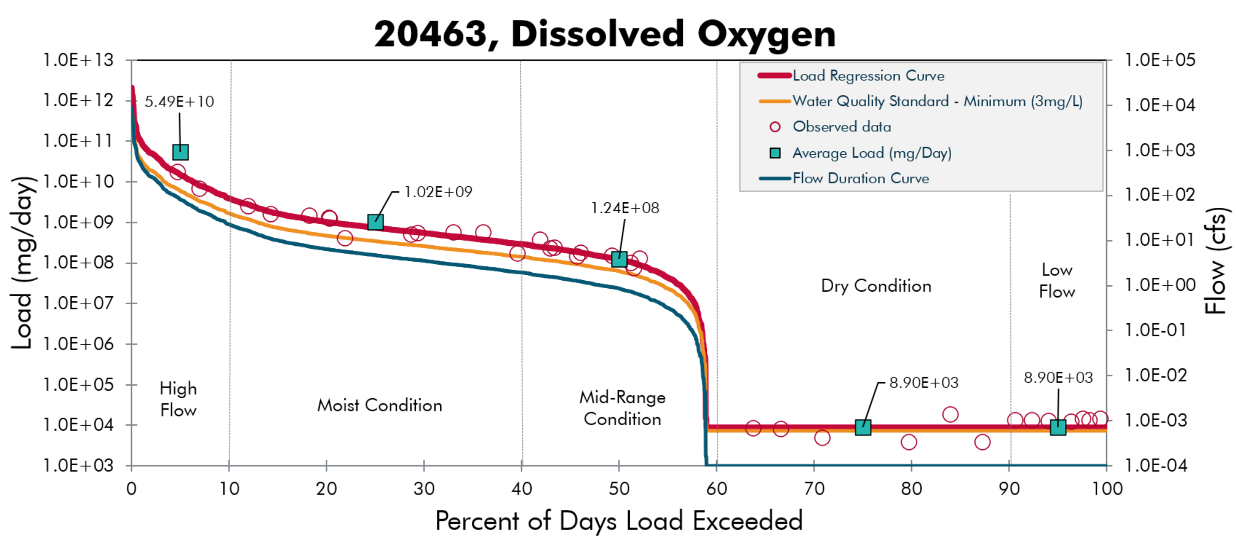

Figure 6. *Dissolved Oxygen LDC for Station 20463*

Station 20462 – Walnut Creek at Decker Prairie Rosehl Road

From its location on Walnut Creek just north of a confluence with Spring Creek, Station 20462 represents the cumulative drainage area of the Walnut Creek subwatershed. Land cover types such as forest, shrubland, grassland and wetland are most common in this area, however, development associated with residential expansion is expected to increase in this area in the future. Of all the streams observed in this report, Walnut Creek is estimated to have the lowest daily average rates of stream flow with the majority falling below 100 cfs. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 7** and **Figure 8** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 4**.

The results of LDC analyses for Station 20462 indicate a need for more extensive reductions in fecal bacteria loading at a broader range of flow conditions. Exceedances of the fecal bacteria geomean water quality standard were observed in all flow conditions except low flows. These broadly distributed loading effects imply that while nonpoint source signals are strongest in this segment, point sources may also be influencing fecal bacteria loads, especially in lower flow conditions. Station 20462 is the only station of the six observed in this analysis that indicated a need for dissolved oxygen improvements. This only occurred at the lowest flow condition, with greater assimilative capacities indicated in all other types of stream flow.

Table 4. *Flow Specific Values for LDC 20462*

Flow Category	**Percent of Days Flow Exceeded**	***E. coli* Percent Reduction Needed - Geomean**	***E. coli* Percent Reduction Needed - Single Sample**	**Dissolved Oxygen Percent Improvement Needed**
High Flows	0-10%	89%	66%	-156%
Moist Conditions	10-40%	41%	-87%	-106%
Mid-Range Conditions	40-60%	22%	-146%	-98%
Dry Conditions	60-90%	4%	-203%	-86%
Low Flows	90-100%	-4396%	-14139%	17%

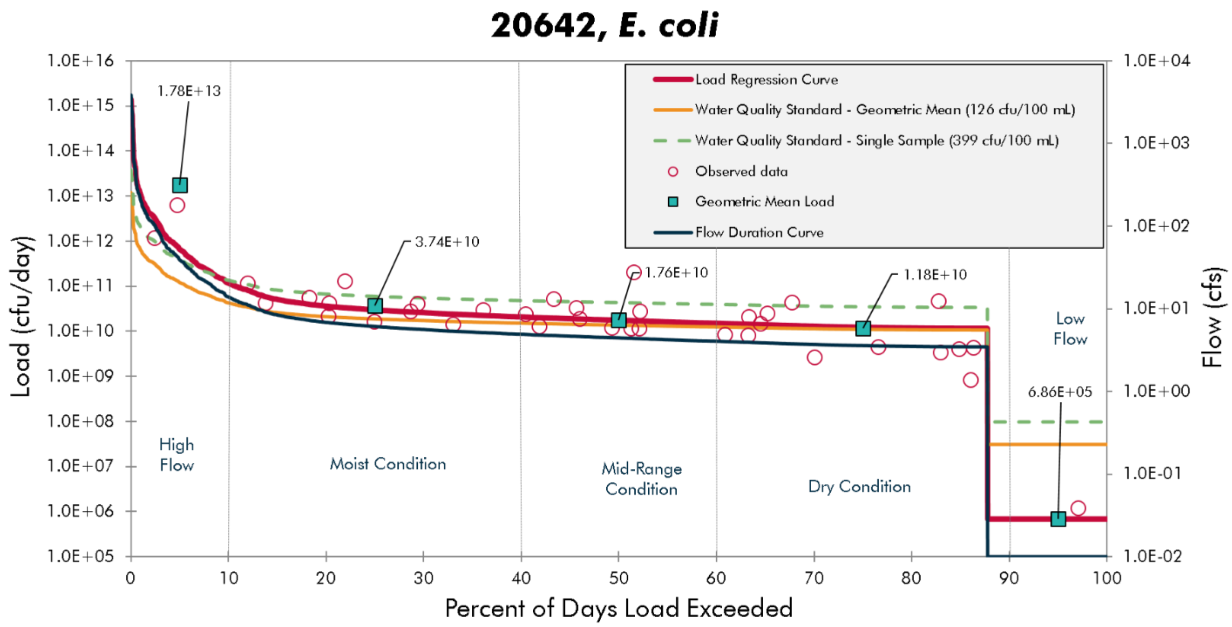

Figure 7. *E. coli* *LDC for Station 20462*

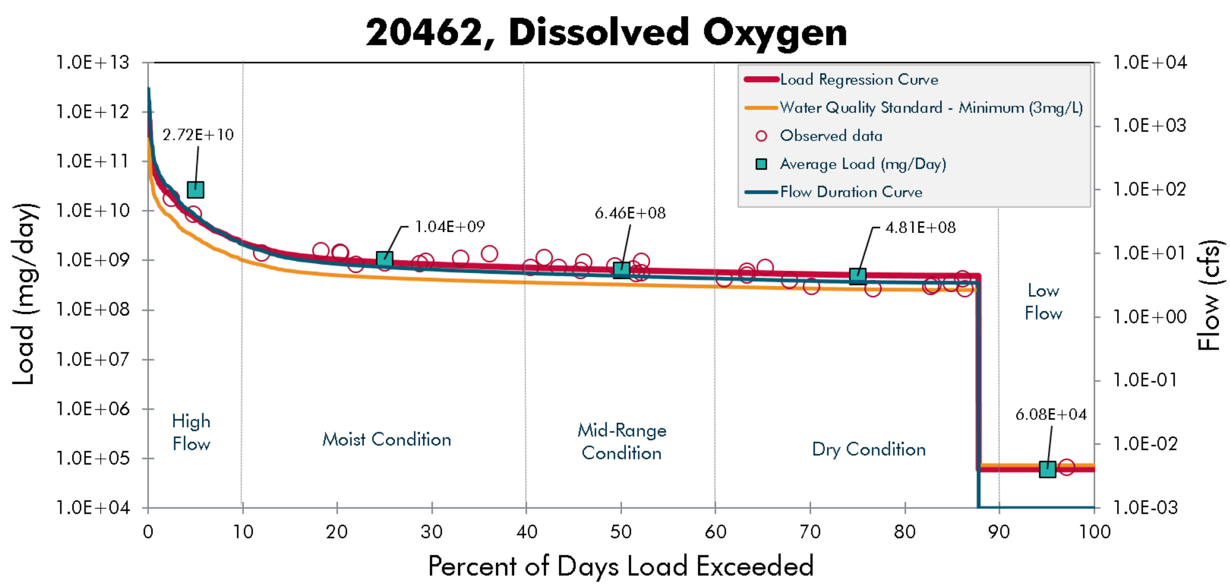

Figure 8. *Dissolved Oxygen LDC for Station 20462*

Station 11314 – Spring Creek at SH 249

As one of the stations located on the main stem of Spring Creek, Station 11314 is important for understanding loading pressures and reduction targets in this system. This station is located near the stream's intersection with SH 249 north of Tomball. A variety of land types cover the subwatershed area draining to this station including mostly grassland in the western reaches transitioning to light development closer to the station location. This land area also includes the highest concentration of agricultural land cover of the other subwatersheds observed in this analysis. As with previously mentioned areas, the subwatershed represented by Station 11314 is expected to experience an increase in development in the coming years. Flow variability is high as extreme events can lead to flow rates in excess of 10,000 cfs—an order of magnitude greater than flows observed on Brushy and Walnut Creeks. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 9** and **Figure 10** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 5**.

Like Station 20462, fecal bacteria at Station 11314 require reduction in high flows and moist, mid-range and dry conditions. Comparative to Station 20462, reduction levels at Station 11314 were higher. *E. coli* geomean loads at low flows were within state standard range. Here, nonpoint source pressures may be compounded by additional stress from point sources. Dissolved oxygen was compliant with state standards at all levels of flow with higher assimilative capacities observed at higher rates of flow.

Table 5. *Flow Specific Values for LDC 11314*

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample	Dissolved Oxygen Percent Improvement Needed
High Flows	0-10%	81%	39%	-151%
Moist Conditions	10-40%	64%	-15%	-123%
Mid-Range Conditions	40-60%	54%	-47%	-113%
Dry Conditions	60-90%	20%	-153%	-89%
Low Flows	90-100%	-475%	-1722%	-45%

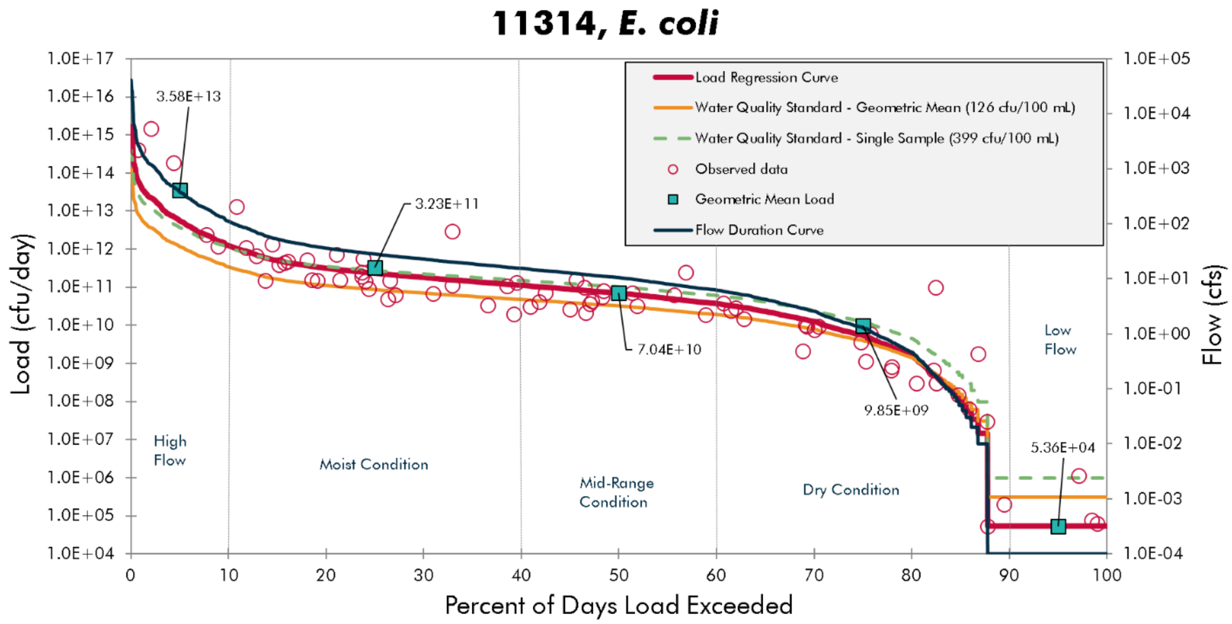

Figure 9. *E. coli LDC for Station 11314*

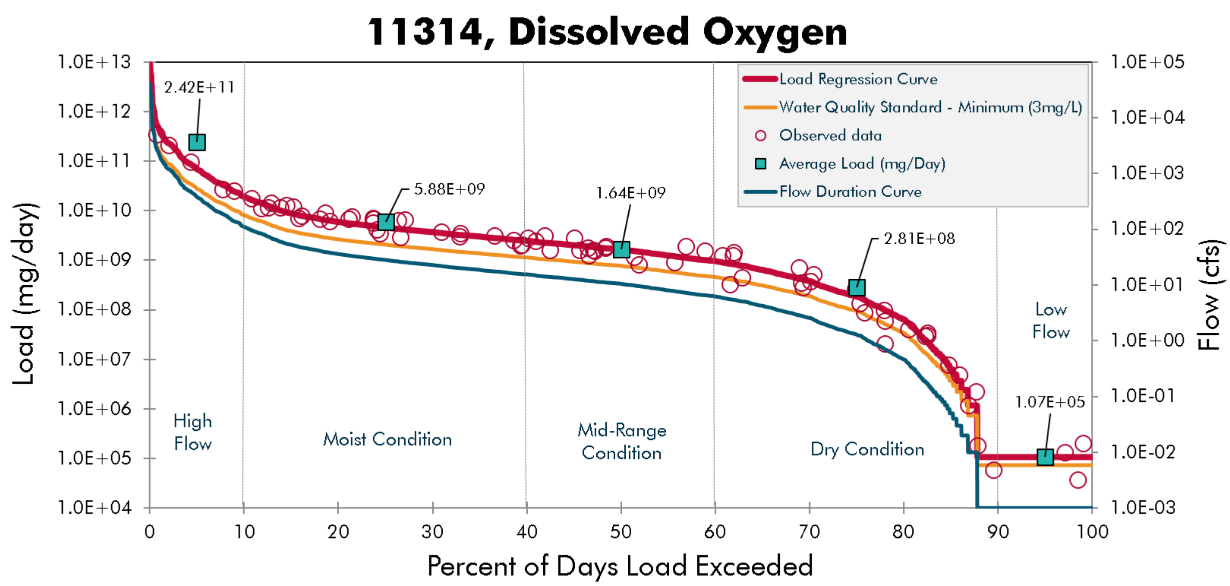

Figure 10. *Dissolved Oxygen LDC for Station 11314*

Station 11185 – Willow Creek at Gosling Road

Moving east across the greater Spring Creek Watershed, Station 11185 can be found on Willow Creek near its confluence with Spring Creek. The drainage area represented by this station is home to the city of Tomball and is covered by a majority of developed land types. This area will continue to develop in the near future. Stream flow on Willow Creek typically ranges between 0 and 1000 cfs with the exception of extreme high-flow events. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 11** and **Figure 12** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 6**.

The results of LDC analyses for Station 11185 are noticeably different from analyses conducted on stations west of this point in that greater geomean loads are observed throughout the curve. Larger reductions in fecal bacteria are recommended at this station compared to previous stations in high flow and moist conditions, but loading became less severe in mid-range conditions and finally fell within the standard range for dry conditions and low flows. This indicates a strong influence from nonpoint source pressures in this subwatershed. Dissolved oxygen was consistently shown to be within the standard range at all flow conditions observed at this station.

