

Bacteria Modeling Report for the Greens Bayou Watershed

October 2024

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SECTION 1: INTRODUCTION

Greens Bayou flows east and south from its headwaters near the crossing of State Highway 249 and the Sam Houston Tollway. The Greens Bayou watershed is composed of the drainage area of the classified segments Greens Bayou Above Tidal (1016) and Houston Ship Channel (HSC)/Greens Bayou Tidal (1006), as well as smaller unclassified segment tributaries including Halls Bayou (1006D), Garners Bayou (1016A), and a network of natural and manmade drainage channels. This watershed area spans approximately 208 square miles within Harris County (**Figure 1**). Land cover in the watershed is mostly developed with the exception of some forested and woody wetland areas clustered around the waterways that run through the area (**Figure 1**). Major transportation corridors include Interstate 10, Interstate 45, Interstate 69/US Highway 59, the Hardy Toll Road, the Sam Houston Tollway/Beltway 8, State Highway 90 and State Highway 249. The watershed overlaps portions of Houston, Humble, Atascocita, and Cloverleaf. Pollution associated with development is expected to increase with growing populations.

The most recent version of the Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) (Texas Integrated Report)¹ produced by the Texas Commission on Environmental Quality (TCEQ) indicated exceedances of state water quality standards in Greens Bayou and its tributaries². Specifically, high concentrations of the fecal indicator bacteria *Escherichia coli* (*E. coli*) and Enterococci resulting in impairments to contact recreation use were observed. Because fecal indicator bacteria such as *E. coli* and Enterococci are found in the digestive systems of people and animals, detecting high concentrations of this organism in surface water indicates potential contamination from sources such as untreated sewage, agricultural runoff, or deposits from wild animals. Especially in cases where human waste pressures are indicated, there is also a likelihood that additional pathogens could be present in waterways. Without taking action to manage sources of contamination, recreation activities such as swimming and wading in streams will not be safe for communities of the watershed.

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

¹ This report references the 2022 version of the Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d). These assessments determine which streams are classified as having impairments (measurements exceeding numerical or other specific state water quality standards) or concerns (exceedances of screening levels or other non-numeric/specific criteria).

² A more detailed analysis of water quality is discussed further in the Preliminary Acquired Data Analysis Report for the Greens Bayou Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the Greens Bayou Modeling Quality Assurance Project Plan) are available for review at <https://greensbayoupartnership.weebly.com/documents.html>.

The following sections of this document will discuss:

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

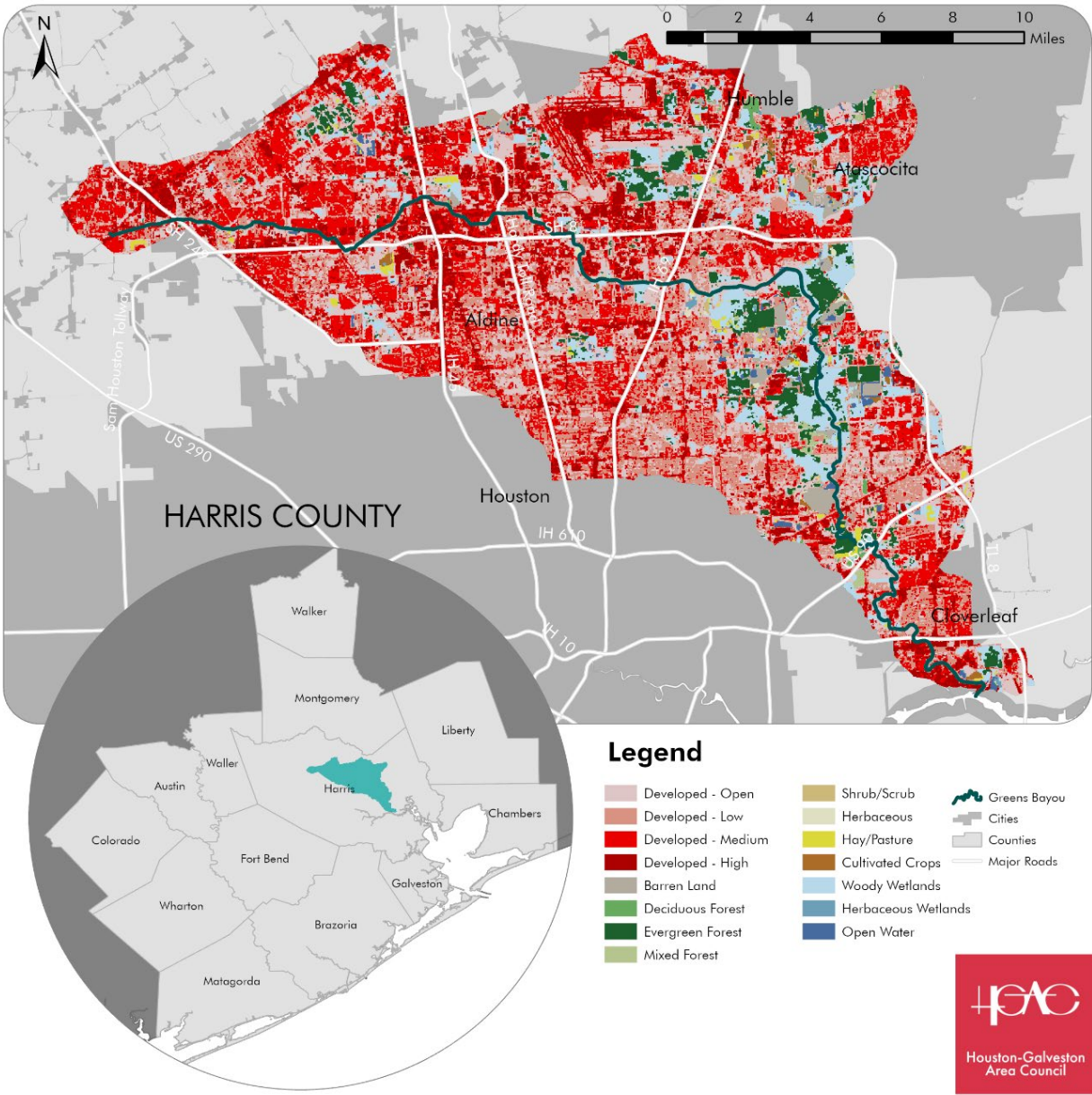


Figure 1. The Greens Bayou watershed, land cover, and regional context

SECTION 2: PROJECT NEEDS

Model results are an important resource for stakeholders seeking to make watershed planning decisions. By observing modeled data, stakeholders will develop a better understanding of what pollutant sources are impacting the watershed, at what magnitudes pollutants are delivered to the system, where pollutant pressures are spatially distributed, and how to address these concerns most effectively. Beyond this primary need, the combination of modeling results, other data analyses, and stakeholder input is essential to the fulfillment of Element A of the United States Environmental Protection Agency (EPA) 9-element model for watershed-based plans³.

Needs specific to the development of a WPP for Greens Bayou and its tributaries include:

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

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

SECTION 3: MODEL SELECTION AND ANALYSIS DESIGN

3.1 Model Selection

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

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

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

³ As referenced at <https://www.epa.gov/nps/handbook-developing-watershed-plans-restore-and-protect-our-waters>

utilization of a base assumption for wildlife impacts throughout the watershed. This helps to bridge the gap that the SELECT model can sometimes face when limited by sparse or insufficient wildlife data.

3.2 Analysis Design

According to findings from the most recent version of the Texas Integrated Report produced by TCEQ, the most widespread and frequently occurring impairment in the Greens Bayou watershed is caused by high levels of fecal indicator bacteria, which can indicate the presence of fecal waste and pathogens in surface water. Concerns for low levels of DO were also observed throughout the watershed as well as an impairment for aquatic life use due to depressed DO on an unnamed tributary to Greens Bayou (1016D_01). Water quality and spatial data used in this report were collected from quality assured sources including the Surface Water Quality Monitoring Information System and the National Hydrography Dataset. Using LDCs and SELECT models, the following analyses were designed to consider:

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

Model results from LDCs and SELECT evaluations were combined to link reduction goals to specific source loads and develop effective water quality improvement strategies for the WPP. Future reduction targets derived from this assessment represent five-year benchmarks through the year 2050.

SECTION 4: LDC EVALUATIONS

4.1 Overview

LDCs were used to characterize the relationship between pollutant loads and stream flow. By determining the difference between modeled loads and the maximum loads permitted by state water quality standards, reduction targets can be estimated. Because impairments due to elevated levels of fecal indicator bacteria and depressed levels of DO were noted for segments in this watershed in the latest Texas Integrated Report produced by TCEQ, LDCs were used for both sets of pollutants.

4.2 Load Estimation

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

To calculate LDCs for Greens Bayou and its tributaries, stream flow data from the United States Geological Survey (USGS) and Clean Rivers Program (CRP) water quality data from the Surface Water Quality

Monitoring Information System were used. USGS gage data is ideal to produce flow duration curves used in LDC analyses due to the long-term, continuous measurements recorded by the gages. Based on the percentage of days during the study period in which flows of a known magnitude are observed, a flow duration curve is developed and plotted. Additional curves resulting from the multiplication of state water quality standards and values of the flow duration curve are added to the plot to represent the maximum allowable contaminant loads during each flow condition. Finally, individual observed pollutant levels collected during the study period and a curve modeled from these observations are plotted. For areas where the modeled curve exceeds the maximum allowable contaminant load curve, reductions are needed.

4.3 Site Selection

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

- 1) **Greens Above Tidal - Upper (SW1)** – the drainage area of Assessment Unit (AU) 1016_01, the upper third of Greens Bayou Above Tidal. Like the rest of the subwatersheds, land cover in this subwatershed is densely developed. This waterbody represents the headwaters of Greens Bayou Above Tidal. This area is represented by Station 13778 (Greens Bayou at Knobcrest Drive) and stream flow was assessed from USGS gage 08075900.
- 2) **Greens Above Tidal - Middle (SW2)** – the drainage area of AU 1016_02, the middle third of Greens Bayou Above Tidal. This area is represented by USGS gage 08076000 which was used to measure flow at Station 11371 (Greens Bayou at US 59).
- 3) **Greens Above Tidal - Lower (SW3)** – the drainage area of AU 1016_03, the lower third of Greens Bayou. While still a heavily developed area, forest and wetland land cover types are more prevalent compared to other subwatersheds. This area is represented by Station 11369 (Greens Bayou at Tidwell Road). This station is not represented by a USGS gage, but because it occurs on the same water body as a gaged station (11371), stream flow was estimated by applying a drainage area ratio. To do this, the drainage area of 11371 was compared to that of 11369 to determine a ratio to use as a multiplier for daily mean stream gage measurements taken at 11371.
- 4) **Garners Bayou (SW4)** – the drainage area of Segment 1016A, which is made up of the full length of Garners Bayou. While still a heavily developed area, forest and wetland land cover types are more prevalent compared to other subwatersheds. Ambient data for this area are represented by Station 11125 (Garners Bayou at SH Loop 8). This station is represented by USGS gage 08076180.
- 5) **Halls Bayou (SW5)** – the drainage area of Halls Bayou (Segment 1006D), a tributary to Greens Bayou. Ambient data for this area are represented by Station 11126 (Halls Bayou at Jensen Drive). This station is represented by USGS gage 08076500.
- 6) **Houston Ship Channel (HSC)/Greens Bayou (SW6)** – the drainage area of the tidal portion of Greens Bayou (AU 1006_03). Ambient data were collected from Station 18363 (Greens Bayou at Market Street). As with Station 11369 in SW3, stream flow data were assessed by applying a drainage area ratio. However, as the station is tidally influenced, the reference gage data was taken from a nearby watershed of similar size and geography on Goose Creek in Baytown, TX (08067525). Additionally, a seawater flow adjustment formula was applied using regression values between flow and salinity collected at 18363.

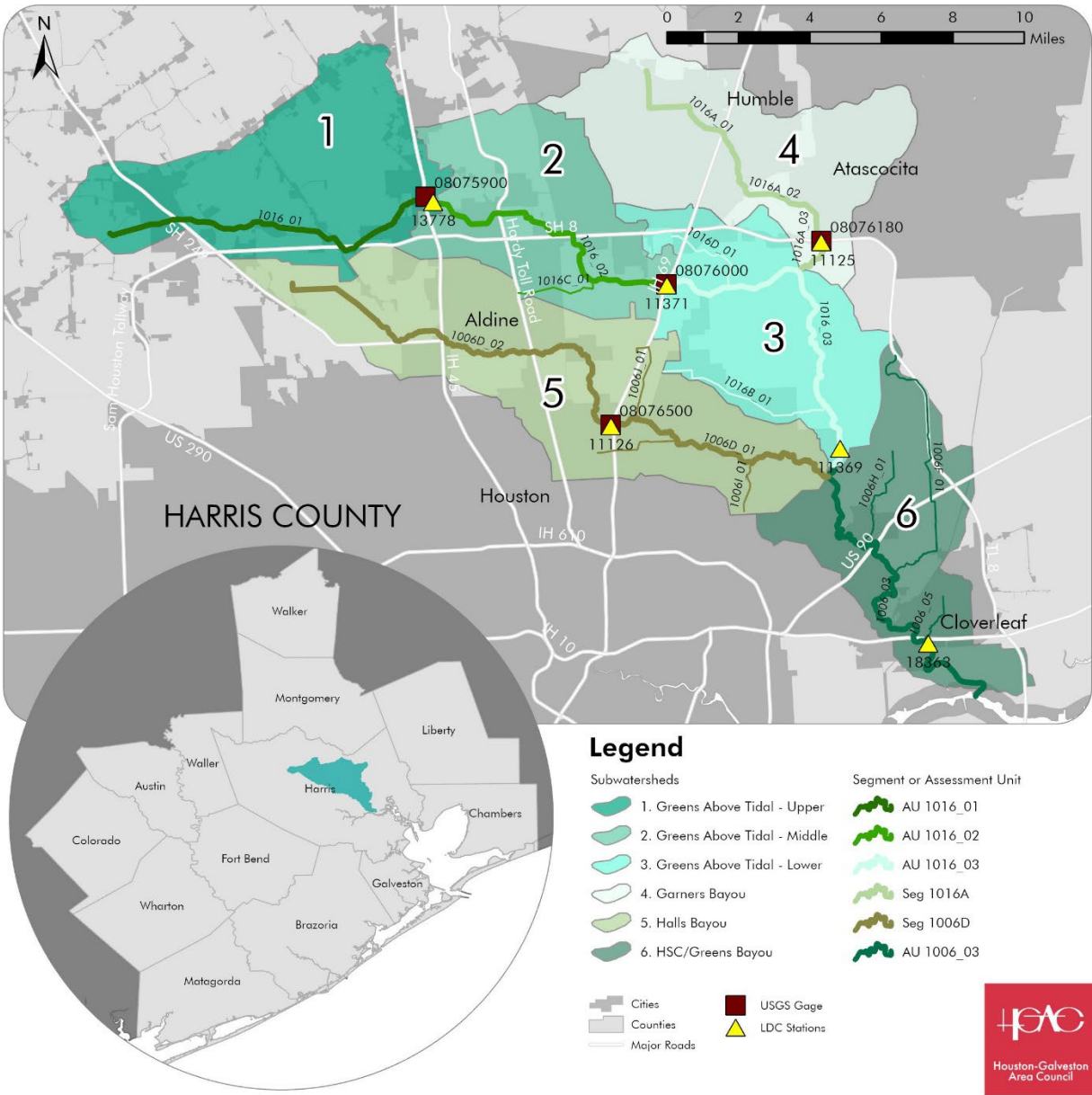


Figure 2. Subwatersheds of the Greens Bayou watershed

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 CRP. In general, most monitoring stations are sampled by CRP partners on a quarterly frequency for a suite of field, bacteriological, and conventional parameters. The final determination of the regulatory status of each segment is based primarily on these ambient data. The impetus for development of the WPP was formed largely in response to the current regulatory status of Greens Bayou and its tributaries, therefore ambient data is a relevant source of information for informing stakeholder decisions. Ambient data used for LDC analyses were collected in the Greens Bayou watershed between 2013 and 2023 at five locations (**Figure 2; Table 1**).

Table 1. LDC locations

LDC Site	CRP Station	USGS Gage	Assessed Area
Greens Bayou at Knobcrest Drive	13778	08075900	Subwatershed 1
Greens Bayou at US 59	11371	08076000	Subwatershed 2
Greens Bayou at Tidwell Road	11369	No Gage	Subwatershed 3
Garners Bayou at SH Loop 8	11125	08076180	Subwatershed 4
Halls Bayou at Jensen Drive	11126	08076500	Subwatershed 5
Greens Bayou at Market Street	18363	No Gage	Subwatershed 6

4.4 Data Development

In addition to location and availability of stream flow data, sufficiency and consistency of ambient data collection were important factors leading to the selection of the six CRP stations used for LDC analysis. The number of quality assured data values for bacteria and DO are expressed in **Table 2**. All stations in the Greens Bayou watershed have at least 10 years of data available and range from 35 to 95 samples for bacteria and 75 to 198 samples for DO.

