Section 3

Identifying Pollutant Sources

Photo Credit: Jessica Casillas

Section 3. Identifying Pollutant Sources

The process of identifying, characterizing, and quantifying causes and sources of pollution in a watershed provides a rational basis for devising effective solutions to improve water quality. The Partnership used a variety of tools, combined with local knowledge and guidance, to investigate the water quality challenges facing the Spring Creek watershed. The purpose of these efforts is to provide local stakeholders the information and context to make informed and effective decisions for their communities.

Investigation Methodology

The process of investigating causes and sources of pollution in the watershed used a series of successive steps to bridge the gap between the known existence of impairments and concerns, and the calculation of defensible estimations of causes and sources of pollution to meet the needs of the stakeholders[1].

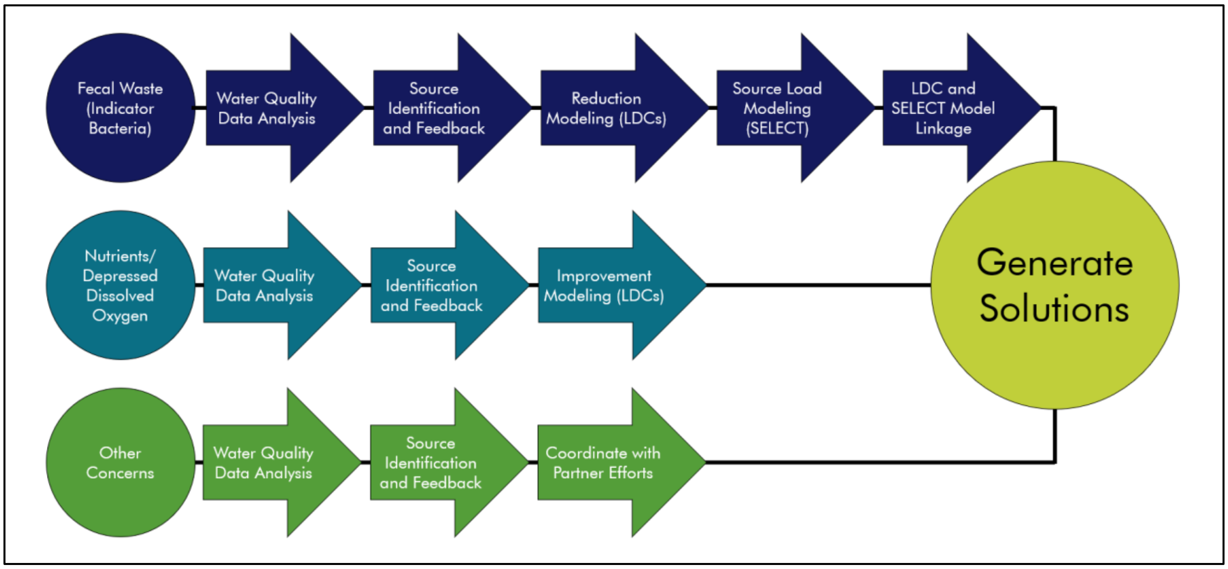

Figure 1. Pollutant source investigation flow chart

Water Quality Goals

The applicability of each step to different pollutants/conditions of concern is based on the water quality goals established by the stakeholders (see Section 1), and is noted in parentheses for each step.

- **Water quality data analysis (all water quality issues)** — Project staff identified status and trends in ambient water quality monitoring data and discharge data

[1] More detailed information on the development of this investigation methodology and selection of models can be found in the Bacteria Modeling Report, located at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_4.3_spring_creek_bacteria_modeling_report_032321.pdf

from wastewater treatment plants. These analyses identify the extent and variability of water quality issues and highlight differences between areas in the watershed.

- **Source identification and feedback (all water quality issues)** — The Partnership used local knowledge, data from other efforts, field reconnaissance, and map analysis to identify potential sources. These steps help to shape subsequent analyses by focusing efforts on sources of priority in the watershed.
- **Source load modeling (fecal waste)** — H-GAC worked with the Partnership to estimate the potential amount of fecal waste/*E. coli* generated in the watershed using computer models guided by local knowledge and feedback. These efforts identified the potential total fecal loads, mix of sources responsible, and variation between different areas of the watershed.
- **Reduction/Improvement modeling (fecal waste, DO)** — H-GAC worked with the Partnership to estimate the amount of improvement needed to meet water quality standards for various areas in the waterway. Results were generated by computer models using then-current water quality monitoring data. These processes generated the percent reduction for *E. coli* and the percent improvement for DO levels (see Section 4).
- **Source and improvement linkage (fecal waste)** — As the primary focus and sole impairment in the watershed, fecal indicator bacteria estimates were needed to establish numeric reduction goals for *E. coli*. This process applied the percent reduction targets from the improvement modeling to *E. coli* source load estimations to generate the amount of source load that needed to be reduced to achieve the water quality standard (see Section 4).
- **Coordinate with partner efforts (other concerns)** — Most specifically in the case of flood mitigation, the primary focus of developing recommendations for concerns outside the scope of this WPP was coordinating with partners.
- **Emphasize human wastewater as a priority** – While models may downplay the contribution of human wastewater, the stakeholders emphasized the greater risk human waste carries, the greater likelihood it is to be in proximity to our communities, and the potential for acute overflow events that don't reflect average daily loads.

Water Quality Analysis

Assessing water quality data sources is the first step in narrowing the search for the causes and sources of pollution. The Partnership reviewed analyses of 1) ambient water monitoring data; 2) volunteer water quality monitoring data; 3) discharge monitoring reports (DMRs) and sanitary sewer overflow (SSO) data from wastewater treatment facilities; and 4) results from similar projects in the area. While these analyses are summarized here, greater detail on the methods and results can be found in the *Water*

Quality Data Analysis Summary Report[2] prepared for this WPP. The primary goals of the analyses were to better understand water quality conditions, characterize the quality of wastewater contributions, and identify the availability of sufficient data for the models. The analyses focused on a five-year period of data to represent the most current conditions, but also relevant trends in recent years.

Figure 2. Water quality monitoring by the Clean Rivers Program

Ambient Water Quality Monitoring Data

Ambient water quality data are collected at over 400 sites in the 13-county Houston-Galveston region by H-GAC, local partners, and TCEQ as part of the Clean Rivers Program[3]. Most monitoring stations are sampled by CRP partners[4]. Waterways are inherently dynamic systems, and water quality at any given time can vary greatly

[2] Available on the project website at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_3.3_spring_creek_data_analysis_summary_report.pdf

[3] More information about this state-wide water quality monitoring program can be found at: https://www.tceq.texas.gov/waterquality/clean-rivers

[4] More information about the specific monitoring and programmatic details of the local CRP can be found at: https://www.h-gac.com/clean-rivers-program/information/

dependent on conditions at the time[5]. However, a history of ambient water quality samples helps characterize the range of conditions that may be present in a waterway and is important for the identification of trends over time. The final determination of the regulatory status of each segment is based primarily on these ambient data. Goals and decisions for this WPP were established in part due to the regulatory status, and therefore ambient data is an important source of information for informing stakeholder decisions.

The Spring Creek system is heavily monitored, with 20 active monitoring stations: six on the main body, one on Brushy Creek (1008J), one on Walnut Creek (1008I), one on Mill Creek (1008A), two on Willow Creek (1009H), one on Bear Branch (1008E), two on Upper Panther Branch (1008B), four on Lake Woodlands (1008F), and two on Lower Panther Branch (1008C; **Figure 3**; **Table 1**). Data for all stations are representative of ten years of sampling and are enough to describe the conditions during the study period.

Table 1. CRP monitoring station locations in the Spring Creek watershed

Station	Site Location
11312	Spring Creek at Riley Fussel Rd.
11313	Spring Creek Bridge at I-45
11314	Spring Creek at SH 249
11323	Spring Creek at Rosehill-Decker Rd.
17489	Spring Creek at Kuykendahl Rd. northeast of Houston
18868	Spring Creek at Roberts Cemetery Rd. west-northwest of Tomball
20463	Brushy Creek at Glenmont Estates Boulevard
20462	Walnut Creek at Decker Prairie Rosehl Rd. northwest of Tomball
21957	Mill Creek at FM 149 north of Tomball
11185	Willow Creek at Gosling Rd.
20730	Willow Creek at Tuwa Rd. 859 m downstream of FM 2920 Rd.
16631	Bear Branch Bridge 300 m north of Shadow Bend and Research Forest Dr. intersection
16629	Upper Panther Branch 80 m upstream of 5402 Research Forest Dr.
16630	Upper Panther Branch 60 m downstream of 5402 Research Forest Dr.
16481	Lake Woodlands at western reach in The Woodlands
16482	Lake Woodlands at south end in The Woodlands
16483	Lake Woodlands at mid-point in The Woodlands
16484	Lake Woodlands at north end in The Woodlands
16422	Lower Panther Branch 270 m downstream of Sawdust Rd.
16627	Lower Panther Branch at footbridge 265 m upstream of Sawdust Road

[5] For this section, 24-hour DO data is discussed. In terms of technical terminology under CRP, 24-hour DO sampling is not considered "ambient" data, but rather, "biased sampling" because it is often collected during certain seasonal timeframes. Due to the nature of the 24-hour data for this project, and the basic categorization of this report, it is discussed as ambient data.

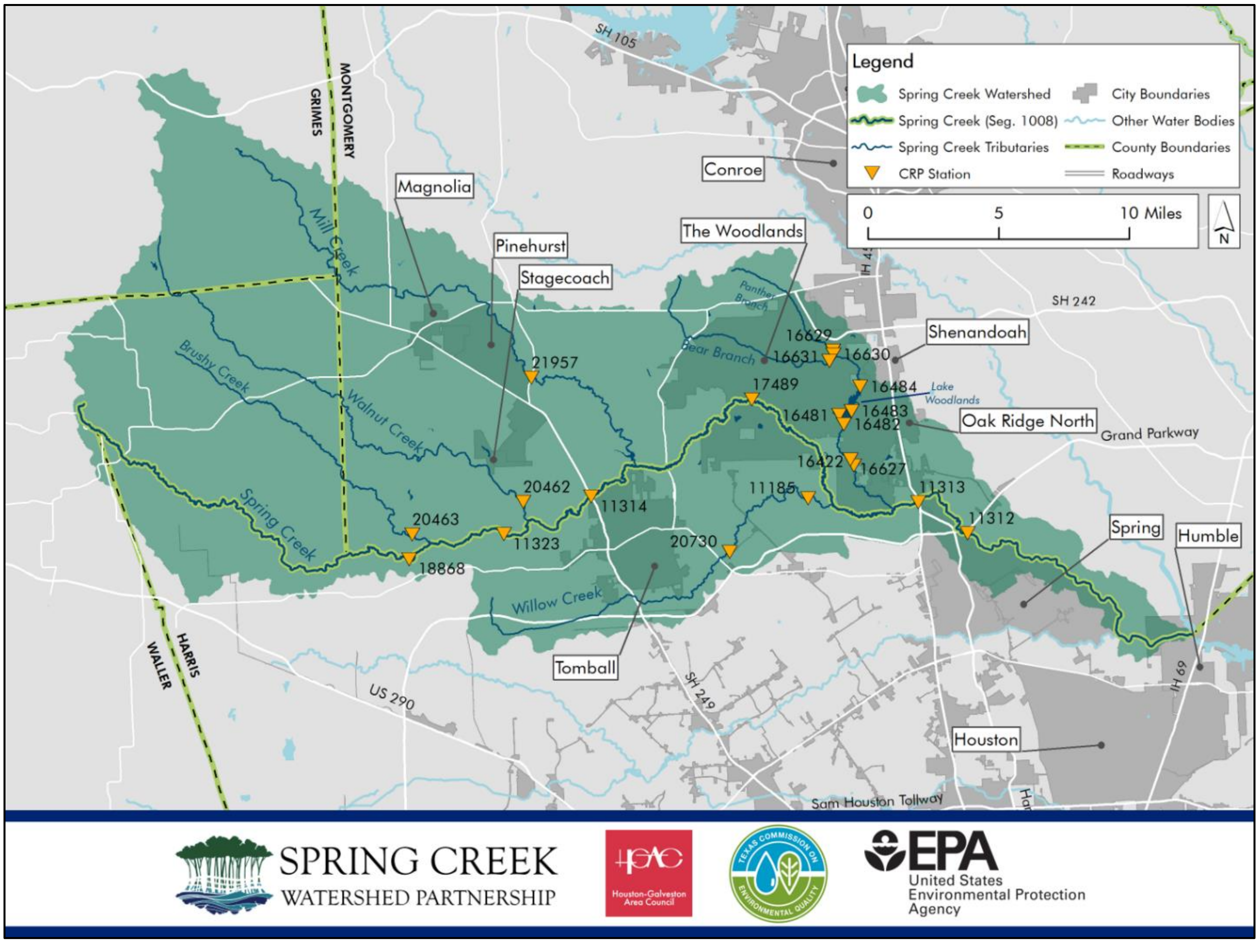

Figure 3. Spring Creek watershed monitoring stations

Constituents of Concern

Routine ambient water quality monitoring under the CRP includes sampling for a suite of conventional, bacteriological, and field parameters. For this evaluation, a subset of those parameters most closely related to the goals of the WPP and characterization studies has been selected for in-depth analysis. The parameters reviewed were:

- ***E. coli*** — a bacterial indicator of the presence of fecal wastes, and an indicator of the safety of waterways for human recreation.
- **DO (grab)** — an indicator of the ability of the waterway to support aquatic life.
- **Temperature** — an indicator of a waterway's ability to hold oxygen, and a means for correlating other indicators to conditions in the waterways.
- **pH** — an indicator of the acidity or alkalinity of water, which may affect aquatic life and other uses.

- **Chlorophyll-*a* (Chl-*a*)** — an indicator of aquatic plant productivity and action, which can indicate areas in which algal blooms or elevated nutrient levels are present, and thus potentially depressed DO.
- **Nitrate (NO_3-N) and Nitrite (NO_2-N)** — a measure of nitrogenous compounds and indicator of nutrient levels (and thus potential DO impacts).
- **Ammonia Nitrogen (NH_3-N)** — a measure of specific nitrogenous compound that can impact aquatic life and is an indicator of nutrient levels and potentially of improperly treated sewage effluent.
- **Total Phosphorus (TP)** — an indicator of nutrient levels, especially in relation to potential for algal blooms and depressed DO in elevated levels.
- **Total Suspended Solids (TSS)** — a measure of the number of suspended particles in water that indicates the potential of light infiltration in the water column and the presence of particulate matter which *E. coli* may use as substrate.

The analyzed data covers 2009-2019 to show a broad historic view. The primary questions this evaluation sought to answer relate to:

- The sufficiency of the data to characterize conditions,
- The spatial component of variations in water quality conditions,
- The extent of water quality issues, and
- Trends in water quality conditions, including any observable seasonal patterns.

H-GAC completed the assessment on the segment level, with attention to any unclassified tributaries which may be experiencing water quality issues.

Monitoring Analysis

A summary of ambient data represented as the geomean of each parameter for its period of record is shown in **Table 2** below. These results are comparable to that of the 2020 Integrated Report, though not identical due to the use of overlapping datasets. Where the 2020 Integrated Report examined surface water data collected from 2011-2018, this analysis extends the dataset to cover 2009-2019 where possible. Cells filled in with the darker shade indicate geomeans that exceed criteria or screening levels, while cells filled in with the lighter shade represent results that are in compliance with criteria or better than the screening level. Lack of shading indicates the data is not being compared to criteria or screening levels.