Table 6. *Flow Specific Values for LDC 11185*

Flow Category	**Percent of Days Flow Exceeded**	***E. coli* Percent Reduction Needed - Geomean**	***E. coli* Percent Reduction Needed - Single Sample**	**Dissolved Oxygen Percent Improvement Needed**
High Flows	0-10%	98%	94%	-128%
Moist Conditions	10-40%	77%	28%	-170%
Mid-Range Conditions	40-60%	18%	-161%	-194%
Dry Conditions	60-90%	-27%	-302%	-204%
Low Flows	90-100%	-79%	-468%	-212%

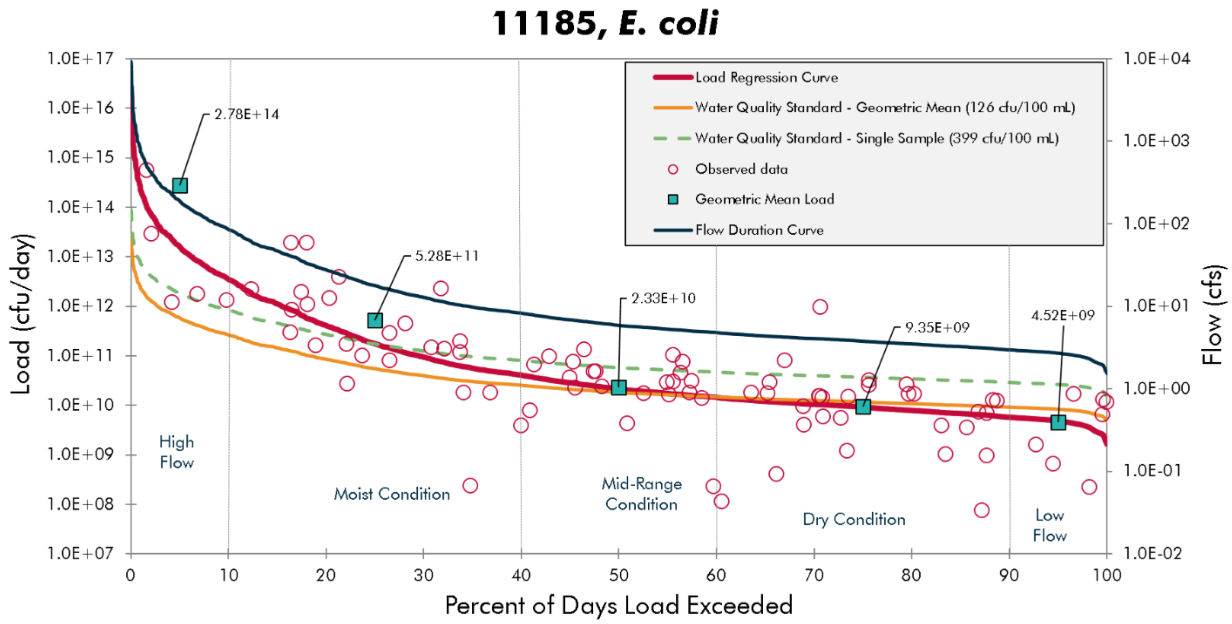

Figure 11. *E. coli LDC for Station 11185*

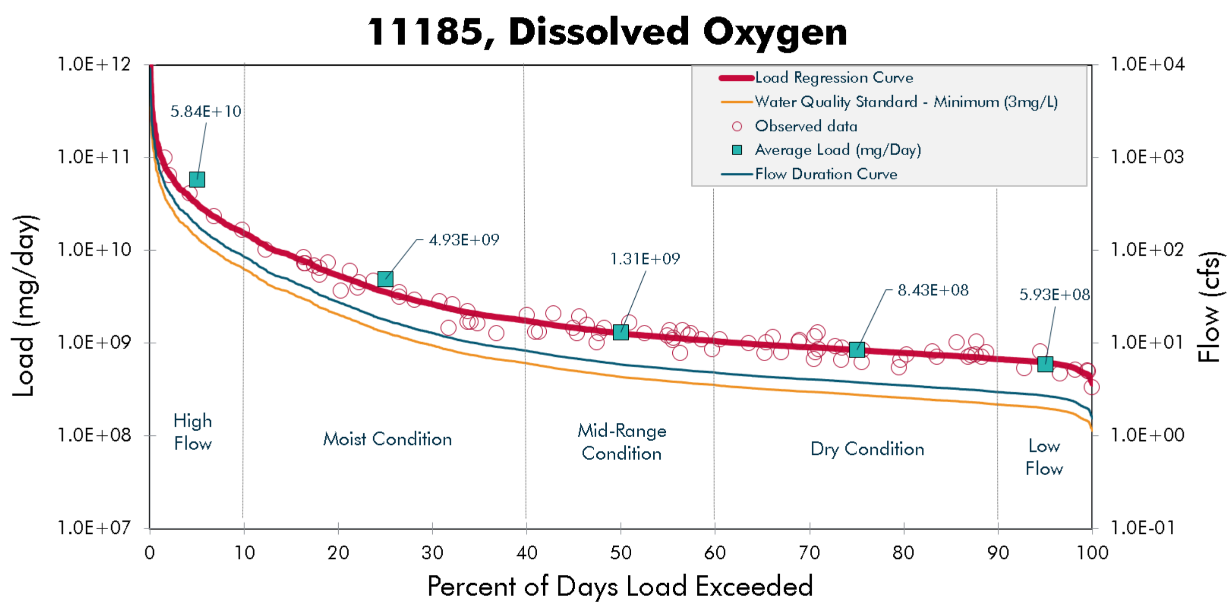

Figure 12. *Dissolved Oxygen LDC for 11185*

Station 16627 – Lower Panther Branch at Footbridge 265 M Upstream of Sawdust Road

Station 16627 is found in the Panther Branch subwatershed on Lower Panther Branch between Lake Woodlands and a confluence with Spring Creek. This station represents the drainage area of the most heavily developed subwatershed reviewed in this report. The Township of the Woodlands and the city of Shenandoah overlap this subwatershed which is bordered by development along the I-45 corridor to the east. Stream flow at this station is similar to that observed on Willow Creek with the majority of flows occurring at rates below 1000 cfs. Streamflow increased during extreme high flow events and exceeded 10,000 cfs at one timepoint associated with heavy rainfall brought on by Hurricane Harvey. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 13** and **Figure 14** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 7**.

The results of LDC analyses for Station 16627 indicate that appreciable fecal bacteria load reductions are needed in high flow conditions and moderate reductions are needed in moist conditions. No exceedances of the *E. coli* geomean water quality standard were observed in any other flow conditions. Nonpoint sources are indicated as the greater influence on fecal bacteria loading in this segment. Dissolved oxygen loads were shown to be consistently within the standard range at this station. LDC results suggest assimilative capacity for dissolved oxygen decreased with lower rates of flow.

Table 7. *Flow Specific Values for LDC 16627*

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample	Dissolved Oxygen Percent Improvement Needed
High Flows	0-10%	92%	76%	-245%
Moist Conditions	10-40%	50%	-57%	-120%
Mid-Range Conditions	40-60%	-12%	-254%	-80%
Dry Conditions	60-90%	-61%	-408%	-63%
Low Flows	90-100%	-140%	-661%	-46%

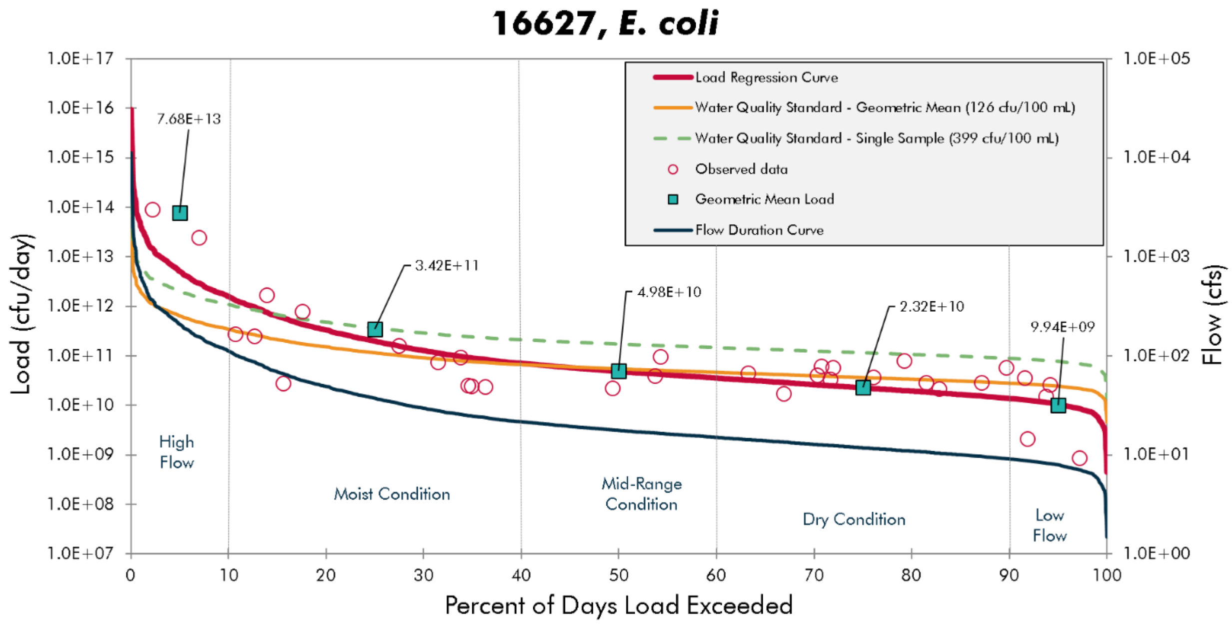

Figure 13. *E.* coli *LDC for Station 16627*

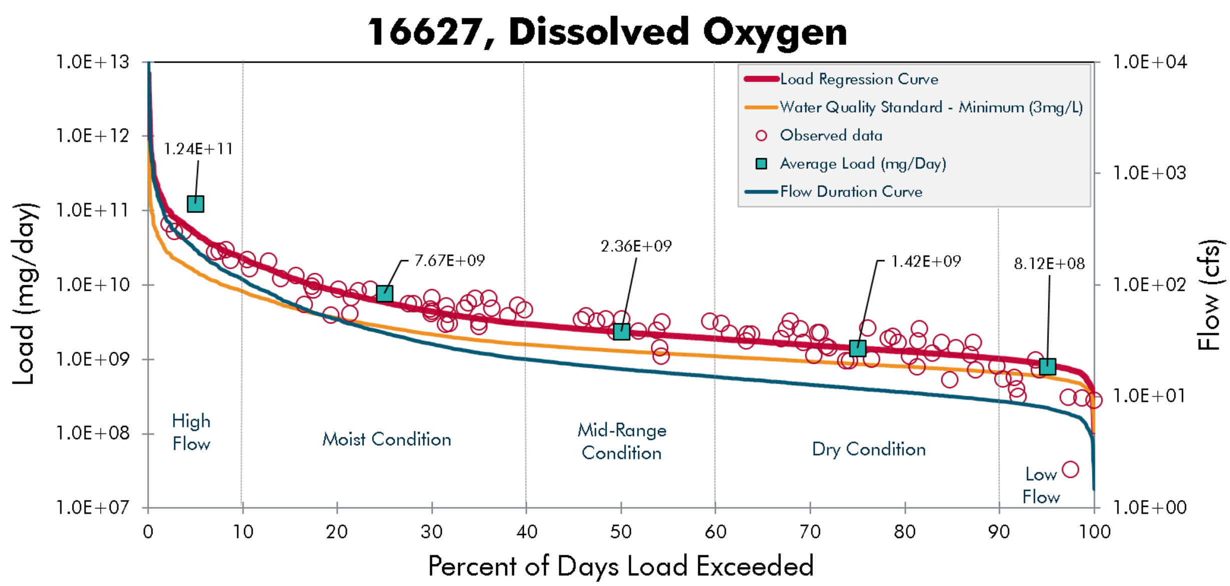

Figure 14. *Dissolved Oxygen LDC for Station 16627*

Station 11313 – Spring Creek Bridge at I-45

Station 11313 is the furthest downstream station observed in this report. It is located at the point where Spring Creek crosses I-45 on the farthest western edge of the city of Spring. The drainage area represented by this station spans westward to SH 249 and overlaps high intensity development areas of the Woodlands. Land cover in this subwatershed is largely developed with most of its natural areas occurring along riparian corridors. The highest rates of flow of all the stations observed in this report occurred at this location. LDC results for *E. coli* and dissolved oxygen at this station are shown in **Figure 15** and **Figure 16** respectively, and reduction and improvement values necessary to bring water quality into compliance with state standards are shown in **Table 8**.

The results of LDC analyses for Station 11313 are similar to those observed in other downstream segments—particularly Station 20462. Exceedances of the *E. coli* water quality standard were observed in periods of high flow and in moist and mid-range conditions. Fecal bacteria geomean loads observed in dry and low flows were within the acceptable standard range. Because higher reductions are needed at higher rates of flow, nonpoint sources of fecal bacteria loading are the greater concern at this site. Dissolved oxygen loads were within range of the standard at all flow conditions with high assimilative capacity observed throughout.

Table 8. *Flow Specific Values for LDC 11313*

Flow Category	Percent of Days Flow Exceeded	*E. coli* Percent Reduction Needed - Geomean	*E. coli* Percent Reduction Needed - Single Sample	Dissolved Oxygen Percent Improvement Needed
High Flows	0-10%	95%	85%	-159%
Moist Conditions	10-40%	73%	13%	-177%
Mid-Range Conditions	40-60%	33%	-113%	-187%
Dry Conditions	60-90%	-9%	-244%	-193%
Low Flows	90-100%	-78%	-463%	-200%

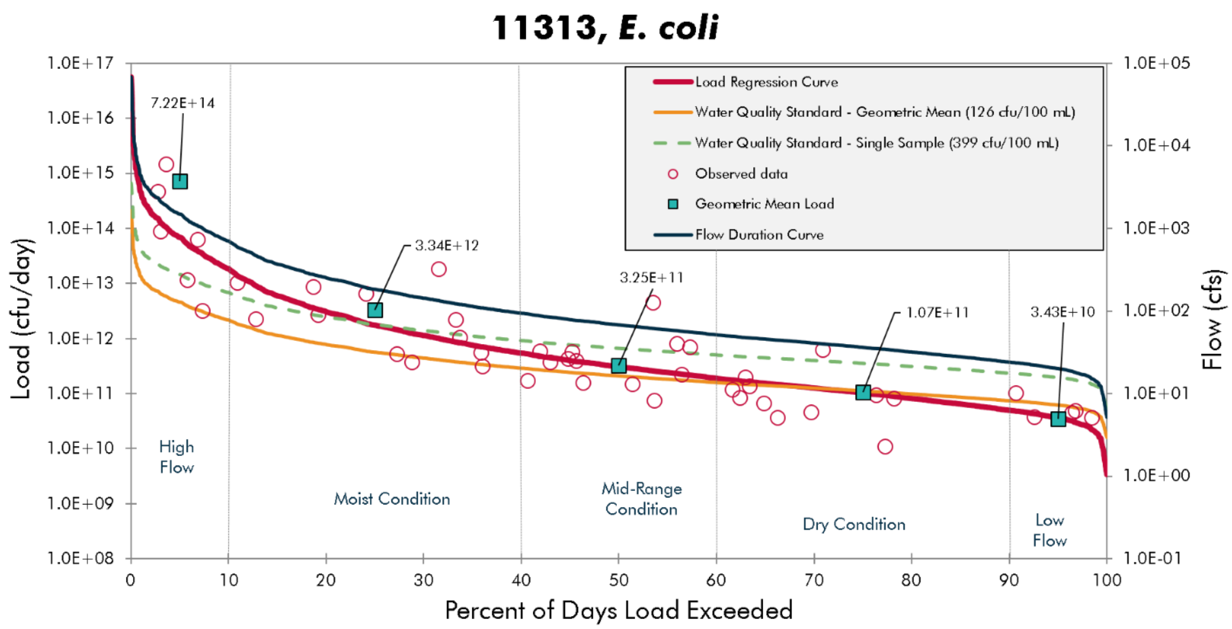

Figure 15. *E. coli LDC for Station 11313*

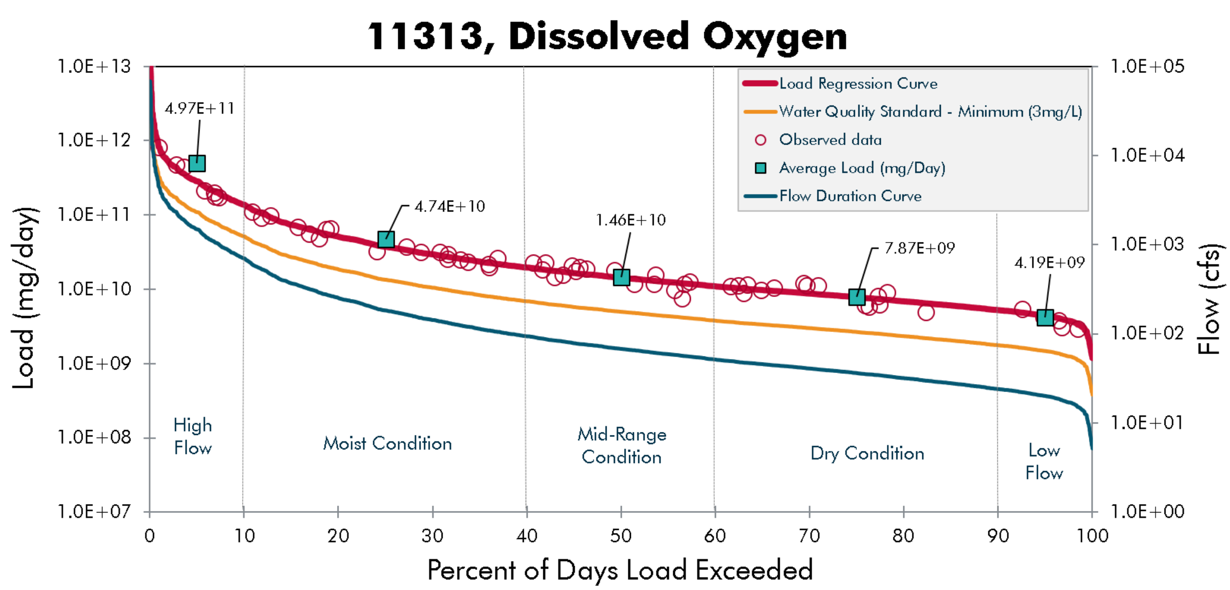

Figure 16. *Dissolved Oxygen LDC for Station 11313*

4.6 LDC Summary and Fecal Indicator Bacteria Reduction Targets

Results of LDC analyses for Spring Creek have been reviewed internally and subjected to thorough stakeholder analysis. H-GAC staff discussed these results with stakeholders at partnership meetings and in more focused, one-on-one conversations. Stakeholder support and positive feedback support confidence in the estimated levels of fecal bacteria loadings and reduction targets for the Spring Creek Watershed.