Table 2. Number of samples by station

LDC Location	Station	# of Bacteria Samples	# of DO Samples
Greens Bayou at Knobcrest Drive	13778	85	82
Greens Bayou at US 59	11371	86	83
Greens Bayou at Tidwell Road	11369	95	94
Garners Bayou at SH Loop 8	11125	80	75
Halls Bayou at Jensen Drive	11126	86	80
Greens Bayou at Market Street	18363	35	198

4.5 LDC Implementation

Project staff used the data referenced above to generate flow curves and LDCs. While both geomean and single sample data for fecal bacteria were assessed, at each station observed in this report, only the geomean results were used for determining reduction targets. Values labeled “Geometric Mean Load” (gray squares) represent the geometric mean of the modeled bacteria load values within a specific flow condition. The distance between this point and the standard curve represents the reduction needed (represented as percentages on corresponding table). Negative values indicate that no reductions or improvements are needed in associated stream flow conditions. When interpreting DO results, it should be noted that even though LDCs may not indicate that DO levels require improvement, this evaluation may skew the impact of outliers. The TCEQ assessment of several of the unclassified tributaries and assessment units of the main stem indicated concerns and impairments related to various standards or screening levels regarding DO

levels based on the outlying exceedances. The data also naturally skew toward high DO samples because monitoring is not conducted at night, when the daily DO cycle leads to lower DO levels in some conditions. No appreciable issues were identified in LDC development based on quality assured internal review, however results of these analyses will be discussed in greater detail with project stakeholders to verify accuracy and representativeness.

Station 13778 – Greens Bayou at Knobcrest Drive

Station 13778 is located on AU 1016_01, the headwaters section of Greens Bayou. As with all other subwatersheds, the majority (92%) is developed. The majority (99%) of daily average rates of stream flow in cubic feet per second (cfs) on AU 1016_01 are estimated to be between 0 and 1,000 cfs. The highest 1% of flows ranged from 1,000 to just over 10,000 cfs with the highest recorded value occurring during the peak of Hurricane Harvey in 2017.

The results of LDC analyses for bacteria at Station 13778 (**Figure 3; Table 3**) indicate a need for significant reductions in *E. coli* geomean loads expressed in billion colony forming units per day (cfu/day) at all five levels of flow conditions. Results of the LDC analysis for DO in milligrams per day (mg/day) (**Figure 4; Table 3**) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, therefore, the LDC results are likely accurate.

Table 3. Flow specific values for LDC 13778

Flow Category	Percent of Days Flow Exceeded	<i>E. coli</i> Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	96.72%	-53.87%
Moist Conditions	10-40%	91.46%	-62.96%
Mid-Range Conditions	40-60%	87.83%	-65.87%
Dry Conditions	60-90%	86.23%	-66.82%
Low Flows	90-100%	84.42%	-67.75%

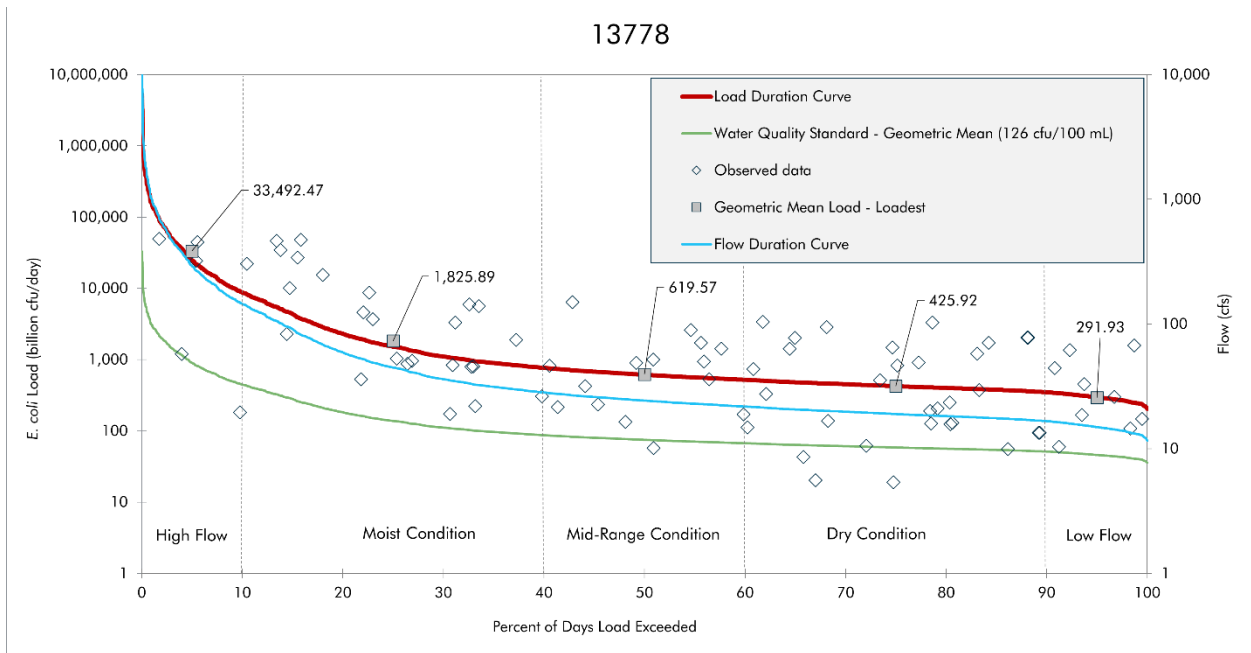


Figure 3. *E. coli* LDC for Station 13778

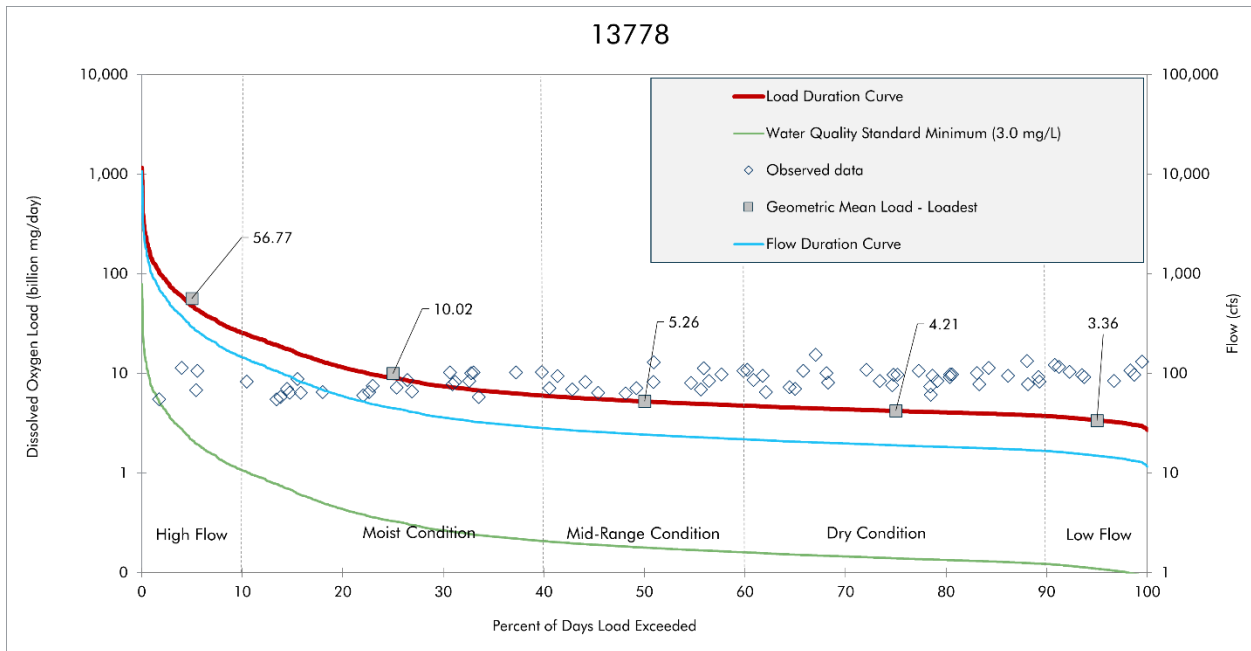


Figure 4. DO LDC for Station 13778

Station 11371 – Greens Bayou at US 59

Station 11371 is located on AU 1016_02, the middle portion of Greens Bayou Above Tidal. Developed areas make up 90% of the land cover in the drainage area for this waterbody. At this station, 99% of flows ranged from 0 to 2,000 cfs. The top 1% ranged from 2,000 to 20,000 cfs. As with 13778, the highest flows were observed during the flooding associated with Hurricane Harvey in 2017.

The results of LDC analyses for Station 11371 (**Figure 5; Table 4**) indicate that fecal bacteria require reduction in all five flow conditions. Comparative to Station 13778, reduction levels at Station 11371 were lower especially for mid-range through low flow conditions. Results of the LDC analysis for DO (**Figure 6; Table 4**) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, therefore, the LDC results are likely accurate.

Table 4. Flow specific values for LDC 11371

Flow Category	Percent of Days Flow Exceeded	<i>E. coli</i> Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	98.65%	-49.59%
Moist Conditions	10-40%	83.69%	-54.50%
Mid-Range Conditions	40-60%	57.00%	-56.27%
Dry Conditions	60-90%	40.54%	-56.85%
Low Flows	90-100%	19.77%	-57.38%

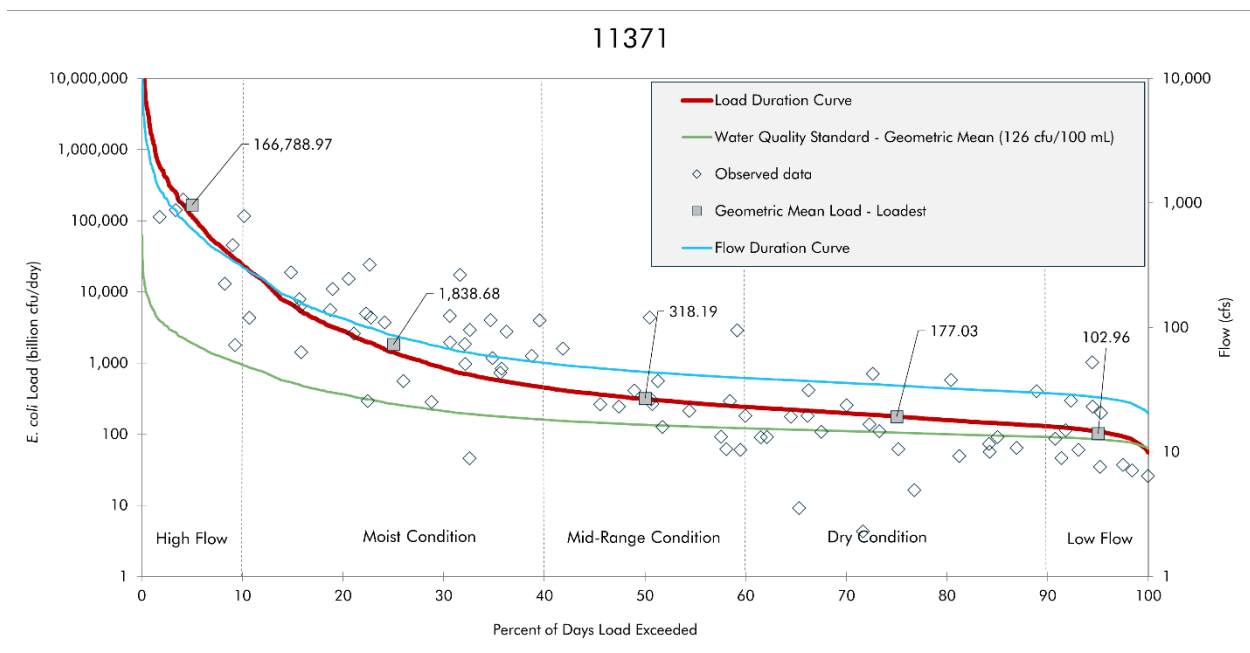


Figure 5. *E. coli* LDC for Station 11371

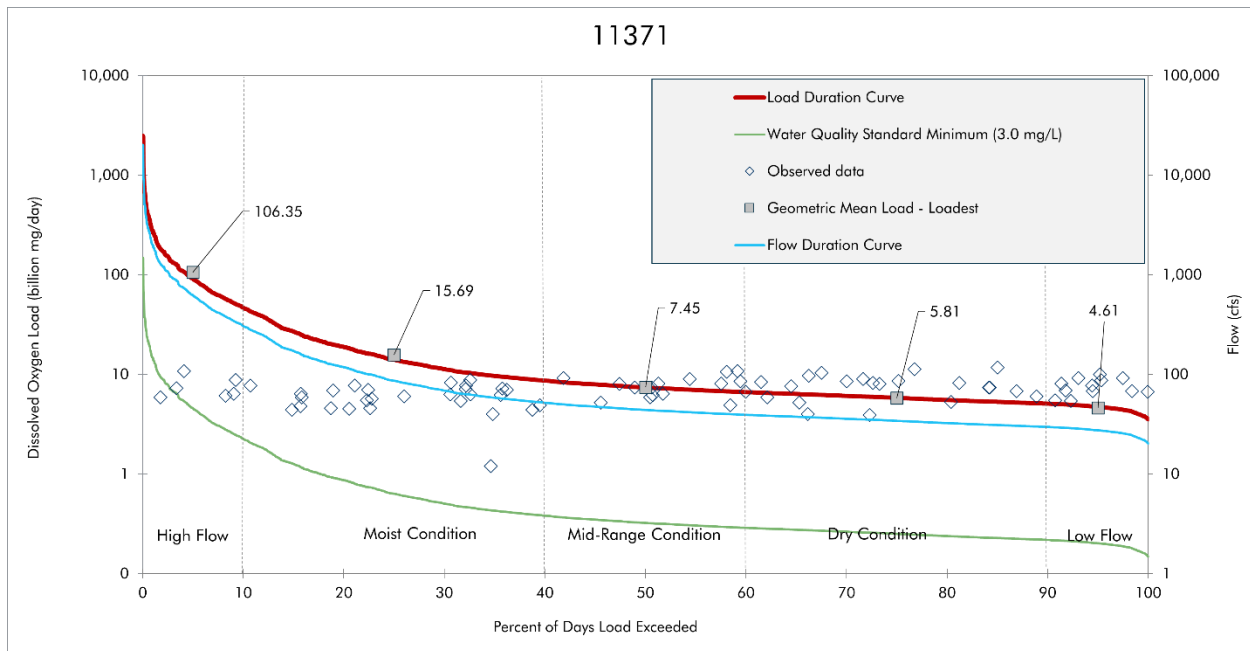


Figure 6. DO LDC for Station 11371

Station 11369 – Greens Bayou at Tidwell Road

Station 11369 is located on the lower portion of Greens Bayou Above Tidal (AU 1016_03). While the majority (56%) of the subwatershed is comprised of developed areas, this subwatershed also has the highest percentage (29%) of wetland and a fair amount (7%) of forested area. Stream flow on this portion of the bayou ranged from 0 to 1,860 cfs with exceptional flows associated with flooding events ranging between 1,860 and 19,000 cfs.

The results of LDC analyses for Station 11369 (Figure 7; Table 5) show that reductions in fecal bacteria are recommended for all flow conditions excluding low flow. Results of the LDC analysis for DO (Figure 8; Table 5) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, however, a tributary to this AU (1016D_01) was indicated as not supported for aquatic life use due to depressed DO.

