Water Quality Modeling Report

for the Clear Creek Watershed Protection Plan

August 2022

Clear Creek Watershed Partnership

H-GAC Houston-Galveston Area Council

Texas Commission on Environmental Quality

EPA United States Environmental Protection Agency

Water Quality Modeling Report

for the Clear Creek Watershed Protection Plan

August 28, 2022

(Revised through January, 2023)

This document was prepared by the Houston-Galveston Area Council for the stakeholders of the Clear Creek Watershed Partnership and the Texas Commission on Environmental Quality (TCEQ). This project is funded by a Clean Water Act Section 319(h) grant from the United States Environmental Protection Agency administered by the TCEQ.

Table of Contents

Abbreviations

AgriLife	Texas A&M AgriLife Extension
AVMA	American Veterinary Medical Association
BST	Bacteria Source Tracking
CAFO	Concentrated Animal Feeding Operation
CFS	Cubic Feet per Second
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
H-GAC	Houston-Galveston Area Council
HUC	Hydrologic Unit Code
LDC	Load Duration Curve
MGD	Million Gallons a Day
MUDs	Municipal Utility Districts
NASS	National Agricultural Statistics Service
OSSF	Onsite Sewage Facility
RMU	Resource Management Unit
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SSO	Sanitary Sewer Overflow
SWCDs	Soil and Water Conservation Districts
TCEQ	Texas Commission on Environmental Quality
USGS	United States Geologic Survey
WPP	Watershed Protection Plan
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

Figures

Tables

1.0 Introduction

Clear Creek flows through portions of Harris, Galveston, Brazoria, and Fort Bend counties in Texas, and is a primary tributary to the popular recreation destinations of Clear Lake and Galveston Bay. From its developing headwaters, Clear Creek makes its way through dense suburban and urban development on its way to its confluence with Clear Lake (Figure 1) and is a major drainage conveyance for communities in the area. Along the way, the creek accumulates pollutants leading to numerous water quality issues related to natural and human activity in its watershed. The elevated levels of fecal waste in the creek's water can impact public health and conditions impacting the amount of dissolved oxygen (DO) in the water can endanger aquatic life and local economic benefits from tourism and fisheries. The dense development of the watershed has created challenges for local stakeholders as they seek to address the impacts of these and other pollutant sources for the waterway that connects their communities.

To serve the development of a watershed protection plan (WPP) for Clear Creek, the Houston-Galveston Area Council (H-GAC) conducted a series of modeling efforts[1] to better understand the watershed's sources of pollution. The intent of these efforts was to inform decisions by local stakeholders in addressing water quality issues in their communities and bring Clear Creek back into compliance with state water quality standards.

These efforts included an estimation of the necessary reduction of fecal indicator bacteria[2] (fecal bacteria) loads in project waterways, analysis of the necessary improvement of DO in waterways, and characterization and quantification of the potential source loads of fecal waste in the corresponding watersheds. Load duration curves (LDCs) were used to establish the fecal bacteria reduction and DO improvement goals at key monitoring sites on the project waterways. The Spatially Explicit Load Enrichment Calculation Tool (SELECT) was used in conjunction with stakeholder input to identify and quantify potential fecal bacteria sources. The purpose of this effort was to set fecal bacteria reduction targets and to evaluate the spatial distribution and relative prominence of individual sources and their potential cumulative impact. The results of the fecal bacteria analyses will be used in the WPP project to guide selection and siting of implementation measures and to serve as a baseline against which to measure future progress.

---

[1] The water quality issues evaluated in this modeling report were identified by data acquired and assessed under the project's Water Quality Data Collection and Trends Report, available on the project website at https://clearcreekpartnership.weebly.com/uploads/9/6/6/3/9663419/clear_creek_water_quality_trends_report_phase_1_final.pdf.

[2] Throughout this document and model results, references to "fecal bacteria" should be taken to refer to species *E. coli* (for freshwater portions of the system) and Enterococcus (for marine segments of the system) as indicator bacteria of fecal waste, or, in reference to loads, number of fecal bacteria as a representation of fecal waste.

This document will discuss the:

- Project needs (Section 2);
- Model selection and analysis design (Section 3);
- Load duration curve analyses (Section 4);
- SELECT analyses (Section 5); and
- Outcomes and implications of the analyses (Section 6).