Some of the most important observations to be made from the LDC analysis of Spring Creek and its tributaries are:

- All of the assessed locations display a high assimilative capacity for dissolved oxygen loading at all levels of flow with the exception of Station 20462 in the lowest flow conditions,
- *E. coli* loading exceeded the standard in high flow and moist conditions across the watershed, and
- *E. coli* loading in other flow conditions varied among sites.

Generally, dissolved oxygen assimilative capacity for stream segments throughout the watershed is well within the range of state water quality standards. In some segments, this capacity becomes more limited with decreased stream flow. These segments include Lower Panther Branch, Upper Spring Creek, Brushy Creek, and Walnut Creek. In the case of Walnut Creek, dissolved oxygen requires a 17% improvement to comply with the standard at low flow conditions. Stream flow gauge and flow estimation data relating to the sites assessed on the aforementioned segments indicate lower observed flows relative to those observed on Willow Creek and mid-Spring Creek.

LDC analyses of fecal bacteria loads at all sites throughout the watershed indicated a need for considerable reductions in high flow and most conditions. Reduction needs at lower levels of flow varied among sites. Sites on the western side of the watershed (20463, 20462 and 11314) require more moderate reductions relative to those recommended in more developed areas, however, reductions are recommended for a wider range of flow levels (high flows through dry conditions). On the eastern side of the watershed, sites 16627, 11185 and 11313 bore stronger resemblances to each other in that reductions of greater magnitude are required at the highest flow conditions relative to those recommended in the west. Dry to low flow conditions are within range of the standard at these sites and only moderate reductions are needed at mid-range conditions for 16627 and 11313.

Because of the similarities in model results between sites 16627, 11185 and 11313, their respective stream segments and watershed areas were grouped together to differentiate the downstream portion of the watershed from the subwatersheds draining into Spring Creek's headwaters. By designating these two generalized attainment areas as shown in **Figure 17**, overall reduction targets compromising between over-generalization of the total watershed and overly conservative reduction targets for individual subwatersheds at different rates of flow can be applied in the development of a WPP. Overall reduction targets for each attainment area were determined by selecting a representative station for the area and taking a weighted average of the LDC reduction targets produced for that station based on rates of flow. Therefore, where W represents the weighting factor (percent of flows) at high flow (*h*), moist (*m*), mid-range (*mr*), dry (*d*), and low flow (*l*) conditions, and R represents the reduction value required at each rate of flow, the weighted average reduction can be calculated as follows:

$$\text{Weighted Average Reduction} = \frac{\mathrm{W}h\mathrm{R}h + \mathrm{W}m\mathrm{R}m + \mathrm{W}mr\mathrm{R}mr + \mathrm{W}d\mathrm{R}d + \mathrm{W}l\mathrm{R}l}{\mathrm{W}h + \mathrm{W}m + \mathrm{W}mr + \mathrm{W}d + \mathrm{W}l}$$

For example, Station 11314 is the farthest downstream station in the attainment area of the headwaters of Spring Creek and was used to represent the area as shown in **Table 9**. At the high flow category which represents the top 10% of flows, an *E. coli* reduction of 81% is recommended. *E. coli* observed in the next 30% of flows (moist conditions) require a reduction of 64% and *E. coli* observed in the following 20% of flows (mid-range conditions) require a 54% reduction. Finally, *E. coli* observed in dry conditions comprising the following 30% of flows only require a 20% reduction. Low flow conditions are not factored into this calculation as no reductions were indicated by the LDC model. The calculation for the weighted average reduction for Station 11314 is shown below:

$$\text{Weighted Average Reduction} = \frac{(10 \times 81) + (30 \times 64) + (20 \times 54) + (30 \times 20)}{10 + 30 + 20 + 30}$$

$$\text{Weighted Average Reduction} = \frac{810 + 1920 + 1080 + 600}{90}$$

$$\text{Weighted Average Reduction} = \frac{4410}{90} = 49$$

This calculation was also used to determine the weighted average fecal bacteria reduction needed at Station 11313 which was selected as the best representative station in the downstream attainment area. While Station 11313 occurs well upstream of the confluence of Spring Creek and the West Fork of the San Jacinto River at the terminal end of the watershed area, it is the furthest downstream station in the attainment area with accompanying stream gage data. Only weighting factors and reduction targets from high, moist and mid-range flows were considered as no reductions were indicated by the LDC model at dry and low flow conditions. The resulting value is shown in **Table 9**.

***Table 9**. Attainment Areas and Fecal Indicator Bacteria Load Reduction Goals*

Attainment Area	LDC Station	Subwatersheds	Weighted Average *E. coli* Reduction Target
Headwaters	11314	1, 2, 3 and 4	49%
Downstream	11313	5, 6, 7 and 8	63%

With the exception of a 17% improvement suggested in low flow conditions on Walnut Creek, LDC results for dissolved oxygen did not indicate the need for improvement. No specific percentage goals were developed for dissolved oxygen in the two attainment areas designated for this watershed. However, the LDCs for dissolved oxygen offer a means to evaluate the relative health of the system in regard to dissolved levels, which may be used by stakeholders to shape future decisions about implementation measures. It should also be noted that this data may not represent the full variability of dissolved oxygen conditions, so this should not be taken to indicate no improvement of dissolved oxygen is warranted at the attainment area or overall watershed level.

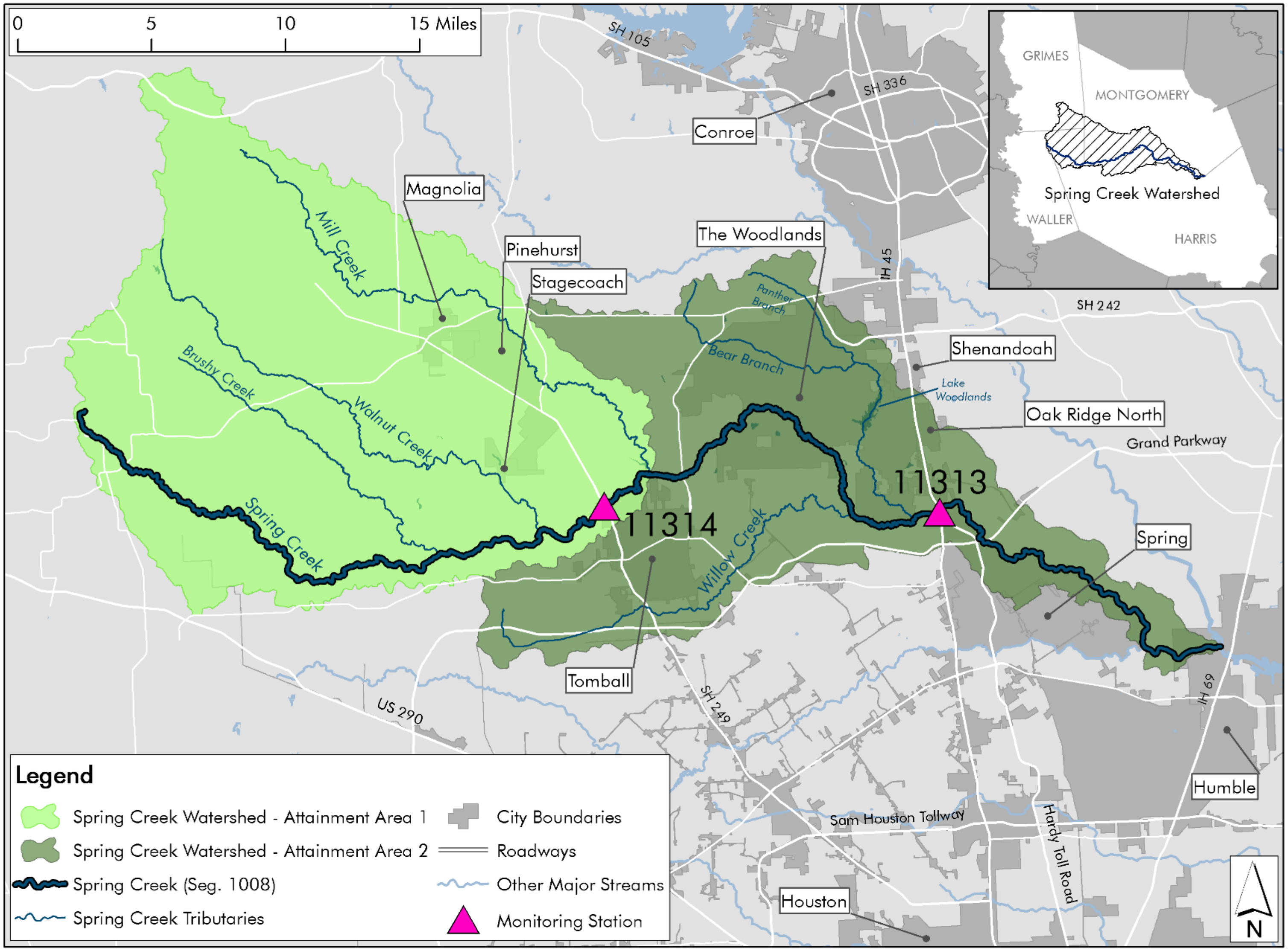

***Figure 17.** Fecal Indicator Bacteria Attainment Areas*

SECTION 5: SELECT EVALUATIONS

5.1 Overview

SELECT is a GIS-based tool for estimating potential fecal bacteria loads in a watershed area developed by the Spatial Sciences Laboratory and the Biological and Agricultural Engineering Department at Texas A&M University[5]. This analysis can also determine the relative contributions of fecal indicator bacteria made by a range of potential sources, and expresses source contribution data spatially by subwatershed. SELECT analyses result from the combination of land use and land cover data, known source locations (e.g. outfalls), literature assumption values for nonpoint sources (e.g. pet waste, livestock census data, wildlife population density), and stakeholder input. The model does not account for instream loading or other natural processes which may affect fecal bacteria concentrations, nor does it estimate the relative proximity of loading sources to the waterway. Therefore, all references to load estimates in this section refer to potential source loads and not necessarily the actual amount of fecal bacteria transported into the streams and tributaries of the Spring Creek Watershed.

In order to meet the needs of this project, modifications to the original SELECT model were made. The first of these modifications is the use of buffers or zones within a specified distance from a feature (in this case, waterways) to differentiate source load estimations by proximity to streams. Loads generated adjacent to streams are more likely to contribute to instream loading. Because the original SELECT model cannot account for fate and transport of pollutant loads, incorporating buffers around riparian corridors and assigning lower loading rates to sources located in areas outside the buffer minimizes overrepresentation of sources located farther from waterways. Without this consideration, false equivalencies could be interpreted between loads of equal size but different location relative to riparian corridors. For the purposes of this project, 100 percent of the waste generated by sources within a 300-foot buffer zone was assumed to impact waterways. For sources located in areas outside this zone, only 25 percent of the total waste was assumed to be transmitted to the stream network. For sources with no associated spatial data (e.g. deer population density per acre), uniform distribution was assumed for appropriate land uses both inside and outside the buffer boundaries.

The second modification made to the original design of the SELECT model was to estimate fecal bacteria loading changes associated with increased development in five-year increments throughout the next 25 years. By accounting for changes in spatial distribution and magnitude of source loads related to predicted changes in land use between current conditions[6] and the year 2045, reduction estimates can be anticipated at the loading rate observed in the present day and those projected in the future. As with any forecasting effort, a certain level of uncertainty is expected with these predictions especially as they relate to sources assumed to be linked to land use types. For example, in this model, wildlife populations are assumed to decrease as developed area increases within the watershed. This does not account for the adaptability of wildlife to consolidate or redistribute within the watershed area. Further monitoring and assessments of such sources should be incorporated into the management recommendations of the WPP in order to more accurately account for these factors and counteract this uncertainty.

[5] Additional information about SELECT can be found at http://ssl.tamu.edu/media/11291/select-aarin.pdf. Information about specific implementation of SELECT for this project can be found in the project modeling QAPP.
[6] At the time of this report, the most updated land use data represents parcel allocations in the year 2018 for Waller, Harris, and Montgomery Counties (Grimes County not included from regional data).

5.2 Source Survey

Determining potential sources of fecal waste as identified by fecal indicator bacteria is the first step toward developing SELECT analyses. To do this, source surveys or characterizations of known and estimated loading impacts specific to the watershed area are conducted by evaluating spatial data, land use estimates, imagery reconnaissance, and stakeholder feedback. Project staff considered the following factors in their development of the source survey of the Spring Creek Watershed:

- Known Sources – spatially referenced data typically associated with permit locations including:
    - Wastewater treatment facility (WWTF) locations and discharge monitoring reports,
    - Permitted onsite sewage facility (OSSF) locations,
    - Concentrated animal feeding operation (CAFO) locations and violations, and
    - Sanitary sewer overflow (SSO) records.
- Land Cover and Land Use Analyses – spatial distribution of specific land cover types within the watershed and respective to each subwatershed were estimated based on national land cover datasets and H-GAC proprietary data.
- Imagery Reconnaissance – aerial imagery, online map assets such as Google Maps, Google Streetview and Google Earth, and stakeholder feedback were used to identify source locations and discussion points to review with stakeholders.
- Stakeholder Feedback – insight and engagement of the local community is a critical component of this analysis and to the overall understanding of the watershed area. Stakeholder knowledge was shared at partnership meetings, one-on-one meetings with local parties, and one-on-one meetings with regional experts and agencies such as the Texas Parks and Wildlife Department, Texas State Soil and Water Conservation Board, and others.

Throughout the modeling process, stakeholders will be consulted regularly at partnership meetings, small workgroups and in one-on-one discussions to review model results and recommend revisions as needed. As mentioned previously, the source survey provides a general outline on which the SELECT models and discussions with stakeholders can be based.

Preliminary results of the source survey by general category are summarized in **Table 10**. These early estimates may differ from outcomes of the SELECT models and do not account for increases or decreases in loading associated with watershed change over time. Following the table, modeled sources will be discussed in detail and results of SELECT analyses will be shown spatially and organized by subwatershed to display relative contribution to the total watershed load.

Table 10. *Fecal Indicator Bacteria Source Survey*

Category	Source	Origin	Estimated Extent (Preliminary)
Human Waste	WWTFs	Improperly treated sewage from permitted outfalls	Minor
	OSSFs	Failing or improperly routed OSSFs	Moderate
	SSOs	Untreated sewage from wastewater collection systems	Minor to Moderate (locally)
	Direct Discharge	Untreated wastes from areas without OSSF or WWTF service	Minor
	Land Deposition	Improperly treated or applied sewage sludge	Minor
Agriculture	Cattle	Runoff or direct deposition	Moderate
	Horses	Runoff or direct deposition	Minor to Moderate (locally)
	Sheep & Goats	Runoff or direct deposition	Minor
	Pigs	Runoff	Minor
	CAFOs	Improperly treated discharge from permitted facilities	Not Expected
Wildlife	Deer	Runoff or direct deposition	Minor to Moderate (locally)
	Birds	Direct deposition	Minor, No Data
	Bats	Direct deposition	Minor, No Data
	Other Wildlife	Runoff or direct deposition	Moderate, No Data
Domestic Animals	Dogs (pets)	Runoff	Major
	Dogs (feral)	Runoff	Minor (locally)
	Cats (pets)	Runoff	Not Expected
	Cats (feral)	Runoff	Not Expected to Minor
Invasive Animals	Feral Hogs	Runoff or direct deposition	Moderate
Other	Dumping	Runoff or direct deposition	Minor (locally)
	Sedimentation	Erosion or mining operations	Not Applicable[7]

[7] While not a source of fecal bacteria, suspended sediment in waterways can decrease die-off from insolation, etc.

WWTFs

Wastewater utilities serve a number of communities throughout the watershed and occur in various sizes and capacities. For areas outside city boundaries, centralized waste treatment is most commonly managed by municipal utility districts and other districts. Considering all types of WWTFs, 78 permitted facilities are found within the watershed boundary of Spring Creek. Discharge monitoring report data was available for 61 of these facilities and was incorporated into the SELECT model. Size of WWTFs vary greatly throughout the watershed and range between capacities of less than 0.1 millions of gallons per day (MGD) to 10 MGD.

According to the results of a previous data review[8], WWTFs in the Spring Creek Watershed are not expected to be major contributors to fecal indicator bacteria loading. However, as the risks associated with human waste processed by WWTFs can be considerable in the event of improper treatment or other localized incidents, it is important to consider estimates of potential WWTF loadings in the overall SELECT model. These estimates are derived by multiplying the total discharge capacity of each facility by the state water quality standard for fecal bacteria. For future projections, models continued to estimate fecal bacteria loads at the state standard but adapted flow rates to reflect the projected increase in the number of households within service area boundaries. As many facilities discharge well below their maximum permitted rates, this results in a potential overestimation of fecal bacteria loading from this source. As noted previously, this method is still deemed appropriate for this watershed in order to account for exceedances or variations throughout daily discharges that could have greater impacts to public health.

Current WWTF loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 18**. As loads were estimated to reflect the impacts of direct outfalls, all results are indicated within the buffer zone surrounding the watershed stream network. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 11**. In **Figure 19**, forecasted total watershed loads from WWTFs are plotted in five-year increments through the year 2045.