Table 5. Flow specific values for LDC 11369

Flow Category	Percent of Days Flow Exceeded	<i>E. coli</i> Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	98.90%	-57.67%
Moist Conditions	10-40%	81.22%	-59.98%
Mid-Range Conditions	40-60%	43.41%	-60.84%
Dry Conditions	60-90%	18.17%	-61.12%
Low Flows	90-100%	-15.07%	-61.38%

11369

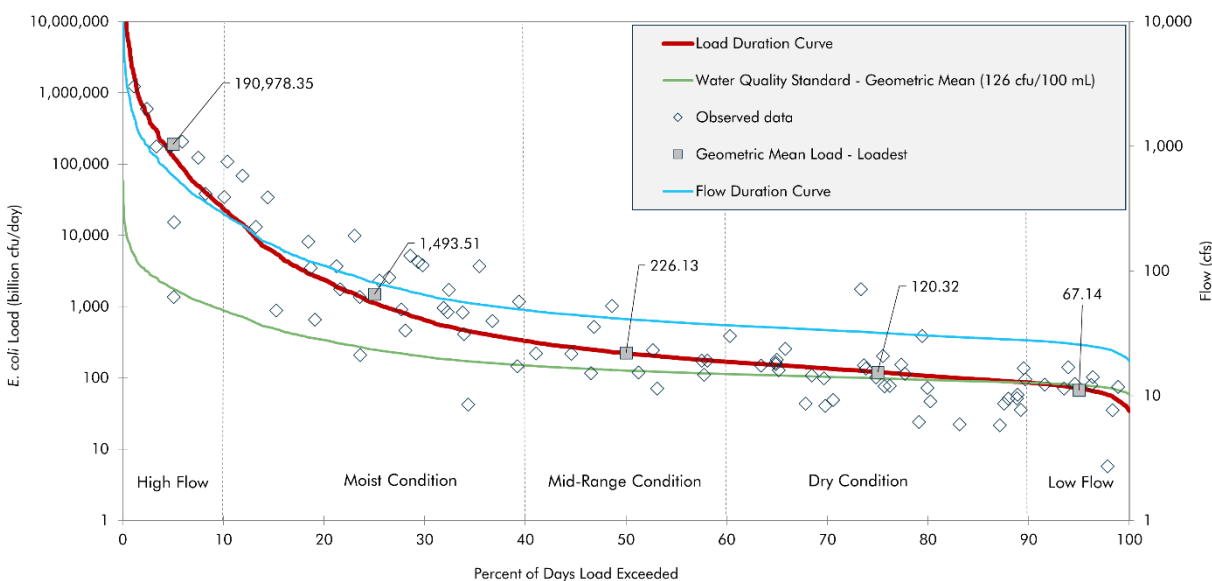


Figure 7. *E. coli* LDC for Station 11369

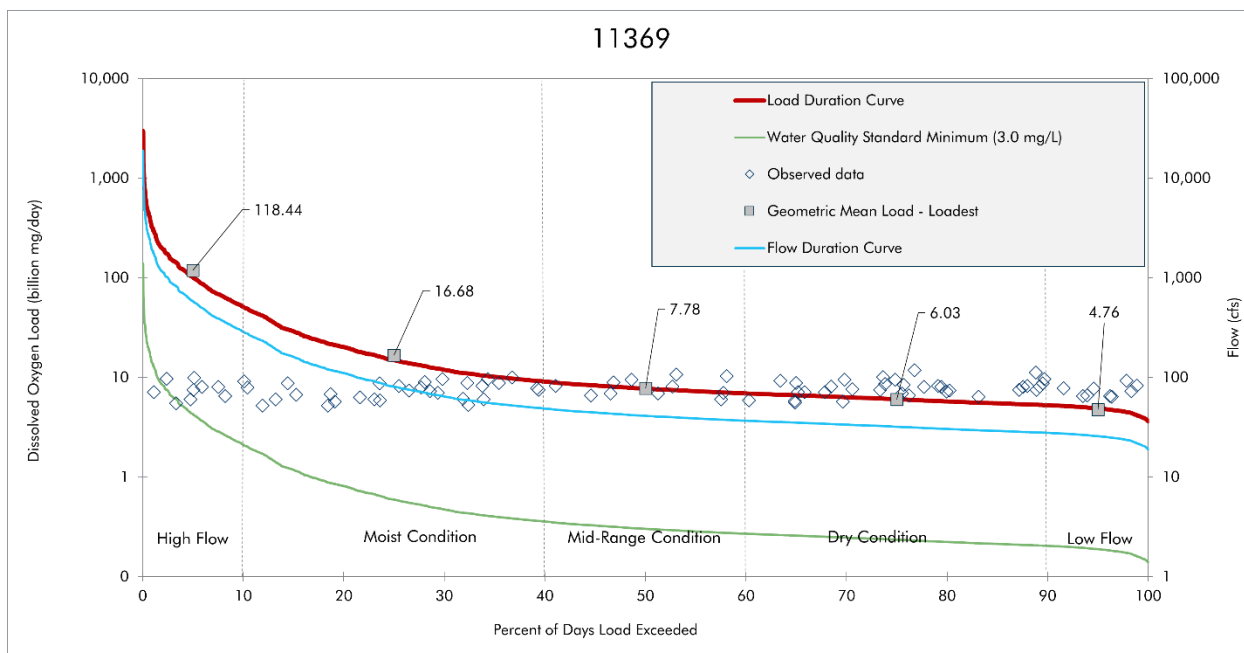


Figure 8. DO LDC for Station 11369

Station 11125 – Garners Bayou at SH Loop 8

Station 11125 occurs on Garners Bayou (1016A), a tributary to Greens Bayou. Developed areas make up 71% of the land cover in the drainage area for this waterbody. Other notable land cover types include 12% wetlands and 11% forested areas. This makes it the most heavily forested subwatershed of the six areas analyzed. Most flows ranged from 0 to 930 cfs with the top 1% of flows ranging between 930 and 15,500 cfs.

The results of LDC analyses for Station 11125 (**Figure 9; Table 6**) indicate that considerable *E. coli* reductions needed in all five flow conditions. Results of the LDC analysis for DO (**Figure 10; Table 6**) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, therefore, the LDC results are likely accurate.

Table 6. Flow specific values for LDC 11125

Flow Category	Percent of Days Flow Exceeded	<i>E. coli</i> Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	96.46%	-52.96%
Moist Conditions	10-40%	82.91%	-58.05%
Mid-Range Conditions	40-60%	72.15%	-59.51%
Dry Conditions	60-90%	66.78%	-60.03%
Low Flows	90-100%	58.49%	-60.67%

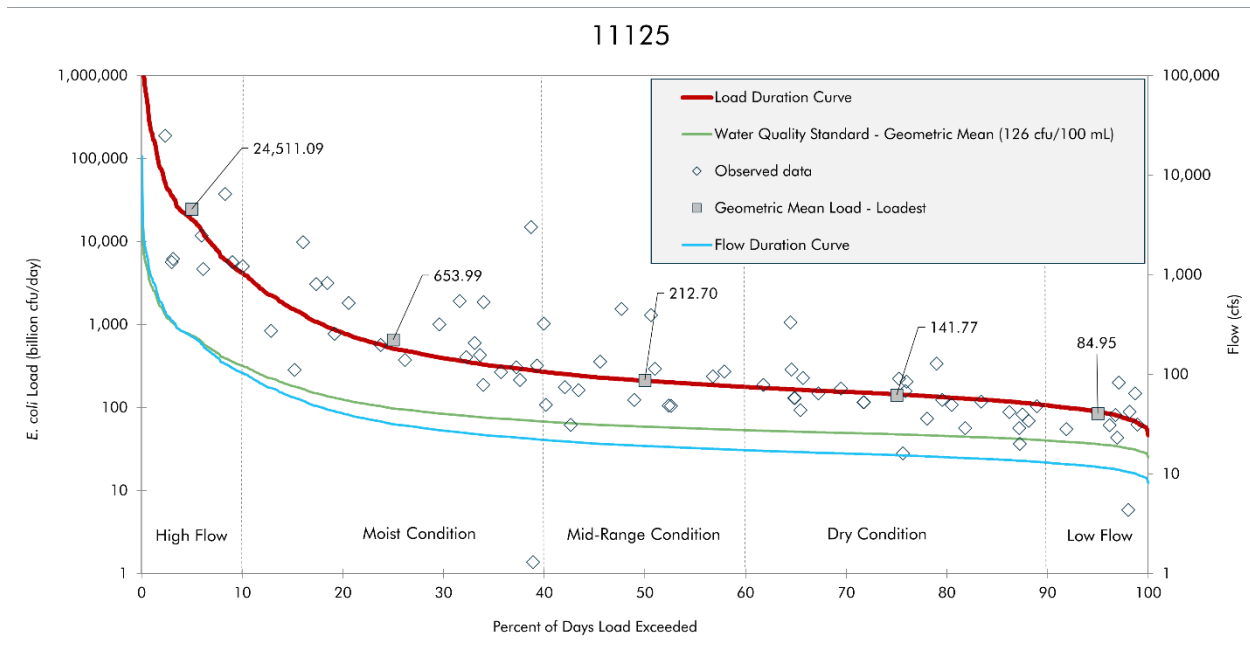


Figure 9. *E. coli* LDC for Station 11125

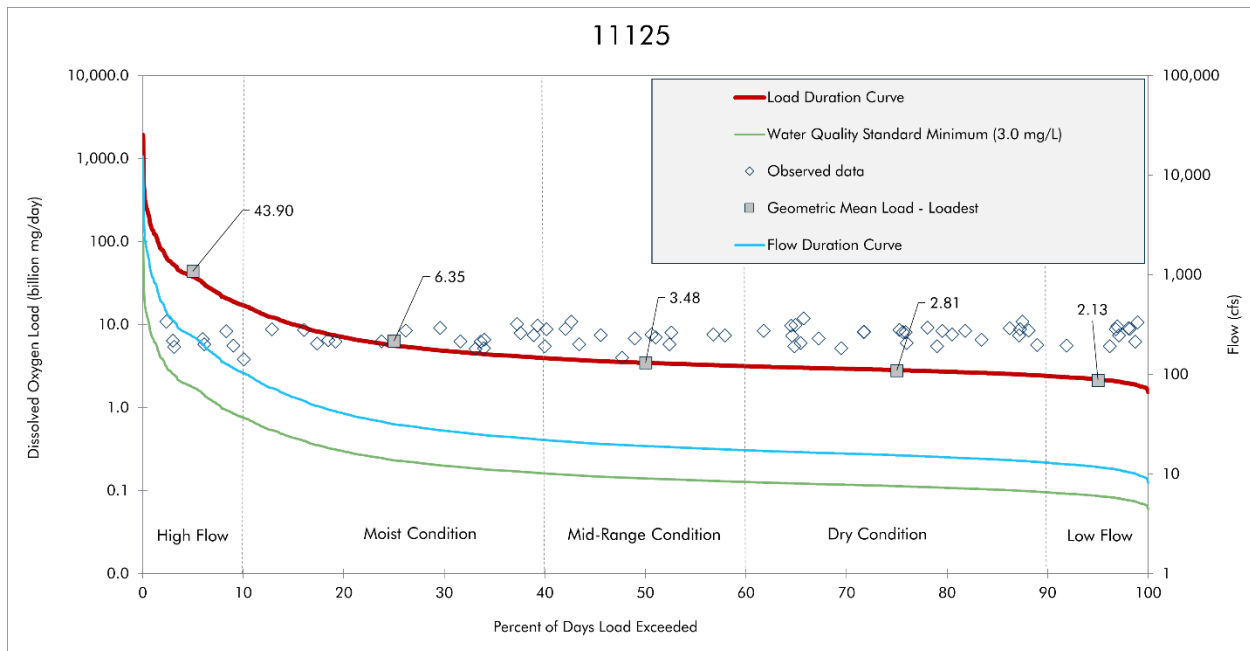


Figure 10. DO LDC for Station 11125

Station 11126 – Halls Bayou at Jensen Drive

Station 11126 occurs on Halls Bayou (1006D), a tributary to Greens Bayou. The drainage area for this waterbody is dominated by developed land cover types (93%). The lowest rates of flow of all the stations observed in this report occurred at this location. Most flows ranged from 0 to 630 cfs with the top 1% of flows associated with flooding events ranging between 630 and 5,000 cfs.

At Station 11126 (**Figure 11; Table 7**), exceedances of the *E. coli* water quality standard were observed in all periods of flow, however, a reduction of only 2% is indicated in low flow conditions. Results of the LDC analysis for DO (**Figure 12; Table 7**) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, therefore, the LDC results are likely accurate.

Table 7. Flow specific values for LDC 11126

Flow Category	Percent of Days Flow Exceeded	<i>E. coli</i> Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	99.70%	-51.20%
Moist Conditions	10-40%	92.76%	-52.14%
Mid-Range Conditions	40-60%	77.54%	-52.48%
Dry Conditions	60-90%	53.87%	-52.69%
Low Flows	90-100%	2.03%	-52.90%

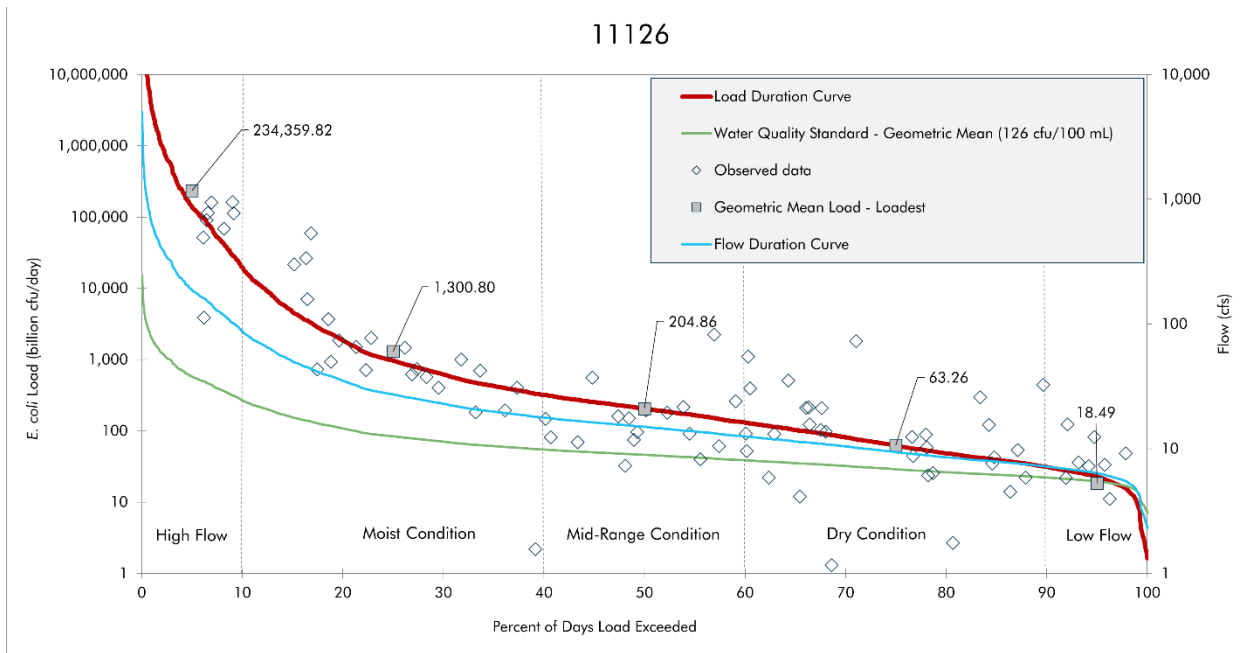


Figure 11. *E. coli* LDC for Station 11126

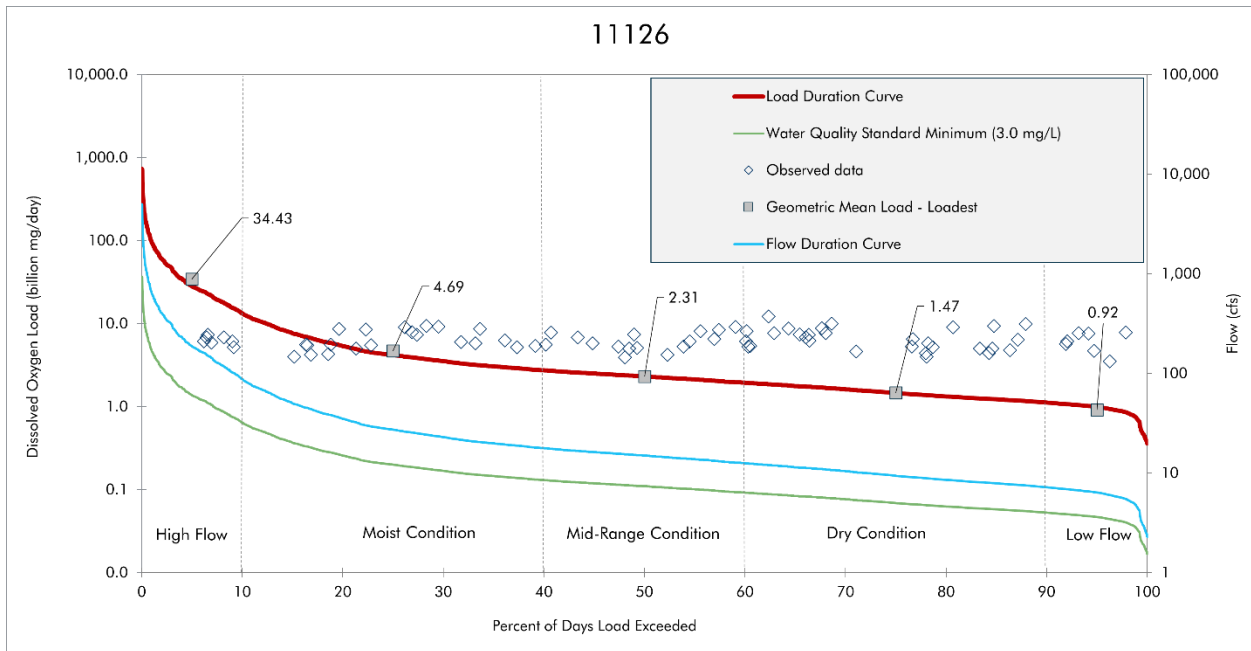


Figure 12. DO LDC for Station 11126

Station 18363 – Greens Bayou at Market Street

Station 18363 occurs on the HSC/Greens Bayou Tidal (AU 1006_03) upstream of a confluence with HSC/Buffalo Bayou Tidal. The drainage area for this waterbody is largely developed (80%) with a fair amount (12%) of wetland land cover types. Most flows ranged from 0 to 685 cfs with the top 1% of flows associated with flooding events ranging between 685 and 20,000 cfs.

Because this station is tidally influenced, Enterococci rather than *E. coli* was used as the fecal indicator bacteria for surface water. At Station 18363 (Figure 13; Table 8), exceedances of the Enterococci water quality standard were observed in all periods of flow excluding low flow conditions. Results of the LDC analysis for DO (Figure 14; Table 8) show all negative values which indicate that no improvements are recommended in order to attain the DO minimum standard for surface water at this site. An aquatic life impairment due to depressed DO was not indicated for this AU, therefore, the LDC results are likely accurate.