2.0 Project needs

Two primary needs drive the use of modeling in watershed-based planning. First and foremost, modeling is a primary tool for empowering stakeholders to make informed decisions. Model results can characterize the required reductions, and the extent, spatial distribution, and relative prominence of pollutant sources. This information provides stakeholders guidance and a defensible rationale on which to base decisions about implementation measures, scale, and location. Secondly, the use of model results, in conjunction with other data and stakeholder input, helps fulfill Element A of the EPA's 9-element model for watershed-based plans[3].

For the Clear Creek effort, the specific needs served by this modeling effort were to:

- Identify the flow conditions in which water quality standard exceedances (elevated fecal bacteria and depressed DO) were occurring (LDCs);
- Determine reduction goals[4] to ensure future water quality standard compliance (LDCs);
- Evaluate potential loads for fecal indicator bacteria as a proxy for the presence of fecal waste (SELECT);
- Define the spatial and comparative relationships between sources and subwatersheds with a quality-assured modeling solution (SELECT);
- Provide robust opportunities for stakeholder feedback and input into the modeling process (all); and
- Provide a set of loading data that could be used in conjunction with reduction targets from load duration curves to determine source load reductions[5] (SELECT).

Additionally, because the watershed area is still undergoing some development, both current and future source loading conditions needed to be assessed. The project area is detailed in Figure 1.

---

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

[4] Or in the case of DO, improvement goals. Because DO is a positive constituent, within appropriate range for the watershed, changes in DO are discussed in terms of increasing, rather than decreasing, DO concentrations.

[5] More information about the modeling methodology can be reviewed in the modeling QAPP at https://clearcreekpartnership.weebly.com/project-documents.html.