[8] See the Water Quality Data Analysis Summary Report, available at http://springcreekpartnership.com.

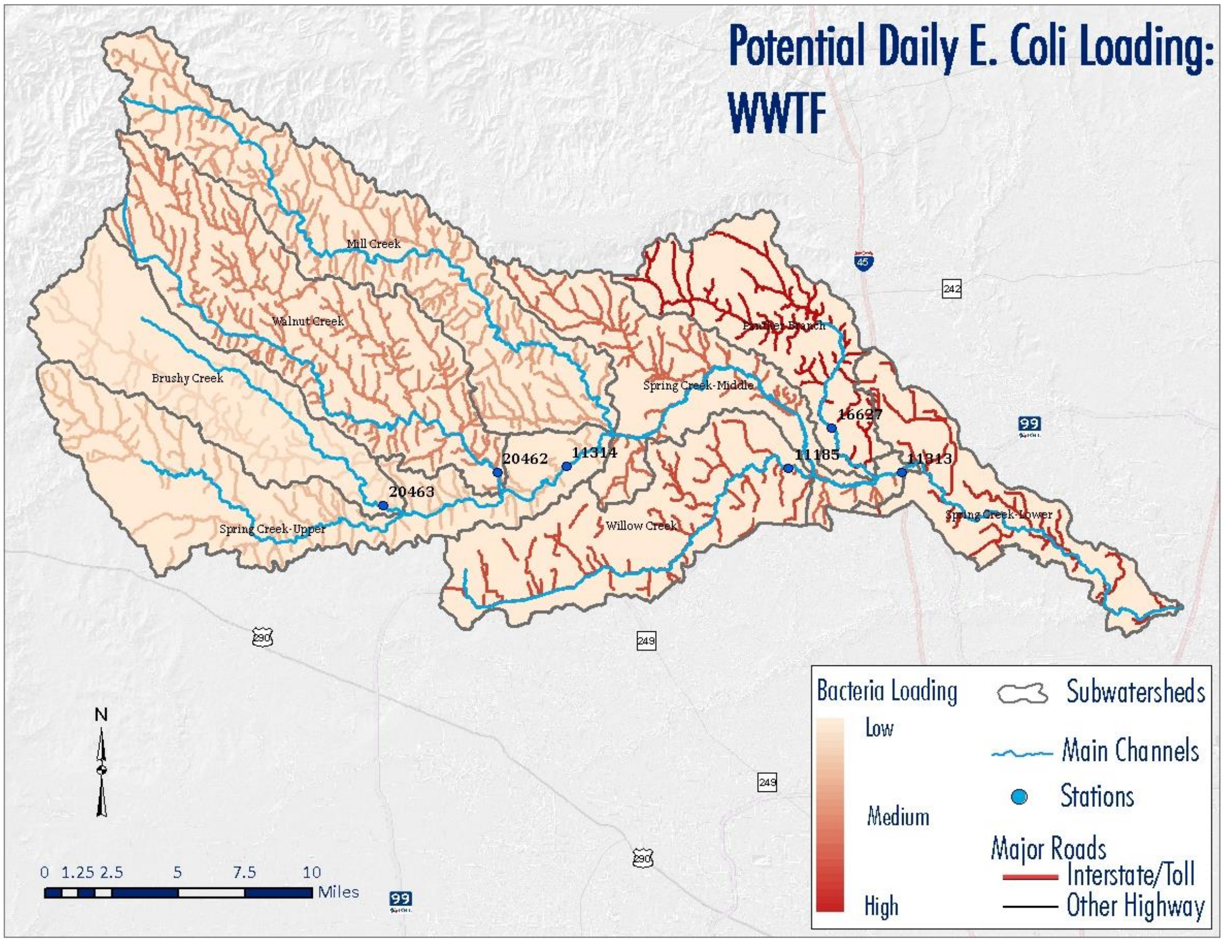

Figure 18. E. coli *Loadings from WWTFs by Subwatershed*

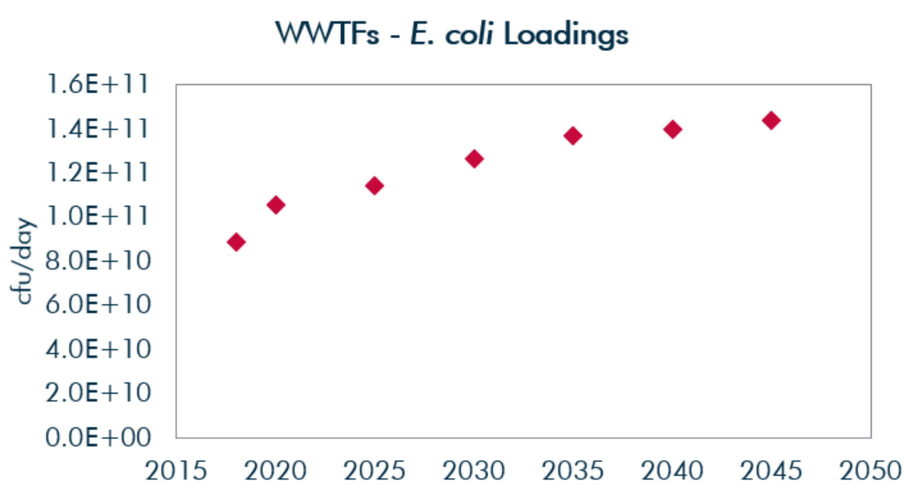

Figure 19. *Future* E. coli *Loadings from WWTFs*

Table 11. Wastewater Outfalls and Loadings by Subwatershed

	# of Outfalls	Load Estimate	Subwatershed Percent of Total Load
1	9	1.66E+09	2%
2	7	2.03E+09	2%
3	1	1.91E+07	0%
4	6	3.05E+08	0%
5	24	1.76E+10	20%
6	12	7.67E+09	9%
7	6	3.49E+10	39%
8	13	2.45E+10	28%
Total	**78**	**8.87E+10**	**100%**

In the Spring Creek Watershed, fecal bacteria loading from WWTFs is more prevalent in developed areas where WWTF densities and sizes are greater. When considering the expansion of development throughout the watershed in the coming 25 years, overall fecal bacteria loading in the watershed is expected to increase. However, the values of fecal bacteria loads delivered to Spring Creek and its tributaries via WWTFs are several orders of magnitude lower than those estimated for other modeled sources described in this section. Therefore, WWTFs are still considered only minor contributors to overall potential fecal bacteria loading in the watershed. These sources are still important to consider in the WPP however, as the health risks associated with any introduction of improperly treated human waste by WWTFs into the watershed are far greater than those associated with other sources[9].

OSSFs

While centralized wastewater treatment is more common in developed areas, OSSFs are more likely to be used in parts of the watershed outside service area boundaries such as rural communities. OSSFs such as septic and aerobic systems are an efficient and effective way to manage wastewater, however, aging or improperly maintained units run the risk of failing. Significant sources of fecal bacteria can be transmitted to waterways in the event of an OSSF failure.

To estimate OSSF distribution throughout the Spring Creek Watershed, the spatial data of permitted units collected under a 604(b) agreement between H-GAC and TCEQ, and quality assured under the auspices of that contract[10]. Where portions of the watershed overlapped with areas outside the H-GAC region such as Grimes County, Texas State Data Center population projections were used. This dataset in not comprehensive as some data may be subject to insufficiencies such as a lack of geocoding. This uncertainty is accounted for in the SELECT model through an estimation of any unrecorded or otherwise unpermitted OSSF units in the watershed area based on land use. Unpermitted OSSF units throughout the watershed were estimated by assessing the number of occupied parcels outside service area boundaries that were not indicated in the permitted OSSF database. Loading rates observed from improperly maintained and failed systems were used to estimate total load contribution from OSSFs. Literature values for OSSF failure rates range between 10 and 15%. For the purposes of this report, a conservative estimate of 10% failure rate was

[9] Results of quantitative microbial risk assessment studies, including work done in the Leon River (https://oaktrust.library.tamu.edu/handle/1969.1/158640) have indicated that sources with equivalent loads may have pronounced differences in expected microbial risk, with human sources being the most potentially problematic.

[10] Use of this acquired data is detailed in the project modeling QAPP for this project.

applied to the combined total number of permitted units and unpermitted units indicated by the current dataset and for each of the five-year interval projections through 2045. This method has been used for watershed projects in nearby areas and was supported by local stakeholders.

Current OSSF loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 20**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 12**. In **Figure 21**, forecasted total watershed loads from OSSFs are plotted in five-year increments through the year 2045.

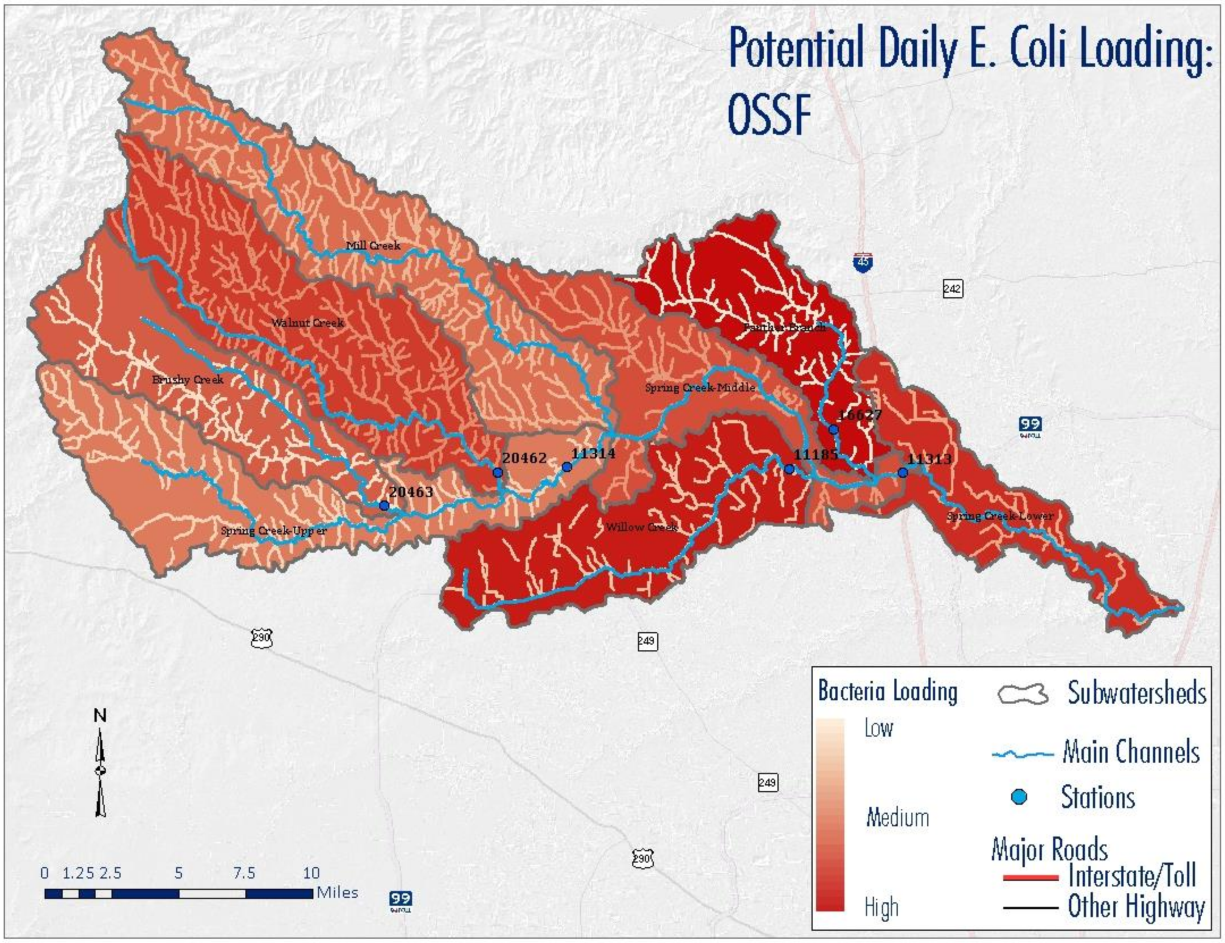

***Figure 20**. E. coli Loading from OSSFs by Subwatershed*

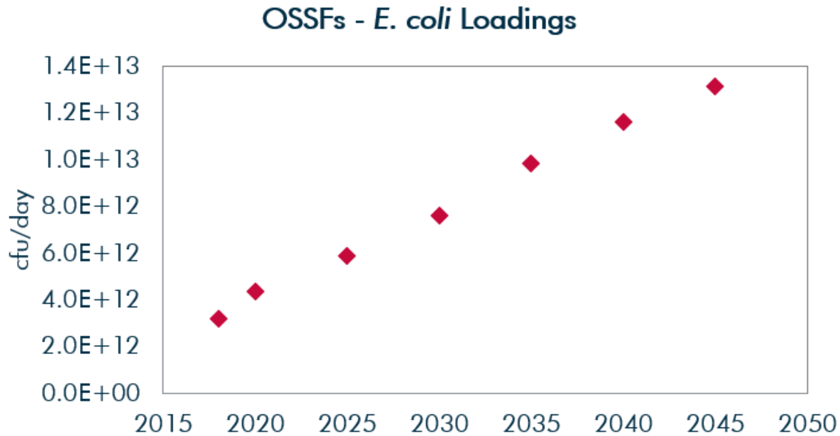

Figure 21. *Future* E. coli *Loadings from OSSFs*

Table 12. *OSSFs and Loadings by Subwatershed*

	OSSFs Outside Buffer	OSSFs Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
SW1	2012	635	1.87E+11	5.89E+10	8%
SW2	4070	1303	3.77E+11	1.21E+11	16%
SW3	2199	539	2.04E+11	5.00E+10	8%
SW4	1882	544	1.75E+11	5.05E+10	7%
SW5	4977	610	4.62E+11	5.66E+10	16%
SW6	3758	999	3.49E+11	9.27E+10	14%
SW7	5286	398	4.90E+11	3.69E+10	16%
SW8	4446	886	4.12E+11	8.22E+10	15%
TOTAL	**28630**	**5914**	**2.66E+12**	**5.49E+11**	**100%**

OSSF loadings are expected to continue to increase through 2045 as residential development increases throughout the watershed. These future projections are still based on an assumed 10% failure rate; however, stakeholders may choose to incorporate continued monitoring of these systems in the coming years as OSSF installments age. In the event that systems are found to exceed the 10% failure rate, a new percentage value may be determined. Failure rates among these newly developed systems are likely to be lower as regular maintenance will be required by permit. As improperly maintained OSSFs could also have a negative impact on property values, communities may be more likely to adhere to routine maintenance standards. However, as the health risks associated with any introduction of improperly treated human waste by OSSFs into the watershed are far greater than those associated with other sources, these sources are still important to consider in the WPP.

Dogs

Domestic and feral dog populations are significant contributors to fecal bacteria contamination in densely developed areas, and are a common source of loading in the greater Houston region. Waste from other domestic pets (e.g., cats) is typically managed through collection in waste receptacles, whereas dog waste is more likely to be deposited directly into the environment.

For SELECT analysis, fecal bacteria loading from dog populations will be estimated by assessing pet ownership. Statistical data for Texas established by the American Veterinary Medical Association[11] of 0.6 dogs per household were used in SELECT models. This value was applied to current household data and future projections through 2045. This method has been used in other WPP projects with similar land use and drainage areas. Additionally, stakeholder feedback received during reviews of model results lead to a slight revision of these assumptions based on the specific characteristics of the Spring Creek Watershed. Stakeholder insights on recent efforts to control pet waste including development of pet waste station infrastructure, and community use of waste bags, etc. already underway in the watershed. To account for this, the estimated load based on 0.6 dogs per household was further reduced by 20%.

Current dog loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 22**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 13**. In **Figure 23**, forecasted total watershed loads from dogs are plotted in five-year increments through the year 2045.