Table 8. Flow specific values for LDC 18363

Flow Category	Percent of Days Flow Exceeded	Enterococci Percent Reduction Needed - Geomean	DO Percent Improvement Needed
High Flows	0-10%	90.62%	-61.05%
Moist Conditions	10-40%	75.22%	-54.98%
Mid-Range Conditions	40-60%	59.23%	-51.52%
Dry Conditions	60-90%	43.86%	-49.15%
Low Flows	90-100%	-3.43%	

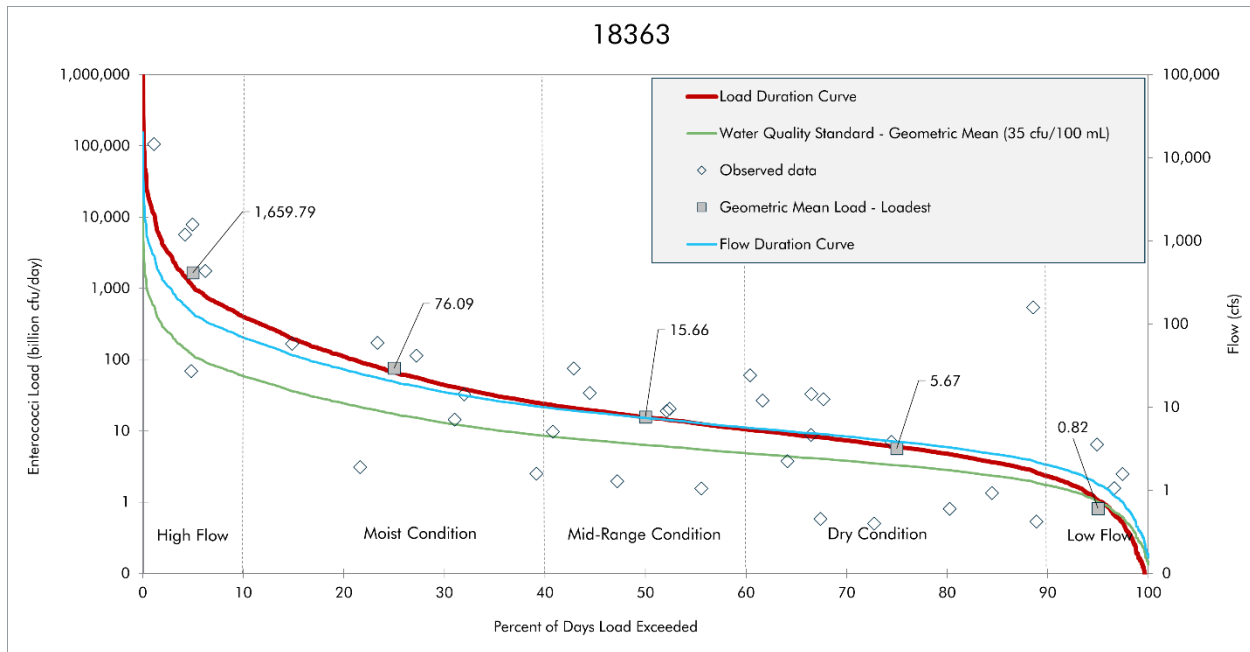


Figure 13. Enterococci LDC for Station 18363

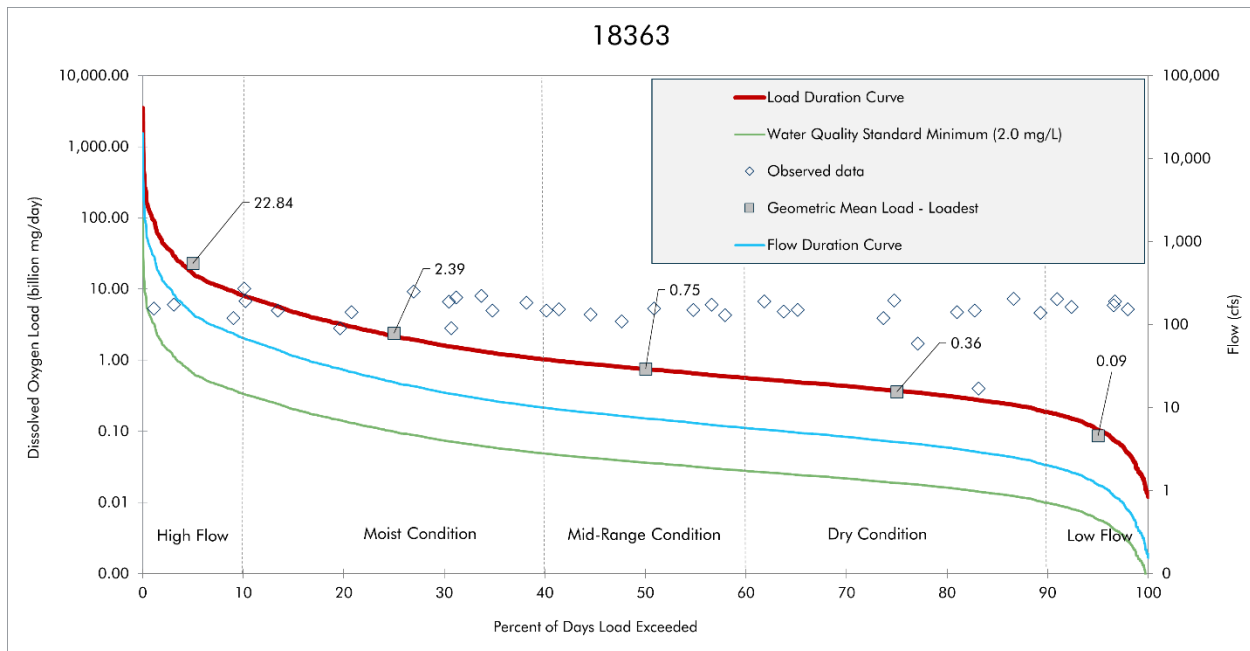


Figure 14. DO LDC for Station 18363

4.6 LDC Summary

Currently, LDC results for the Greens Bayou watershed have been reviewed internally but have not been subjected to thorough stakeholder analysis. H-GAC staff hope to discuss these results with stakeholders at future partnership meetings and in more focused, one-on-one conversations. This will further refine the assessment to produce data that most accurately reflect fecal bacteria loadings and reduction targets for the Greens Bayou watershed.

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

- Fecal indicator bacteria loading exceeded the standard in high flow through dry conditions across the watershed.
- Fecal indicator bacteria loading in other low conditions varied among sites.
- No needed improvements in DO were indicated through the LDC analyses, but DO is still a constituent of concern per results of TCEQ's latest Texas Integrated Report.

Flow magnitudes varied among sites and the results of LDC analyses for fecal indicator bacteria were not similar enough between subwatersheds to consider, grouping any of them into larger attainment areas for implementation.

SECTION 5: SELECT EVALUATIONS

5.1 Overview

SELECT is a GIS-based tool for estimating potential fecal bacteria loads in a watershed area developed by the Spatial Sciences Laboratory and the Biological and Agricultural Engineering Department at Texas A&M University⁴. This analysis can also determine the relative contributions of fecal indicator bacteria made by a range of potential sources and expresses source contribution data spatially by subwatershed. SELECT analyses result from the combination of land use and land cover data, known source locations (e.g., outfalls), literature assumption values for nonpoint sources (e.g., pet waste, livestock census data, wildlife population density), and stakeholder input. The model does not account for instream loading or other natural processes which may affect fecal bacteria concentrations, nor does it estimate the relative proximity of loading sources to the waterway. Therefore, all references to load estimates in this section refer to potential source loads and not necessarily the actual amounts of fecal bacteria transported into the streams and tributaries of the Greens Bayou watershed.

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

The second modification made to the original design of the SELECT model was to estimate fecal bacteria loading changes associated with increased development in five-year increments throughout the next 25 years. By accounting for changes in spatial distribution and magnitude of source loads related to predicted changes in land use between current conditions⁵ and the year 2050, reduction estimates can be anticipated at the loading rate observed in the present day and those projected in the future. As with any forecasting effort, a certain level of uncertainty is expected with these predictions especially as they relate to sources assumed to be linked to land use types. For example, in this model, wildlife populations are assumed to decrease as developed area increases within the watershed. This does not account for the adaptability of wildlife to consolidate or redistribute within the watershed area. Further monitoring and assessments of such sources should be incorporated into the management recommendations of the WPP to more accurately account for these factors and counteract this uncertainty.

⁴ Additional information about SELECT can be found at <http://ssl.tamu.edu/media/11291/select-aarin.pdf>. Information about specific implementation of SELECT for this project can be found in the project modeling QAPP.

⁵ At the time of this report, the most updated land use data represents parcel allocations in the year 2020 for Harris County.

5.2 SELECT Results

Wastewater Treatment Facilities (WWTFs)

Wastewater utilities serve a number of communities throughout the watershed and occur in various sizes and capacities. For areas outside city boundaries, centralized waste treatment is commonly managed by municipal utility districts and other districts. Considering all types of WWTFs, 117 permitted facilities with discharge monitoring report data are found within the watershed boundary of Greens Bayou. Size of WWTFs vary throughout the watershed and range between capacities of less than 0.1 millions of gallons per day (MGD) to 10 MGD.

According to the results of a previous data review⁶, WWTFs in the Greens Bayou watershed are not expected to be major contributors to fecal indicator bacteria loading. However, as the risks associated with human waste processed by WWTFs can be considerable in the event of improper treatment or other localized incidents, it is important to consider estimates of potential WWTF loadings in the overall SELECT model. These estimates are derived by multiplying the total discharge capacity of each facility by the state water quality standard for fecal bacteria. As loads were estimated to reflect the impacts of direct outfalls, all results are indicated within the buffer zone surrounding the watershed stream network. 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 to account for exceedances or variations throughout daily discharges that could have greater impacts to public health.

In the Greens Bayou watershed, fecal bacteria loading from WWTFs is more prevalent in the Lower Greens Bayou Above Tidal and Garners Bayou subwatersheds where WWTF densities and sizes are greater (**Figure 15; Table 9**).

When considering the anticipated expansion of the population throughout the watershed in the coming 25 years, overall fecal bacteria loading in the watershed is expected to increase (**Figure 16**). However, the values of fecal bacteria loads delivered to Greens Bayou and its tributaries via WWTFs are several orders of magnitude lower than those estimated for other modeled sources described in this section. Therefore, WWTFs are still considered only minor contributors to overall potential fecal bacteria loading in the watershed. These sources are still important to consider in the WPP however, as the health risks associated with any introduction of improperly treated human waste by WWTFs into the watershed are far greater than those associated with other sources⁷.

⁶ A more detailed analysis of water quality is discussed further in the Preliminary Acquired Data Analysis Report for the Greens Bayou Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the Greens Bayou Modeling Quality Assurance Project Plan) are available for review at <https://greensbayoupartnership.weebly.com/documents.html>.

⁷ 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.

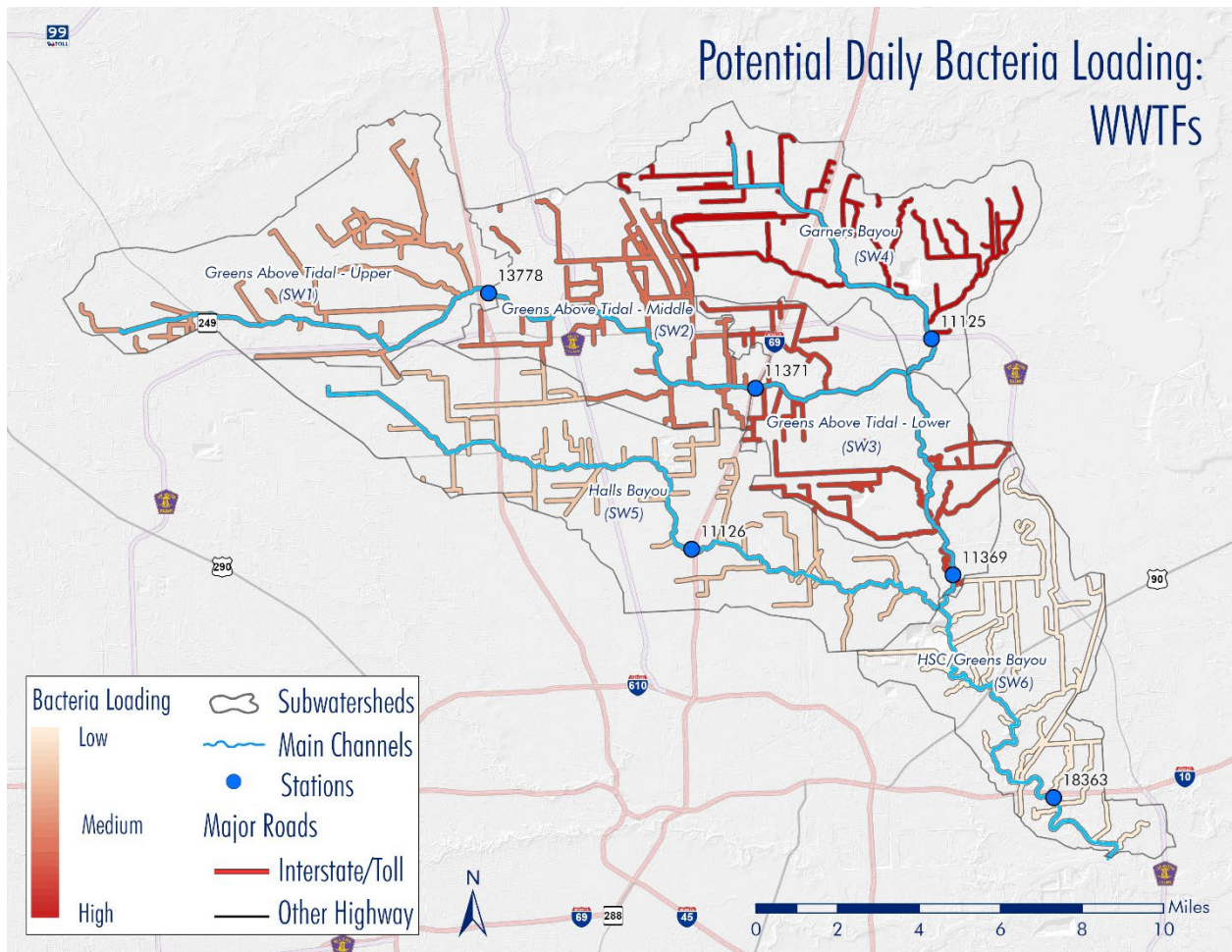


Figure 15. Bacteria loadings from WWTFs by subwatershed

WWTF - Bacteria Loadings

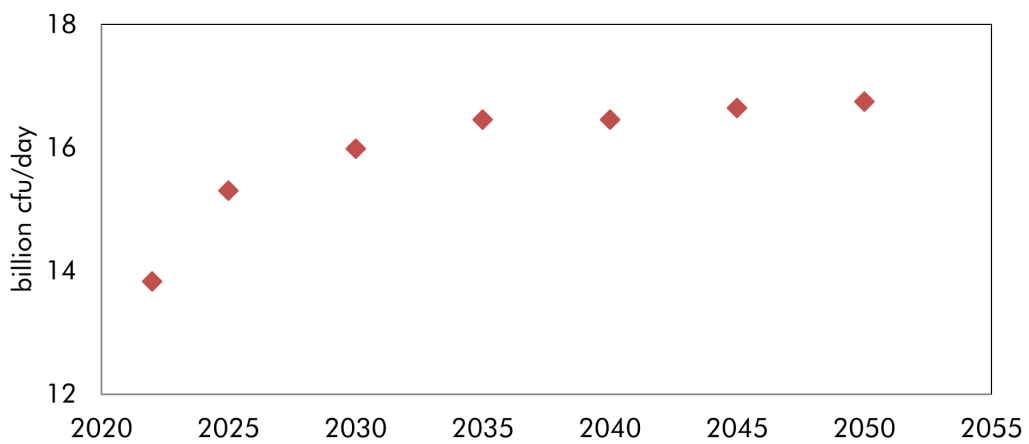


Figure 16. Future bacteria loadings from WWTFs

Table 9. Wastewater outfalls and loadings by subwatershed

Subwatershed	# of Outfalls	Load Estimate in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	24	2.38	17%
Greens Above Tidal - Middle (SW2)	14	2.41	18%
Greens Above Tidal - Lower (SW3)	12	2.79	20%
Garners Bayou (SW4)	14	4.73	34%
Halls Bayou (SW5)	43	1.09	8%
HSC/Greens Bayou (SW6)	10	0.43	3%
Total	117	13.83	100%

On-Site Sewage Facilities (OSSFs)

While centralized wastewater treatment is 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.

OSSF distribution throughout the Greens Bayou watershed was estimated using the spatial data of permitted systems collected under a federal 604(b) grant agreement between H-GAC and TCEQ, and quality assured under the auspices of that contract⁸. This dataset is 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 OSSFs in the watershed area based on land use. Regardless of permit information, OSSFs throughout the watershed were estimated by assessing the number of occupied parcels outside wastewater service area boundaries. 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%⁹. Due to the history of OSSF failures in this watershed area as documented in a study by WaterEngineers, Inc. on behalf of the East Aldine Management District¹⁰, a slightly more aggressive estimate of 20% failure rate was applied to the number units indicated by the current dataset and for each of the five-year interval projections through 2050. This method is subject to review in further focused workgroup discussions with the partnership.

OSSF loadings are highest in the subwatersheds of Lower and Upper Greens Bayou Above Tidal (**Figure 17; Table 10**), and are expected to increase through 2050 as the population increases throughout the watershed (**Figure 18**). These future projections are based on an assumed 20% failure rate. If systems are found to exceed the 20% failure rate, a new percentage value may be determined. However, stakeholders may choose to incorporate continued monitoring of these systems in the coming years as OSSF installments age. Failure rates among these newly developed systems are likely to be lower as regular maintenance will be required by permit. As improperly maintained OSSFs could also have a negative impact on property values, communities may be more likely to adhere to routine maintenance standards. However, as the health risks associated with any introduction of improperly treated human waste by

⁸ Use of this acquired data is detailed in the project modeling QAPP for this project available for review at <https://greensbayoupartnership.weebly.com/documents.html>.