Table 2. Analysis of water quality data collected between 2009 and 2019

Para-meter	Criteria	Unit	Geomean Results by Segment								
			1008	1008A	1008B	1008C	1008E	1008F	1008H	1008I	1008J
E. coli	126	cfu/ 100mL	228.41	73.35	73.35	150.85	146.56	42.37	207.05	201.73	232.58
DO (grab)	Various	mg/L	6.88	6.26	6.26	6.38	6.39	8.51	7.73	6.04	5.52
pH	9 (high) 6.5 (low)	NA	7.44	7.4	7.4	7.71	7.49	8.45	7.62	7.34	7.05
Chl-*a*	14.1	mg/L	1.89					16.31			
NO_3-N	1.95	mg/L	0.64	1.94	1.94	2.27	0.31	1.07	6.09		
NO_2-N	NA	mg/L	0.04								
NO_3-N + NO_2-N	NA	mg/L	0.22	2.22	2.22	2.45	0.38	1.23		0.23	0.09
NH_3-N	0.33	mg/L	0.06	0.14	0.14	0.14	0.12	0.11	0.11	0.1	0.12
TP	0.69	mg/L	0.24	0.73	0.73	1.08	0.27	0.87	1.65	0.21	0.15
TSS	NA	mg/L	16.51	8.42	8.42	18.61	17.09	18.09	11.48	17.55	9.77

Water Quality Parameter Trends

By examining all parameters collected from surface water samples in the Spring Creek watershed and how measurements for those parameters have changed over time, trends in the data were determined. Statistically significant ($p < 0.0545$) trends observed in these analyses are summarized in **Table 3** below. Cells filled in with the darker shade indicate trends that could be negatively impacting water quality such as increasing nutrient levels and decreasing dissolved oxygen. Cells filled in with the lighter shade represent trends that support good water quality such as decreasing fecal indicator bacteria levels and increasing dissolved oxygen. Lack of shading indicates results that are predicted to be of neutral impact to water quality. Results for parameters with stable trends over time are not represented in **Table 3**. Consequently, parameter measurements that exceeded water quality standards but remained consistently high throughout the study period (such as *E. coli*) may not be captured by the summary.

Table 3. Water quality trends by segment

Segment	Parameter	Trend	N
Spring Creek, 1008	DO (grab)	Increasing	470
Spring Creek, 1008	Nitrate and Nitrite	Increasing	52
Spring Creek, 1008	Total Phosphorus	Decreasing	461
Mill Creek, 1008A	DO (grab)	Increasing	43
Mill Creek, 1008A	Nitrate and Nitrite	Decreasing	43
Upper Panther Branch, 1008B	Ammonia Nitrogen	Increasing	66
Upper Panther Branch, 1008B	DO (grab)	Increasing	198
Lower Panther Branch, 1008B	Ammonia Nitrogen	Increasing	66
Bear Branch, 1008E	Ammonia Nitrogen	Increasing	33
Bear Branch, 1008E	DO (grab)	Increasing	98
Bear Branch, 1008E	Total Phosphorus	Increasing	33
Lake Woodlands, 1008F	Ammonia Nitrogen	Increasing	132
Lake Woodlands, 1008F	*E. coli*	Decreasing	132
Lake Woodlands, 1008F	TSS	Decreasing	128
Willow Creek, 1008H	*E. coli*	Increasing	177
Willow Creek, 1008H	pH	Decreasing	175
Brushy Creek, 1008J	DO (grab)	Increasing	37
Brushy Creek, 1008J	pH	Increasing	39

Relationship to Flow

Parameter measurements and their relationships to flow conditions were considered in this analysis. Further work on the relationship between flow, bacteria, and DO was completed as part of the model development explained in Section 4. According to the results of the models, surface water in the Spring Creek watershed is likely impacted by nonpoint source pollution. This is indicated by fecal indicator bacteria concentrations that are observed to increase with flow magnitude.

Ambient Data Analysis Summary

Of the ambient water quality parameters observed, geomean values for fecal indicator bacteria levels measured between 2009 and 2019 exceeded state water quality standards most frequently. Of the segments with geomeans that exceeded criteria, Willow Creek (1008H) showed an increasing trend in *E. coli* over time. Only Mill Creek (1008A), Upper Panther Branch (1008B) and Lake Woodlands

(1008F) showed geomean values for *E. coli* within criteria levels. In fact, *E. coli* levels in Lake Woodlands have followed a significant decreasing trend over time.

Nutrients also seem to pose a challenge to water quality in the Spring Creek Watershed. Total phosphorous geomeans exceeded screening levels on Panther Branch (1008B and 1008C), Lake Woodlands (1008F) and Willow Creek (1008). Nitrate nitrogen geomeans were also found to be above screening levels on the lower portion of Panther Branch (1008C) and Willow Creek (1008H). Spatially, these exceedances occur in the eastern third of the watershed where developed areas are most prevalent.

Low levels of DO are a concern noted in the 2020 Integrated Report that are not necessarily captured in this analysis. This is most likely due to the overlap of datasets observed—The 2020 Integrated Report observed data collected from 2011-2018 whereas this analysis uses 2009-2019 as the study period.

Targeted assessment and application of best management practices could be expected to reduce or remove impairments and concerns in these watersheds.

Stream Team Monitoring

While the WPP relies on quality assured data for trends analyses and model inputs, volunteer data provided by local Texas Stream Team (TST) monitors can be a valuable supplement to routine monitoring sites by providing hints at conditions in areas outside the existing data. One of the most valuable elements of TST data is the observational information from the volunteers. There are four active TST sites in the Spring Creek watershed. Project staff reviewed the data at the beginning of the project to help define areas of interest and to guide informal decisions on field reconnaissance. The data will be used in conjunction with formal data sources and analyses to help identify WPP effectiveness going forward.

Wastewater Treatment Facility Discharge Data

Discharges from wastewater treatment facilities (WWTFs) are regulated by water quality permits from TCEQ which require stringent limits for effluent quality. Human waste has a relatively high potential to cause human illness[6], so identifying trends in permit exceedances for *E. coli* by WWTFs is important in understanding overall impacts to human health related to contaminated waterways. Additionally, effluent (especially if improperly treated) can be a source of nutrient or other precursors to depressed DO.

[6] While the project considers many sources of fecal bacteria, recent research has indicated that human waste has a significantly higher risk of causing sickness in humans as compared to animal sources. Additional information about one research project illustrating this concept can be reviewed at http://oaktrust.library.tamu.edu/handle/1969.1/158640?show=full.

There are 61 permitted WWTFs in the Spring Creek Watershed (**Figure 4**; **Error! Reference source not found.**).

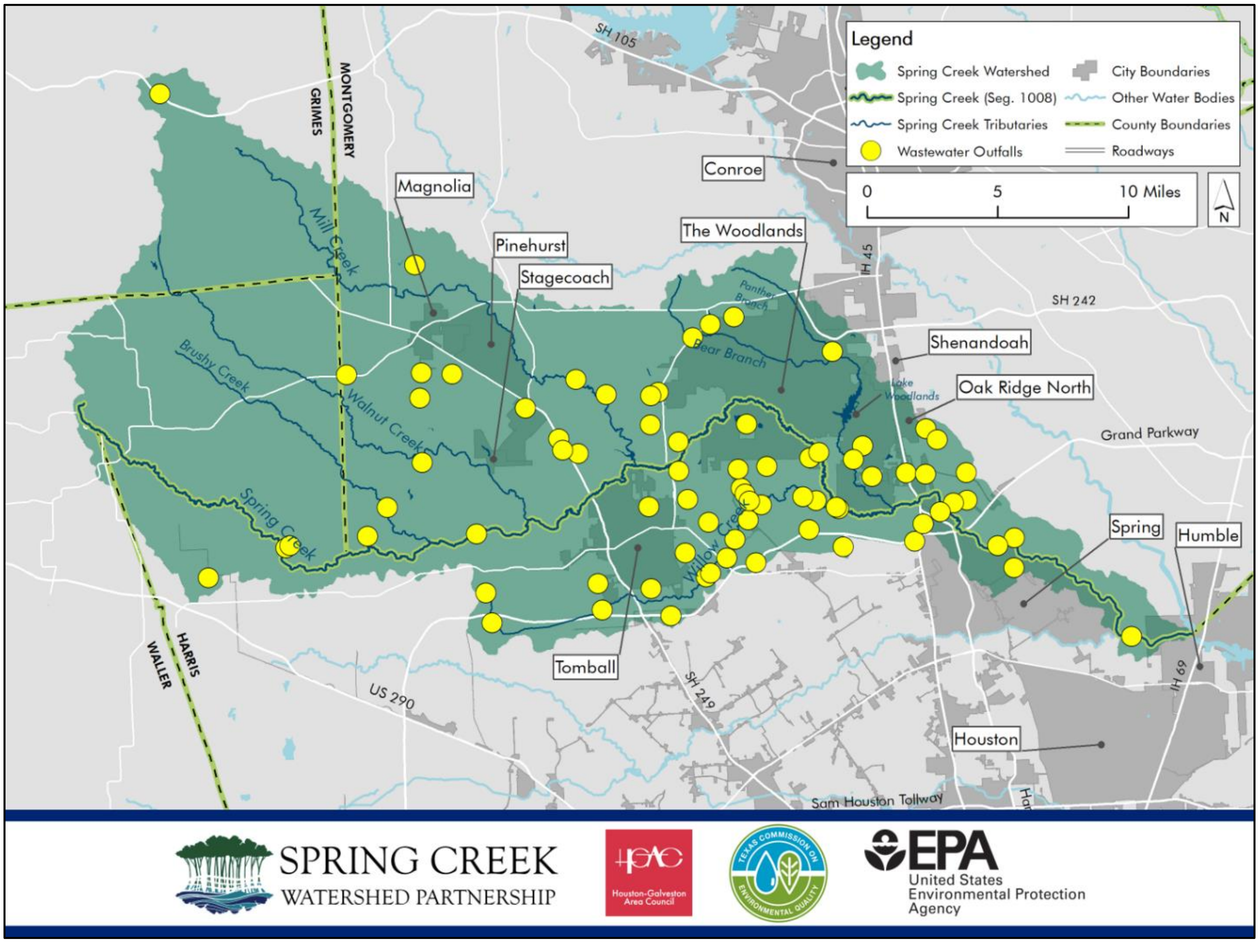

Figure 4. WWTFs in the Spring Creek watershed

Discharges from WWTFs are monitored on a regular basis (with a frequency dependent on plant size and other factors). The data from these required sampling events are submitted to (and compiled by) TCEQ as DMRs. As with any self-reported data, there is an expectation that some degree of uncertainty or variation from conditions may occur, but these DMRs are the most comprehensive data available for evaluating WWTFs in the watershed.

Project staff evaluated[7] DMRs from TCEQ reported between 2014 and 2019 by WWTF permit holders in the Spring Creek watershed. Five parameters common to most WWTF permits were assessed including: *E. coli*, TSS, ammonia nitrogen (NH_3-N), DO, and five-

[7] For more detail, see the Water Quality Data Analysis Summary Report on the project website at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_3.3_spring_creek_data_analysis_summary_report.pdf

day carbonaceous biochemical oxygen demand (CBOD5). While some parameters are themselves constituents of concern, all are indicators of the presence or potential presence of untreated/improperly treated waste[8]. The parameter evaluations were based on the regulatory permit limits specific to each plant, and consider the number of exceedances by each plant, in each year, in each segment, and as a percentage of the total samples.

E. coli

As with surface water sampled throughout the watershed to gage ambient conditions, discharge from WWTFs is assessed for compliance with state water quality standards. In the case of *E. coli*, the permitted geomean standard for bacteria concentrations is 126 cfu/100 mL whereas the grab sample standard is 399 cfu/100 mL. For this analysis, compliance with permit limits for bacteria were compared across segments, plant types, years, and seasons. Exceedance statistics are summarized in **Table 4**.

Table 4. DMR bacteria exceedance statistics, 2014-2019

Parameter	Number of Plants	Percent of Plants	Percent of Reports
Plants in DMR Dataset	61		
Plants Reporting Bacteria	61		
Total Records	6,082		
Less than 1% Violations[9]	32	52.5%	
1% to 5% Violations	20	32.8%	
5% to 10% Violations	6	9.8%	
10% to 25% Violations	3	4.9%	
Greater than 25% Violations	0	0.0%	
Exceedances of Geomean	24		0.4%
Exceedances of Single Grab	88		1.4%
Total Exceedances	112		1.8%

Overall, the results of the analyses of DMR *E. coli* data indicated that the total number of exceedances reported was small relative to the total number of DMR

[8] In consideration of the nutrient loading capacity of the plants, it should be noted that many nutrient parameters are not standard plant permit limits, and thus may not be tested. Based on review of correlations between nutrient parameters and flow for many stations, the analyses did show a likelihood of plants as nutrient loading sources for non-permit limit parameters, particularly in effluent-dominated streams.

[9] Several plants in the watershed have more stringent limits (*e.g.*, 63 cfu/100mL) depending on site-specific conditions, or participation in TMDL projects like the Houston-area Bacteria Implementation Group (BIG). For all analyses, the actual limit for each plant was used in comparison with its plant-specific results. The range of limits applied to the average and maximum conditions ranges from 63 to 399 cfu/100ml.

reports submitted for the period of 2014 to 2019 (112 out of 6,082 records). Further, only 9 plants out of 61 exceeded the bacteria standard in >5% of their samples. Maximum grab values were more commonly exceeded than geomean limits which suggests high variability in the data. Seasonality was not observed to be significant in shaping trends in bacteria concentrations. Evaluations of plant size relative to number of exceedances revealed that small plants (<0.5 million-gallons per day (MGD)) reported the most violations of any size category for both the geomean and single sample standards. This may be in part due to relative frequency of monitoring, wherein large plants monitor more frequently and have more data to include in a geomean calculation, or it may be due to operational differences between larger manned plants and smaller unmanned plants. While WWTFs may be appreciable contributions under certain conditions and in localized areas, the DMR analysis indicates that they are not likely a significant driver of segment bacteria impairments due to the comparatively few exceedances. However, due to the relatively higher risk of pathogens from human waste, and proximity to developed areas, WWTF exceedances are still a point of concern for stakeholders.

Dissolved Oxygen

DO levels in WWTF effluent help indicate the efficiency of treatment processes. DO is generally more stable in effluent than it can be in ambient conditions because it is less subject to natural processes and variation in insolation. DO is measured in milligrams per liter (mg/L), and the permit limits can vary based on the receiving water body and other factors. Unlike other contaminants, DO limits are based on a minimum, rather than maximum level, and represent a grab sample as opposed to a 24-hour monitoring event. Generally, permit limits for the data reviewed ranged between 4-6 mg/L. Evaluations for compliance with the permit limits were for all records, between years, and by season. 61 plants reported DO results during this period. The outcomes are summarized in the tables below. **Table 5** summarizes the overall statistics of DO data reported by WWTFs in the Spring Creek watershed.

Table 5. DMR DO exceedance statistics, 2014-2019

Parameter	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting DO	61	
Total Records	4,082	
Total Exceedances	20	0.5%

Very few (20 of 4,082 total reports) samples fell below the minimum standard. After arranging the data temporally, no annual or seasonal trends were observed in the reported data. However, in light of the low occurrence of exceedance relative to the overall dataset, determining trends from these values may not accurately represent DO dynamics in the Spring Creek Watershed. Due to the findings of this analysis, it is unlikely that low DO levels in the waterways of the Spring Creek Watershed are being driven by WWTF effluent. As with the results of the bacteria analysis, it is important to note that periodic impacts to DO levels may occur on a localized level, but may not be well represented in this broad analysis. While the impacts of WWTFs on DO levels may not be a chronic or widespread issue in the watershed, an analysis of DO values reported in DMRs is still a critical component of this project especially as it pertains to identifying localized impacts.