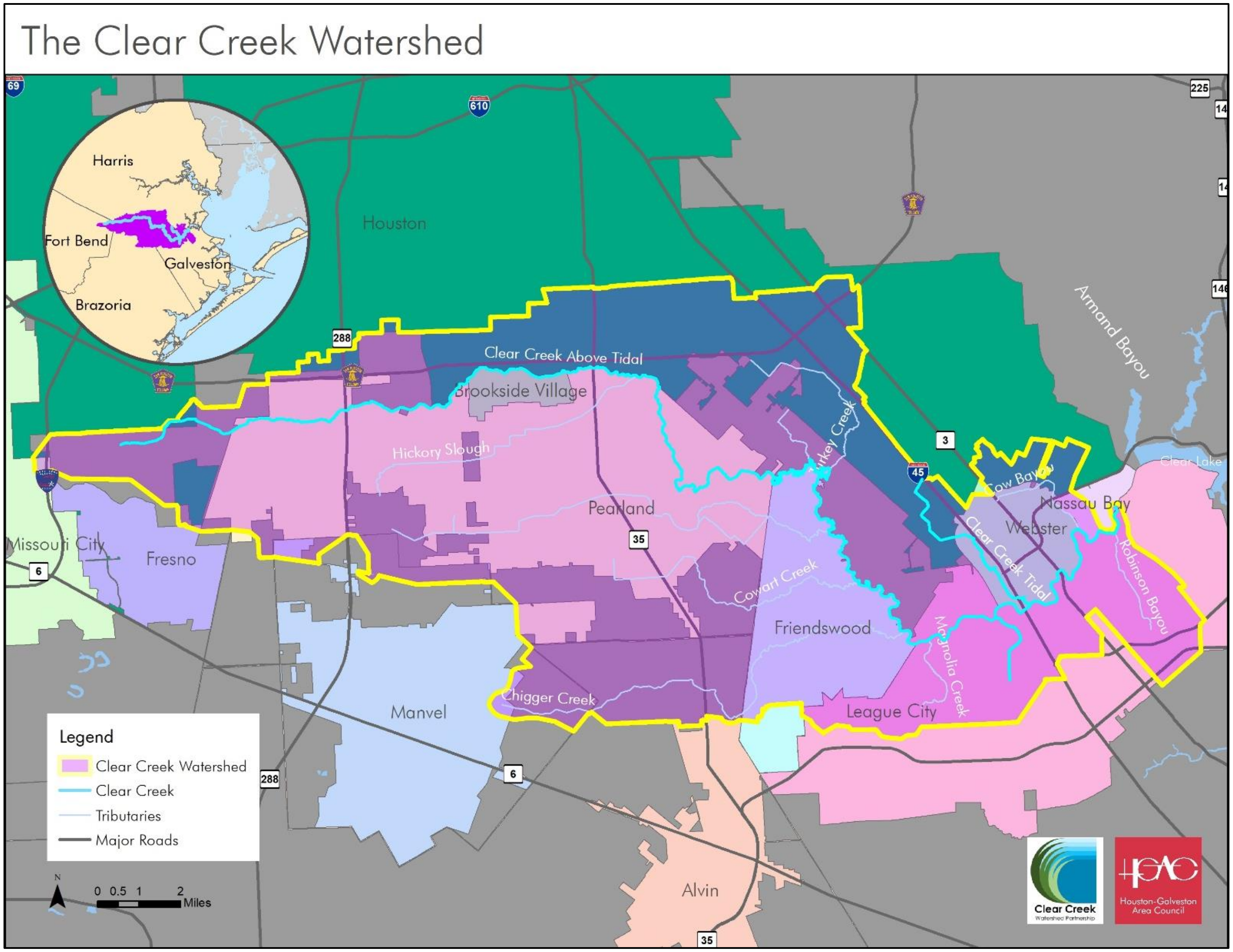

Figure 1 - The Clear Creek Watershed Protection Plan Project Area

3.0 Model Selection and Analysis Design

Model Selection

Several models were considered during the development phase of the project. The primary aim of model selection was to match the needs of stakeholder information to the complexity of the model. LDCs and SELECT were chosen due to their balance between efficiency and complexity, their widespread use in similar local WPP projects, and their sufficiency to meet the project needs identified in Section 2. For the tidal portion of the system, a modified implementation of LDCs were used to simulate tidal action.

A key point of discussion in the project development process was to the sufficiency of linkage between LDCs and SELECT. Neither model accounts for fate and transport of pollutants between source loads and instream conditions. Between the deposit of source loads and the introduction of loads to waterways, many biotic and abiotic factors act on both the waste in general, and the indicator bacteria specifically. These factors can include both positive and negative changes to loads. Based on discussions between H-GAC, TCEQ, and EPA in this and prior projects, the use of a linear relationship between LDC reduction percentages and source loads was held to be viable for the level of precision needed for the project's decisions. While it possible to achieve a higher level of precision using more complex models (SWAT, among others), the additional degree of detail is only an incremental improvement in terms of supporting stakeholder decisions. The additional cost, time, and complexity involved in utilizing fate and transport approaches was not deemed to be a worthwhile tradeoff for the incremental advantage they pose for this application. The inclusion of long-term monitoring and effectiveness assessment as part of the WPP focus on adaptive management further limits the necessity of additional predictive accuracy. With this preliminary decision made, the utilization of LDCs and SELECT best meets the project's focus on "modeling to the need." To help ensure that this approach is as conservative as possible, a modified approach to SELECT that accounts for high-level consideration of transmission potential was implemented.

To account for concerns about SELECT's focus on estimating total potential load, regardless of distance from waterways, project staff chose to employ a modified implementation of SELECT that added a "buffer" scenario. In the buffered version, loads for areas outside of a buffer area around waterways are considered less likely to enter waterways and are discounted. An additional challenge of using SELECT is the inability to fully represent most wildlife contributions due to lack of sufficient data. This project added a conservative base assumption for wildlife loads, ensuring that SELECT remained the most viable modeling tool for the project objectives.

Analysis Design

The primary drivers for the WPP in Clear Creek are the water quality impairments and/or concerns listed for this segment[6]. The primary water quality issue identified as being of interest to this project are fecal waste and its associated pathogens (as evidenced by elevated levels of fecal indicator bacteria). Once LDCs and SELECT were chosen as the models for estimating load reductions and source load characterization, the design for the modeling project's implementation considered:

- whether appropriate amounts of water quality and flow data existed to develop LDCs;
- what flow conditions needed to be addressed, including complications of developing LDCs for tidal areas;
- at which monitoring locations progress toward water quality goals would be assessed;
- what potential sources needed to be modeled, and what data existed for those sources;
- how to define the best assumptions for data sources;
- what future time period(s) to model in SELECT, and how to develop projected values for those future conditions;
- how to employ and interpret the buffer approach in SELECT; and
- how local input would be incorporated into the analyses.

These considerations, as well as public input from the stakeholders and other technical advisors, formed the basis for the analysis design. The underlying data for the project were developed from quality assured sources[7]. The underlying watershed delineations were developed from comparison of various commonly used watershed boundary layers and locally developed data[8], adjusted to reflect conditions on the ground, and to segregate tributaries and segment sections in subwatersheds. Specific implementations of the subwatershed delineation and resulting assessment area derivation is discussed in the modeling descriptions in Sections 4 and 5.