⁹ Reed, Stowe & Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Texas On-site Wastewater Treatment Council.

¹⁰ See: https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2002483472_Aldine.pdf

OSSFs into the watershed are far greater than those associated with other sources, these sources are still important to consider in the WPP.

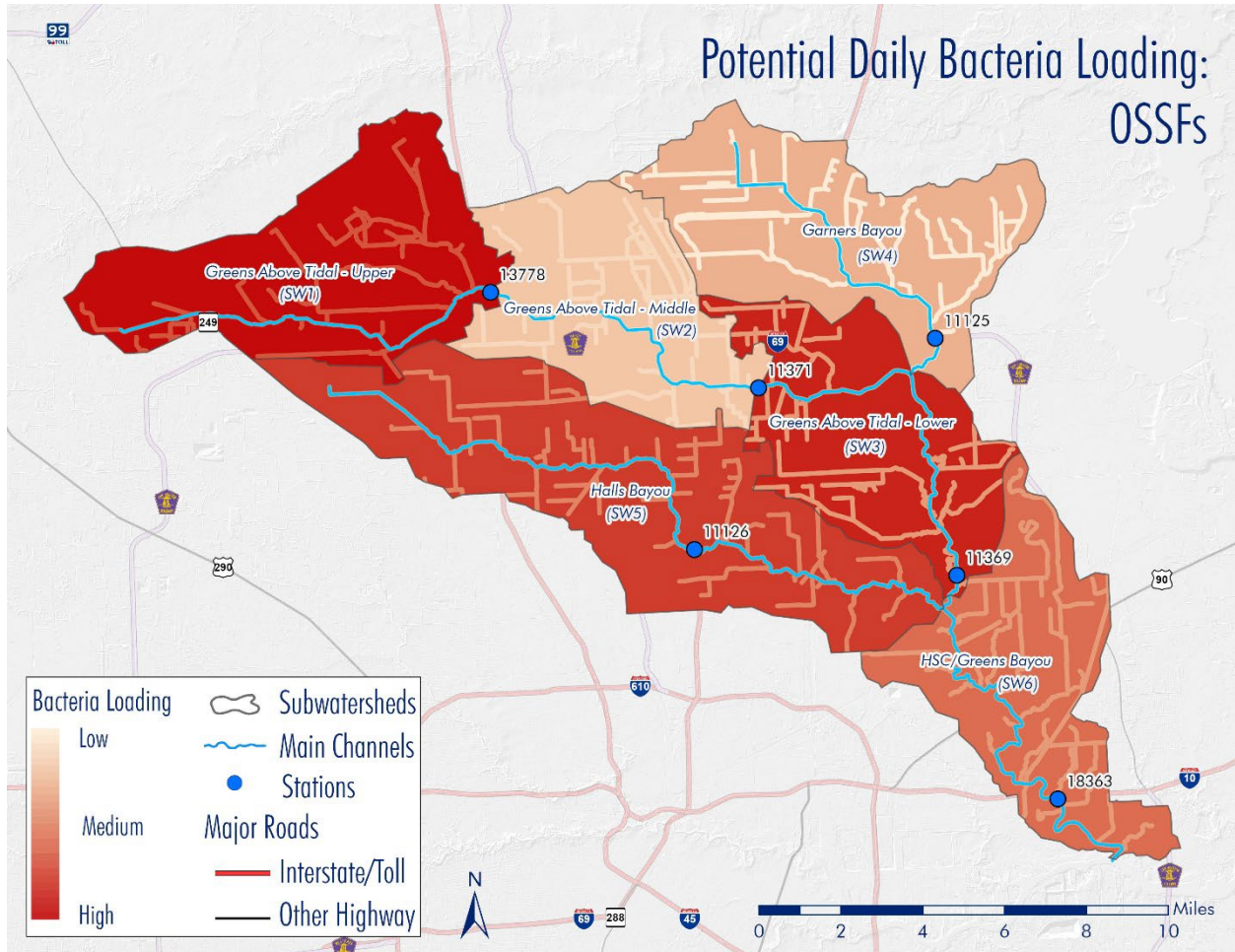


Figure 17. Bacteria loading from OSSFs by subwatershed

OSSF - Bacteria Loadings

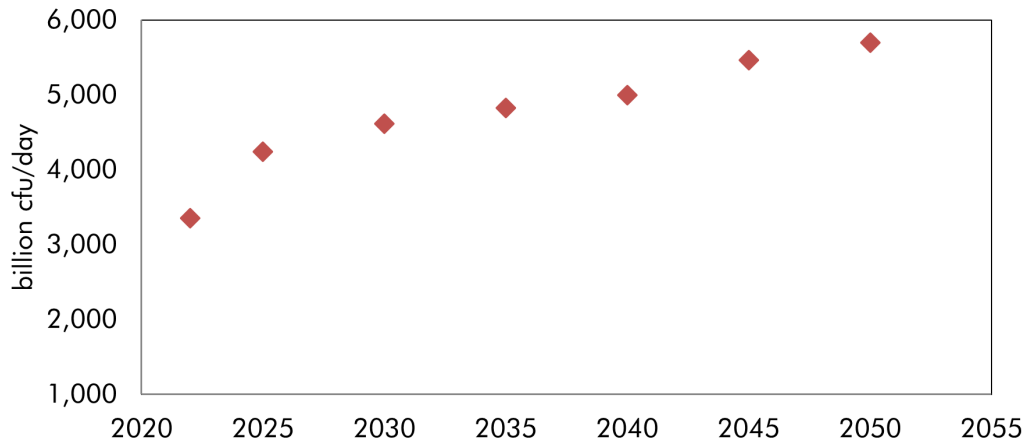


Figure 18. Future bacteria loadings from OSSFs

Table 10. OSSFs and loadings by subwatershed

Subwatershed	OSSFs Outside Buffer	OSSFs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	4,268	421	791.71	312.38	33%
Greens Above Tidal - Middle (SW2)	390	46	72.35	34.13	3%
Greens Above Tidal - Lower (SW3)	4,152	181	770.20	134.30	27%
Garners Bayou (SW4)	631	40	117.05	29.68	4%
Halls Bayou (SW5)	3,695	320	685.42	237.44	21%
HSC/Greens Bayou (SW6)	1,466	181	271.94	134.30	12%
TOTAL	14,602	1,189	2,708.67	882.23	100%

Dogs

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

For SELECT analysis, fecal bacteria loading from dog populations was estimated by assessing pet ownership. Statistical data for Texas established by the American Veterinary Medical Association¹¹ of 0.6 dogs per household were used in SELECT models. This value was applied to current household data and future projections through 2050. Finally, these estimates were reduced by 20% to account for dog owners practicing proper pet waste management. While this method has been used in other WPP projects with similar land use and drainage areas, stakeholder feedback received during reviews of model results could lead to a revision of these assumptions based on the specific needs of the Greens Bayou watershed.

¹¹ As referenced at <https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx>

Stakeholder insights will be of particular importance to source load estimation of dog waste due to recent efforts to control pet waste throughout the region. Loading estimations could be adjusted to reflect management strategies and community use of waste bags, etc. already underway in the watershed.

Dog ownership, and therefore dog waste, is most densely concentrated in the subwatersheds of Upper Greens Bayou Above Tidal, Halls Bayou, and Houston Ship Channel. (**Figure 19; Table 11**). As the human population of the watershed increases in the coming years, dog populations will also increase (**Figure 20**).

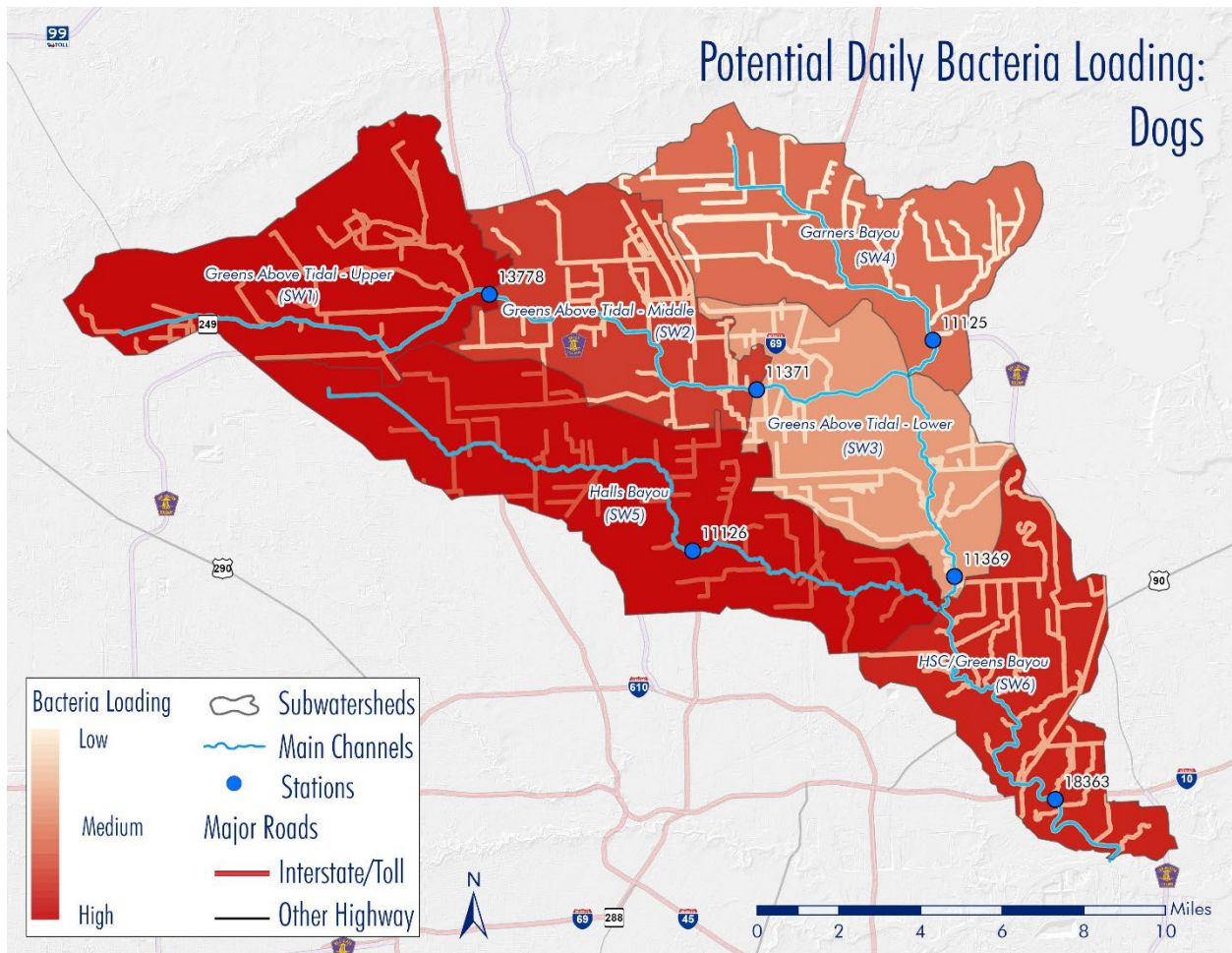


Figure 19. Bacteria loading from dogs by subwatershed

Dogs - Bacteria Loadings

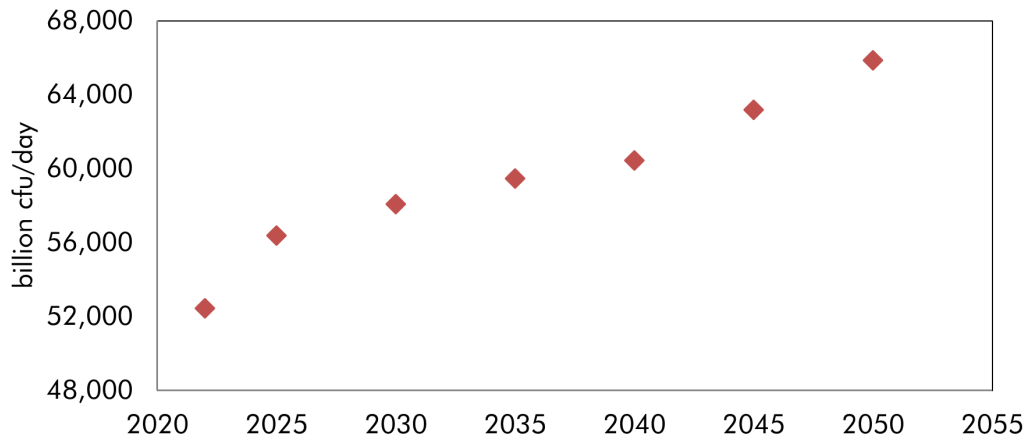


Figure 20. Future bacteria loading from dogs

Table 11. Dogs and loadings by subwatershed

Subwatershed	Dogs Outside Buffer	Dogs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	24,350	1,591	12,175.20	3,182.40	29%
Greens Above Tidal - Middle (SW2)	8,290	792	4,145.10	1,584.00	11%
Greens Above Tidal - Lower (SW3)	5,425	666	2,712.30	1,332.00	8%
Garners Bayou (SW4)	6,908	447	3,454.20	894.00	8%
Halls Bayou (SW5)	25,451	1,882	12,725.40	3,764.40	32%
HSC/Greens Bayou (SW6)	8,443	1,132	4,221.30	2,264.40	12%
Total	78,867	6,510	39,433.50	13,021.20	100%

Cattle

Agricultural land, grassland, and pastures are most common in the eastern and southern 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 2022 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 Greens Bayou watershed, a ratio of the county’s portion of the watershed’s acreage in appropriate land cover types was applied to agricultural census data from the county. This approach ensures that the density of cattle in the county’s applicable land cover acreage (hay/pasture) was the same as the density in the watershed’s applicable land use acreage. In addition, reductions were made from the current (2022) calculation for each of the subsequent five-year intervals in order to reflect declining livestock populations observed throughout the state at a rate proportional to the difference in 2017 and 2022 agricultural census values. Model results generated from these assumptions will be reviewed with stakeholders for accuracy.

Cattle loads from the Lower Greens Bayou Above Tidal subwatershed are greater compared to other subwatersheds (Figure 21; Table 12). Projections of future fecal bacteria loading by cattle decrease over

the next 25 years (**Figure 22**). This rate of decline reflects statewide trends in decreasing livestock populations.