Total Suspended Solids

To determine the efficiency of wastewater treatment in removing solids, TSS is evaluated. Bacteria use suspended particles as a protected growth medium and can therefore occur in greater concentrations when TSS is high. Additionally, TSS can be useful as an indicator that inefficient treatment may have led to other waste products (nutrients, *etc.*) being elevated in effluent. Permit limits for TSS include a concentration based (average) limit in mg/L and a total weight-based limit in weight per day. Both average and maximum monitored results exist for most plants. Evaluations for compliance with concentration and total weight permit limits were made for the overall dataset and for annual and seasonal data. The summary of reports made for TSS measurements and the number of exceedances of the concentration and weight standards are presented in **Table 6** below.

Table 6. DMR TSS exceedance statistics, 2014-2019

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting TSS	61	
Total Records	8,090	
Exceedances of Concentration	88	1.1%
Exceedances of Weight	38	0.5%
Total Exceedances	126	1.6%

Compared to the total number of reports submitted between 2014 and 2019, the total frequency of exceedance is very small (less than 2%). Viewing the data annually, there does not seem to be any significant pattern to either concentration, weight or combined total violations. Of the four seasons, samples exceeding the concentration and weight standards seem to be most prevalent during the winter months. Though periodic, local impacts may not be captured by these results, water quality throughout the Spring Creek watershed is unlikely to be impacted by TSS from WWTFs at the watershed level. Seasonal analysis showed that samples exceeding the concentration and weight standards occurred with the highest frequency in winter months, but the overall percentage of samples exceeding the standards compared to the total number of reports was negligibly small. Despite this, observing TSS in WWTF effluent is still worth considering when moving forward with best management practices for water quality. As mentioned previously, TSS is often correlated with nutrient and bacteria levels, and can be tracked as a measure of WWTF improvement.

Ammonia Nitrogen

Ammonia nitrogen is a component that indicates negative impacts to water quality due to nutrient loading. Further, it can be toxic to humans and wildlife. Deficiencies in wastewater treatment that lead to improperly treated sewage entering waterways can be indicated by elevated levels of ammonia nitrogen. Similar to TSS, concentration and weight measurements are used to assess compliance of ammonia nitrogen levels with permit limits. In **Table 7** below, the results of samples reported to be in exceedance of the standard as reported between 2014 and 2019 are summarized.

Table 7. DMR ammonia nitrogen exceedance statistics, 2014-2019

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting Ammonia Nitrogen	61	
Total Records	8,092	
Exceedances of Concentration	129	1.6%
Exceedances of Weight	65	0.8%
Total Exceedances	194	2.4%

The results of the analyses of ammonia nitrogen reported by Spring Creek watershed WWTFs between 2014 and 2019 show that exceedances do not follow any annual pattern but are more common in spring and summer months with summer capturing the highest frequency of concentration and weight violations. However, the total number of exceedances reported for ammonia nitrogen comprise less than 3% of the total reported values. This indicates that WWTFs are generally operating within permit limits and that ammonia inputs from WWTFs are not likely a chronic issue of importance for Spring Creek waterways. Periodic, localized impacts may not be as apparent when using a broad scope analysis. Ammonia nitrogen may still have use as an indicator of WWTF efficiency much in the same way as TSS and will therefore continue to be considered for best management practices in the watershed.

Oxygen Demand

CBOD5 measures the depletion of oxygen over time by biological processes, and indicates the efficiency of treatment. It is not a pollutant itself, but is informative of the water quality of effluent from WWTFs. In **Table 8** below, the exceedances of concentration and weight standards for CBOD5 in relation to the total number of reported values are summarized.

Table 8. DMR CBOD5 exceedance statistics, 2014-2019

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting Ammonia Nitrogen	61	
Total Records	8,164	
Exceedances of Concentration	17	0.2%
Exceedances of Weight	11	0.1%
Total Exceedances	28	0.3%

CBOD5 exceedances were relatively rare in this DMR dataset compared to the other observed parameters. No annual pattern was observed and though exceedances were most frequent seasonally in the winter, the small number of exceedances limits the applicability of any trends. From this analysis, it can be assumed that WWTFs are not likely a chronic source of poor CBOD5 values in the waterways of the Spring Creek watershed. As with previous analyses however, it should be noted that determining periodic and localized impacts may require further investigation.

Discharge Data Analysis Summary

Exceedances for all constituents compared to their permit standards were revealed in this analysis. However, plants in the Spring Creek watershed were largely found to be in compliance with their permit limits for the majority of the period of study. It is unlikely that WWTFs are an appreciable source of contamination in the watershed on a chronic, wide-ranging scale. However, this broad analysis may underrepresent localized impacts of WWTF outfalls. For example, a spatial examination of individual plant locations and their respective sizes and exceedances of bacteria standards yielded results indicating high percentages of exceedance from small plants west of the most developed parts of the watershed. This spatial analysis also showed that plants of various sizes reporting exceedances between 5 and 10% of their total records were located on the more developed eastern half of the watershed.

WWTFs may not be the largest source of bacteria, but effluent from these facilities has an inherently higher pathogenic potential than other sources due to the treatment of human waste. Additionally, unlike other sources of natural and diffuse fecal waste in the watersheds, WWTF effluent has both regulatory controls and voluntary measures by which improperly treated wastewater may be addressed. Given the nature of WWTF effluent as a human pollutant, and our direct ability to influence its character, WWTF bacteria should be considered as a potential focus for some best management practices. While other constituents (e.g. nutrients) are not necessarily any more harmful than other sources in the watershed, the principle of direct control of effluent applies to their consideration as well. This is exacerbated for nutrients given the lack of permit limits for some nutrient parameters, and the likelihood that WWTFs may be appreciable nutrient loading sources in effluent dominated streams.

Sanitary Sewer Overflows

Though SSOs occur episodically, they represent a high-risk vector for bacteria contamination because they can have concentrations of bacteria several orders of magnitude higher than treated effluent. Untreated sewage can contain large volumes of raw fecal matter, making it a significant health risk where SSOs are sizeable and/or chronic issues. The causes of SSOs vary from human error to infiltration of rainwater into sewer pipes. Data used for these analyses is self-reported and may vary in quality. Even in the best of circumstances, the ability to accurately gauge SSO volumes or even occurrences in the field is limited by several factors. Actual SSO volumes and incidences are generally expected to be greater than reported due to these fundamental challenges. Known causes of SSOs were broken into four broad categories with several subcategories each, to reflect the breakdown in TCEQ's SSO database. It should be noted, however, that this categorization depends on the accuracy of the data reported by the utilities. Additionally, while a single cause is typically listed on the SSO report, many SSOs are caused by a combination of factors.

This study considered five years of TCEQ SSO violation data for 2014-2019. There were 131 SSO records from 26 plants considered for the watershed area. Of those 26 plants, 11 plants had ≥5 SSOs, and of those 11 plants, 5 plants had ≥10 SSOs. However, number of SSOs did not correspond well to volume of SSOs. Only 4 plants had a cumulative SSO volume greater than 50,000 gallons, and only one of those plants had a number of SSOs >5. Below, tables and figures reflect the breakdown of SSOs by year and cause, for number and volume, respectively.

As shown in **Table 9**, there was not a strong trend in number of SSOs over time. In terms of cause by number, the general category of weather-related issues accounted for 23.7% of the overall total, malfunctions and operational issues accounted for 35.9%, blockages accounted for 29.8%, and 10.7% were listed as unknown causes.

Table 9. Number of annual SSO events

CAUSE	2014	2015	2016	2017	2018	2019
Weather	**1**	**0**	**8**	**7**	**9**	**6**
Rain / Inflow / Infiltration	1		8	1	9	6
Hurricane				6		
Malfunctions	**5**	**5**	**10**	**6**	**13**	**8**
WWTF Operation or Equipment Malfunction	2		4	1	5	1
Power Failure	1	1	1	2	1	
Lift Station Failure	2	1	3	1	3	3
Collection System Structural Failure		3	1	2	4	4
Human Error			1			
Blockages	**6**	**9**	**5**	**1**	**10**	**8**
Blockage in Collection System-Other Cause	3	5	2	1	6	2
Blockage in Collection System Due to Fats/Grease	1	3	3		3	4
Blockage Due to Roots/Rags/Debris	2	1			1	2
Unknown Cause	**0**	**2**	**3**	**1**	**5**	**3**
TOTAL	**12**	**16**	**26**	**15**	**37**	**25**

While numbering SSO events informs how frequently these overflows impact the watershed, volume of overflow is an indicator of the magnitude of impact. The results summarized in **Table 10** indicate that as with number of events, there was no real temporal trend in volume of events. Of note, though 2017 had the second lowest total overflow volume reported over the five years of study, over 80% of the overflow volume was associated with a hurricane event (Hurricane Harvey). Apart from that isolated event and a high volume of overflows caused by blockages in 2015, malfunctions were the most common cause of high volume overflows throughout the study period.

Table 10. Annual SSO events by volume (in gallons)

CAUSE	2014	2015	2016	2017	2018	2019
Weather	**500**	**0**	**44,300**	**58,700**	**12,301**	**10,294**
Rain / Inflow / Infiltration	500		44,300	300	12,301	10,294
Hurricane				58,400		
Malfunctions	**31,010**	**19,300**	**87,748**	**11,090.5**	**150,374**	**52,723**
WWTF Operation or Equipment Malfunction	26,000		2,050	0.5	724	10,000
Power Failure	3,000	300	2,500	10,000	2,500	
Lift Station Failure	2,010	1,500	62,300	100	53,850	35,023
Collection System Structural Failure		17,500	500	990	93,300	7,700
Human Error			20,398			
Blockages	**20,750**	**50,000**	**4,880**	**2,400**	**80,350**	**8,915**
Blockage in Collection System-Other Cause	17,000	23,500	3,395	2,400	22,100	5,980
Blockage in Collection System Due to Fats/Grease	1,950	25,500	1,485		8,250	1,915
Blockage Due to Roots/Rags/Debris	1,800	1,000			50,000	1,020
Unknown Cause	**0**	**1,970**	**77,060**	**100**	**925**	**36,500**
Total	**52,260**	**71,270**	**213,988**	**72,290.5**	**243,950**	**108,432**

Of the total volume of overflows reported from 2014-2019, malfunctions were responsible for 46.2%. Blockages comprised 21.9% of the overall volume, weather contributed 16.5% and unknown causes led to the remaining 15.3%. These overall contributions are important to consider in a general sense for estimating impacts to the watershed area.

Report Data Analysis Summary

Of the 26 plants that reported SSOs between 2014 and 2019, 11 had ≥5 SSOs (5 of those had ≥10). The number of occurrences was not necessarily indicative of overflow volume. Only one of the 4 plants reporting a cumulative SSO volume greater than 50,000 gallons had >5 SSOs. There was not a strong annual or seasonal trend in number or volume of SSOs. In terms of general cause, 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.

While this data is useful, it should be noted that it is also self-reported and may vary in quality. Overflow volumes and numbers of events may be greater than the values recorded in the report data. In addition, causes may be overgeneralized due to multiple factors ultimately resulting in SSOs.

In watersheds where bacteria and nutrient loading are of particular concern, the impacts of SSOs are important to understand due to their concentrations of untreated human waste. These events pose a high risk to human health especially due to their proximity to urban populations. Further, despite their episodic occurrences, SSOs can be extreme loading sources in the sense of volume introduced in a short time frame. Though SSOs do not have the same potential to have chronic impacts on waterways as effluent from high volume WWTFs, for the aforementioned reasons, it is still critical to consider SSO management among the best management practices selected to improve water quality in the Spring Creek watershed.

Other Water Quality Studies

The Spring Creek watershed has been the focus of several water quality efforts in addition to this WPP and ongoing TCEQ and CRP monitoring. While the results from these studies can point to nuance in water quality issues, data from these studies is spread out over differing time periods and derived from different methodologies. For that reason, the data may not be directly comparable to the water quality analyses of this report (or subsequent modeling results). Regardless, the findings of these efforts are informative in directing the investigations of this WPP. The Partnership reviewed results from the following projects:

Lake Houston TMDL

TCEQ projects that culminated in the Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston[10] and subsequent implementation plan[11] covered a broad area of the Lake Houston watersheds, including Spring Creek and Willow Creek. The findings of the TMDL analyses are less current or granular than the analyses generated for this WPP, but indicate a similar pattern of impairments and concern.

Summary of Water Quality Analyses

This review of water quality data is foundational for understanding and characterizing water quality concerns in the Spring Creek watershed, and for informing subsequent stakeholder decisions. The analyses served to answer questions regarding the sufficiency of the data, the extent and severity of water quality trends, seasonality of water quality issues, and the potential impact of wastewater effluent and SSOs.

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[10] Available for review at: https://www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-lakehoustontmdl_adopted.pdf

[11] Available for review at: https://www.tceq.texas.gov/assets/public/waterquality/tmdl/00BIG/42-HoustonRegionBacterialPlan-approved.pdf

Data meeting the criteria for sufficiency were used to determine what constituents of water quality are of greatest concern and the extent to which their impacts have been observed throughout the area waterways. As indicated in the 2020 Integrated Report results for this watershed, an analysis of the SWQMIS dataset identified high levels of the fecal indicator bacteria *E. coli* as the most pervasive impact to water quality. Further, elevated nutrient (nitrate nitrogen and total phosphorous) levels observed in the highly developed eastern third of the watershed present challenges to water quality. Depressed DO levels were also highlighted in several segments in the 2020 Integrated Report, but comparable results were not captured in this analysis. This is most likely due to the incomplete overlap of datasets observed for each report with the analysis described herein including more recent data where increasing trends in DO have been observed.

Permitted wastewater effluent was unlikely to be a widespread or chronic water quality issue but requires further investigation on limited spatial scales and timeframes. However, understanding these discharges is still critical to the development of this project as WWTFs without permit limits for certain nutrients act as source loads—particularly in effluent-dominated streams. Further, as treatment facilities for human waste, improper treatment indicators identified in DMR analyses can have greater implications for risk to human health.

An analysis of SSO reports from the Spring Creek watershed indicated that 42.3% of reporting plants experienced 5 or more SSO events between 2014 and 2019. Plants reporting 10 or more events throughout the study period accounted for 19.2% of the data. Number of events did not correspond to magnitude of overflow volume, however. For both frequency of SSO events and volume of overflow, malfunctions were among the most common for the general cause categories. However, it is important to note that while only one cause is usually listed on the report, multiple compounding factors can lead to SSOs. Ultimately, causes listed in SSO reports are prone to a degree of subjectivity as opposed to more quantitative measurements. While the episodic overflow volumes reported during these events are relatively small compared to the scale of effluent produced by WWTFs, SSO inputs are of particular concern due to the untreated nature of the sewage associated with them and the subsequent risk to human health.

As future growth projections indicate that increased development in the watershed is likely, the balance of pollutant sources and current hydrologic processes could be altered significantly in the coming years. These changes could result in further water quality impacts without intervention. Subsequent efforts should be made to identify causes and sources of the primary constituent of concern (indicator bacteria), and to characterize nutrient sources further to identify areas within the project watersheds most vulnerable to pollutant loadings and/or best suited for the implementation of management strategies.

Source Identification

Using the information generated through the water quality data analyses, the next step in characterizing pollution in the watershed was to evaluate potential causes and sources. The results of this source identification and prioritization process assisted the Partnership in understanding the range of potential sources, and guided the subsequent modeling efforts that estimated the loads from fecal waste and nutrient sources. Fecal waste sources were the primary focus of these efforts, but potential sources of depressed DO, nutrients, and other stakeholder concerns were also considered in relation to potential solutions.