[6] The source for impairment or concern status is the 2022 Texas Integrated Report of Surface Water Quality, which describes the assessment process and results for these segments. The State of Texas assesses its waterways every two years, based on seven years of data. These assessments form the basis by which segments (defined portions of waterways) and their tributaries are classified as having impairments (inability to meet a state water quality standard for which a numerical or other specific limit exists) or concerns (levels of constituents which exceed screening levels or other criteria, but for which numerical or specific limits do not exist). The existence of an impairment is usually the primary driver for developing watershed-based plans for affected segments. More information on the assessments can be accessed at https://www.tceq.texas.gov/waterquality/assessment/305_303.html .

[7] For more information, please refer to the Quality Assurance Project Plan for this effort, found at https://clearcreekpartnership.weebly.com/project-documents.html.

[8] H-GAC compared National Hydrography Dataset Plus (NHD+) datasets, the United States Geologic Survey (USGS) Hydrologic Unit Code 12 (HUC 12) watershed boundaries, Harris County Flood Control District subwatershed delineations, and other local watershed boundary sources. In an evaluation of the different layers against aerials and known hydrologic boundaries, the Harris County Flood Control District data was closest to expected actual drainage patterns.

The overall intent for the design of the LDC analyses was to generate fecal bacteria reduction targets and identify necessary DO improvements at strategic locations in the project waterways (based on existing monitoring locations and/or USGS flood gauge stations). The primary focus of these efforts was the fecal indicator bacteria impairment; subsequent discussion of reduction loads refers specifically to that aspect of the LDC effort. The end use of these fecal bacteria targets was in their application to estimated source loads to generate reduction loads.

The design for the fecal bacteria source load characterization with SELECT was based on identifying appropriate source(s), and load assumptions by source, and generating total potential loads that characterized contributions by source and by spatial location (subwatersheds).

To generate final source load reductions, the percent reduction targets from the LDCs were applied to the source loads from SELECT to generate reduction loads. Future reduction targets assumed that any estimated additional source loads would be added to current condition reduction target loads. The resulting current and future reduction loads were generated for each of the LDC stations that would be used for long term assessment, with the intent of targeting BMPs sufficient to meet these reduction targets specific to each area. Source load reduction targets were developed for each of the 5-year projection milestones, with a focus on 2035 as the target year for compliance.

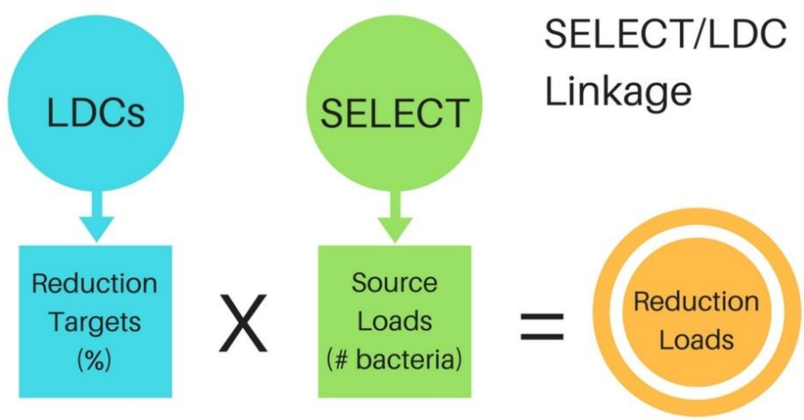

Figure 2 - SELECT/LDC Linkage

More information on the design operation and results for each analysis are found in Section 4 (LDCs), Section 5 (SELECT), and Section 6 (Final Results)

4.0 Load Duration Curves

Overview

This section describes the design, implementation, review, and results for the LDC evaluation efforts for this project. The LDCs characterize the relationship between flow and fecal bacteria[9] concentrations and establish the reduction targets needed to comply with the water quality standard. They were also used to identify DO improvement needs.