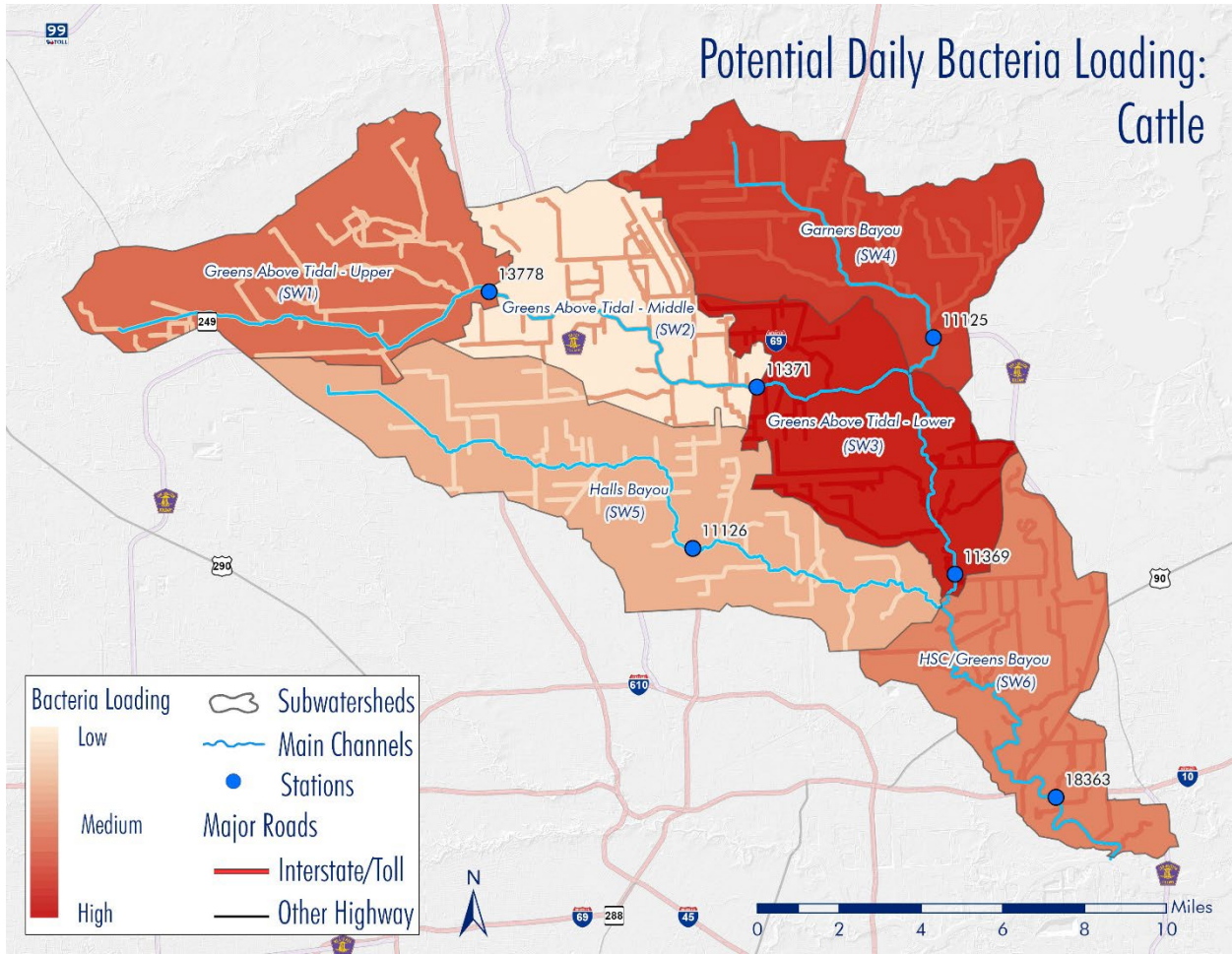


Figure 21. Bacteria loading from cattle by subwatershed

Cattle - Bacteria Loadings

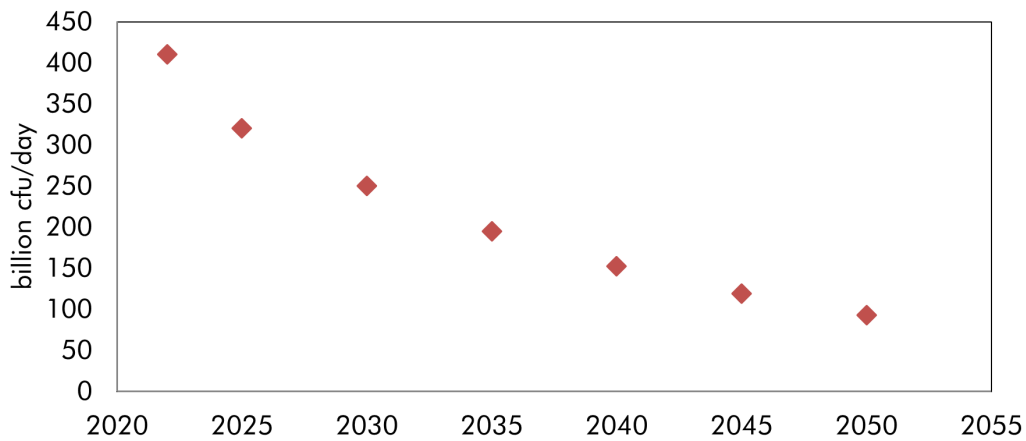


Figure 22. Future bacteria loading from cattle

Table 12. Cattle and loadings by subwatershed

Subwatershed	Cattle Outside Buffer	Cattle Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	45	6	30.18	15.98	11%
Greens Above Tidal - Middle (SW2)	17	9	11.39	23.02	8%
Greens Above Tidal - Lower (SW3)	91	41	61.51	110.05	42%
Garners Bayou (SW4)	59	13	39.53	33.99	18%
Halls Bayou (SW5)	24	6	16.11	15.86	8%
HSC/Greens Bayou (SW6)	36	11	24.52	28.64	13%
Total	272	86	183.24	227.54	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. 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. Discussions with watershed stakeholders are ongoing and may result in a revised method to more accurately reflect horse populations in the Greens Bayou watershed.

As with cattle, horse bacteria loading is highest in the Lower Greens Bayou Above Tidal subwatershed (**Figure 23; Table 13**). The rate of decline in **Figure 24** reflects statewide trends in decreasing livestock populations.

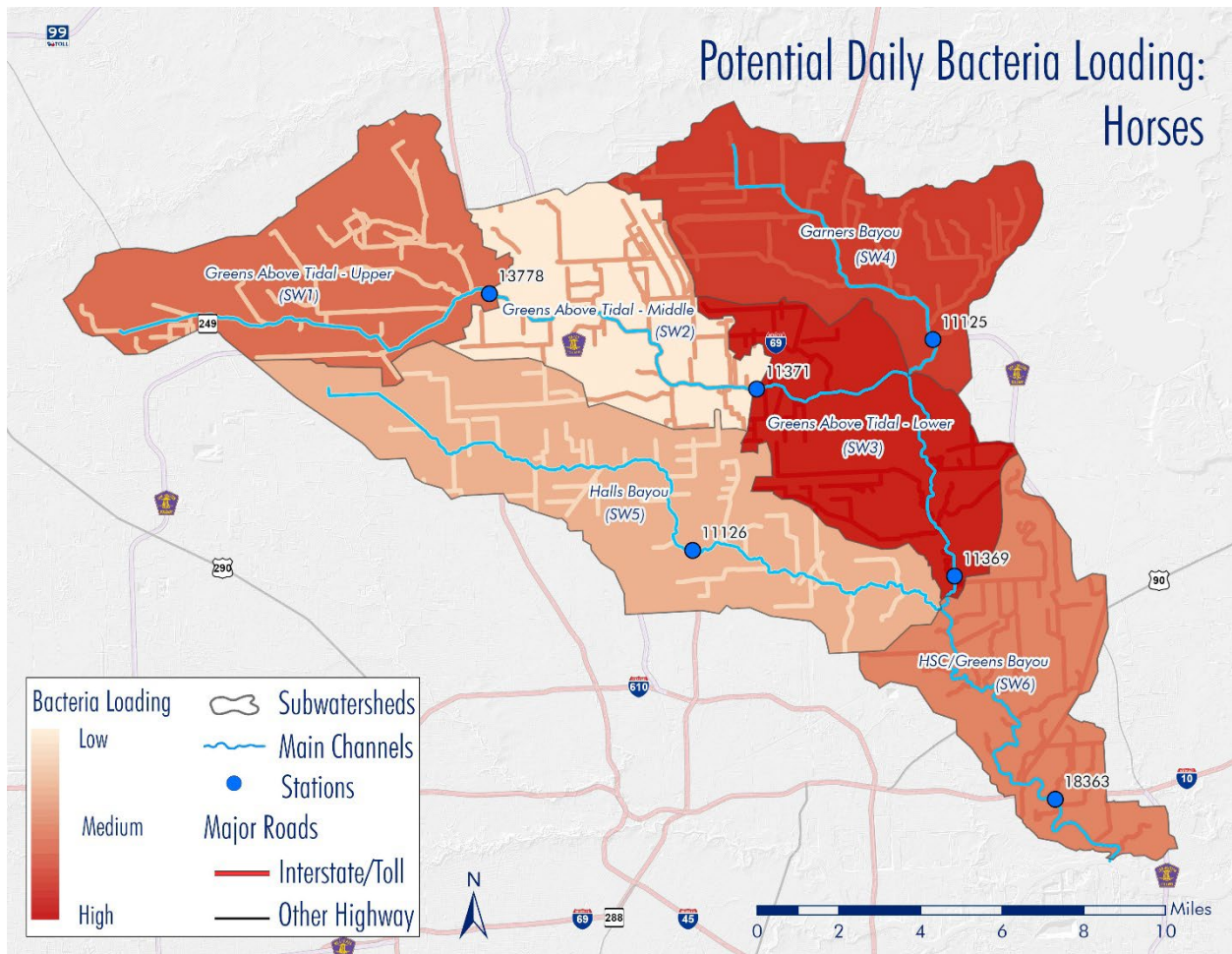


Figure 23. Bacteria loading from horses by subwatershed

Horses - Bacteria Loadings

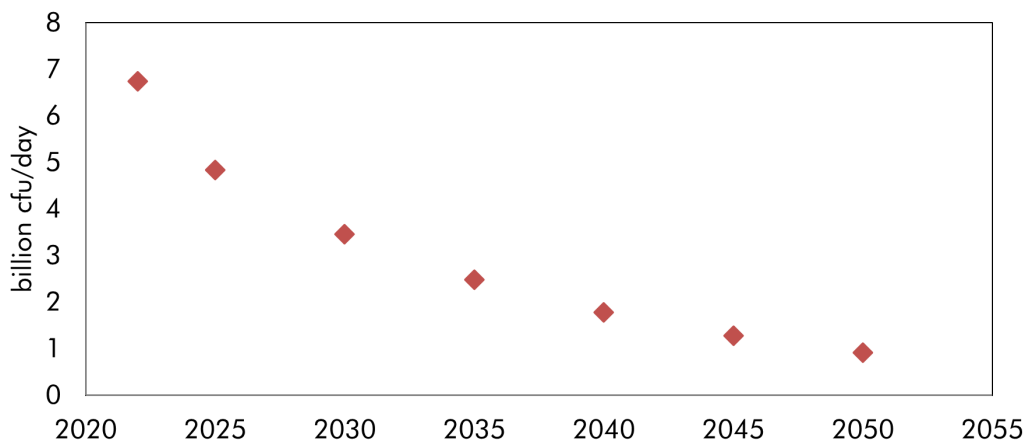


Figure 24. Future bacteria loadings from horses

Table 13. Horses and loadings by subwatershed

Subwatershed	Horses Outside Buffer	Horses Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	9	1	0.50	0.26	11%
Greens Above Tidal - Middle (SW2)	4	2	0.19	0.38	8%
Greens Above Tidal - Lower (SW3)	19	9	1.01	1.81	42%
Garners Bayou (SW4)	12	3	0.65	0.56	18%
Halls Bayou (SW5)	5	1	0.26	0.26	8%
HSC/Greens Bayou (SW6)	8	2	0.40	0.47	13%
Total	57	18	3.01	3.74	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. Assessment and revision of the initial population estimates may be explored after further discussion with stakeholder groups.

Sheep and goat bacteria loading bears a strong special similarity to cattle and horse bacteria loading with the highest concentration occurring in the Lower Greens Bayou Above Tidal subwatershed (**Figure 25; Table 14**). This is likely due to the highest percentage of agricultural land of any of the subwatersheds occurring in the drainage area for Lower Greens Bayou Above Tidal subwatershed. As with other agricultural animals, sheep and goat populations are expected to decline as a result of statewide trends in decreasing livestock populations. (**Figure 26**).

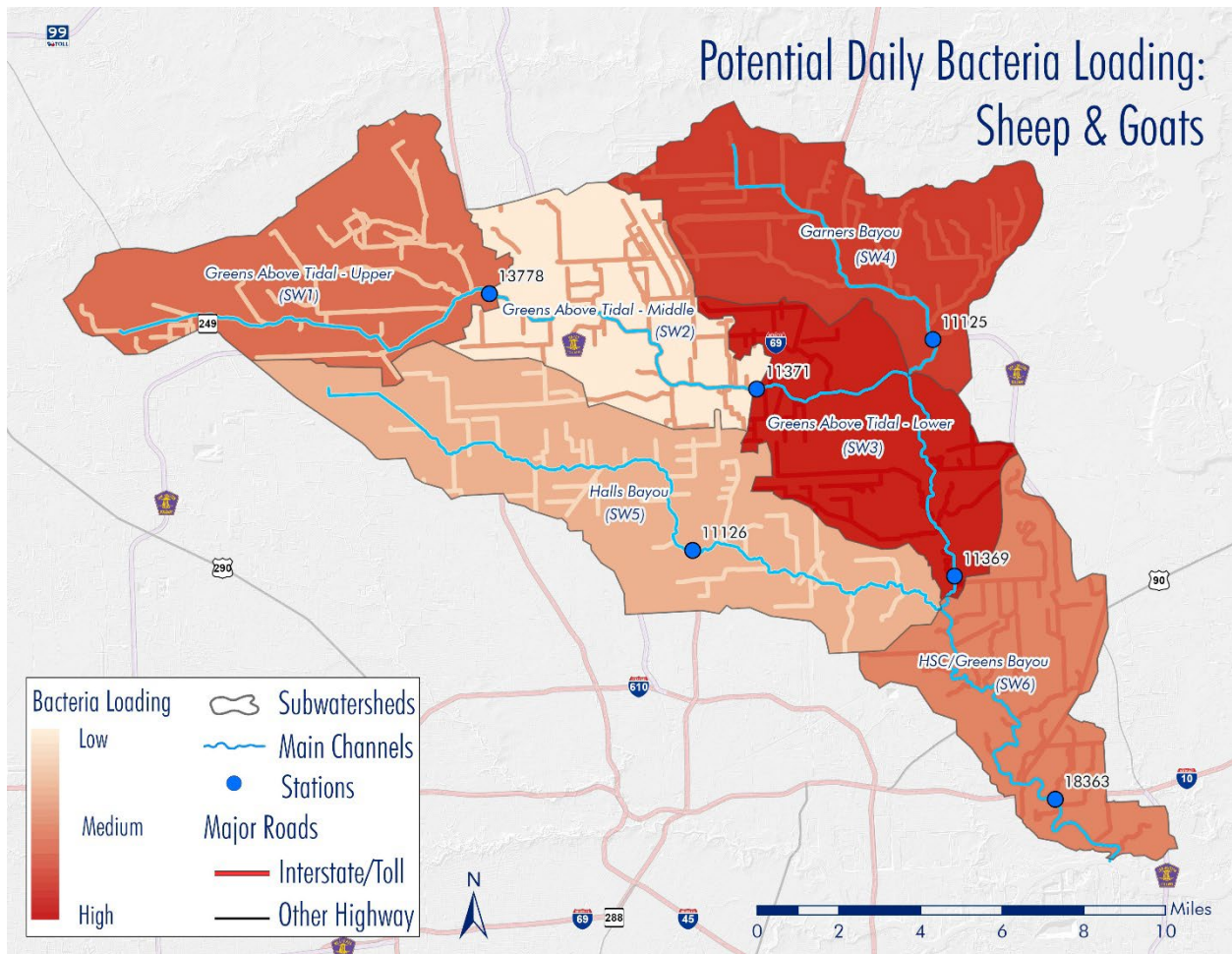


Figure 25. Bacteria loadings from sheep and goats by subwatershed

Sheep and Goats - Bacteria Loadings

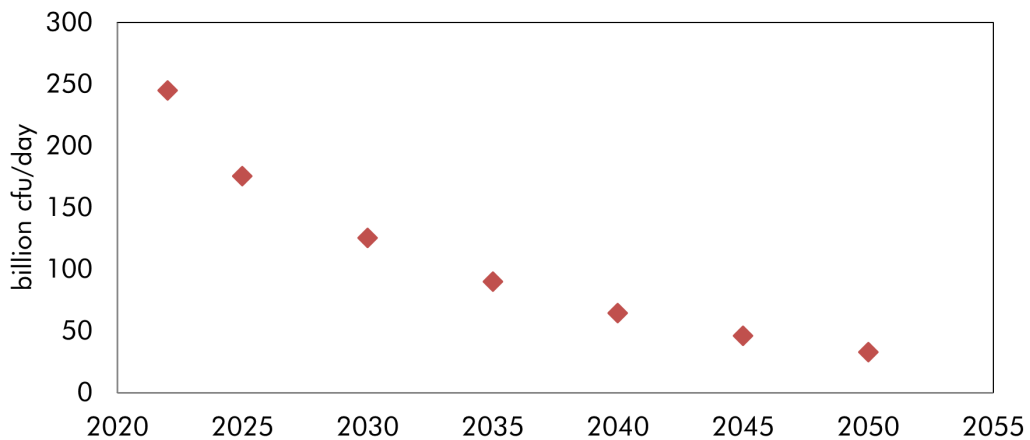


Figure 26. Future bacteria loadings from sheep and goats

Table 14. Sheep and goats and loadings by subwatershed

Subwatershed	Sheep & Goats Outside Buffer	Sheep & Goats Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	8	1	18.00	9.53	11%
Greens Above Tidal - Middle (SW2)	3	2	6.79	13.73	8%
Greens Above Tidal - Lower (SW3)	16	7	36.68	65.64	42%
Garners Bayou (SW4)	10	2	23.57	20.27	18%
Halls Bayou (SW5)	4	1	9.61	9.46	8%
HSC/Greens Bayou (SW6)	6	2	14.62	17.08	13%
Total	47	15	109.27	135.71	100%

Deer

Forests and open grasslands 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, natural areas and open and low intensity developed areas were considered as possible deer habitat for the purposes of load estimation. Assessment and revision of the initial population estimates may be explored after further discussion with stakeholder groups. Resource Management Unit population density data accessed from the Texas Parks and Wildlife Department assuming one deer for every 40.2 acres of forest, shrubland and open developed areas was used to estimate deer populations and their associated fecal bacteria loading potential. In low intensity developed areas, deer density was assumed to be one deer for every 80.4 acres. With this 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.

Estimated deer bacteria loadings were highest in Garners Bayou and Lower Greens Bayou Above Tidal subwatersheds (**Figure 27; Table 15**). Despite their ability to adapt to more developed land areas when faced with the loss of natural habitat, deer populations in the Greens Bayou watershed are predicted to slightly decrease over time (**Figure 28**). As the SELECT model only accounts for gains and losses of fecal bacteria load pressures, migration between parcels could be underestimated. Further discussions with stakeholders will focus on assessing the accuracy of these estimations and what modifications may be appropriate for data adjustment.