Fecal Waste Source Identification

Waste from all warm-blooded animals is a potential source of *E. coli* contamination. *E. coli* are not necessarily themselves the source of potential health impacts; however, they signify the presence of fecal waste as well as a host of other pathogens associated with fecal waste. There is a wide array of potential fecal waste sources in the watershed. The potential mix of sources in a watershed can vary greatly in both spatial and seasonal contexts. The preliminary process of identifying potential fecal waste sources in a watershed is discussed as being a "source survey"[12]. The results of the survey shaped further analysis under the source modeling efforts of the project.

Source Survey

Characterizing fecal waste pollution in watersheds, and development of analyses to estimate potential loading, requires a consideration of potential sources. In any watershed with a mix of land uses, fecal waste can be produced by a broad mix of sources; this is especially true in a large, diverse watershed like Cypress Creek. The existence and location of some sources are known from existing data (e.g., WWTF outfalls), while many nonpoint sources need to be evaluated from a mix of literature values, land cover analysis, imagery and road reconnaissance, and a robust process of stakeholder review and feedback. As part of developing the source survey, the Partnership completed the following assessments:

- **Known Source Characterization** — Existing data was used to generate information on discrete (usually permitted) sources. Data sources included[13]:

[12] For greater detail on the source survey and subsequent bacteria modeling outcomes, please refer to the Bacteria Modeling Report, available online at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_4.3_spring_creek_bacteria_modeling_report_032321.pdf

[13] More information on data sources and quality objectives can be found in the project quality assurance project plan (QAPP), available online on the project website at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_modelingqapp_executed.pdf

- WWTF outfall locations and DMRs (TCEQ outfall locations and DMR records)
- Permitted on-site sewage facility (OSSF) locations (H-GAC proprietary data provided by local governments)
- Concentrated animal feeding operations (CAFOs) (TCEQ CAFO locations and violations data from TCEQ Central Registry records)
- SSOs (TCEQ SSO database)

- **Land Cover Analysis** — Staff reviewed national land cover datasets and H-GAC proprietary land cover datasets to determine the mix of land cover types within the watershed, and within each subwatershed, in a spatial context. The watershed includes a mix of land cover types, so no sources were eliminated based on lack of land cover (*i.e.*, available habitat/use). Statistics and spatial coverage developed during this analysis were used as the basis of populating diffuse sources whose assumptions were tied to specific land cover types in modeling efforts.
- **Imagery Reconnaissance** — Staff utilized aerial imagery, online map assets (Google Maps, Google Maps Streetview, Google Earth) and stakeholder feedback to identify any specific locations, specific sources, or issues to raise with stakeholders for further clarification. Examples of items derived from this analysis were:
    - Presence of horse stables
    - Small, unincorporated communities
    - Recreation use
    - Developmental projects in the watershed
- **Road Reconnaissance** — Staff also conducted ongoing road reconnaissance throughout the watershed specific to this task and as part of all activities in the watershed. Specific items noted or affirmed during road reconnaissance included:
    - Presence of deer in appreciable numbers in lightly developed areas
    - Progress of development (especially in the headwaters attainment area)
    - Sign of feral hog activity in some areas
    - General character of observable agricultural activities
- **Stakeholder Feedback** — Stakeholder engagement was a primary focus of the source survey. Local knowledge was a key aspect of understanding source composition in the area. Project staff engaged stakeholder consideration of sources through:
    - Direct discussion of sources at Partnership meetings
    - Direct discussion of sources at source-based Work Group meetings
    - One-on-one meetings with local stakeholders

- One-on-one meetings with state and regional experts/agencies (*e.g.*, the Texas Parks and Wildlife Department (TPWD), TSSWCB, and others)

Stakeholder feedback specific to the identified sources is discussed later in this section, relative to each source. In general, stakeholder feedback upheld staff expectations of usual sources, and helped refine extent and scale of expected source contributions (*e.g.*, rates of dog ownership, presence of deer in developed areas, hog activity levels, horse stable activity, presence of specific problem sites/dumping) The ultimate selection of sources to include in the model was based on stakeholder decisions and affirmation of H-GAC's proposed modeling methodology, through the revision process.

The estimated extents of the source survey general categories reflect preliminary understandings, rather than the modeled outcomes or final stakeholder feedback (**Table 11**). Note that these extents reflect current estimated status, and some sources may be expected to increase or decrease in the period assessed by this modeling effort. The results of the fecal waste source survey were used to guide the development of the load estimation modeling described later in this section.

Figure 5. Recreation in Spring Creek

Table 11. Fecal waste source survey

Category	Source	Origin	Estimated Extent
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[14]	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[15]

[14] Other wildlife is used throughout this document as a means of designating all wildlife populations for which sufficient data doesn't exist and which couldn't be assessed (unlike colonial birds and bat colonies). Stakeholder decisions regarding an assumption for this source is discussed in greater detail in its corresponding section.
[15] While not a source of fecal bacteria, suspended sediment in waterways can decrease die-off from insolation, etc.

Estimating E. coli *Loads*

Understanding the distribution and relative prominence of various sources of fecal waste is crucial to empowering stakeholders to make informed decisions about potential solutions. To quantify the potential number of fecal indicator bacteria being generated in the watershed, the Partnership used a combination of stakeholder knowledge and computer modeling. The goal was to identify how much *E. coli* was being generated by each source, and how those sources were distributed in the watershed.

Spatially Explicit Load Enrichment Calculation Tool

The Spatially Explicit Load Enrichment Calculation Tool (SELECT) is a Geographic Information System (GIS)-based analysis approach developed by the Spatial Sciences Laboratory and the Biological and Agricultural Engineering Department at Texas A&M University[16]. The intent of this tool is to estimate the total potential *E. coli* load in a watershed and to show the relative contributions of individual sources of fecal waste identified in the source survey. Additionally, SELECT adds a spatial component by evaluating the total contribution of subwatersheds, and the relative contribution of sources within each subwatershed. SELECT generates information regarding the total potential *E. coli* load generated in a watershed (or subwatershed) based on land use/land cover, known source locations (WWTF outfall locations, OSSFs, *etc.*), literature assumptions about nonpoint sources (pet ownership rates, wildlife population statistics, *etc.*) and feedback from stakeholders. The potential source load[17] estimates are not intended to represent the amount of *E. coli* actually transmitted to the water, as the model does not account for the natural processes that may reduce pollutants on their way to the water, or the relative proximity of sources to the waterway.

Project staff used an adapted SELECT approach to meet the specific data objectives of this project. The implementation of SELECT used for this modeling effort builds on the original tool by adding two modified components.

- **Buffer Approach** — The stock SELECT model assumes all *E. coli* generated within a watershed will have the same impact on instream loads. For example, loads generated 2 miles from a waterway are counted the same as equivalent loads generated within the riparian corridor. Realistically, loads generated adjacent to the waterways are more likely to contribute to instream conditions. However, SELECT does not provide a means by which to model fate and transport factors. In a situation in

[16] Additional information about SELECT can be found at: http://ssl.tamu.edu/media/11291/select-aarin.pdf

[17] References to loads in this section, unless specifically stated otherwise, should be taken to refer to (potential) source loads, rather than instream loads. As indicated previously, SELECT does not generate instream loading estimates, just the potential source load prior to factors affecting to fate and transport of pollutants.

which a particular source is generally located farther from the waterway, it may be overrepresented compared to a source generally located adjacent to the waterway. For example, if OSSFs in a watershed produced 50 units of waste, but were generally located far from the water, while livestock in a waterway produced the same amount of waste, but generally in the riparian corridor, SELECT would treat these potential loads as equal. For stakeholders making decisions on prioritizing best management practices (BMPs) and sources, this is a false equivalency. To strike a balance between project focus on simple but effective modeling and a desire to understand the potential impact of transmission, this implementation of SELECT differentiates between loads generated inside a buffer area surrounding waterways, and loads generated outside this area. The buffer approach assumes 100 percent of the waste generated within 300 feet of the waterway as being transmitted to the watershed without reduction. Outside of that buffer, only 25 percent of the waste is assumed to be transmitted to the waterway[18]. Sources that lack specific spatial locations (unlike permitted outfalls) are assumed to be distributed uniformly in appropriate land uses, inside and outside the buffer. For example, the total number of deer in the buffer is derived from multiplying the assumed density by the numbers of acres of appropriate land use within buffered areas. This approach is designed to provide a very general conception of the effect of distance from the waterway.

- **Future Projections** — The Spring Creek watershed is undergoing rapid developmental change. Sources estimated based on data collected as of the year 2018[19] are expected to expand in the future. Therefore, *E. coli* reductions based on current conditions would be inadequate to meet future needs. This implementation of SELECT uses regional demographic projection data to estimate future conditions through 2045 in 5-year intervals[20]. Land use change is the primary driver for estimating changes in source contribution, and spatial distribution of loads[21].

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[18] Buffer percentages were based on previously approved WPPs and reviewed on multiple occasions with project stakeholders.

[19] References to "current" modeled conditions throughout this document refer to 2018 estimations, based on the available data at the time of the modeling effort.

[20] 2045 was chosen as a horizon year to coincide with the extent of the regional demographic model projections at the time and also in consideration of likely planning horizon for partner efforts and developmental projects.

[21] All future projections have some level of uncertainty that cannot be wholly controlled for. The H-GAC Regional Growth Forecast (http://www.h-gac.com/regional-growth-forecast/default.aspx) demographic model projections are widely used in the region and in similar WPPs, and thus considered the best available data for making these projections. Some wildlife sources have additional levels of uncertainty because the model assumes that change between land uses eliminates populations tied to the former land use. However, there is not adequate data or analytical approaches within the scope of this project to determine the potential that wildlife populations will change or consolidate by literature values alone. For example, the model assumes a set density of feral hogs per unit of area, populated in appropriate land cover types. Feral hog populations are assumed to stay static because there is insufficient data to make

Watershed conditions can change greatly from year to year based on rainfall patterns, agricultural activities, increased urbanization, and other landscape-scale factors. To balance this inherent degree of variation and uncertainty, stakeholder feedback on sources, model assumptions, and results were used heavily through the generation of the analysis and its eventual use as a prioritization tool for selecting BMPs. The goal of the SELECT modeling in this WPP effort, other than the general characterization of source loading, is to aid in prioritizing which sources to address by showing their relative contributions and locations. The loads generated by SELECT are combined with reduction percentages derived from the models explained in Section 4 to generate source reduction loads. There is an inherent level of uncertainty in any modeling of a dynamic system, but the approach used in this WPP is balanced against the end use of the information to support stakeholder decisions.

The analysis design for this process includes four primary steps:

1) Development of a source survey using known locations/sources, suspected sources derived from projects in similar areas, and stakeholder feedback,
2) Stakeholder review of proposed sources and preliminary population/loading assumptions,
3) Implementation of the model and internal quality review, and
4) Stakeholder review of results and model revision as necessary (**Figure 6**).

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assumptions about rate of population growth. Additionally, if an area containing feral hogs converts to developed land cover, the hogs attributed to that area are eliminated from the calculations. In real conditions, this may instead lead hogs to consolidate in greater densities in remaining habitat up to some carrying capacity. This project acknowledges that uncertainty, and the stakeholders discussed potential methods to address it. However, no sufficient data sources or modeling methods within the scope of this project have been identified to account for wildlife population dynamics. Continual assessment of wildlife populations as a source is recommended in the adaptive management recommendations of the WPP to help overcome this uncertainty.

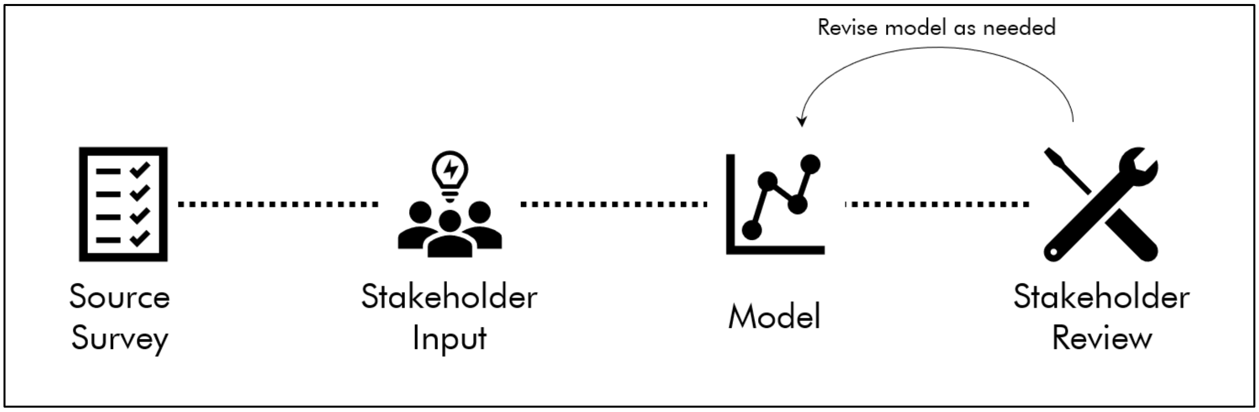

Figure 6. SELECT modeling process

The following subsections detail the sources modeled, including the data used and the feedback received from stakeholders. The maps indicate the relative distribution of source loads and populations, while the charts indicate the relative contribution of different sources. The loadings are given in numbers of *E. coli* per day, using scientific notation[22]. The maps are not comparable to other sources; they show the relative distribution for a given source by color gradation, rather than color being tied to absolute load. The maps also reflect the use of the buffer approach, with darker patches of color adjacent to the waterways, displaying the higher loads from these areas. In viewing the maps, it is important to consider that they display both relative loading by area within a subwatershed (riparian areas versus areas outside the riparian) and between subwatersheds. Lastly the map coloration is based on relative load density (load per acre). Larger subwatersheds will have larger loads, all things being equal. Load density maps help equalize discrepancies in subwatershed size and make fair comparisons.

Wastewater Treatment Facilities

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. Discharge monitoring report data was available for 61 WWTFs within the watershed and was incorporated into the SELECT model. Size of WWTFs vary greatly throughout the watershed and ranged between capacities of less than 0.1 MGD to 10 MGD.

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

[22] For example, 1.0E+12 is equivalent to 1.0×10^{12}, or 1 trillion. E+9 would be billions, E+6 millions, *etc.*

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 7**. As loads were estimated solely from outfall data within the riparian buffer, all spatial results are indicated within the buffer zone surrounding the watershed stream network (no data is available for the land area beyond the buffer). Color intensity indicates loading severity relative to the other streams and may not be directly comparable between this modeled parameter and the remaining sources examined with SELECT analyses. Actual loading estimates by subwatershed are represented in **Table 12**. In **Figure 8**, forecasted total watershed loads from WWTFs are plotted in five-year increments through the year 2045.