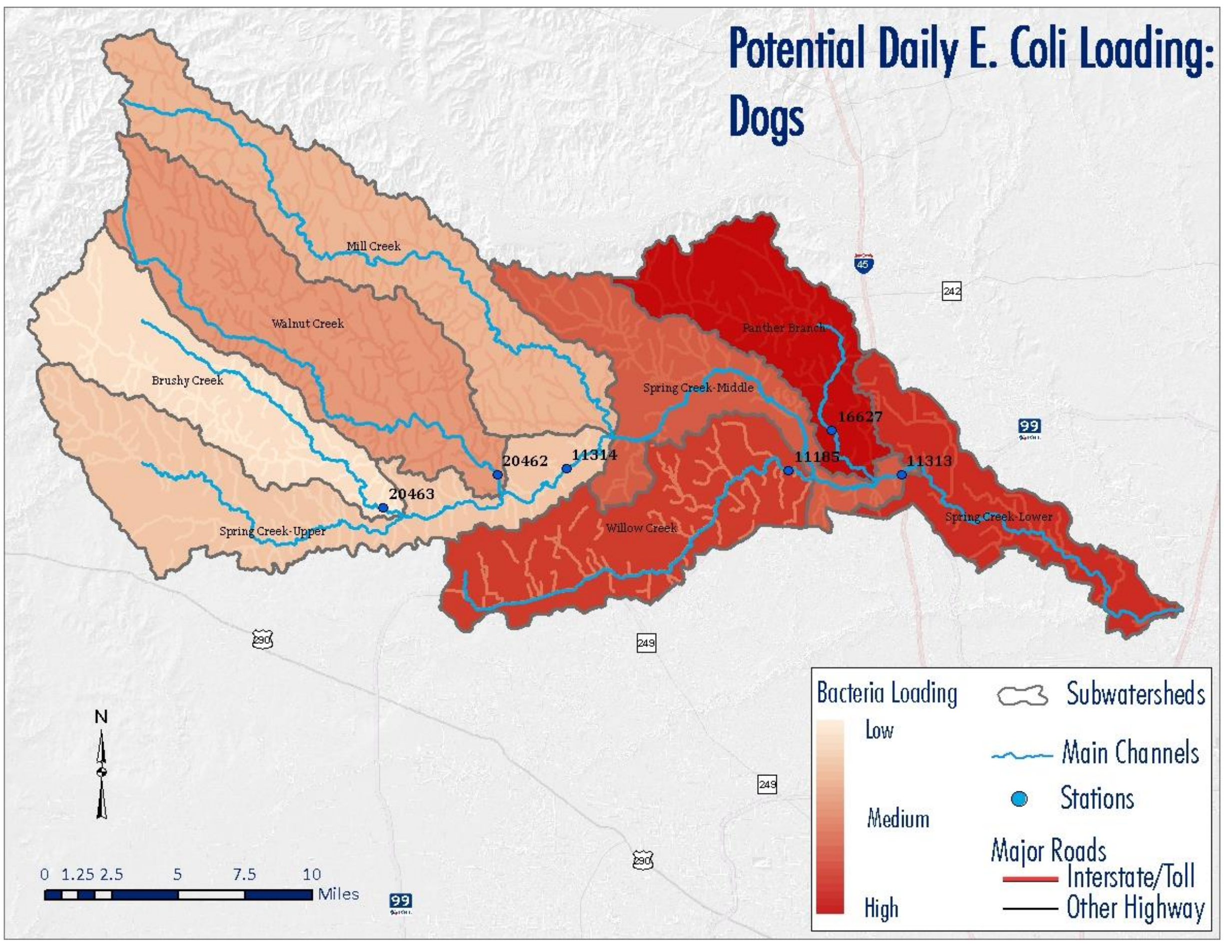

Figure 22. E. coli *Loading from Dogs by Subwatershed*

[11] https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx

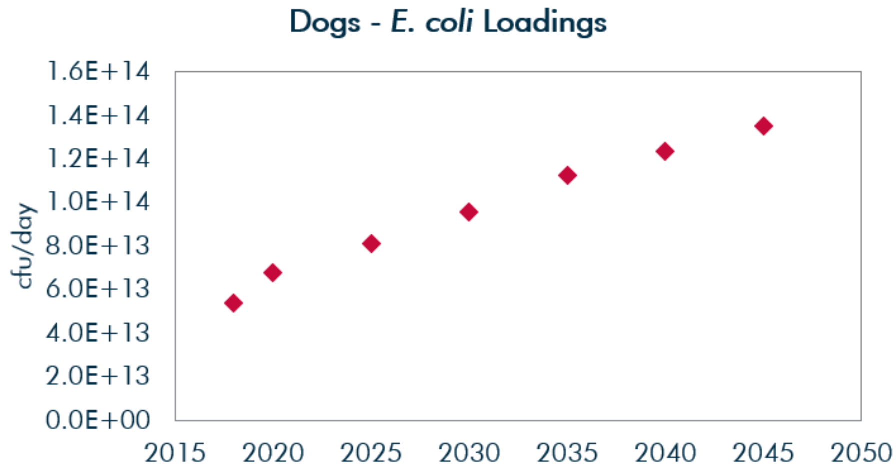

Figure 23. *Future* E. coli *Loading from Dogs*

Table 13. *Dogs and Loadings by Subwatershed*

	Dogs Outside Buffer	**Dogs Within Buffer**	**Load Outside Buffer**	**Load Within Buffer**	**Subwatershed Percent of Total Load**
SW1	2313	750	1.16E+12	1.50E+12	5%
SW2	3369	977	1.68E+12	1.95E+12	7%
SW3	1319	323	6.60E+11	6.47E+11	2%
SW4	2282	498	1.14E+12	9.96E+11	4%
SW5	10101	1433	5.05E+12	2.87E+12	15%
SW6	8313	2002	4.16E+12	4.00E+12	15%
SW7	20050	3425	1.00E+13	6.85E+12	31%
SW8	13342	2179	6.67E+12	4.36E+12	21%
Total	**61089**	**11587**	**3.05E+13**	**2.32E+13**	**100%**

Dog ownership and therefore dog waste is most densely concentrated in the more developed subwatersheds on the east side of the Spring Creek Watershed. Load values associated with this waste are the highest of any modeled sources in current and future conditions. As the human population of the watershed increases with expanding residential development in the coming years, dog populations will also increase.

Cattle

Agricultural land, grassland and pastures are most common in the western reaches of the watershed with smaller concentrated areas of these land cover types distributed throughout. National livestock populations including cattle were most recently assessed in a 2017 census by the United States Department of Agriculture. Census data are available by county and are not specific to the watershed area. To estimate cattle in the Spring Creek Watershed, a ratio of each county's portion of the watershed's acreage in appropriate land cover types to that of the respective county as a whole was applied to agricultural census data from each of the four counties. This approach ensures that the density of cattle in a county's applicable land cover acreage (grassland and pasture/hay) was the same as the density in the watershed's applicable land use acreage. After stakeholder review, this initial estimate was modified further to better reflect observed conditions. Stakeholders indicated that initial estimates distributing cattle populations solely in grassland and pasture/hay land cover areas were inaccurate due to an overestimation of the usage of those areas by cattle. To account for fallow lands or smaller parcels of pasture and grassland not grazed be herds, cattle population estimates were adjusted to 90% of the initial estimate in these land cover areas. Further, stakeholders noted that cattle occasionally use forest and shrubland especially when adjacent to waterways. This observation was reflected in the model by distributing 10% of the cattle population estimate into forested areas within the riparian buffer.

Current cattle loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 24**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 14**. In **Figure 25**, forecasted total watershed loads from cattle are plotted in five-year increments through the year 2045.

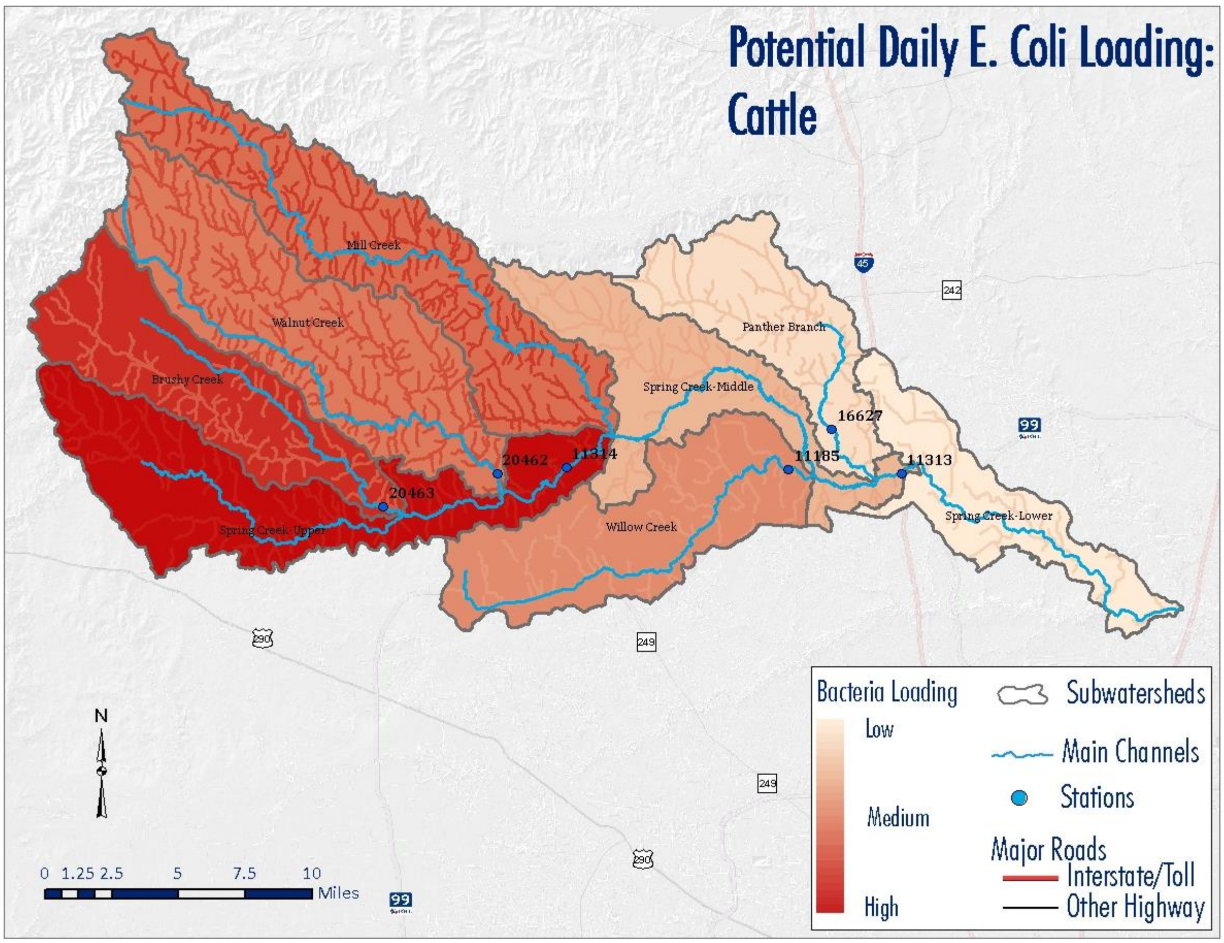

Figure 24. E. coli *Loading from Cattle by Subwatershed*

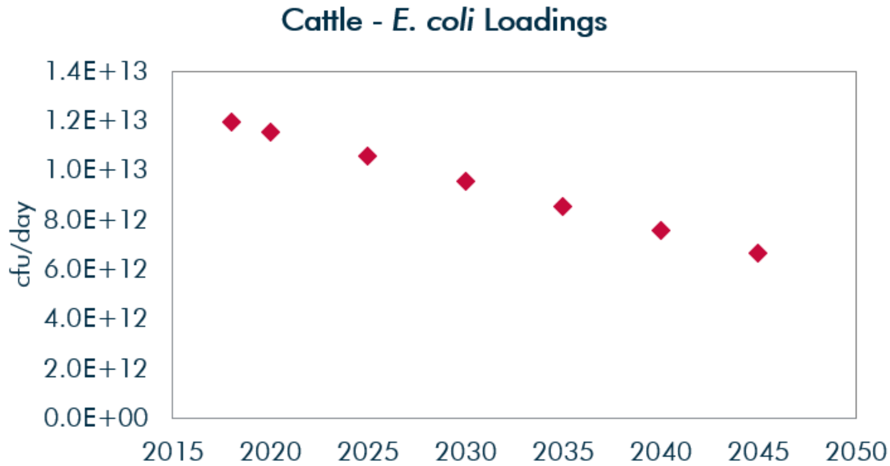

Figure 25. *Future* E. coli *Loading from Cattle*

Table 14. *Cattle and Loadings by Subwatershed*

	Cattle Outside Buffer	Cattle Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
SW1	1105	456	7.5E+11	1.2E+12	17%
SW2	916	407	6.2E+11	1.1E+12	14%
SW3	1996	376	1.3E+12	1.0E+12	20%
SW4	3243	655	2.2E+12	1.8E+12	33%
SW5	798	164	5.4E+11	4.4E+11	8%
SW6	276	122	1.9E+11	3.3E+11	4%
SW7	97	63	6.5E+10	1.7E+11	2%
SW8	61	52	4.1E+10	1.4E+11	2%
Total	**8492**	**2295**	**5.7E+12**	**6.2E+12**	**100%**

Cattle loads from western subwatersheds are greater compared to eastern subwatersheds in more developed areas. Projections of future fecal bacteria loading by cattle decrease over the next 25 years as land use changes are predicted to push residential development farther west throughout the Spring Creek Watershed.

Horses

Similar to cattle, horse population estimates were calculated based on agricultural census data modified by the ratio of watershed area of relevant land use types to total county area. Based on stakeholder feedback, horse populations were similarly distributed 90% to pasture and grassland, and 10% to forested area within the riparian buffer. This method assesses only the horses designated for livestock use in the watershed. Horses owned for recreational purposes may not be well represented by these estimates.

Current horse loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 26**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 15**. In **Figure 27**, forecasted total watershed loads from horses are plotted in five-year increments through the year 2045.

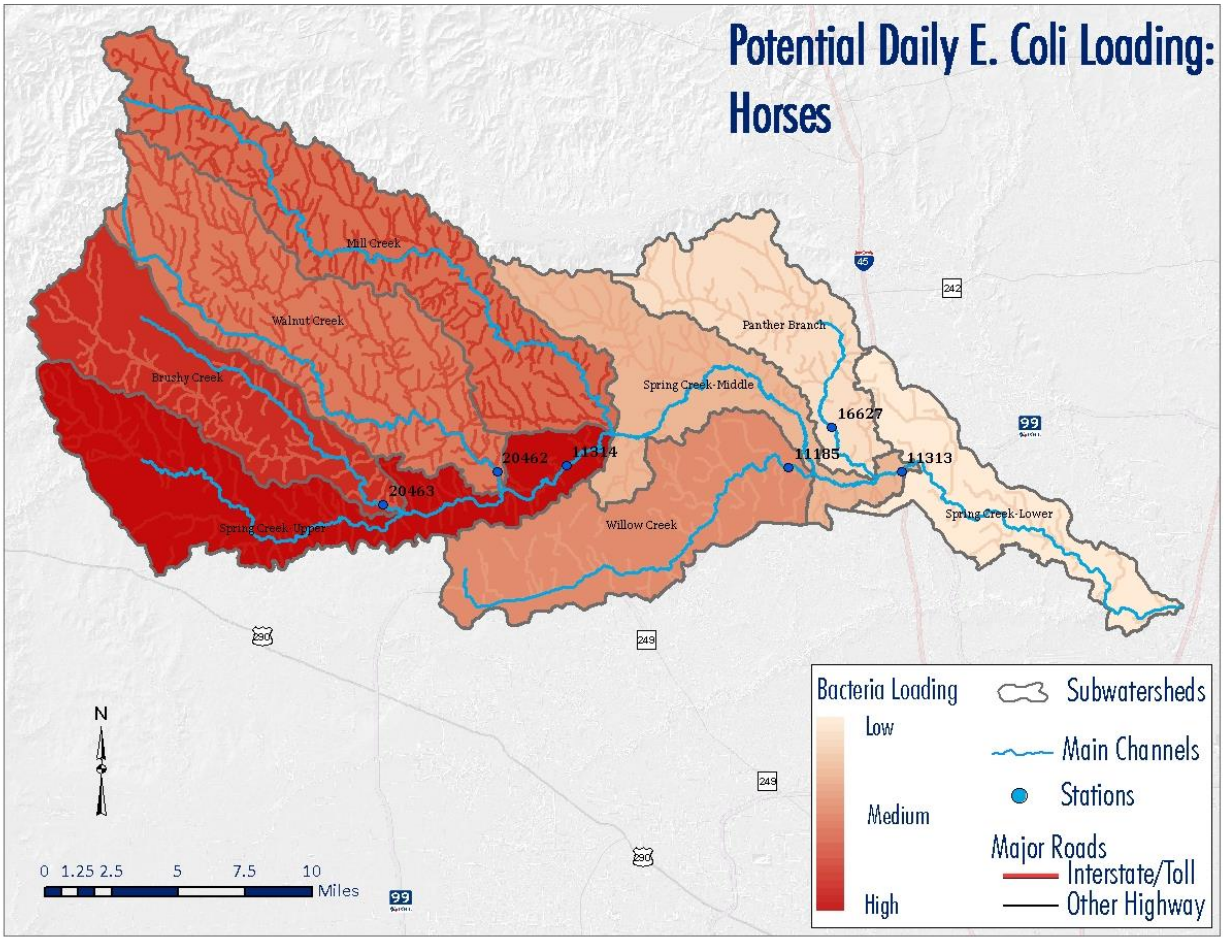

Figure 26. E. coli *Loading from Horses by Subwatershed*

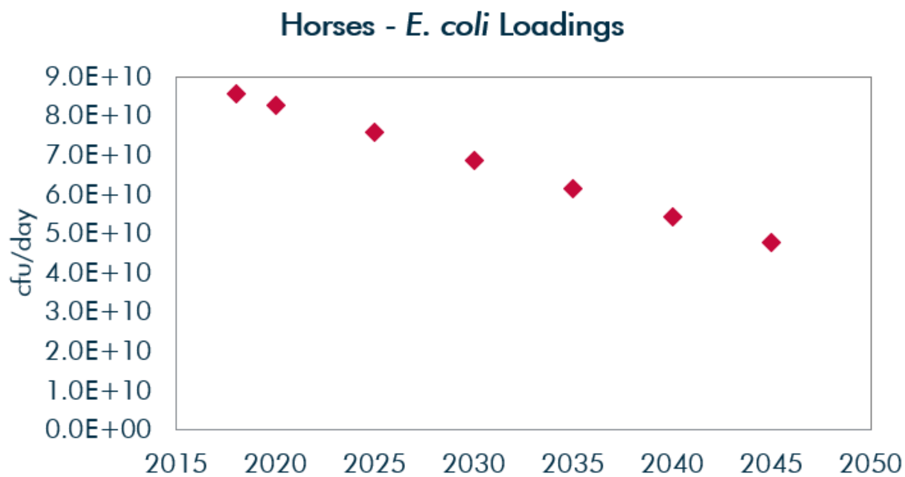

Figure 27. *Future* E. coli *Loadings from Horses*

Table 15. *Horses and Loadings by Subwatershed*

	Horses Outside Buffer	Horses Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
SW1	102	42	5.3E+09	8.8E+09	17%
SW2	84	38	4.4E+09	7.9E+09	14%
SW3	184	35	9.7E+09	7.3E+09	20%
SW4	299	60	1.6E+10	1.3E+10	33%
SW5	74	15	3.9E+09	3.2E+09	8%
SW6	25	11	1.3E+09	2.4E+09	4%
SW7	9	6	4.7E+08	1.2E+09	2%
SW8	6	5	2.9E+08	1.0E+09	2%
Total	**783**	**212**	**4.1E+10**	**4.4E+10**	**100%**

Model results for horse driven fecal bacteria loading in the watershed look similar to those of cattle aside from the smaller relative loading contributions. Another similarity between the two modeled sources is that horse populations are expected to decrease over time as land development expands throughout the watershed.