Load Duration Curves

LDCs use flow data from a stream gauge or other source to create a flow duration curve. The flow curves indicate what percentage of days the flow of water meets certain flow levels, in this case broken into five flow categories from highest to lowest flow conditions. Based on the water quality criteria for a given contaminant, a maximum allowable stream load is calculated for all flow conditions (pollutant criteria concentration multiplied by flow gives total amount of pollutant). Lastly, monitoring data for the contaminant of concern is multiplied by flows to produce a load duration curve, indicating actual contaminant load across all flow conditions. Areas in which the load duration curve line exceeds the maximum allowable load curve line indicate that the standard is generally not being met in those flow conditions. If the areas of exceedance are primarily in high flow conditions, it is likely nonpoint sources are most prominent. If areas of exceedance are instead primarily in the low flow conditions, point sources are more likely suspects. In situations in which there is a mix of flow conditions related to exceedances, or in which contaminants exceed the allowable limit in all conditions, a mix of point and nonpoint sources is likely.

LDCs in tidal areas require a consideration of tidal flows and use a regression of salinity data in observed water quality to calculate a tidal flow if the salinity contribution and delta were significant.

Site Selection

Site selection for LDCs was based on support for a mix of considerations, including known water quality conditions[10], the need for long-term assessment of progress toward the water quality standard, projected needs for BMP siting decisions, and stakeholder input.

Known Water Quality Conditions

Based on a review of historical ambient water quality trends, wastewater treatment plant discharge monitoring reports (DMRs), and sanitary sewer overflow (SSO) information, water quality in the project

[9] As a system with both freshwater and tidal/marine aspects, both *E. coli* (in the freshwater Above Tidal segment 1102) and *Enterococcus* (in the marine-influenced Tidal segment 1101) indicator bacteria were used, specific to their respective segments.

[10] For more information, refer to the Water Quality Data Collection and Trends Analysis Report at https://clearcreekpartnership.weebly.com/project-documents.html.

watershed indicated that conditions in both the assessed tributaries and main channel of two segments of Clear Creek (Above Tidal, Segment 1102; Tidal, Segment 1101) had a degree of variability and potential for continued exceedance. A single station would not be representative of the variability of water quality and flow conditions based on the water quality review. Therefore, 15 LDC locations (Table 1 and Figure 3) were chosen to represent varying conditions in the system, including the relatively large number of unclassified tributaries. Six of the stations are on the main stem (three in each segment), and nine are on the various tributaries (five in Clear Creek Tidal, segment 1101, and four in Clear Creek Above Tidal, segment 1102). Main stem locations were chosen allow consideration of water quality before and after inputs of some large tributaries. This design allows for a greater degree of scrutiny of geographic variability of loads in the watershed, and an ability to target reductions more precisely. Evaluating several areas independently ensures area-specific problems would not be lost when diluted by a larger waterway, and that end results reflect variability of conditions throughout the waterway.

Long Term Assessment Considerations

To ensure data would be available for long-term assessment, potential LDCs locations were drawn from existing Clean Rivers Program monitoring stations, which will provide ongoing data. Flow from all the sites either correspond directly to USGS stream gauges with flow data or were derived using an area ratio formula from the stream gauge data. Tidal sites with significant salinity fluctuation considered tidal volumes in the development of their flows. The existing sites were found to be sufficient to characterize conditions in the waterways, as affirmed by the stakeholders.

BMP Siting Requirements

As discussed previously, LDCs were chosen in part to reflect geographic variability. A greater number of LDC locations is beneficial to use of modeling results to scale and site BMPs (i.e., BMP requirements can be refined to the subwatershed level based on the specific reduction needs of the LDC assessment area in which the subwatershed falls).

Stakeholder Input

Project staff built the aforementioned considerations into a set of LDC locations, which were reviewed with stakeholders in the preliminary meetings of the Clear Creek Watershed Partnership.

Selected LDC Locations

Based on these considerations, project staff conducted all 15 LDC site analyses, three of which would be used to generate fecal bacteria load reduction targets[11] and all of which would be used to identify necessary DO improvement. The final LDC sites, from headwaters to mouth, are indicated in Figure 4 and described in Table 1. Figure 3 represents a simplified network diagram of the system.

Table 1- LDC Locations

Waterway	LDC Site	USGS Gauge	Sub-watershed	Assessed Area
1102, Clear Creek Above Tidal	11452	08076997	1	The main stem site represents the headwaters of the segment, prior to the influence of its major tributaries.
1102C, Hickory Creek	17068	08076997	2	
1102, Clear Creek Above Tidal	20010	08076997	3	This main stem site is upstream of the confluence of several suburban tributaries, in a developed area.
1102D, Turkey Creek	21925	08076997	5	
1102, Clear Creek Above Tidal	11450	08076997	3,4	This main stem site is between the confluence of Turkey Creek and Mary's Creek.
1102B/F, Mary's Creek	16473	08076997	6	
1102A, Cowart's Creek	16677	08076997	7	
1102B, Chigger Creek	16493	08076997	8	
1101, Clear Creek Tidal	16576	08077600	10	This main stem site represents the boundary conditions between the Above Tidal and Tidal segments.
1101A, Magnolia Creek	16611	08076997	9	
1101F, Unnamed Tributary	18591	08076997	11	