Table 12. Wastewater outfalls and loadings by subwatershed

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%**

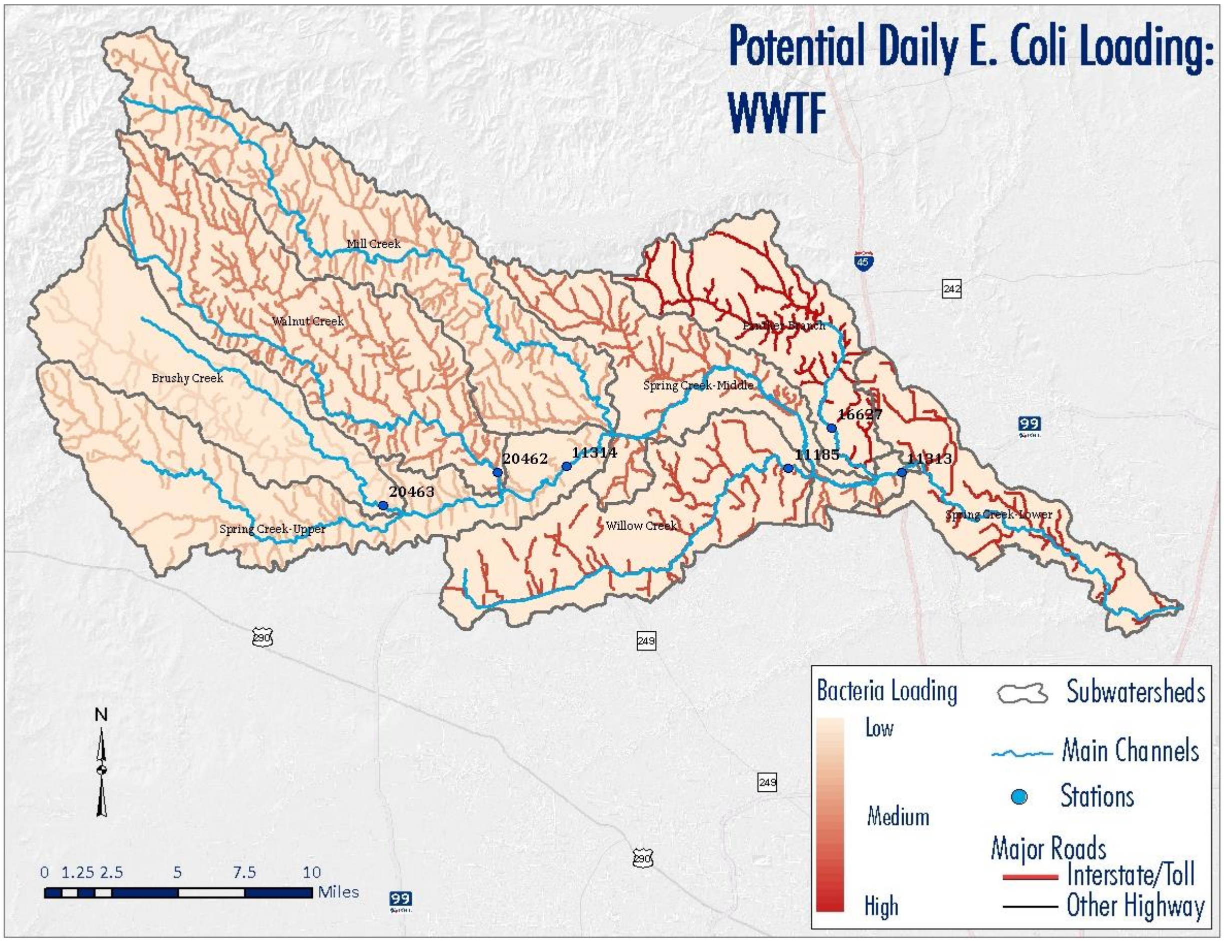

Figure 7. *E. coli* loadings from WWTFs by subwatershed

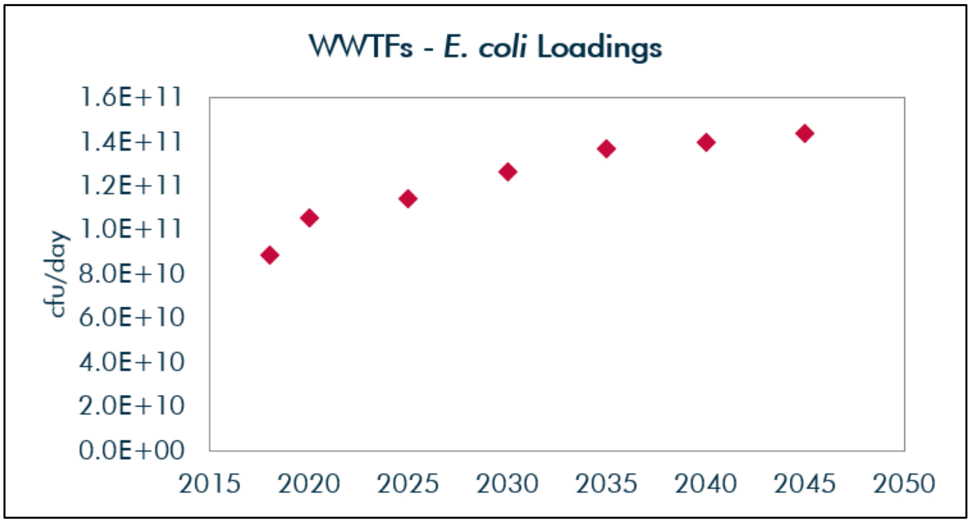

Figure 8. Future *E. coli* loadings from WWTFs

Onsite Sewage Facilities

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[23]. 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 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 9**. 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 10**, forecasted total watershed loads from OSSFs are plotted in five-year increments through the year 2045.

[23] 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.

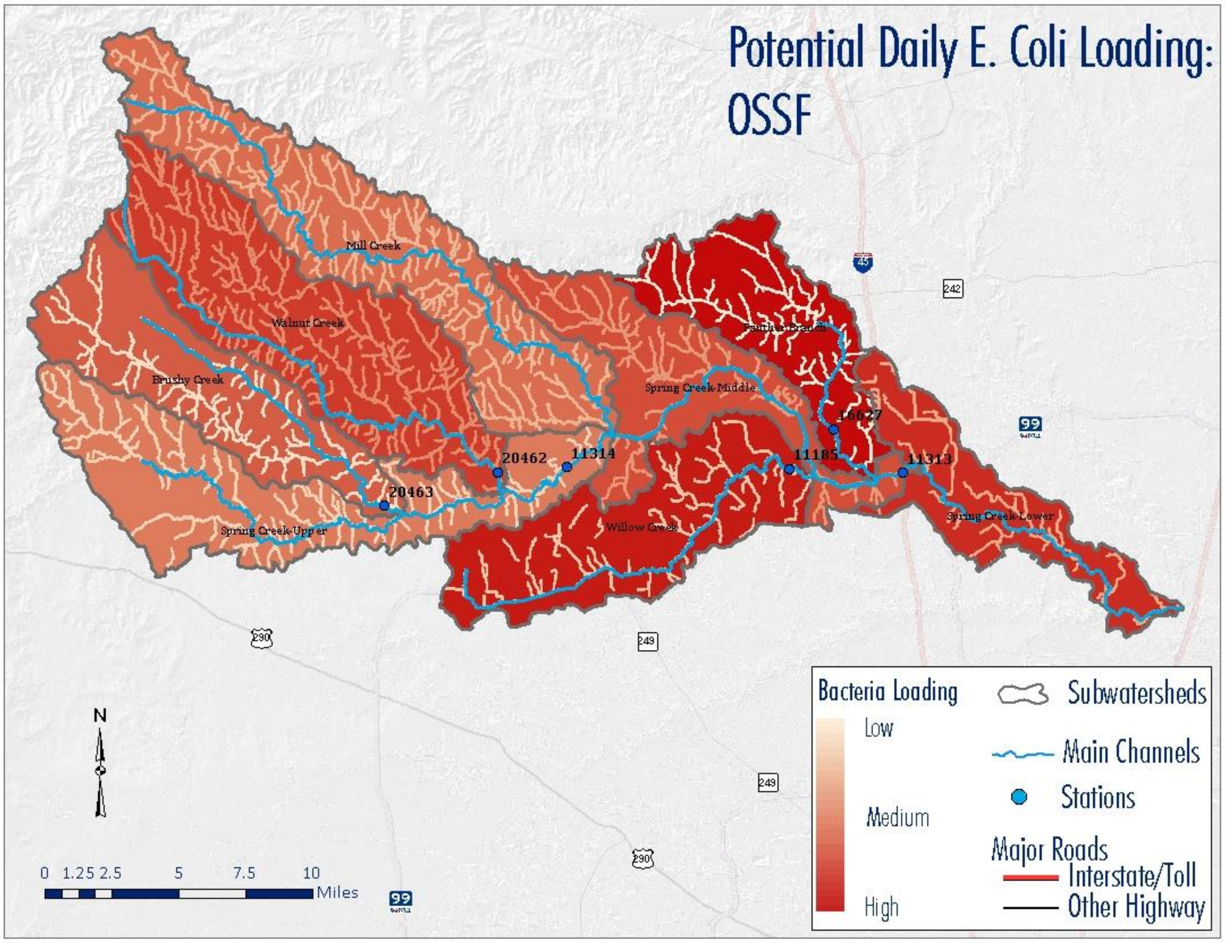

Figure 9. *E. coli* loadings from OSSFs by subwatershed

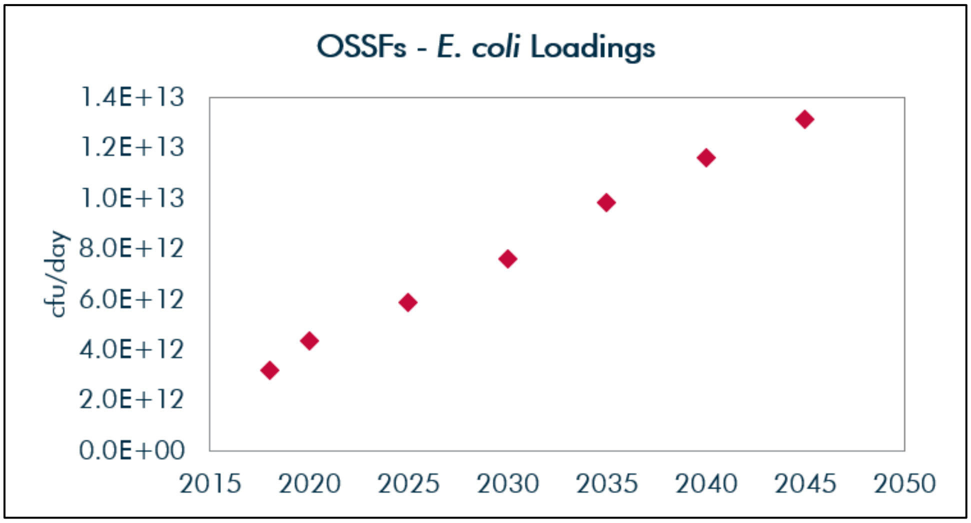

Figure 10. Future *E. coli* loadings from OSSFs

Table 13. OSSFs and loadings by subwatershed

Subwatershed	OSSFs Outside Buffer	OSSFs Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	2,012	635	1.87E+11	5.89E+10	8%
2	4,070	1,303	3.77E+11	1.21E+11	16%
3	2,199	539	2.04E+11	5.00E+10	8%
4	1,882	544	1.75E+11	5.05E+10	7%
5	4,977	610	4.62E+11	5.66E+10	16%
6	3,758	999	3.49E+11	9.27E+10	14%
7	5,286	398	4.90E+11	3.69E+10	16%
8	4,446	886	4.12E+11	8.22E+10	15%
TOTAL	**28,630**	**5,914**	**2.66E+12**	**5.49E+11**	**100%**

Pet Waste

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[24] 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%.

[24] For more information, see: https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx

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 11**. 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 12**, forecasted total watershed loads from dogs are plotted in five-year increments through the year 2045.

Table 14. Dogs and loadings by subwatershed

Subwatershed	Dogs Outside Buffer	Dogs Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	2,313	750	1.16E+12	1.50E+12	5%
2	3,369	977	1.68E+12	1.95E+12	7%
3	1,319	323	6.60E+11	6.47E+11	2%
4	2,282	498	1.14E+12	9.96E+11	4%
5	10,101	1,433	5.05E+12	2.87E+12	15%
6	8,313	2,002	4.16E+12	4.00E+12	15%
7	20,050	3,425	1.00E+13	6.85E+12	31%
8	13,342	2,179	6.67E+12	4.36E+12	21%
Total	**61,089**	**11,587**	**3.05E+13**	**2.32E+13**	**100%**

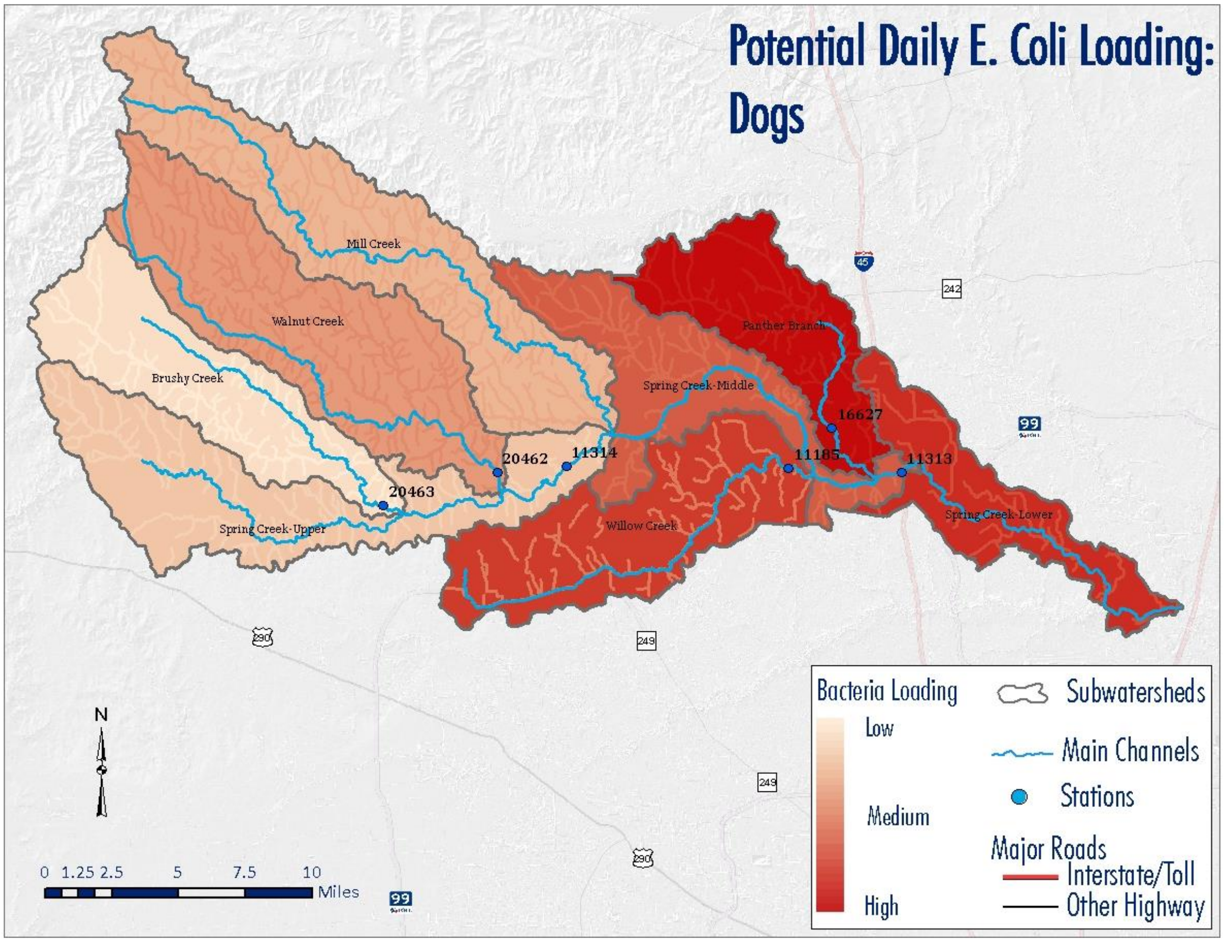

Figure 11. *E. coli* loadings from dogs by subwatershed

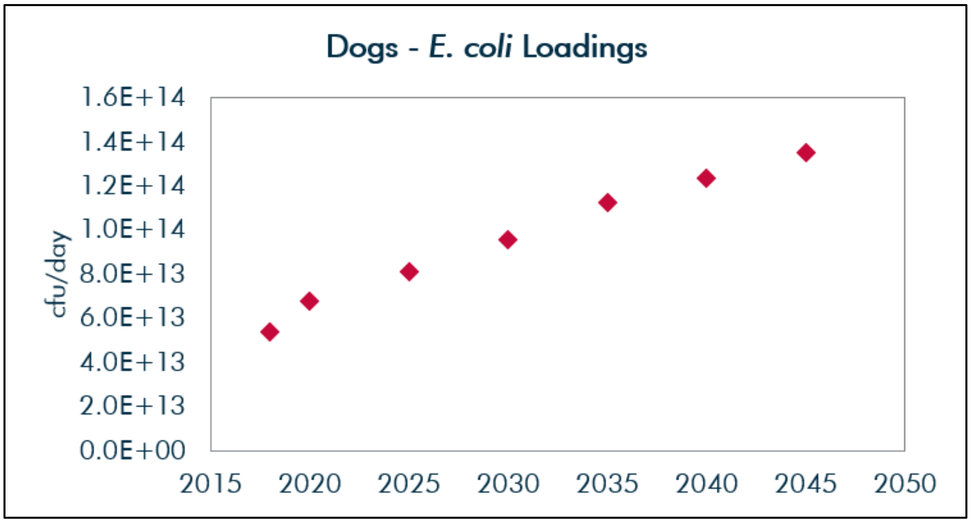

Figure 12. Future *E. coli* loadings from dogs

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 13**. 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 14**, forecasted total watershed loads from cattle are plotted in five-year increments through the year 2045.