Sheep and Goats

Sheep and goat populations represent a smaller portion of the livestock in the watershed, but still retain a presence in rural areas. Both animal populations are grouped into a single statistic in the agricultural census. To estimate the size of these populations, the same method used for cattle and horses was applied to agricultural census data for sheep and goats. Based on stakeholder feedback, sheep and goat populations were similarly distributed 90% to pasture and grassland, and 10% to forested area within the riparian buffer.

Current sheep and goat loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 28**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 16**. In **Figure 29**, forecasted total watershed loads from sheep and goats are plotted in five-year increments through the year 2045.

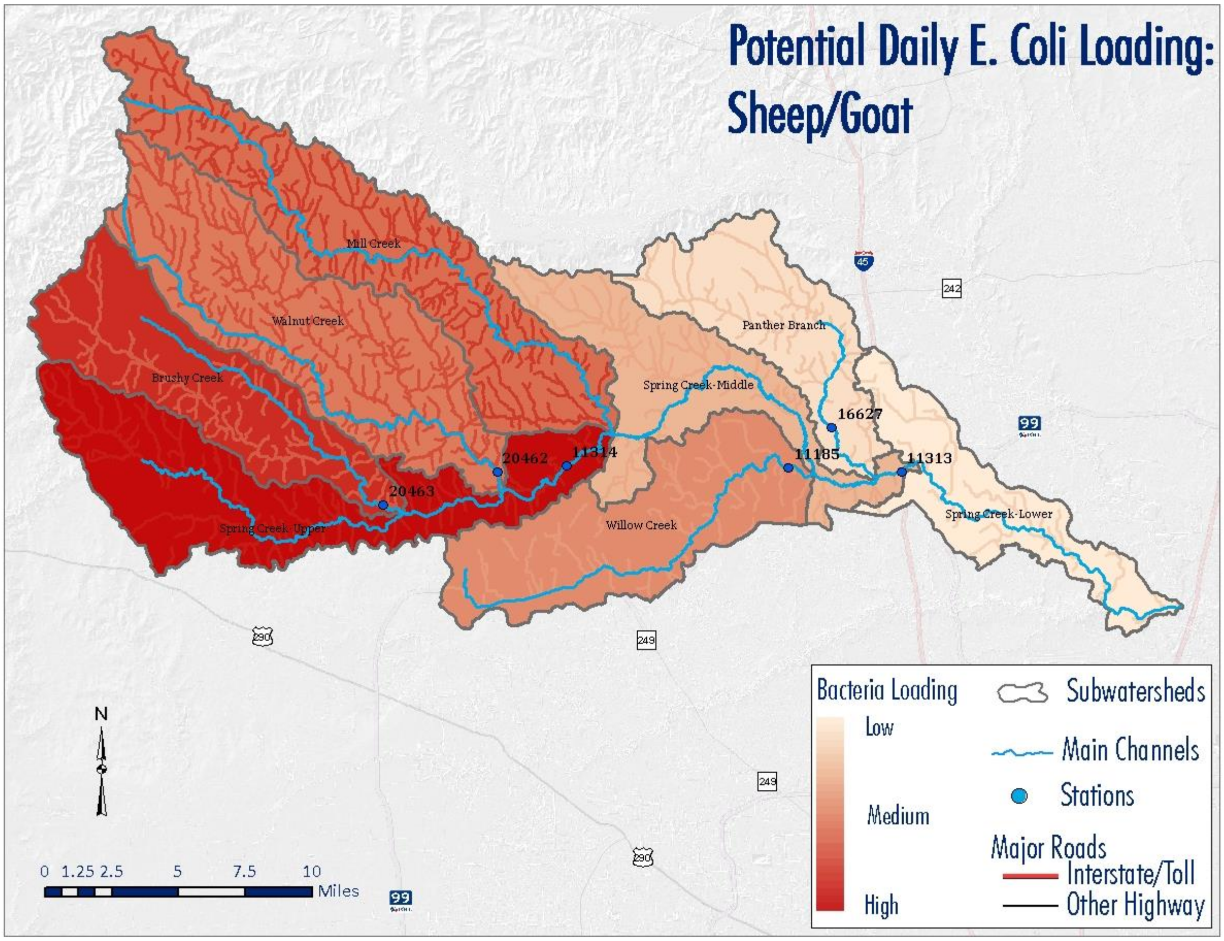

Figure 28. E. coli *Loadings from Sheep & Goats by Subwatershed*

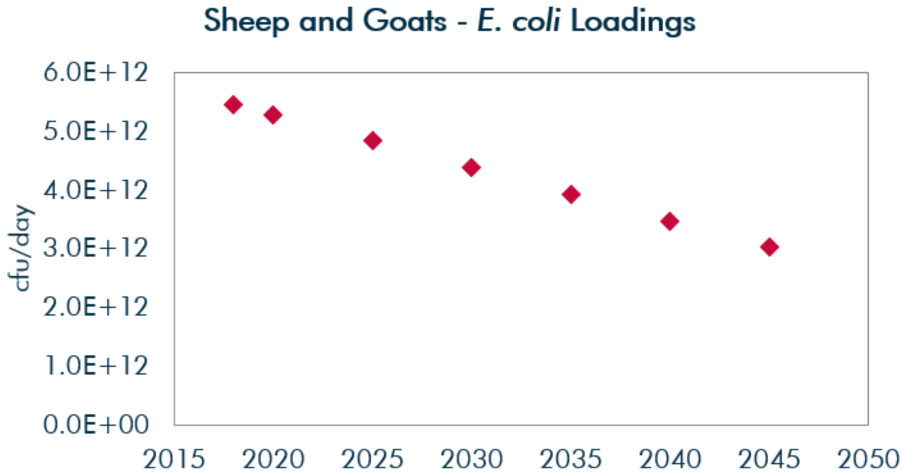

Figure 29. *Future* E. coli *Loadings from Sheep & Goats*

Table 16. *Sheep & Goats and Loadings by Subwatershed*

	Sheep & Goats Outside Buffer	Sheep & Goats Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
SW1	151	63	3.4E+11	5.6E+11	17%
SW2	126	56	2.8E+11	5.0E+11	14%
SW3	274	52	6.2E+11	4.6E+11	20%
SW4	445	90	1.0E+12	8.1E+11	33%
SW5	109	22	2.5E+11	2.0E+11	8%
SW6	38	17	8.5E+10	1.5E+11	4%
SW7	13	9	3.0E+10	7.8E+10	2%
SW8	8	7	1.9E+10	6.4E+10	2%
Total	**1164**	**315**	**2.6E+12**	**2.8E+12**	**100%**

Potential source load distribution and relative contribution by subwatershed are fairly similar between sheep and goats and other livestock animals such as horses and cattle. The greatest loading is expected to occur in the western, headwater section of the watershed whereas subwatersheds in the east show fewer impacts. As with other agricultural animals, sheep and goat populations are expected to decrease over time as land use trends toward development.

Deer

Forests and open areas in the less developed areas of the watershed provide ample habitat area for white-tailed deer. However, deer are among the few species that are adaptable to the encroachment of developed areas. Loss of natural areas may lead deer to explore larger lots of suburban and light urban development as alternative habitat. Because of this, forested areas and open and low intensity developed areas were considered as possible deer habitat for the purposes of load estimation. To estimate deer populations and their associated fecal bacteria loading potential, Resource Management Unit population density data accessed from the Texas Parks and Wildlife Department assuming 1 deer for every 40.2 acres of forest, shrubland and open developed areas. In low intensity developed areas, deer density was assumed to be 1 deer for every 80.4 acres. After consulting with stakeholders, this lower density of 1 deer per 80.4 acres was applied in additional land cover areas including pasture and grassland, wetlands, and barren land. This change was made as stakeholders agreed that deer populations are most concentrated in forested areas, but noted seeing deer in areas also used by feral hog populations. Even with this updated approach, population dynamics are not well represented with respect to movements between land cover types and possible increases in density of natural areas after the built environment extends into previously undeveloped spaces.

Current deer loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 30**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 17**. In **Figure 31**, forecasted total watershed loads from deer are plotted in five-year increments through the year 2045.

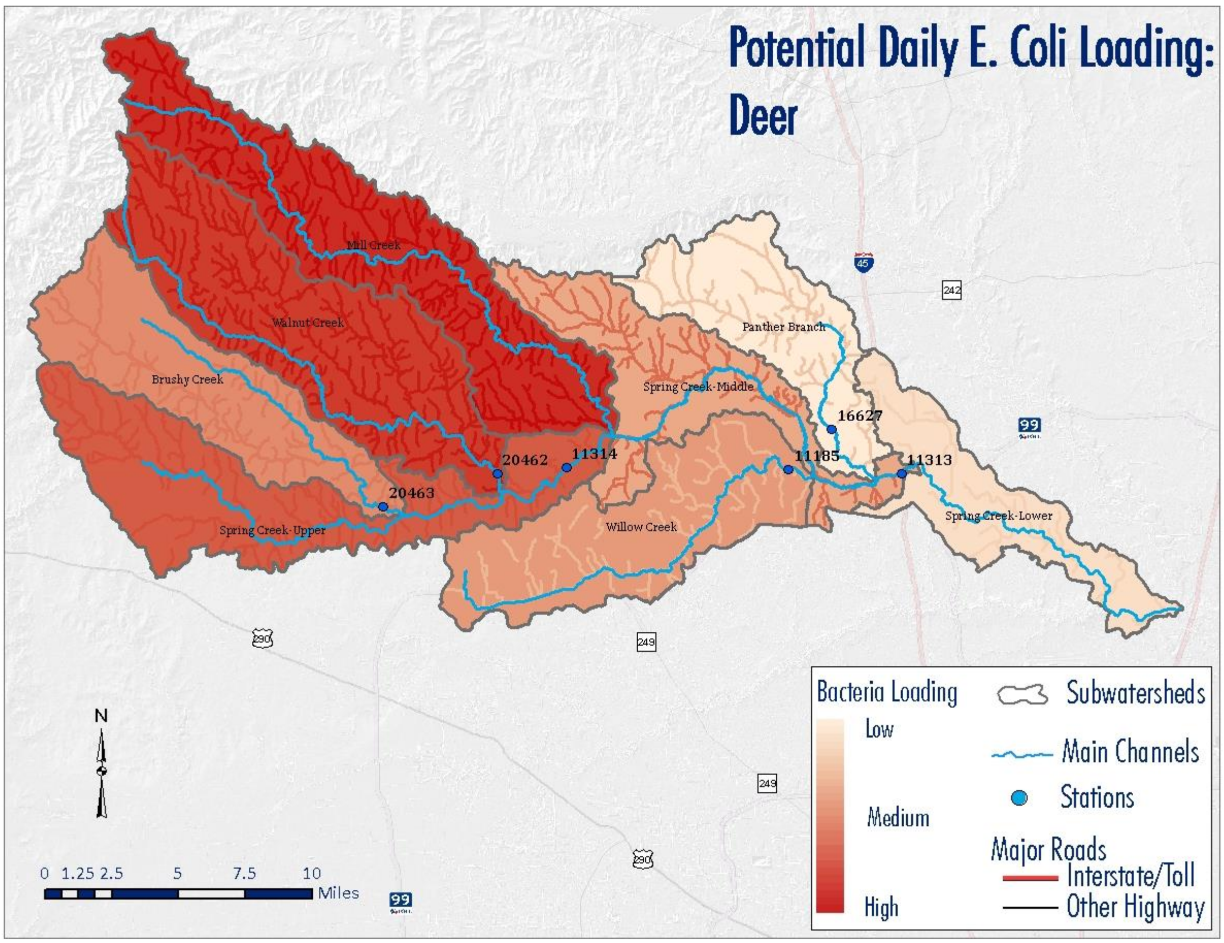

Figure 30. E. coli *Loadings from Deer by Subwatershed*

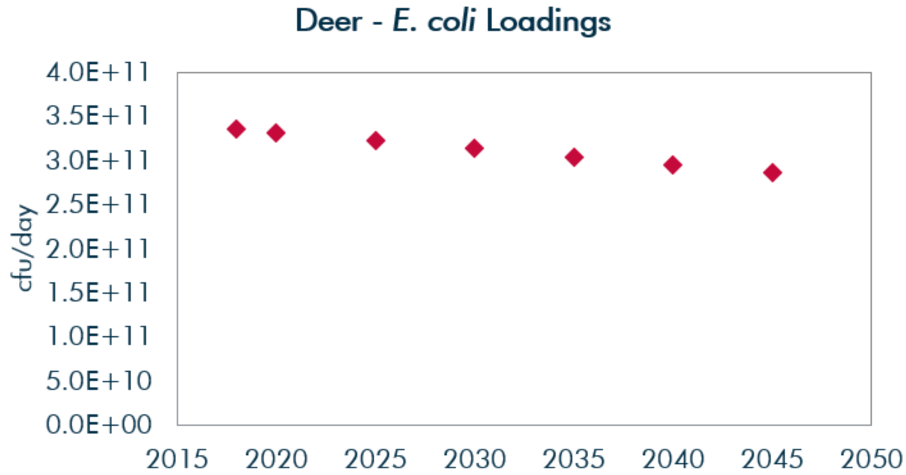

Figure 31. *Future* E. coli *Loadings from Deer*

Table 17. *Deer and Loadings by Subwatershed*

	Deer Outside Buffer	**Deer Within Buffer**	**Load Outside Buffer**	**Load Within Buffer**	**Subwatershed Percent of Total Load**
SW1	633	271	2.8E+10	4.7E+10	22%
SW2	611	256	2.7E+10	4.5E+10	21%
SW3	406	107	1.8E+10	1.9E+10	11%
SW4	464	147	2.0E+10	2.6E+10	14%
SW5	354	73	1.5E+10	1.3E+10	8%
SW6	330	109	1.4E+10	1.9E+10	10%
SW7	244	67	1.1E+10	1.2E+10	7%
SW8	246	64	1.1E+10	1.1E+10	7%
Total	**3287**	**1093**	**1.4E+11**	**1.9E+11**	**100%**

Despite their ability to adapt to more developed land areas when faced with the loss of natural habitat, deer populations in the Spring Creek Watershed are predicted to decrease slightly over time. As the SELECT model only accounts for gains and losses of fecal bacteria load pressures, migration between parcels could be underestimated.

Feral Hogs

In the Houston-Galveston region feral hogs (*Sus scrofa*) are an invasive species that negatively impact agriculture, wildlife species and their habitats, and human landscapes. Efforts to control feral hogs have been carried out by communities within the Spring Creek Watershed that have already recognized the environmental pressures associated with their populations. Feral hogs are of particular concern as carriers of diseases that can be dangerous to domestic livestock, pets, and humans. These animals are known to use land around waterways as shelter and transportation corridors between food resources, and can generate large volumes of waste where they concentrate.

Though they occur in the highest densities along riparian corridors and other natural areas, feral hogs are pervasive and can be found in all land cover types aside from heavily developed areas and open water. Population density estimates used in the SELECT model for feral hog source loads referenced land cover types in the watershed area based on AgriLife literature values[12]. Though initial estimates accounted for hogs in all land cover areas excluding development and open water, stakeholder feedback about observed hog behaviors and migration in the watershed led to a number of changes. First, the headwaters portion of the watershed which is dominated by mostly natural land cover type was assumed to have greater hog densities than the downstream portion. Secondly, hog densities were assumed to follow a gradient from heavy densities in more natural land cover type to lighter densities with increasing proximity to development. In **Table 18**, the specific allocation of hog population density based on stakeholder recommendations is described.