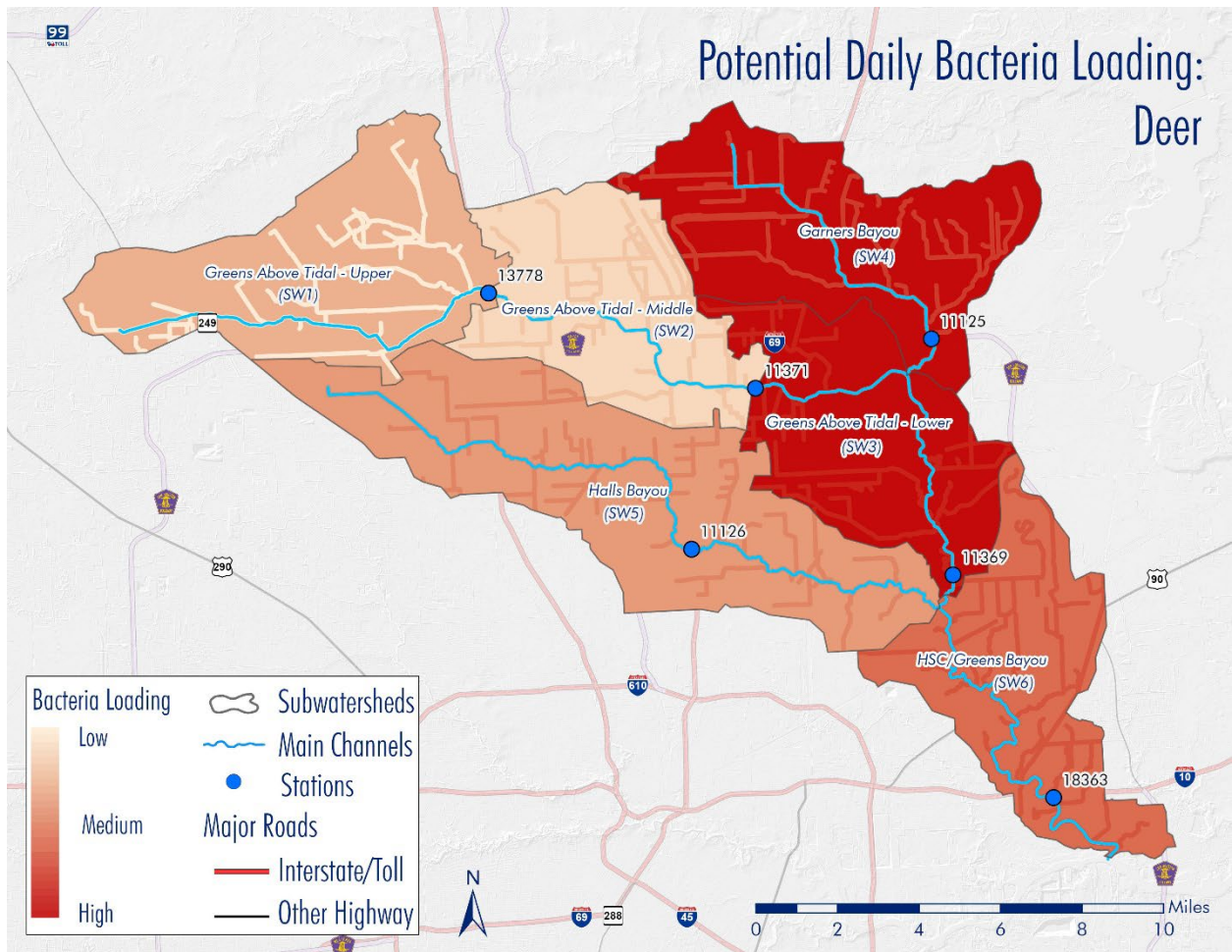


Figure 27. Bacteria loadings from deer by subwatershed

Deer - Bacteria Loadings

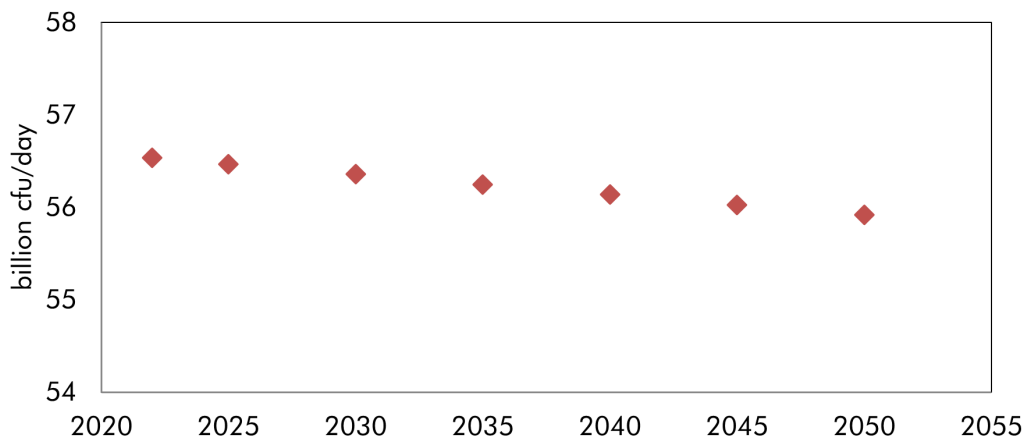


Figure 28. Future bacteria loadings from deer

Table 15. Deer and loadings by subwatershed

Subwatershed	Deer Outside Buffer	Deer Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	61	8	2.66	1.44	7%
Greens Above Tidal - Middle (SW2)	43	15	1.89	2.56	8%
Greens Above Tidal - Lower (SW3)	211	50	9.22	8.75	32%
Garners Bayou (SW4)	216	38	9.44	6.64	28%
Halls Bayou (SW5)	61	5	2.68	3.22	10%
HSC/Greens Bayou (SW6)	84	25	3.65	4.38	15%
Total	675	141	29.54	26.99	100%

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 Greens Bayou 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 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 are based on AgriLife literature values¹². In areas development and open water, hog densities of zero were assumed. In areas of barren land, 8.9 hogs per square mile were assumed. In cultivated areas and pasture, that density increased to 12.7 hogs per square mile. Grasslands, forests, shrublands, and wetland areas were assumed to have an even higher density of 16.4 hogs per square mile. Due to this association with land cover, future projections of feral hog loads will be tied to changes in development.

Potential fecal bacteria loading by feral hogs was estimated to be higher in the Garners Bayou and Lower Greens Bayou Above Tidal subwatershed (**Figure 29; Table 16**). Future projections of feral hog loads predict a steady decline in magnitude as time progresses (**Figure 30**). However, the SELECT model does not account for the adaptability of feral hog populations that have anecdotally been observed to redistribute or condense when faced with the loss of their preferred habitats. Therefore, without literature support or evidence from local stakeholders, the estimates presented in this SELECT model should be considered conservative.

¹² As referenced at <http://agrilife.org/feralhogs/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf>

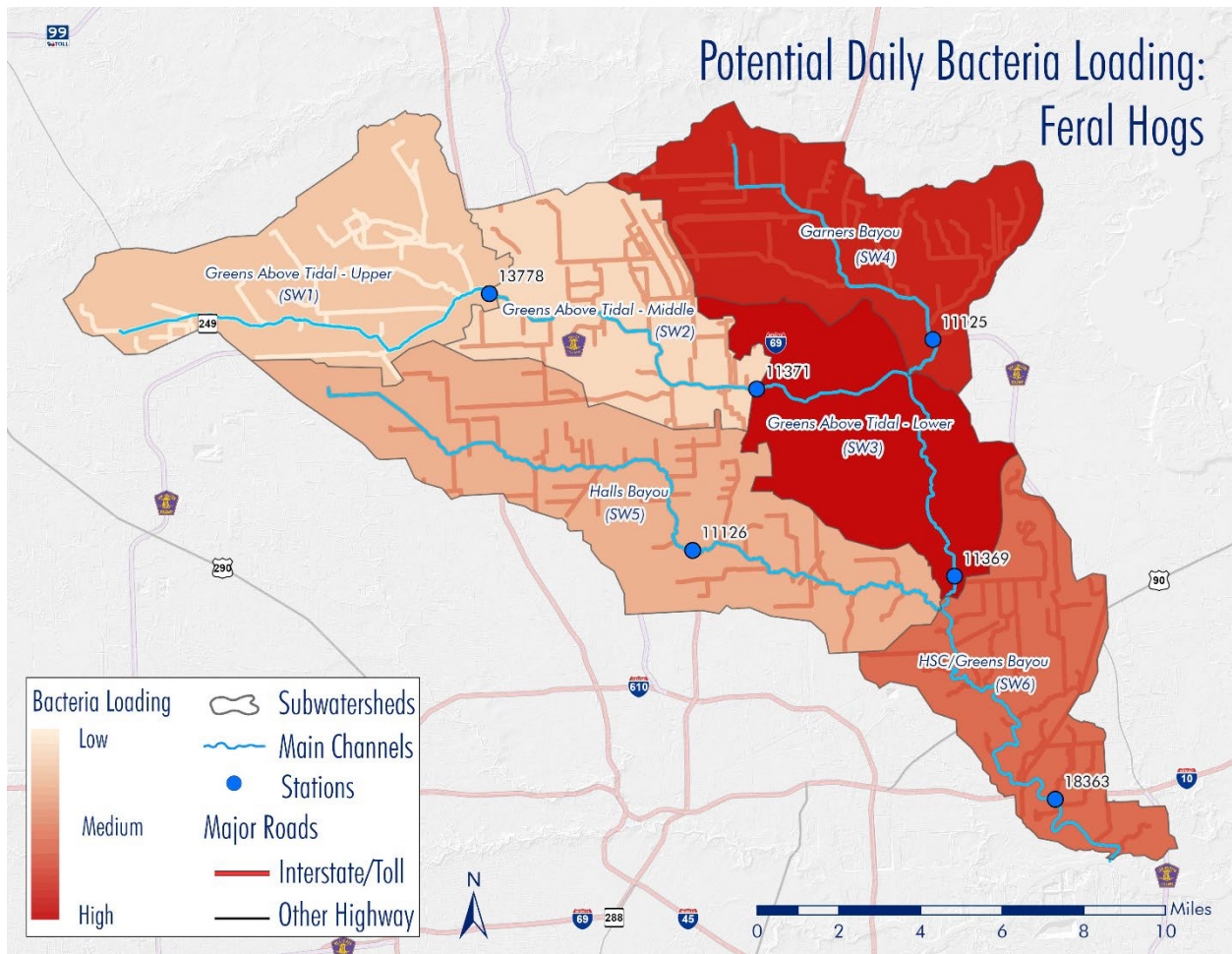


Figure 29. Bacteria loadings from feral hogs by subwatershed

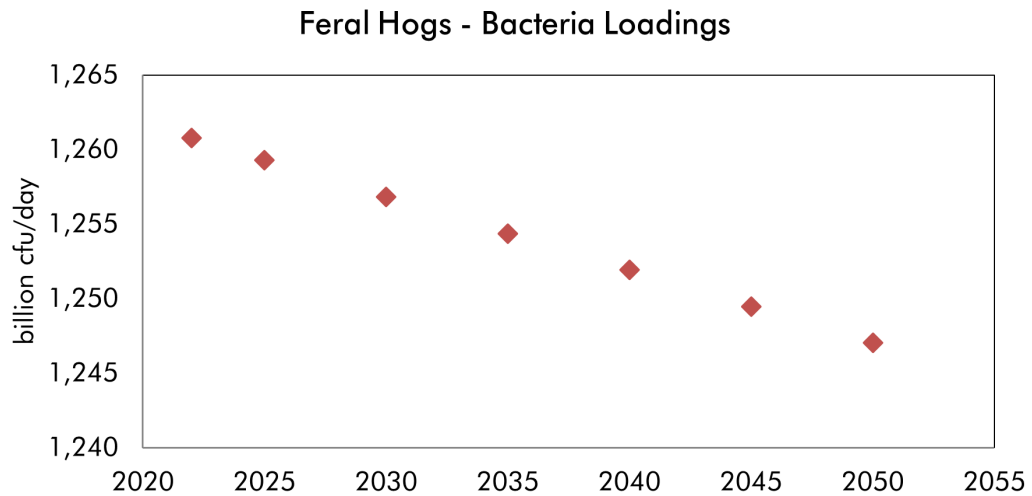


Figure 30. Future bacteria loadings from feral hogs

Table 16. Feral hogs and loadings by subwatershed

Subwatershed	Feral Hogs Outside Buffer	Feral Hogs Within Buffer	Load Outside Buffer in Billion cfu/day	Load Within Buffer in Billion cfu/day	Subwatershed Percent of Total Load
Greens Above Tidal - Upper (SW1)	35	6	48.53	30.38	6%
Greens Above Tidal - Middle (SW2)	30	11	40.86	59.65	8%
Greens Above Tidal - Lower (SW3)	158	38	217.85	208.96	34%
Garners Bayou (SW4)	133	25	183.36	136.13	25%
Halls Bayou (SW5)	42	15	57.83	80.07	11%
HSC/Greens Bayou (SW6)	63	20	85.98	111.20	16%
Total	461	115	634.41	626.39	100%

Other Sources

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

Human Waste – Direct Deposition

In other watershed projects, potential impacts from homeless communities and areas not serviced by centralized or localized wastewater treatment were considered. Further discussion with area stakeholders is needed to assess the extent of these impacts in the Greens Bayou watershed.

Land Deposition of Sewage Sludge

If 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. However, these impacts would likely be addressed in best management practices for agricultural sources of pollution.

Sanitary Sewer Overflows (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 Greens Bayou watershed¹³, SSO events were not found to follow any specific spatial, seasonal, or annual pattern. In terms of general cause, blockages accounted for the highest number of events respective to the other general categories of weather, malfunctions, and unknown causes. In terms of volume, malfunctions contributed the highest overflow observed between 2019 and 2023.

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 values¹⁴ suggested for general causes related to each event multiplied by the highest observed volumes of discharge recorded for each cause. A more conservative method would be to calculate the average daily volume of discharge and use that as the multiplier for cause related load estimates. In other area watershed projects, stakeholders elected to refrain from the aforementioned calculations and treat SSOs as a separate, high-priority item for inclusion in the management strategies outlined in the WPP. SSO data regarding unique events impacting stream segments within the watershed area over the most recent five years of reports provided by TCEQ were used in these assessments. This approach could be explored in the Greens Bayou watershed according to the decision making of the stakeholder group.

Concentrated Animal Feeding Operation (CAFO)

No active CAFOs are in operation within the Greens Bayou 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 significant health risks to the watershed community. Stakeholder knowledge will be critical to an improved understanding of the dynamics and magnitude of avian populations. 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.

¹³ A more detailed analysis of water quality is discussed further in the Acquired Data Analysis Report for the Greens Bayou Watershed. This document and more information on data quality objectives, concerns, and methodologies used in these analyses (detailed in the Greens Bayou Modeling Quality Assurance Project Plan) are available for review at <https://greensbayoupartnership.weebly.com/documents.html>.

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

Bats

Though bats are present in the watershed area, only large colonies of these animals are estimated to have an appreciable impact on water quality. No known nesting sites of significant size or density have been indicated in the Greens Bayou 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 Greens Bayou 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 significant¹⁵ and should be incorporated into fecal bacteria reduction strategies. As no such data are presently available for the Greens Bayou watershed, the understanding of wildlife species in this area will be largely informed by anecdotal information provided by stakeholders and general estimations decided by stakeholder input. In nearby Clear Creek, a similarly developed watershed spanning Harris and Galveston counties, wildlife impacts were assumed to be equivalent to a conservative 20% 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 80% of the total load, and then assuming wildlife to be the other 20%. This method was also applied for Greens Bayou. In addition, the value calculated for the current year (2022) was kept consistent for the subsequent five-year forecasting intervals rather than recalculating 20% of each new total load. This was done with the assumption that no new habitat will become available for wildlife and that their populations will not grow. After reviewing modeled results with stakeholders, this percentage may be adjusted according to the specific needs of the watershed.

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 was 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 and/or episodically. This factor may still be important for stakeholders to consider addressing in the WPP in terms of aesthetic and other regulatory issues.

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

Sediment

Sedimentation has been identified by stakeholders in nearby watersheds including Spring 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 DO levels and have pronounced hydrologic impacts on flow. If stakeholders indicate similar concerns for the Greens Bayou watershed, these concerns will be addressed in the WPP.

5.3 Summary of Results

SELECT analyses indicated the highest loads from the total mix of modeled sources are concentrated in the Halls Bayou subwatershed because of pressures from dog waste and wildlife (**Table 17**). Similarly, there is also a pronounced concentration of loading in the Upper Greens Bayou Above Tidal subwatershed associated with the same pressures previously described (**Table 17**). Future projections for increased overall fecal bacteria loading throughout the watershed are also important to consider in the development of a WPP (**Table 18**). Without taking action to reduce fecal bacteria sources in the watershed, loads will continue to increase between 2022 and 2050 (**Figure 31**), with dogs having the largest estimated increase (**Figure 32**; **Figure 33**). Stakeholder input will be crucial for determining whether less traditional load estimation approaches for wildlife and other sources yield accurate and defensible results for the watershed. Modeled predictions may be adjusted after review with stakeholders at partnership meetings, focused workgroups, and one-on-one conversations.