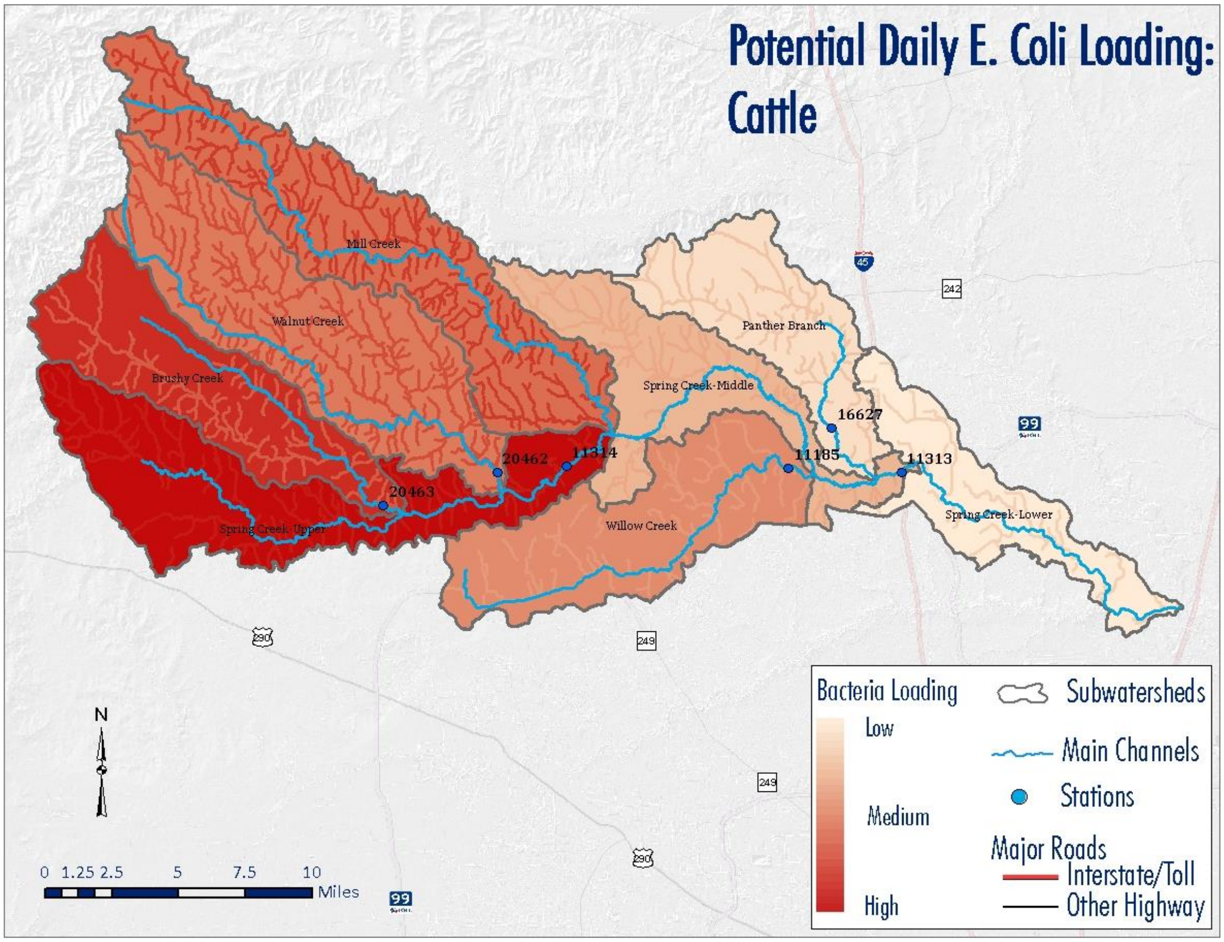

Figure 13. *E. coli* loadings from cattle by subwatershed

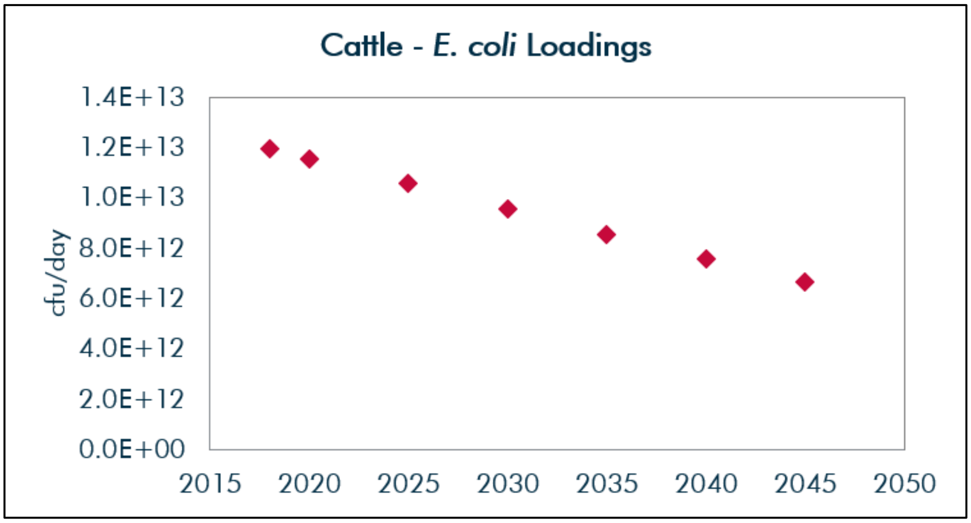

Figure 14. Future *E. coli* loadings from cattle

Table 15. Cattle and loadings by subwatershed

Subwatershed	Cattle Outside Buffer	Cattle Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	1,105	456	7.5E+11	1.2E+12	17%
2	916	407	6.2E+11	1.1E+12	14%
3	1,996	376	1.3E+12	1.0E+12	20%
4	3,243	655	2.2E+12	1.8E+12	33%
5	798	164	5.4E+11	4.4E+11	8%
6	276	122	1.9E+11	3.3E+11	4%
7	97	63	6.5E+10	1.7E+11	2%
8	61	52	4.1E+10	1.4E+11	2%
Total	**8,492**	**2,295**	**5.7E+12**	**6.2E+12**	**100%**

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 15.** *E. coli* loadings from horses by subwatershed. 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 16.** Future *E. coli* loadings from horses, forecasted total watershed loads from horses are plotted in five-year increments through the year 2045.

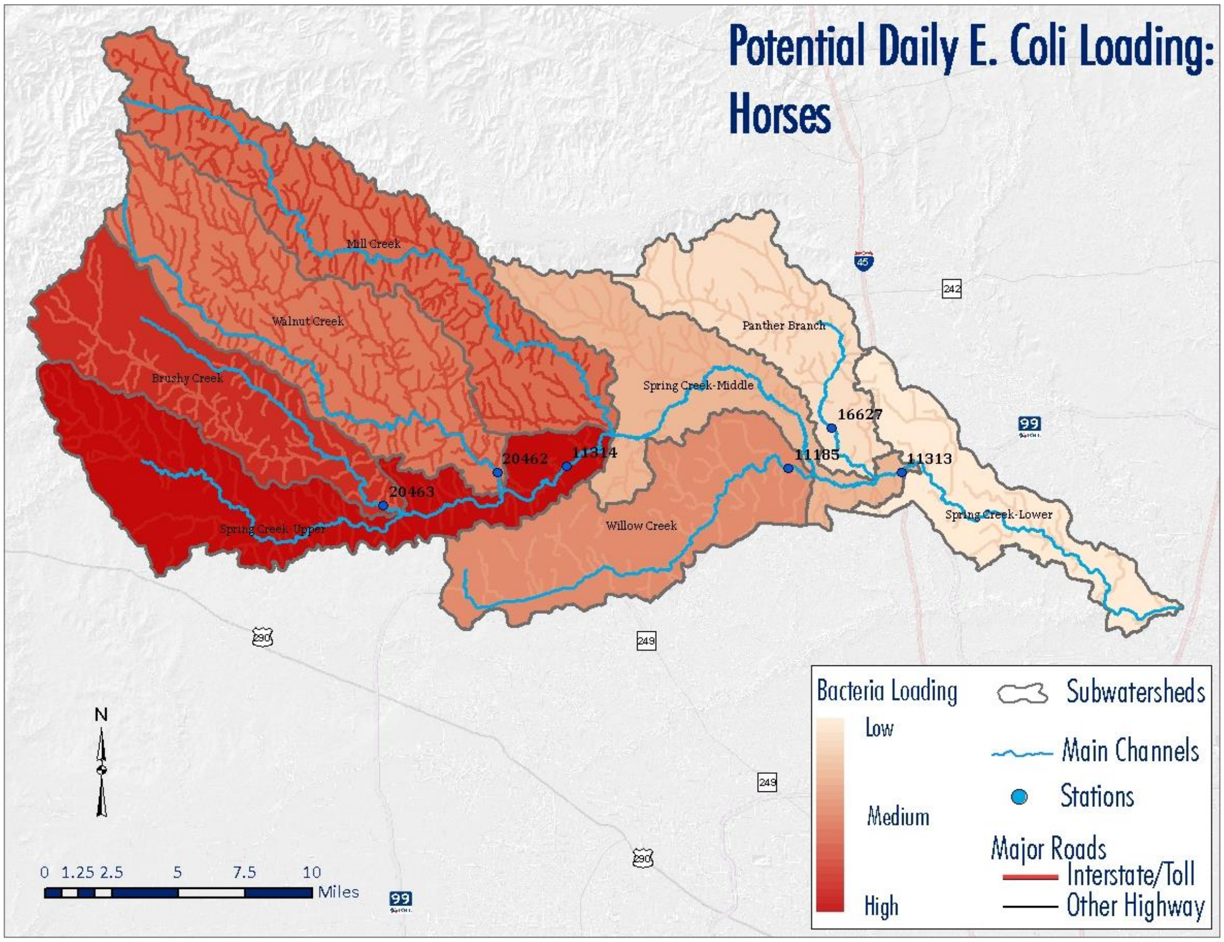

Figure 15. *E. coli* loadings from horses by subwatershed

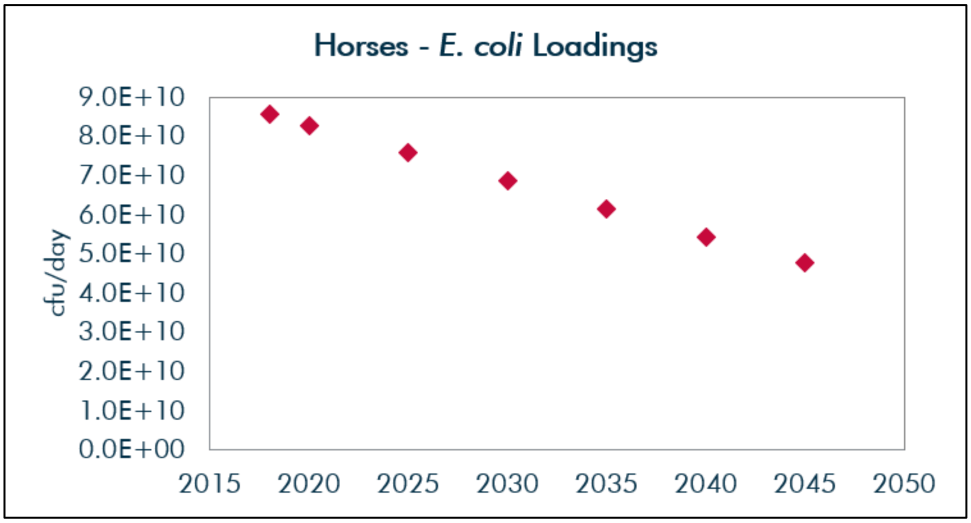

Figure 16. Future *E. coli* loadings from horses

Table 16. Horses and loadings by subwatershed

Subwatershed	Horses Outside Buffer	Horses Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	102	42	5.3E+09	8.8E+09	17%
2	84	38	4.4E+09	7.9E+09	14%
3	184	35	9.7E+09	7.3E+09	20%
4	299	60	1.6E+10	1.3E+10	33%
5	74	15	3.9E+09	3.2E+09	8%
6	25	11	1.3E+09	2.4E+09	4%
7	9	6	4.7E+08	1.2E+09	2%
8	6	5	2.9E+08	1.0E+09	2%
Total	**783**	**212**	**4.1E+10**	**4.4E+10**	**100%**

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 17**. 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 18**, forecasted total watershed loads from sheep and goats are plotted in five-year increments through the year 2045.