Table 18. *Feral hog population density estimates by attainment area and land cover type*

Land Cover Type	**Headwaters** (Upper Spring Creek, Walnut Creek, Brushy Creek, Mill Creek)	**Downstream** (Middle and Lower Spring Creek, Panther Branch, Willow Creek)
Wetlands	16.4 hogs/ square mile	16.4 hogs/ square mile
Forest and Shrubland	16.4 hogs/ square mile	16.4 hogs/ square mile
Grassland and Pasture	16.4 hogs/ square mile	12.7 hogs/ square mile
Cultivated Cropland	12.7 hogs/ square mile	12.7 hogs/ square mile
Barren Land	12.7 hogs/ square mile	12.7 hogs/ square mile
Developed Open Space	12.7 hogs/ square mile	8.9 hogs/ square mile
Low Intensity Developed	12.7 hogs/ square mile	8.9 hogs/ square mile

Current feral hog loading distributions throughout the watershed as well as relative load contribution from each of the subwatersheds draining into Spring Creek are represented in **Figure 32**. Color intensity of subwatershed areas indicates loading severity relative to the other subwatersheds and may not be directly comparable between this modeled parameter and others. Actual loading estimates by subwatershed are represented in **Table 19**. In **Figure 33**, forecasted total watershed loads from feral hogs are plotted in five-year increments through the year 2045.

[12] http://agrilife.org/feralhogs/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf

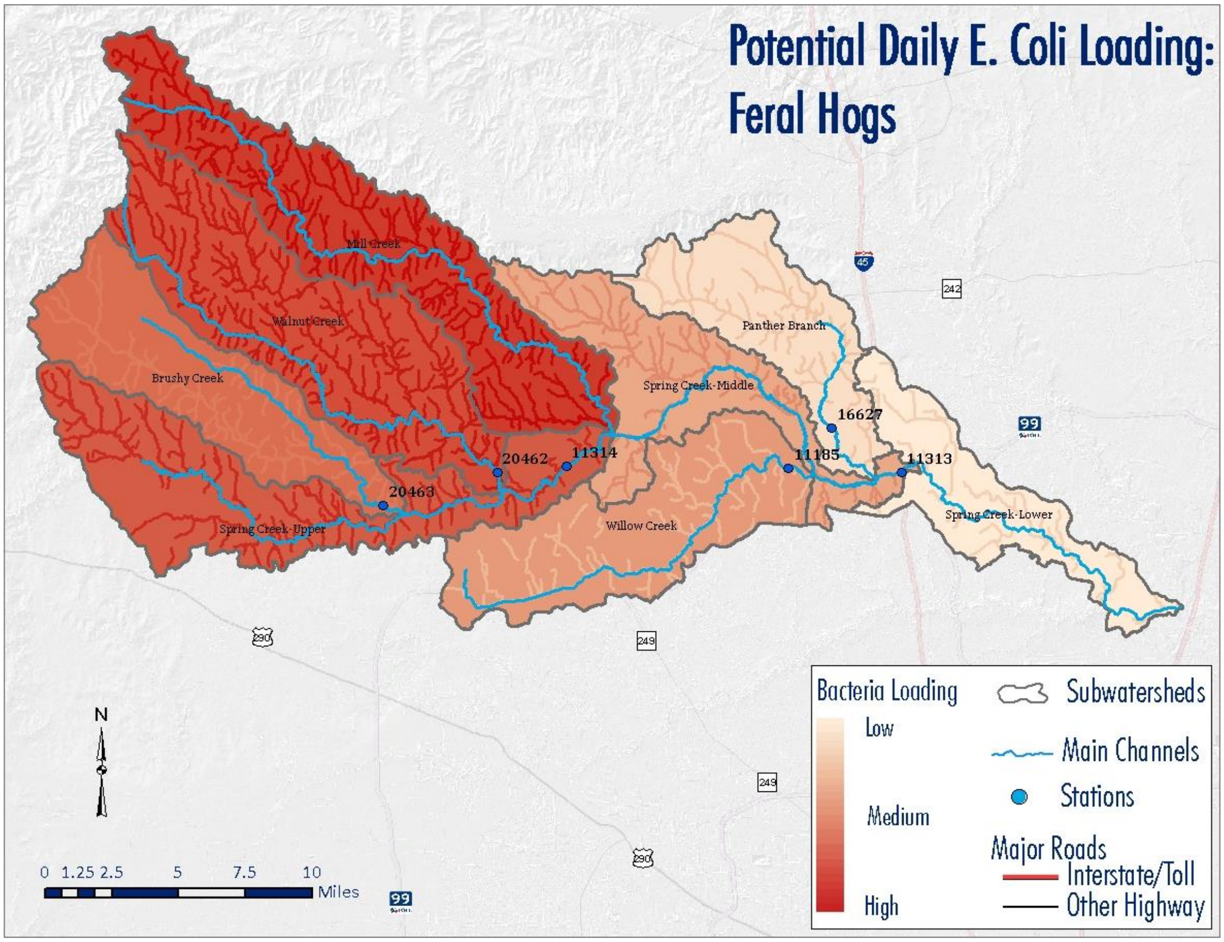

Figure 32. E. coli *Loadings from Feral Hogs by Subwatershed*

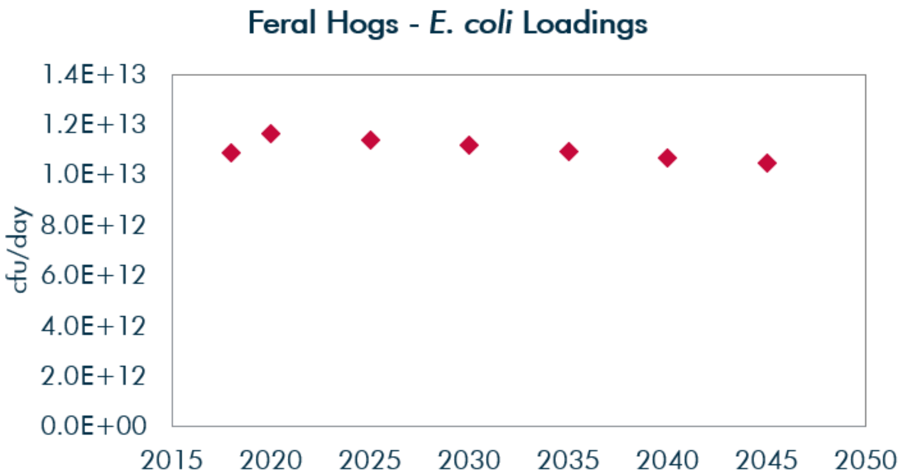

Figure 33. *Future* E. coli *Loadings from Feral Hogs*

Table 19. Feral Hogs and Loadings by Subwatershed

	Feral Hogs Outside Buffer	Feral Hogs Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
SW1	818	333	9.1E+11	1.5E+12	22%
SW2	813	316	9.0E+11	1.4E+12	21%
SW3	617	148	6.9E+11	6.6E+11	12%
SW4	781	213	8.7E+11	9.5E+11	17%
SW5	418	85	4.7E+11	3.8E+11	8%
SW6	369	121	4.1E+11	5.4E+11	9%
SW7	270	75	3.0E+11	3.3E+11	6%
SW8	267	71	3.0E+11	3.2E+11	6%
Total	**4355**	**1361**	**4.8E+12**	**6.1E+12**	**100%**

Potential fecal bacteria loading by feral hogs is likely to be higher in the subwatersheds on the western, less heavily developed side of the watershed. Future projections of feral hog loads predict an overall decline in magnitude as time progresses. However, the SELECT model does not account for the adaptability of feral hog populations that have anecdotally been observed to redistribute or condense when faced with the loss of their preferred habitats. Therefore, the estimates presented in this SELECT model should be considered conservative.

Other Sources

The majority of the project's understanding of fecal bacteria loading in the Spring Creek Watershed is based on the modeled sources described above. However, many other sources are recognized as contributors to the total fecal bacteria load that are less easily characterized. Further explanation regarding how those sources will be accounted for in the WPP development process are described below.

Human Waste – Direct Deposition

In other watershed projects, potential impacts from homeless communities and areas not serviced by centralized or localized wastewater treatment were considered. Based on stakeholder feedback, the populations represented by these groups were not found to be large enough to have appreciable impact

Land Deposition of Sewage Sludge

In the event that improper use of manure spreading or violations of sludge application have occurred in the watershed area, action would be required to intervene and reduce the resulting fecal bacteria loading impacts. No such activity is known in the Spring Creek Watershed, however, these impacts would likely be addressed in best management practices for agricultural sources of pollution.

SSOs

Though SSOs occur episodically, they represent a high-risk vector for fecal bacteria contamination because they can have concentrations of fecal bacteria several orders of magnitude higher than treated effluent. Untreated sewage can contain large volumes of raw fecal waste, making it a significant health risk where SSOs are sizeable or chronic issues. Events are self-reported and may vary in quality. Descriptions of frequencies, causes, durations, and volumes of SSOs may be subject to logistical inadequacies such as unknown duration of discharge, and inability to accurately gage discharge volume. Actual SSO volumes and incidences are generally expected to be greater than reported due to these fundamental challenges.

After reviewing data compiled in SSO reports submitted by permit holders in the Spring Creek Watershed[13], SSO events were not found to follow any specific spatial, seasonal or annual pattern. Malfunctions and operational issues accounted for the highest number of events and overflow volume respective to the other general categories of weather, blockages, and unknown causes. Frequency of SSOs did not correspond well to volume of SSOs.

Due to the episodic nature and spatial inconsistency of SSO events, fecal bacteria loads from these sources are not expected to have an appreciable long-term impact on the overall loading for the watershed and were excluded from SELECT model analysis. Though the estimations of SSO impacts in this watershed are not represented by SELECT models, they are no less important to consider in the overall assessment of fecal bacteria loading. The most extreme method of estimating fecal bacteria loads from SSOs would be to calculate loading based on EPA literature values[14] suggested for general causes related to each event multiplied by the highest observed volumes of discharge recorded for each cause. A more conservative method would be to calculate the average daily volume of discharge and use that as the multiplier for cause related load estimates. In other area watershed projects, stakeholders elected to refrain from the aforementioned calculations and treat SSOs as a separate, high-priority item for inclusion in the management strategies outlined in the WPP. SSO data regarding unique events impacting stream segments within the watershed area over the most recent five years of reports provided by the TCEQ were used in these assessments. Spring Creek Watershed stakeholders elected to adopt this method as well.

CAFO

No active CAFOs are in operation within the Spring Creek Watershed.

Birds

The greater Houston area is well known as part of the great Central Flyway migration path used by various bird populations. Many migratory bird species only utilize the land area for short periods of time while in transit, but migratory waterfowl and resident species represent longer-term populations, especially in coastal marshes. Similar watershed projects have evaluated the potential impact of waterfowl in terms of duration, potential fecal bacteria load, and other considerations, and found them to not be significant sources to be modeled. Colonial birds such as swallows have been identified by other watershed projects as potential sources of fecal bacteria load. Unfortunately, little or no data is available to characterize the impacts of fecal bacteria loading from colonial bird sources or to implicate colonial bird influenced fecal bacteria loading as a significant health risks to the watershed community. Beyond lack of data, relatively small fecal bacteria loads and health risks associated with bird waste compared to human sources, and general lack of management strategies available to deal with wild birds have limited the emphasis of this source as a meaningful component of management efforts in similar projects.

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[13] See https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_3.3_spring_creek_data_analysis_summary_report.pdf.

[14] As referenced at https://www3.epa.gov/npdes/pubs/csossoRTC2004_AppendixH.pdf.

Bats

Though bats are present in the watershed area, only large colonies of these animals are estimated to have an appreciable impact on water quality. No known nesting sites of significant size or density have been indicated in the Spring Creek Watershed.

Other Wildlife

Specific data for wildlife such as coyotes, opossums, rodents, wild cats, skunks, raccoons, and other mammals is not widely available. Similar watershed projects have recognized these wildlife animals as potentially appreciable contributors to fecal bacteria loads, but, lacked a reasonable method for quantifying their potential impacts. One method of improving understanding of wildlife impacts in the Spring Creek Watershed would be to implement fecal bacteria source tracking or assessments of genetic material found in waterways to identify species depositing fecal waste in and around streams. Data collected with this method in other watersheds showed that wildlife impacts are significant[15] and should be incorporated into fecal bacteria reduction strategies. As no such data is presently available for the watershed area of Spring Creek, the understanding of wildlife species in this watershed will be largely informed by anecdotal information provided by stakeholders and general estimations decided by stakeholder input. In nearby Cypress Creek, a novel approach assumed wildlife impacts to be equivalent to a conservative 10% of the other modeled loads assessed in the watershed. The value was generated by finding the total for all other sources in all subwatersheds, setting that total as 90% of the total load, and then assuming wildlife to be the other 10%. Considering the similarities in land use and land cover, scale and hydrology between the watersheds of Cypress Creek and Spring Creek, this method was also be employed here. Stakeholders reviewed these results and agreed that other wildlife are an important component of bacteria loading in Spring Creek but were reluctant to attribute a firm percentage to their influence. However, recognizing that other sources with little data for quantification estimates are at play in this watershed, stakeholders opted to retain this 10% addition to the total estimated load and refer to it more generally as a safety margin.

Cats

Domestic dogs are included in the SELECT model analysis as a concern of particular interest to the watershed due to the likelihood of improperly managed dog waste deposited outdoors making its way to streams via runoff. Domestic cat waste management is typically handled indoors and restricted to litter boxes. Therefore, pet waste from cats were not estimated as part of this project. Feral cats, however, can be a local source when found in sufficiently dense urban populations, though very little data exists to quantify these impacts. Generally, impacts from feral cats may be accounted for in other loading assumptions such as diffuse urban stormwater or as part of the impacts from other wildlife.

Dumping

Illegal dumping is not typically a widespread or appreciable contributor to fecal bacteria loads in watersheds as these events occur locally or episodically. This factor will still be important for stakeholders to consider addressing in the WPP in terms of aesthetic and other regulatory issues.

[15] For example, bacteria source tracking completed by Texas A&M University for Attoyac Bayou showed *E. coli* from wildlife at greater than 50% of load across flow conditions (https://oaktrust.library.tamu.edu/handle/1969.1/152424) and a similar analysis (https://oaktrust.library.tamu.edu/handle/1969.1/149197) conducted for the Lampasas and Leon Rivers showed comparable results.

Sediment

Sedimentation has been identified by area stakeholders as a major concern in the Spring Creek Watershed especially in areas near the confluence of Spring Creek and Cypress Creek. With increased availability of sediment and other suspended solids in waterways, fecal bacteria may benefit from increases in substrate and decreases in insolation that prevent natural processes of die-off. Sedimentation can also impact dissolved oxygen levels and have pronounced hydrologic impacts on flow. The concerns will be addressed in the WPP.

5.3 Summary of Results

SELECT analyses indicated the highest loads from the total mix of modeled sources are concentrated on the eastern side of the watershed in the more highly developed downstream attainment area. In the headwaters attainment area to the west, overall fecal bacteria loads were lower but more heavily influenced by agricultural sources. Future projections for increased overall fecal bacteria loading throughout the watershed are also important to consider in the development of a WPP. Results shown in **Table 20** indicate the estimated current potential loads for all sources by subwatershed. Projected potential load in increments of five years by source are shown in **Table 21**. Assuming no additional action, changes in total load between 2015 and 2045 are shown in **Figure 35**. Relative changes in source contributions between current and future conditions are shown in **Figure 36** and **Figure 37** respectively.

Without taking action to reduce fecal bacteria sources in the watershed, loads will continue to increase between 2018 and 2045. Noticeable changes in source load contributions between current conditions and those projected for 2045 involve decreased impacts from agricultural activity relative to the expansion of sources associated with human development.