Table 17. Daily average bacteria loads in billion cfu/day by source and subwatershed, 2022

Source	Greens Above Tidal - Upper (SW1)	Greens Above Tidal - Middle (SW2)	Greens Above Tidal - Lower (SW3)	Garners Bayou (SW4)	Halls Bayou (SW5)	HSC/ Greens Bayou (SW6)	% Total Load
OSSFs	1,104.10	106.48	904.50	146.73	922.86	406.25	5%
WWTFs	2.38	2.41	2.79	4.73	1.09	0.43	0%
Dogs	15,357.60	5,729.10	4,044.30	4,348.20	16,489.80	6,485.70	72%
Cattle	46.16	34.41	171.56	73.52	31.98	53.16	1%
Horses	0.76	0.56	2.82	1.21	0.52	0.87	0%
Sheep & Goats	27.53	20.52	102.32	43.85	19.07	31.70	0%
Deer	4.09	4.45	17.97	16.08	5.90	8.03	0%
Wildlife	4,155.38	1,499.61	1,418.27	1,238.45	4,402.28	1,795.83	20%
Feral Hogs	78.91	100.51	426.82	319.49	137.89	197.18	2%

Table 18. Daily average bacteria loads in billion cfu/day by source for all milestone years

Source		2022	2025	2030	2035	2040	2045	2050
Human Waste	OSSFs	3,353.47	4,243.31	4,618.95	4,822.44	4,993.85	5,463.90	5,701.53
	WWTFs	13.83	15.30	15.99	16.46	16.46	16.64	16.75
Pets	Dogs	52,454.70	56,373.90	58,069.20	59,472.00	60,429.90	63,195.90	65,854.20
Livestock	Cattle	410.79	320.65	250.29	195.37	152.50	119.04	92.92
	Horses	6.74	4.84	3.47	2.49	1.78	1.28	0.92
	Sheep & Goats	244.99	175.48	125.69	90.02	64.48	46.18	33.08
Wildlife	Deer	56.54	56.47	56.36	56.25	56.14	56.03	55.92
	Wildlife	14,450.47	14,450.47	14,450.47	14,450.47	14,450.47	14,450.47	14,450.47
Invasives	Feral Hogs	1,260.79	1,259.31	1,256.83	1,254.37	1,251.92	1,249.47	1,247.03
TOTAL		72,252.32	76,899.73	78,847.25	80,359.87	81,417.50	84,598.91	87,452.82

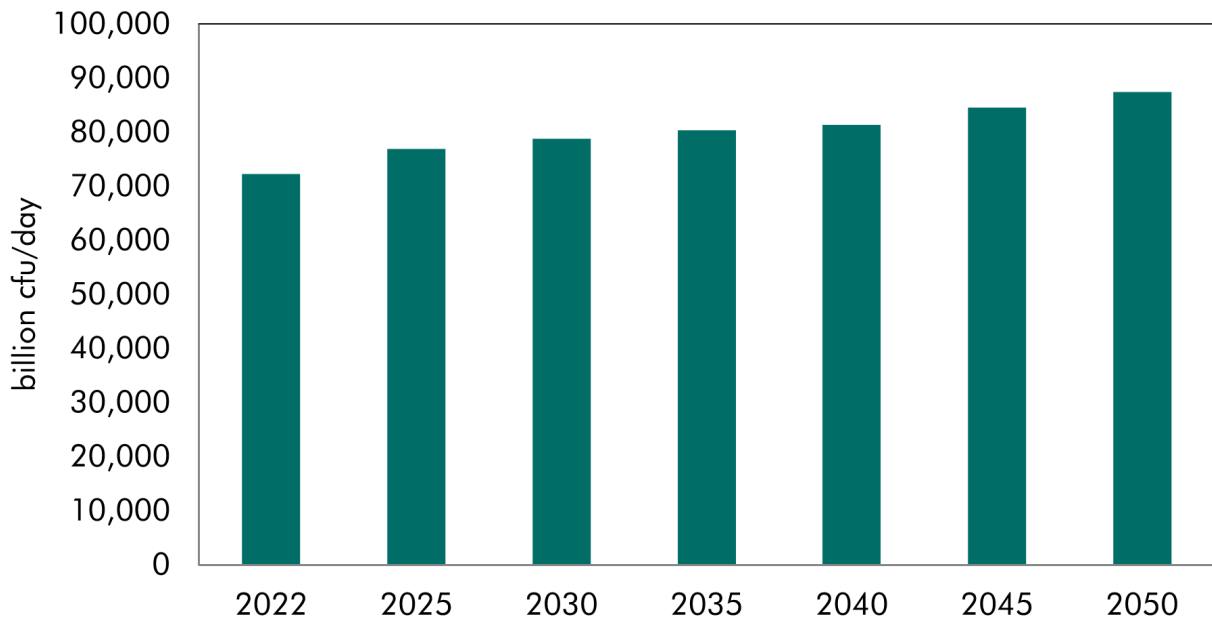


Figure 31. Total potential daily bacteria loads, 2022-2050

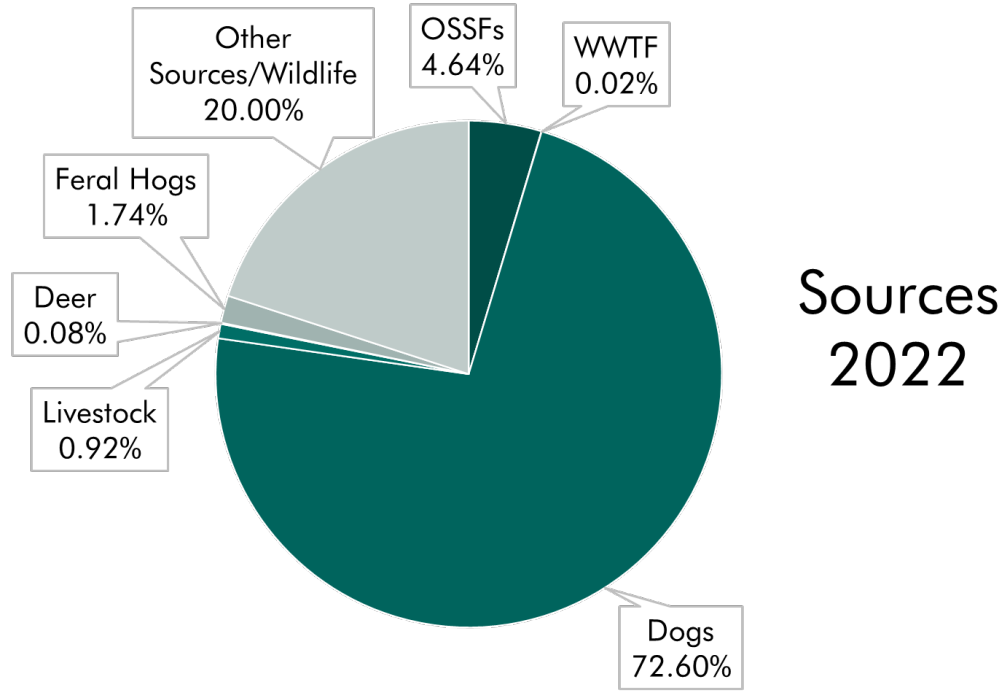


Figure 32. Fecal indicator bacteria source profile, 2022

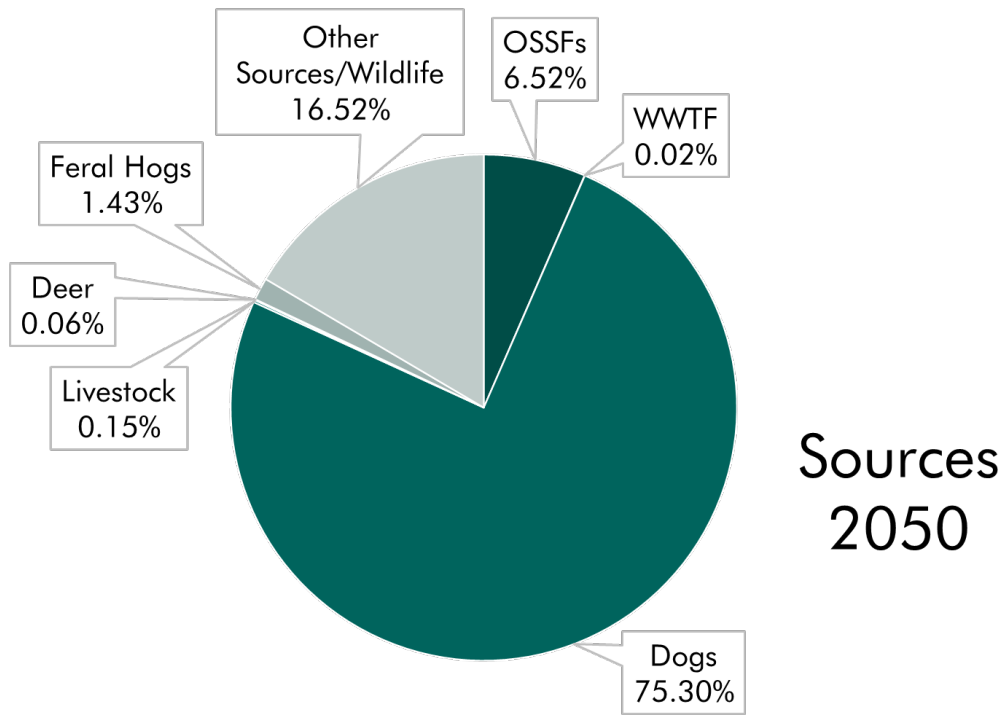


Figure 33. Fecal indicator bacteria source profile, 2050

SECTION 6: OUTCOMES AND IMPLICATIONS

6.1 Overview of Outcomes

The results of LDC and SELECT models generated for this report indicate different fecal bacteria reduction needs for different areas of the watershed dictated by a complex mix of sources which are predicted to shift in coming years. Among these sources, pet waste was determined to be the dominant pollutant in both current and projected scenarios. The methodologies implemented in the design of these model results may be refined by stakeholder feedback as the partnership progresses through the stages of WPP development. From these data, fecal bacteria reduction targets and implementation timelines may be established by linking the results of LDC and SELECT models.

6.2 Model Linkage

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

6.3 Fecal Indicator Bacteria Reduction Targets

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

Milestone Year

Typically, WPPs are written to provide a guideline for making improvements to water quality within a period of five to 15 years. By incorporating five-year intervals into future projections of fecal bacteria loading with the SELECT models used in this report, stakeholders will be able to target any year on the timeline between the present day and 2050 as a milestone year. While intervals closer to the present-day present challenges for organizing and implementing water quality improvement strategies, estimates for fecal bacteria loading further along the timeline are subject to higher levels of uncertainty. Therefore, a

balance must be reached between selecting a milestone year that effectively addresses fecal bacteria loading for a long-term outlook while working within an acceptable margin of error regarding uncertainty. As a compromise, project staff recommend targeting the year 2040 as a milestone for this watershed project. With a WPP approval planned between 2026 and 2027, this would cover a period between 10 and 15 years.

Target Areas

In both LDC and SELECT model results, different fecal bacteria source pressures are indicated in different areas of the watershed. Overall reduction targets for each subwatershed were determined using the representative LDC station for the area and taking a weighted average of the LDC reduction targets produced for that station based on rates of flow. Therefore, where W represents the weighting factor (percent of flows) at high flow (*h*), moist (*m*), mid-range (*mr*), dry (*d*), and low flow (*l*) conditions, and R represents the reduction value required at each rate of flow, the weighted average reduction can be calculated as follows:

$$\text{Weighted Average Reduction} = \frac{WhRh + WmRm + WmrRmr + WdRd + WlRl}{Wh + Wm + Wmr + Wd + Wl}$$

For example, Station 11125 represents the Garners Bayou subwatershed. At the high flow category which represents the top 10% of flows, an *E. coli* reduction of 96% is recommended. *E. coli* observed in the next 30% of flows (moist conditions) require a reduction of 83% and *E. coli* observed in the following 20% of flows (mid-range conditions) require a 72% reduction. Finally, *E. coli* observed in dry conditions comprising the following 30% of flows require a 67% reduction and *E. coli* observed in the lowest 10% of flows (low flow conditions) require a 58% reduction. For stations with negative reductions indicated in the low flow category, no values are factored into the calculation for the last weighted average category. The calculation for the weighted average reduction for Station 11125 is shown below:

$$\text{Weighted Average Reduction} = \frac{(10 \times 96) + (30 \times 83) + (20 \times 72) + (30 \times 67) + (10 \times 58)}{10 + 30 + 20 + 30 + 10}$$

$$\text{Weighted Average Reduction} = \frac{960 + 2,490 + 1,440 + 2,010 + 580}{100}$$

$$\text{Weighted Average Reduction} = \frac{7,480}{100} = 74.8$$

Table 19. Subwatershed fecal indicator bacteria load reduction goals

Subwatershed	LDC Station	Subwatershed	Weighted Average <i>E. coli</i> Reduction Target
Greens Above Tidal - Upper	13778	1	89%
Greens Above Tidal - Middle	11371	2	61%
Greens Above Tidal - Lower	11369	3	53%
Garners Bayou	11125	4	75%
Halls Bayou	11126	5	70%
HSC/Greens Bayou	18363	6	63%

Allocating Reductions

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

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

For the needs of this watershed, project staff recommend the first option as it allows stakeholders some flexibility in focusing short-term efforts on sources indicated as greater pressures in current conditions relative to the milestone year. While proportional allocations are modeled at the subwatershed level and for the total watershed area, project staff further propose targeting results from the subwatersheds. According to these recommendations, both overall reduction targets for each of the subwatersheds and the linkage of the reduction target percentages to the source loadings to generate the target source load reductions for current and 2040 milestone years were calculated (**Table 20**). The allocation of reduction loads by source for each of the subwatersheds were also calculated (**Table 21, Table 22, Table 23, Table 24, Table 25, and Table 26**).

Table 20. 2022 and 2040 source load reduction targets

Subwatershed	Weighted Average Bacteria Reduction Target	2022 Total Source Load in Billion cfu/day ¹⁶	2022 Source Load Reduction Target in Billion cfu/day	Incremental Load, 2022 to 2040 in Billion cfu/day ¹⁷	2040 Total Source Load Reduction Target in Billion cfu/day ¹⁸
1	89%	20,776.91	18,491.45	2,844.61	21,336.06
2	61%	7,498.07	4,573.82	216.77	4,790.59
3	53%	7,091.34	3,758.41	2,605.83	6,364.24
4	75%	6,192.25	4,644.19	1,618.96	6,263.15
5	70%	22,011.40	15,407.98	879.90	16,287.88
6	63%	8,979.15	5,656.87	999.08	6,655.95

¹⁶ Current source load is generated by subwatershed.

¹⁷ The incremental load represents the difference between the 2040 load and the 2022 load. See the next footnote for explanation of its use in generating 2040 source reduction load target.

¹⁸ The 2040 reduction target is generated by through the equation $C_r + (F_t - C_t)$; where C_r = current source reduction load, F_t = future total source load, and C_t = current total source load. In essence, the incremental load generated between 2022 and 2040 is added to whatever existing reduction load exists in 2022. This approach is used because LDCs cannot estimate future reduction percentages, and because it is assumed the waterway will not have additional assimilative capacity in 2040.

Table 21. Load reduction targets by source, SW1

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	5.3%	1,133.81
WWTFs	0.0%	2.44
Dogs	73.9%	15,770.92
Cattle	0.2%	47.40
Horses	0.0%	0.78
Sheep and Goats	0.1%	28.27
Deer	0.0%	4.20
Other Wildlife	20.0%	4,267.21
Feral Hogs	0.5%	81.03
Total	100.0%	21,336.06

Table 22. Load reduction targets by source, SW2

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	1.4%	68.03
WWTFs	0.0%	1.54
Dogs	76.4%	3,660.38
Cattle	0.5%	21.99
Horses	0.0%	0.36
Sheep and Goats	0.3%	13.11
Deer	0.1%	2.85
Other Wildlife	20.0%	958.12
Feral Hogs	1.3%	64.22
Total	100.0%	4,790.59

Table 23. Load reduction targets by source, SW3

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	12.8%	811.76
WWTFs	0.0%	2.50
Dogs	57.0%	3,629.62
Cattle	2.4%	153.97
Horses	0.0%	2.53
Sheep and Goats	1.4%	91.83
Deer	0.4%	16.13
Other Wildlife	20.0%	1,272.85
Feral Hogs	6.0%	383.05
Total	100.0%	6,364.24

Table 24. Load reduction targets by source, SW4

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	2.4%	148.41
WWTFs	0.1%	4.79
Dogs	70.2%	4,397.98
Cattle	1.2%	74.36
Horses	0.0%	1.22
Sheep and Goats	0.7%	44.35
Deer	0.3%	16.27
Other Wildlife	20.0%	1,252.63
Feral Hogs	5.1%	323.14
Total	100.0%	6,263.15

Table 25. Load reduction targets by source, SW5

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	3.2%	514.13
WWTFs	0.0%	0.82
Dogs	75.9%	12,368.82
Cattle	0.1%	23.99
Horses	0.0%	0.39
Sheep and Goats	0.1%	14.30
Deer	0.0%	4.42
Other Wildlife	20.0%	3,257.58
Feral Hogs	0.7%	103.43
Total	100.0%	16,287.88

Table 26. Load reduction targets by source, SW6

Source	% Total Load, 2040	Proportion of 2040 Load Reduction Target in Billion cfu/day
OSSFs	4.5%	301.14
WWTFs	0.0%	0.32
Dogs	72.2%	4,807.63
Cattle	0.6%	39.41
Horses	0.0%	0.65
Sheep and Goats	0.4%	23.50
Deer	0.1%	5.95
Other Wildlife	20.0%	1,331.19
Feral Hogs	2.2%	146.16
Total	100.0%	6,655.95

6.4 Implications of Findings

Models characterizing fecal bacteria loads and sources in the Greens Bayou watershed reinforce the concept of a watershed beset by a diverse range of pressures impacting water quality. Future projections indicate worsening trends in bacteria load without intervention.

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

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