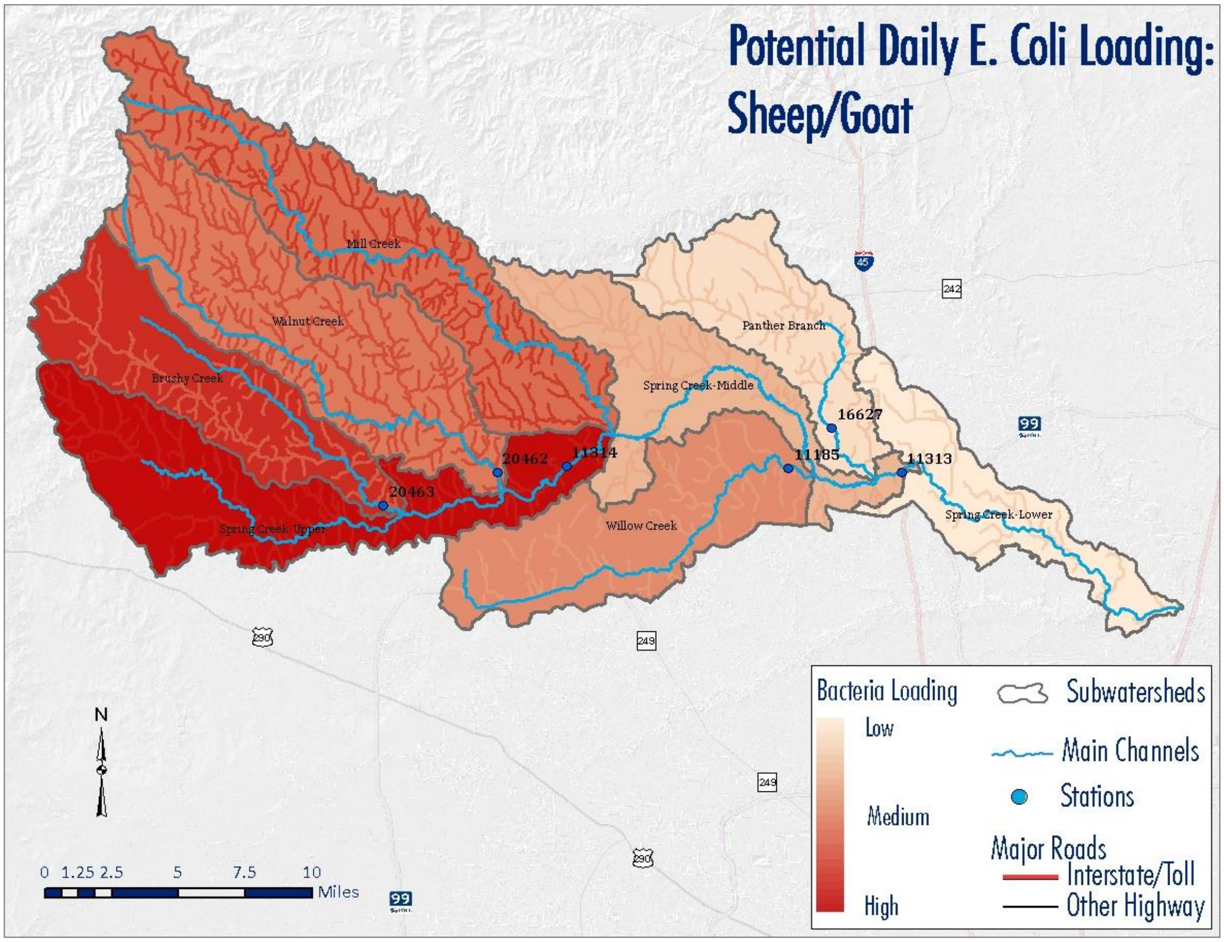

Figure 17. *E. coli* loadings from sheep and goats by subwatershed

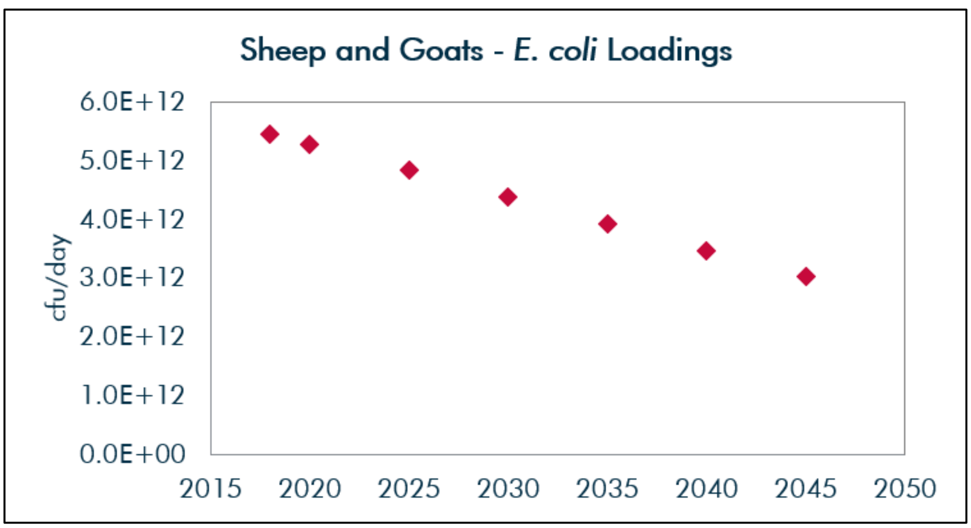

Figure 18. Future *E. coli* loadings from sheep and goats

Table 17. Sheep, goats and loadings by subwatershed

Subwatershed	Sheep & Goats Outside Buffer	Sheep & Goats Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	151	63	3.4E+11	5.6E+11	17%
2	126	56	2.8E+11	5.0E+11	14%
3	274	52	6.2E+11	4.6E+11	20%
4	445	90	1.0E+12	8.1E+11	33%
5	109	22	2.5E+11	2.0E+11	8%
6	38	17	8.5E+10	1.5E+11	4%
7	13	9	3.0E+10	7.8E+10	2%
8	8	7	1.9E+10	6.4E+10	2%
Total	**1,164**	**315**	**2.6E+12**	**2.8E+12**	**100%**

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 19**. 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 18**. In **Figure 20**, forecasted total watershed loads from deer are plotted in five-year increments through the year 2045.

Table 18. Deer and loadings by subwatershed

Subwatershed	Deer Outside Buffer	Deer Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	633	271	2.8E+10	4.7E+10	22%
2	611	256	2.7E+10	4.5E+10	21%
3	406	107	1.8E+10	1.9E+10	11%
4	464	147	2.0E+10	2.6E+10	14%
5	354	73	1.5E+10	1.3E+10	8%
6	330	109	1.4E+10	1.9E+10	10%
7	244	67	1.1E+10	1.2E+10	7%
8	246	64	1.1E+10	1.1E+10	7%
Total	**3,287**	**1,093**	**1.4E+11**	**1.9E+11**	**100%**

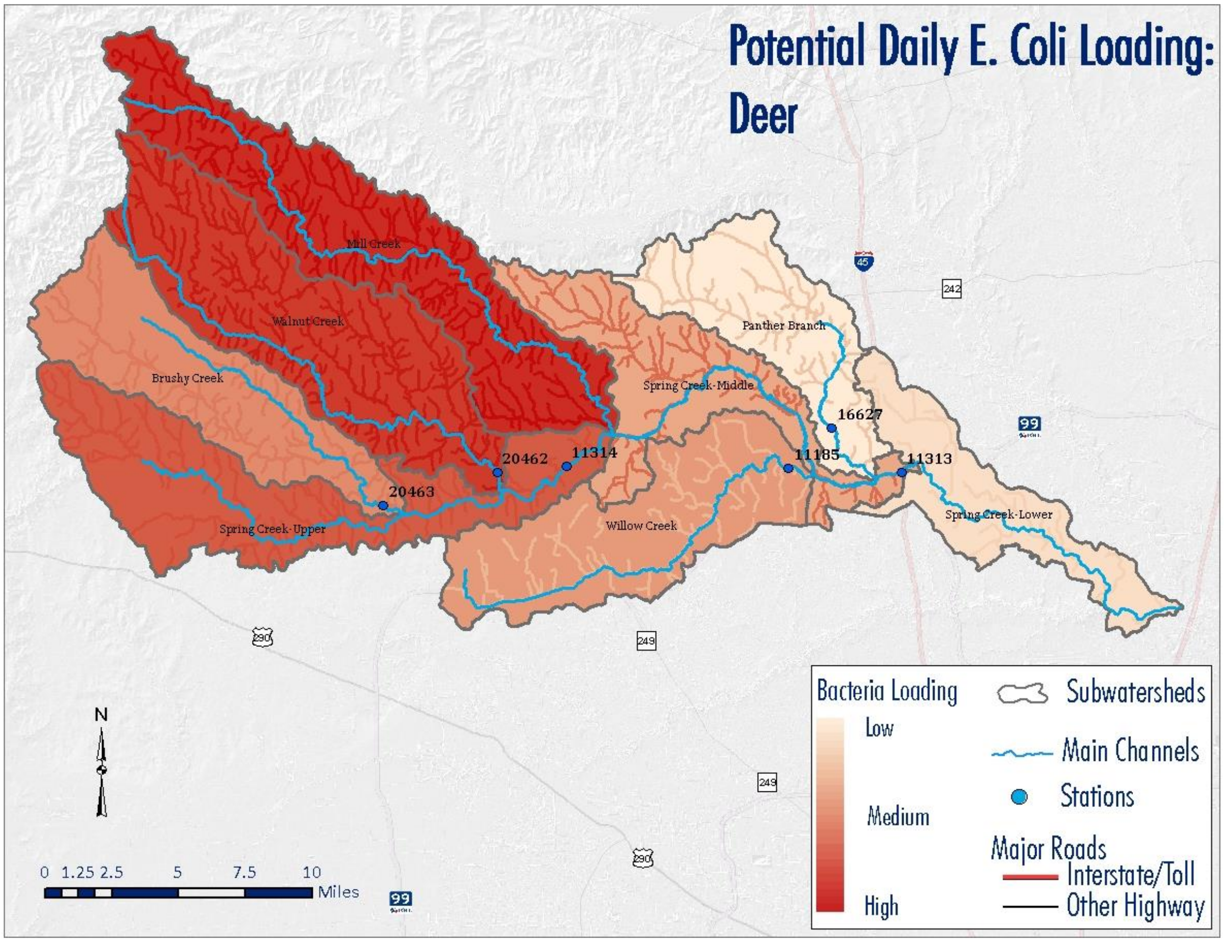

Figure 19. *E. coli* loadings from deer by subwatershed

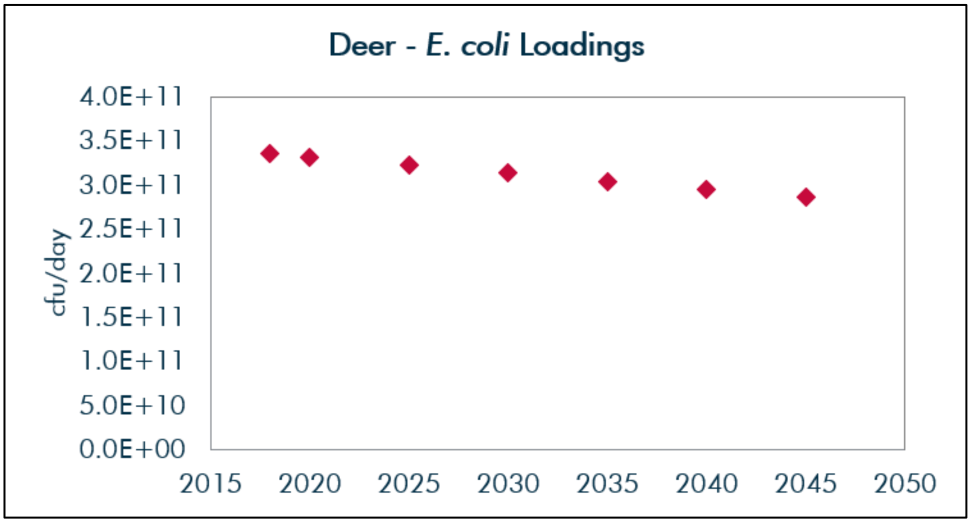

Figure 20. Future *E. coli* loadings from deer

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[25]. 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 19**, the specific allocation of hog population density based on stakeholder recommendations is described.

Table 19. Feral hog population density 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

[25] For more information, see: http://agrilife.org/feralhogs/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf

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 21**. 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 20**. In **Figure 22**, forecasted total watershed loads from feral hogs are plotted in five-year increments through the year 2045.

Table 20. Feral hogs and loadings by subwatershed

Subwatershed	Feral Hogs Outside Buffer	Feral Hogs Within Buffer	Load Outside Buffer	Load Within Buffer	Subwatershed Percent of Total Load
1	818	333	9.1E+11	1.5E+12	22%
2	813	316	9.0E+11	1.4E+12	21%
3	617	148	6.9E+11	6.6E+11	12%
4	781	213	8.7E+11	9.5E+11	17%
5	418	85	4.7E+11	3.8E+11	8%
6	369	121	4.1E+11	5.4E+11	9%
7	270	75	3.0E+11	3.3E+11	6%
8	267	71	3.0E+11	3.2E+11	6%
Total	**4355**	**1361**	**4.8E+12**	**6.1E+12**	**100%**

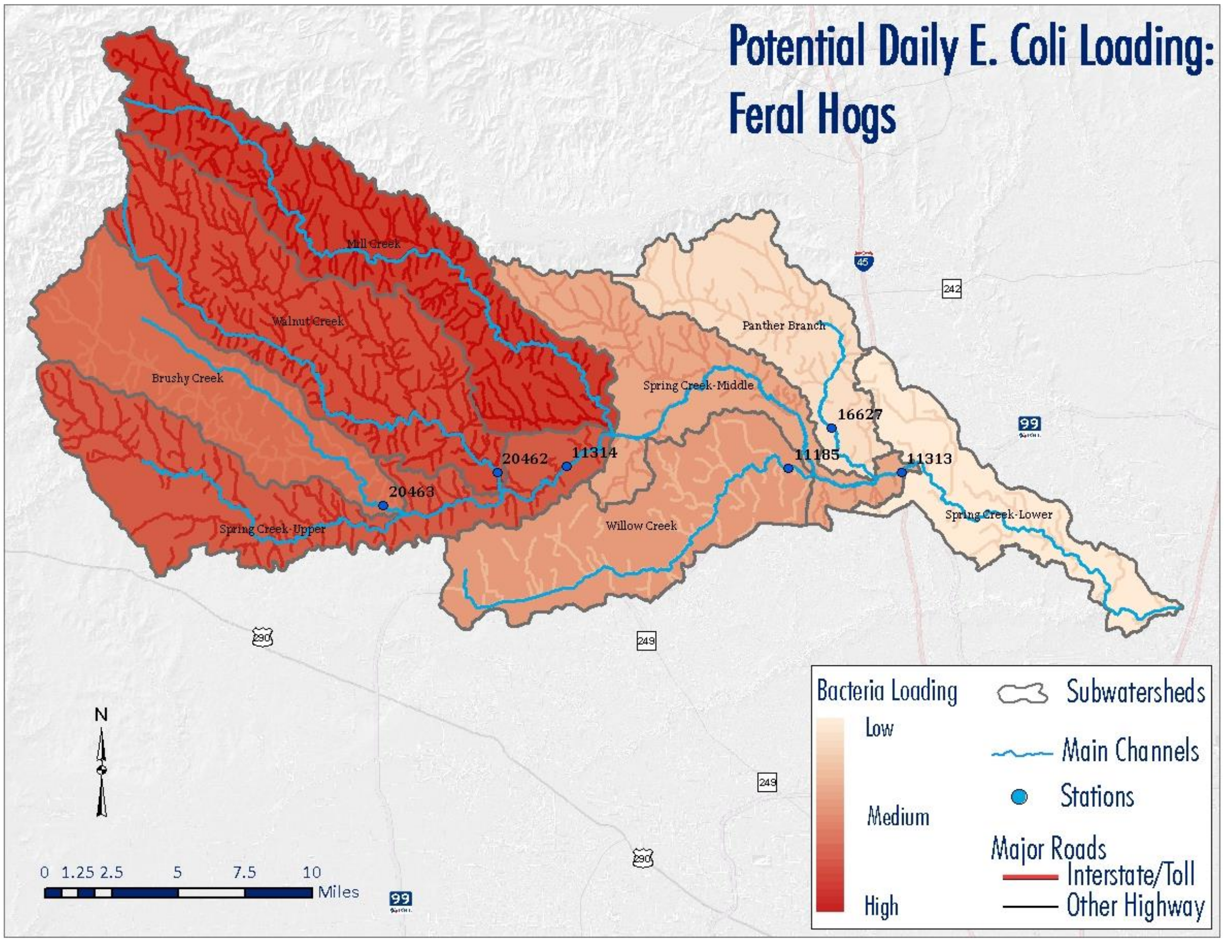

Figure 21. *E. coli* loadings from feral hogs by subwatershed

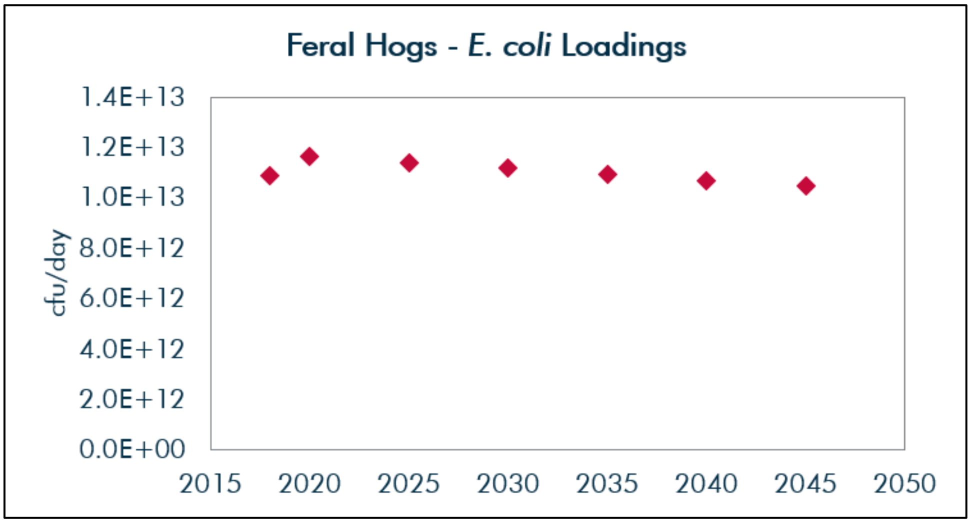

Figure 22. Future *E. coli* loadings from feral hogs

Other Sources of Fecal Waste

The primary other potential sources, and the reasons for not including them in the estimates are elaborated upon here. In general, sources which are not specifically included in the SELECT estimates are still potential targets of mitigation as part of the WPP, especially on a localized scale, depending on the source being discussed. While some of the wildlife populations discussed were not specifically modeled, their contributions are included in this project in the 10% safety margin load estimate.