Figure 34. *Nature preserve in the Spring Creek Watershed*

Table 20. *Current Fecal Indicator Bacteria Daily Average Loadings by Source and Subwatershed*

	SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**SW7**	**SW8**	**Percent of Total Load**
WWTFs	1.7E+09	2.0E+09	1.9E+07	3.1E+08	1.8E+10	7.7E+09	3.5E+10	2.4E+10	**0%**
OSSFs	2.5E+11	5.0E+11	2.5E+11	2.3E+11	5.2E+11	4.4E+11	5.3E+11	4.9E+11	**3%**
Dogs	2.7E+12	3.6E+12	1.3E+12	2.1E+12	7.9E+12	8.2E+12	1.7E+13	1.1E+13	**57%**
Cattle	2.0E+12	1.7E+12	2.4E+12	4.0E+12	9.8E+11	5.1E+11	2.4E+11	1.8E+11	**12%**
Horses	1.4E+10	1.2E+10	1.7E+10	2.8E+10	7.0E+09	3.7E+09	1.7E+09	1.3E+09	**0%**
Sheep & Goats	9.0E+11	7.9E+11	1.1E+12	1.8E+12	4.5E+11	2.4E+11	1.1E+11	8.2E+10	**6%**
Deer	7.5E+10	7.1E+10	3.6E+10	4.6E+10	2.8E+10	3.3E+10	2.2E+10	2.2E+10	**0%**
Feral Hogs	2.4E+12	2.3E+12	1.3E+12	1.8E+12	8.4E+11	9.5E+11	6.3E+11	6.1E+11	**12%**
Safety Margin	9.2E+11	1.0E+12	7.1E+11	1.1E+12	1.2E+12	1.1E+12	2.0E+12	1.4E+12	**10%**
TOTAL	**9.2E+12**	**1.0E+13**	**7.1E+12**	**1.1E+13**	**1.2E+13**	**1.1E+13**	**2.0E+13**	**1.4E+13**	**100%**

Table 21. *Daily Average Fecal Indicator Bacteria Loadings by Source for All Milestone Years*

Source		**2018**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**
Human Waste	WWTFs	8.87E+10	1.05E+11	1.14E+11	1.26E+11	1.37E+11	1.40E+11	1.44E+11
	OSSFs	3.20E+12	4.37E+12	5.86E+12	7.60E+12	9.82E+12	1.16E+13	1.31E+13
Pets	Dogs	5.37E+13	6.78E+13	8.09E+13	9.59E+13	1.12E+14	1.24E+14	1.35E+14
Livestock	Cattle	1.19E+13	1.15E+13	1.06E+13	9.58E+12	8.57E+12	7.58E+12	6.65E+12
	Horses	8.55E+10	8.27E+10	7.58E+10	6.87E+10	6.14E+10	5.43E+10	4.77E+10
	Sheep & Goats	5.45E+12	5.27E+12	4.83E+12	4.38E+12	3.92E+12	3.46E+12	3.04E+12
Wildlife	Deer	3.35E+11	3.32E+11	3.23E+11	3.14E+11	3.04E+11	2.95E+11	2.86E+11
Invasive Species	Feral Hogs	1.09E+13	1.17E+13	1.14E+13	1.12E+13	1.09E+13	1.07E+13	1.05E+13
Other	Safety Margin	9.52E+12	1.12E+13	1.27E+13	1.43E+13	1.62E+13	1.75E+13	1.87E+13
TOTAL		**8.37E+13**	**9.5E+13**	**1.1E+14**	**1.3E+14**	**1.4E+14**	**1.6E+14**	**1.8E+14**

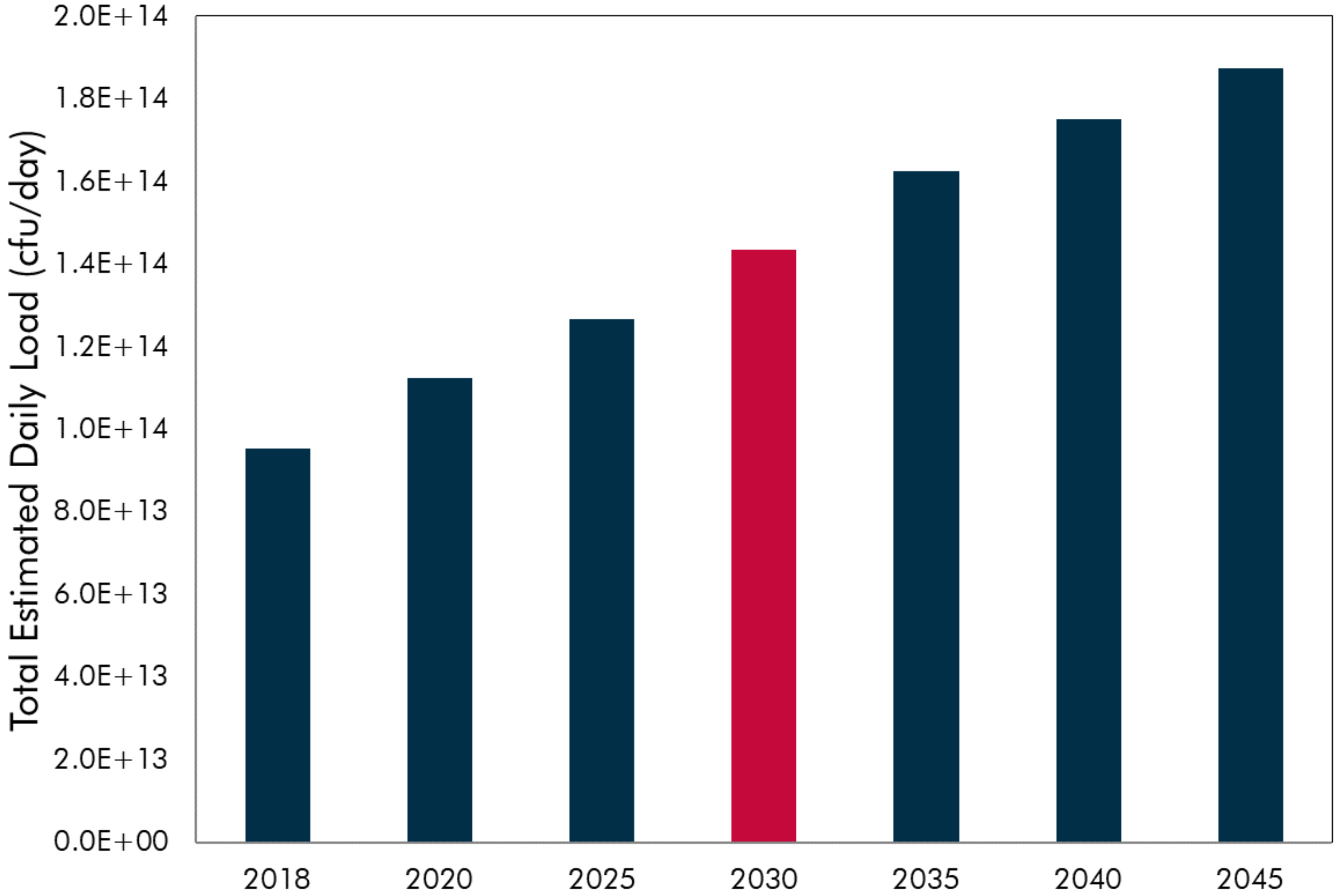

Figure 35. *Total Potential Daily Loads, 2018-2045*

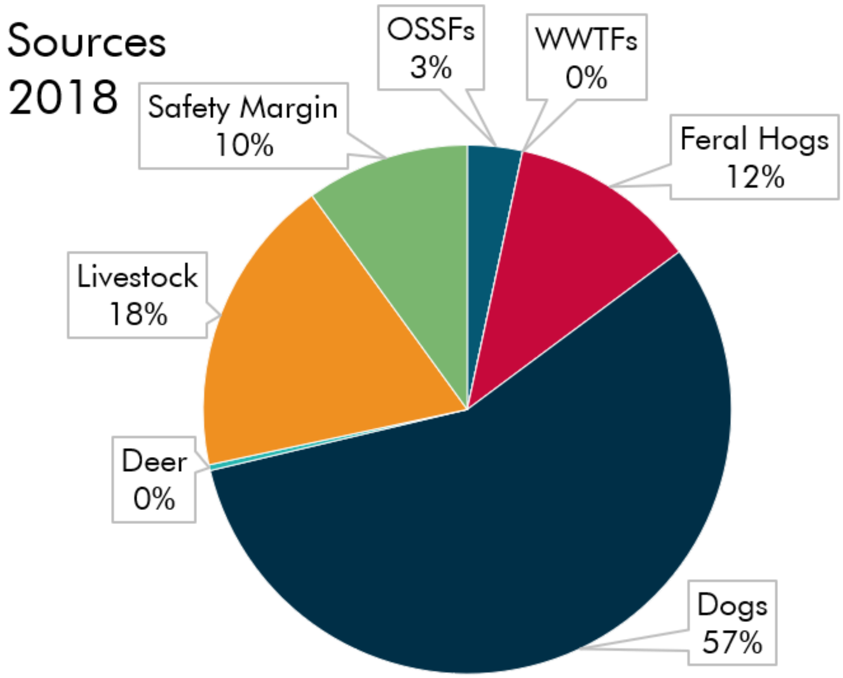

***Figure 36.** Fecal Indicator Bacteria Source Profile, 2018*

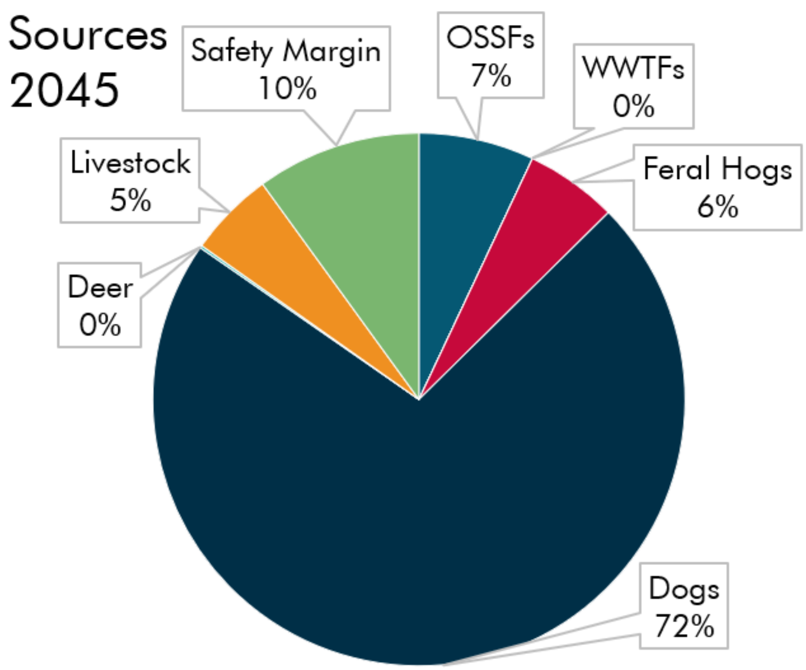

***Figure 37.** Fecal Indicator Bacteria Source Profile, 2045*

Section 6: Outcomes and Implications

6.1 Overview of Outcomes

The results of LDC and SELECT models generated for this report indicate different fecal bacteria reduction needs for different areas of the watershed dictated by a complex mix of sources which are predicted to shift in coming years. Among these sources, dog waste which is most concentrated in the developed downstream areas of the watershed was determined to be the dominant pollutant in both current and projected scenarios. From this data, fecal bacteria reduction targets and implementation timelines may be established by linking the results of LDC and SELECT models.

While dissolved oxygen levels throughout the watershed were also observed in this report, no numeric improvement goals were determined as the vast majority of LDC results indicated compliance with state water quality standards. Any deficiencies with dissolved oxygen may still be addressed by multi-benefit solutions enacted by stakeholders to address other water quality concerns. These solutions are likely to have broad ranging positive effect on other concerns for water quality including high nutrient and chlorophyll *a* levels.

6.2 Model Linkage

LDC analyses helped to determine fecal bacteria reduction targets at different rates of streamflow for different sites throughout the watershed area. These models also helped identify similar spatial trends that will aid in the selection of target areas for implementing specific fecal bacteria reduction strategies. SELECT models helped to spatially visualize potential fecal bacteria loads contributed by known sources and characterize the proportion of those loads to each other and to the overall total. This is important for determining how to approach fecal bacteria reduction throughout the watershed most effectively. The methods used to generate both LDC and SELECT models were developed with H-GAC and TCEQ project staff for quality assurance. Fate and transport relationships of fecal bacteria loads were not captured in these analyses, however, modifications were made to the base SELECT model in order to infer generalized linear relationships between source loading instream and in the watershed area at large. Most importantly, a buffer zone was established around the stream network which led to the distinction between sources directly impacting waterways and those with more indirect effects delivered via runoff and other high flow events. The level of precision achieved with more complex models does not produce an appreciably more useful level of information for stakeholders determining best management practices for their watershed. Other WPPs in the region have used similarly modified SELECT models with success as an efficient, accessible method of answering the needs of a project of this scale. Though a certain level of uncertainty is acknowledged in this approach, the general outcomes of these assessments will be defensible and suitable for guiding implementation.

6.3 Fecal Indicator Bacteria Reduction Targets

Three main points help to guide the decision-making process for determining fecal bacteria reduction targets. First, a checkpoint must be determined for gaging the progress of actions taken to improve water quality in the watershed. This checkpoint is referred to as a milestone year. Secondly, managers must decide the scope of reduction targets and whether they will apply to specific target areas or if they will be more effective on a larger scale. Finally, reduction targets should be allocated proportional to the known sources contributing to fecal bacteria loading in the watershed.

Milestone Year

Typically, WPPs are written to provide a guideline for making improvements to water quality within a period of five to 15 years. By incorporating five-year intervals into future projections of fecal bacteria loading with the SELECT models used in this report, stakeholders will be able to target any year on the timeline between the present day and 2045 as a milestone year. While intervals closer to the present day present challenges for organizing and implementing water quality improvement strategies, estimates for fecal bacteria loading further along the timeline are subject to higher levels of uncertainty. Therefore, a balance must be reached between selecting a milestone year that effectively addresses fecal bacteria loading for a long-term outlook while working within an acceptable margin of error in regard to uncertainty. After discussing these points at partnership meetings, stakeholders selected the year 2030 as a milestone for this watershed project. With a WPP approval planned for late 2021, this would cover a period of just under 10 years.

Target Areas

In both LDC and SELECT model results, a clear difference in fecal bacteria source management need is indicated between areas of more natural land cover in the western headwater attainment area of the watershed and the attainment area downstream which is more heavily developed. Therefore, project staff recommend using these two attainment areas as the base level target areas for determining fecal bacteria reductions. Water quality data collected within the extents of those two areas can be used to calculate reduction goals relative to the needs of the headwaters and downstream portions of the watershed. The most representative sites for water quality respective to each attainment area are 11314 – Spring Creek at SH 249 and 11313 – Spring Creek Bridge at I-45.

Allocating Reductions

Many methods can be implemented to determine the most appropriate course for allocating reductions to different fecal bacteria loading sources in a watershed area. Among them are:

1) Allocating reduction targets relative to source contributions estimated for the milestone year,
2) Allocating reduction targets subjectively based on implementation strategies deemed most feasible and effective by area stakeholders, and
3) Allocating reduction targets relative to source contributions estimated for current conditions.

For the needs of this watershed, project staff recommended the first option as it allows stakeholders some flexibility in focusing short-term efforts on sources indicated as greater pressures in current conditions relative to the milestone year. While proportional allocations are modeled at the subwatershed level, the attainment area level and for the total watershed area, project staff further proposed targeting results from the attainment areas in particular.

According to the recommendations detailed above, reduction targets were calculated by source at the attainment area level. Overall reduction targets for each of the attainment areas and the linkage of the reduction target percentages to the source loadings to generate the target source load reductions for the current year and the 2030 milestone year are indicated in **Table 22**. The allocation of reduction loads by source for each of the two attainment areas in the 2030 milestone year are summarized in **Table 23**.

Table 22. Current and 2035 Source Load Reduction Targets

Attainment Area	Subwatersheds	Weighted Average *E. coli* Reduction Target	Current Total Source Load[16]	Current Source Load Reduction Target	Incremental Load, 2018 to 2030[17]	2030 Total Source Load Reduction Target[18]
Headwaters	1, 2, 3 and 4	49%	3.75E+13	1.84E+13	1.60E+13	3.43E+13
Downstream	5, 6, 7 and 8	63%	5.78E+13	3.64E+13	3.22E+13	6.86E+13

Table 23. 2030 Source Reduction Loads Distributed by Source and Attainment Area

	Headwaters			**Downstream**		
	Source Load	% Total Load	Reduction Load	Source Load	% Total Load	Reduction Load
WWTFs	8.49E+09	0%	5.46E+09	1.18E+11	0%	8.97E+10
OSSFs	3.15E+12	6%	2.02E+12	4.45E+12	5%	3.40E+12
Dogs	2.46E+13	46%	1.58E+13	7.12E+13	79%	5.43E+13
Cattle	8.09E+12	15%	5.20E+12	1.49E+12	2%	1.14E+12
Horses	5.80E+10	0%	3.73E+10	1.07E+10	0%	8.15E+09
Sheep & Goats	3.70E+12	7%	2.38E+12	6.81E+11	1%	5.19E+11
Deer	2.13E+11	0%	1.37E+11	1.01E+11	0%	7.70E+10
Feral Hogs	8.24E+12	15%	5.30E+12	2.93E+12	3%	2.24E+12
Safety Margin	5.35E+12	10%	3.43E+12	9.00E+12	10%	6.86E+12
Total	**5.35E+13**	**100%**	**3.43E+13**	**9.00E+13**	**100%**	**6.86E+13**

6.4 Implications of Findings

The Spring Creek Watershed is similar to many areas in the region which are experiencing rapid land use change resulting from proximity to the growing Houston area and development along transportation corridors. Models characterizing fecal bacteria loads and sources impacting Spring Creek reinforce the concept of a watershed in transition. Future projections indicate that the expansion of developed areas will reduce sources of fecal bacteria loading associated with wildlife and agriculture, particularly in the headwaters attainment area. However, any losses of fecal bacteria loading from these sources will be counteracted and even outweighed by increases in sources tied to development.

[16] Current source load is generated by summing the source loads for the subwatersheds within the attainment area.
[17] The incremental load represents the difference between the 2035 load and the 2018 load. See the next footnote for explanation of its use in generating 2035 source reduction load target.
[18] The 2035 reduction target is generated through the equation $C_r+(F_l-C_l)$; where C_r= current source reduction load, F_l = future total source load, and C_l = current total source load. In essence, the incremental load generated between 2018 and 2035 is added to whatever reduction load exists in 2018. This approach is used because LDCs cannot estimate future reduction percentages, and because it is assumed the waterway will not have additional assimilative capacity in 2035.

Action must be taken to reduce fecal bacteria loading and improve overall water quality in Spring Creek and its tributaries in order to ensure the waterways are safe for recreation, aquatic life, and myriad other uses. Without executing appropriate management strategies, current water quality issues will be compounded by future loads, leading to degrading water quality in the coming years.

Models generated for this report are intended to provide the best available information to stakeholders hoping to take such action in the watershed. As with all models, a certain level of uncertainty is acknowledged. However, by combining quality assured methods with stakeholder feedback, project staff worked to minimize uncertainty wherever possible. By assessing current and predicted trends in water quality presented in this report and understanding the impacts of sources influencing fecal bacteria loads, stakeholders can form effective plans specific to their watershed that can help to make positive changes in water quality that will benefit their communities today and in the future.

Figure 38. *Spring Creek*