- **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[26], 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[27] suggested for general

[26] For more detail, see the Water Quality Data Analysis Summary Report on the project website at: https://springcreekpartnership.weebly.com/uploads/1/3/0/7/130710643/10159_3.3_spring_creek_data_analysis_summary_report.pdf

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

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 TCEQ were used in these assessments. Spring Creek watershed stakeholders elected to adopt this method as well.

- **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.

- **CAFOs**
  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.

- **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[28] 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

[28] 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.

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.

- **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.

Summary of E. coli *Source Modeling 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 21** 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 22**. Assuming no additional action, changes in total load between 2018 and 2045 are shown in **Figure 23**. Relative changes in source contributions between current and future conditions are shown in **Figure 24** and **Figure 25** 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.

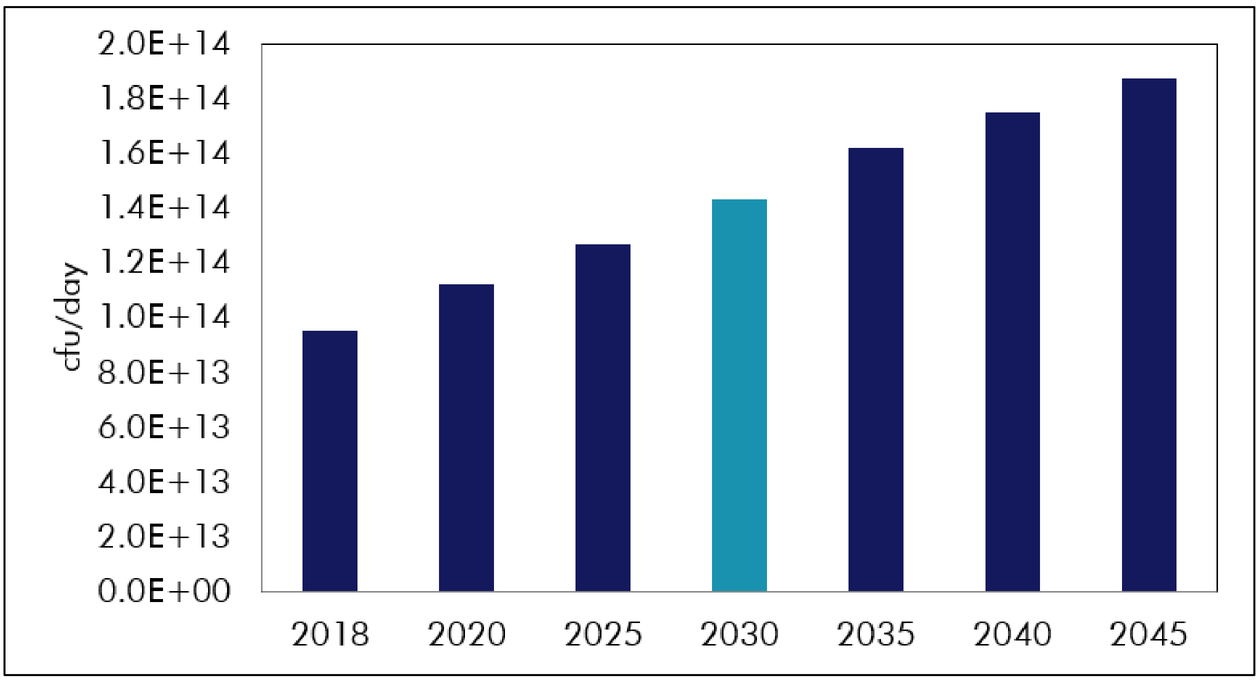

Figure 23. Potential total *E. coli* loads, 2018-2045

Table 21. Current *E. coli* loadings by source and subwatershed

Source	Subwatershed								% Total Load
	1	2	3	4	5	6	7	8	
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 22. *E. coli* 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		**9.5E+13**	**1.1E+14**	**1.3E+14**	**1.4E+14**	**1.6E+14**	**1.8E+14**	**1.9E+14**

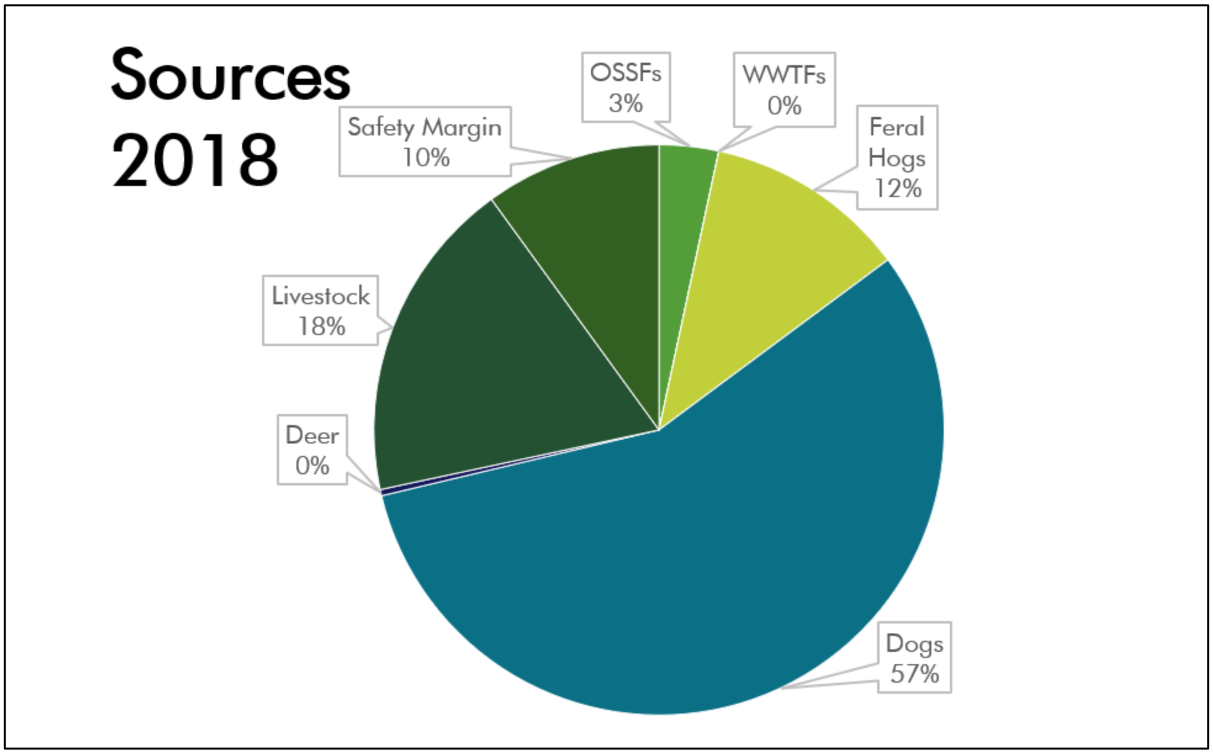

Figure 24. *E. coli* source profile, 2018

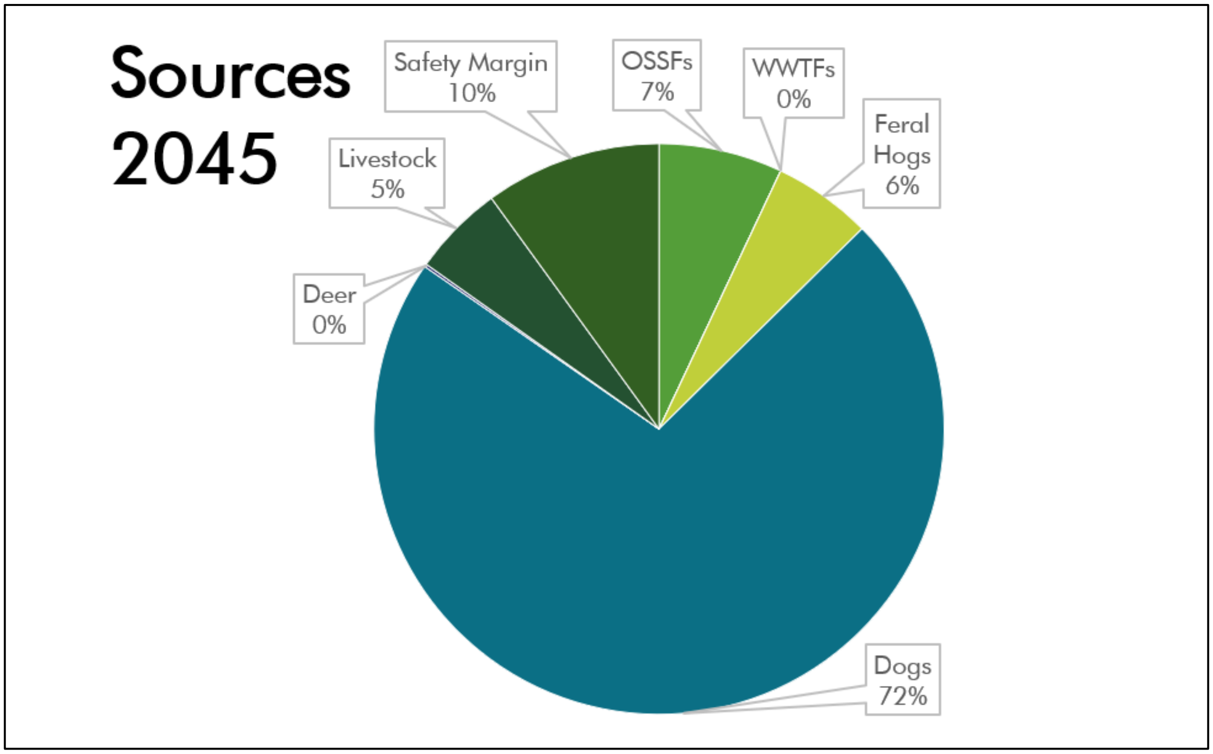

Figure 25. *E. coli* source profile, 2045

Implications of Fecal Waste Source Characterization Findings

The findings of the fecal waste source characterization and modeling efforts for Spring Creek reinforce the image of a watershed in transition. Driven by the general growth of the Houston area, and pushing outward from transportation corridors, the project area has seen significant growth in recent decades and will continue to do so in coming years. Developmental changes will reduce legacy agricultural sources in many areas, especially the headwaters area west of SH 249. The loss of load from agricultural activities will be outweighed by the increases of sources derived from developed areas. The increasing loads highlight the need for intervention through the WPP and other means. Current water quality issues will be compounded by future loads, leading to degrading water quality through the planning period absent any effort to the contrary.

Uncertainty is present throughout the assumptions and methodologies of this modeling approach, as noted throughout this document. Project staff used the best available data and stakeholder feedback to minimize uncertainty wherever possible, but the results should be taken in the context of their use in characterizing fecal waste pollution on a broad scale, and for scaling and siting BMPs. For these purposes, the level of uncertainty and precision of the results was deemed to be acceptable by the stakeholders. Further refinement of results may be needed in the future considering changing conditions. While bacteria source tracking or other analyses quantifying host organism DNA instream were not a function of this project, it may be a consideration in the future to further characterize sources, identify location-specific challenges, and refine the linkage between source loads and instream conditions.

Nutrient Source Characterization

Dissolved oxygen (DO) is essential for supporting aquatic communities. Depressed DO issues can result from a variety of causes. The multitude of potential precursors to depressed DO make it difficult to identify the cause of resulting water quality issues in a waterway. However, excessive nutrient inputs from human use (*e.g.*, landscaping and agricultural fertilizers) are sources that stakeholders have the greatest potential to change. High levels of nutrients entering waterways during rain events can foster blooms of algae. As these algal blooms begin to die off, the decomposition of the algae utilizes oxygen in the water which depresses levels of oxygen available for other aquatic life. Even if it is only part of the overall mix of causes for DO issues, reductions or mitigations of nutrient use will reduce the risk of low DO levels. The Partnership evaluated the available means to characterize nutrients, in the context of the water quality goals they established. Because DO is not an impairment in the watershed, and because many of the sources of nutrients overlap with sources of fecal waste[29], the Partnership focused its investigation efforts on identifying potential solutions and specific areas of concern.

Other Concerns

No specific modeling was conducted for other stakeholder concerns such as flooding, trash, and sediment. However, stakeholder feedback was taken on problem areas, and project staff developed recommendations for coordinating with partner efforts and programs overlapping these concerns as part of the recommended solutions of this WPP.

Flooding

Flooding was a primary concern for stakeholders in the watershed. Based on stakeholder discussions and ongoing conversations with key partners, the project identified several potential areas of overlap with flood mitigation efforts by the Harris County Flood Control District, and United States Army Corps of Engineers (USACE). The potential use of natural infrastructure as supplement to flood mitigation projects, the conservation of open space, and the inclusion of water quality concerns in flood project design were all areas of needed coordination during the implementation of this WPP.

Trash

No specific sites of appreciable concern were designated by stakeholders, and no formal survey of trash was conducted under this project. However, trash in the waterway is an ongoing and visible concern for the stakeholders, especially in denser urban areas of the downstream watershed, where trash enters through stormwater and sheet flow. Project staff identified several ongoing efforts in the watershed that would be important points of coordination, with the intent of including trash in water quality conversations, and vice versa.

Sediment

Sediment transfer from within and outside of the watershed was an issue raised by several stakeholders and is mirrored by similar conversations in adjacent watersheds like the West Fork San Jacinto River and Cypress Creek. No formal modeling or assessment was completed to identify erosion/deposition patterns in the watershed. However, given the link to flooding, downstream issues with reducing reservoir capacity in Lake Houston, and the potential for sediment-laden waters to enhance fecal bacteria transport, further coordination is needed.

[29] Recommendations for best practices for bacteria sources are expected to be beneficial in reducing nutrient contamination as well (*e.g.*, reducing animal waste high in both fecal pathogens and nitrogenous compounds).