[11] Station 11333 is intermediate between 20457 and 11332 and does not reflect the input from the relatively large Little Clear Creek system. It is useful for many of the considerations noted in the preceding discussion of site selection, but its watershed is not useful to break out from station 11332 as the areas are not different enough to form unique subdivisions of the watershed. Therefore, the watershed is split between headwaters, transitional area, and downstream/developed.

1101, Clear Creek Tidal	11446	08077600	10	This main stem site represents a transition to the wider waterway the creek will become as it nears its confluence with Clear Lake at the end of the system.
1101C, Cow Bayou	17928	08076997	12	
1101D, Robinson Bayou	16475	08076997	13	
1101, Clear Creek Tidal	16573	08077600	10	This main stem site nominally represents the conditions at the end of the system, located within the confluence with Clear Lake.

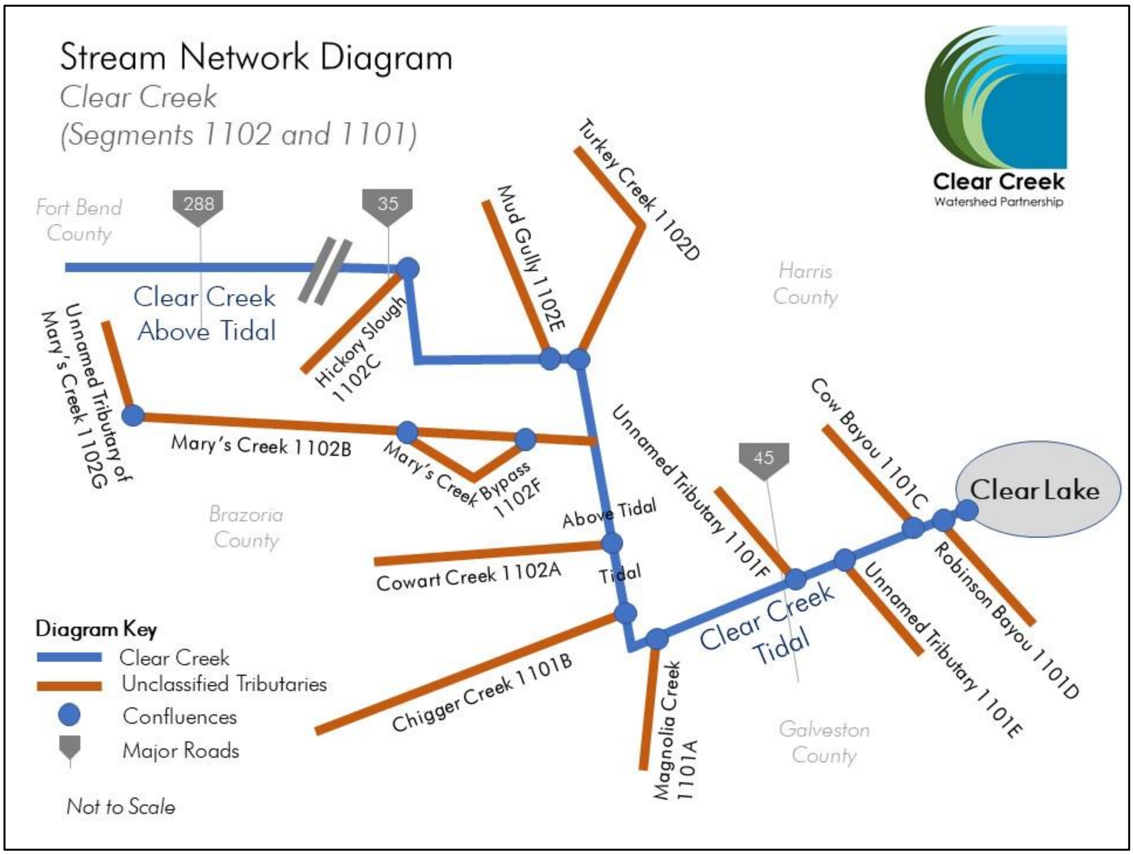

Figure 3 - Stream Network Diagram

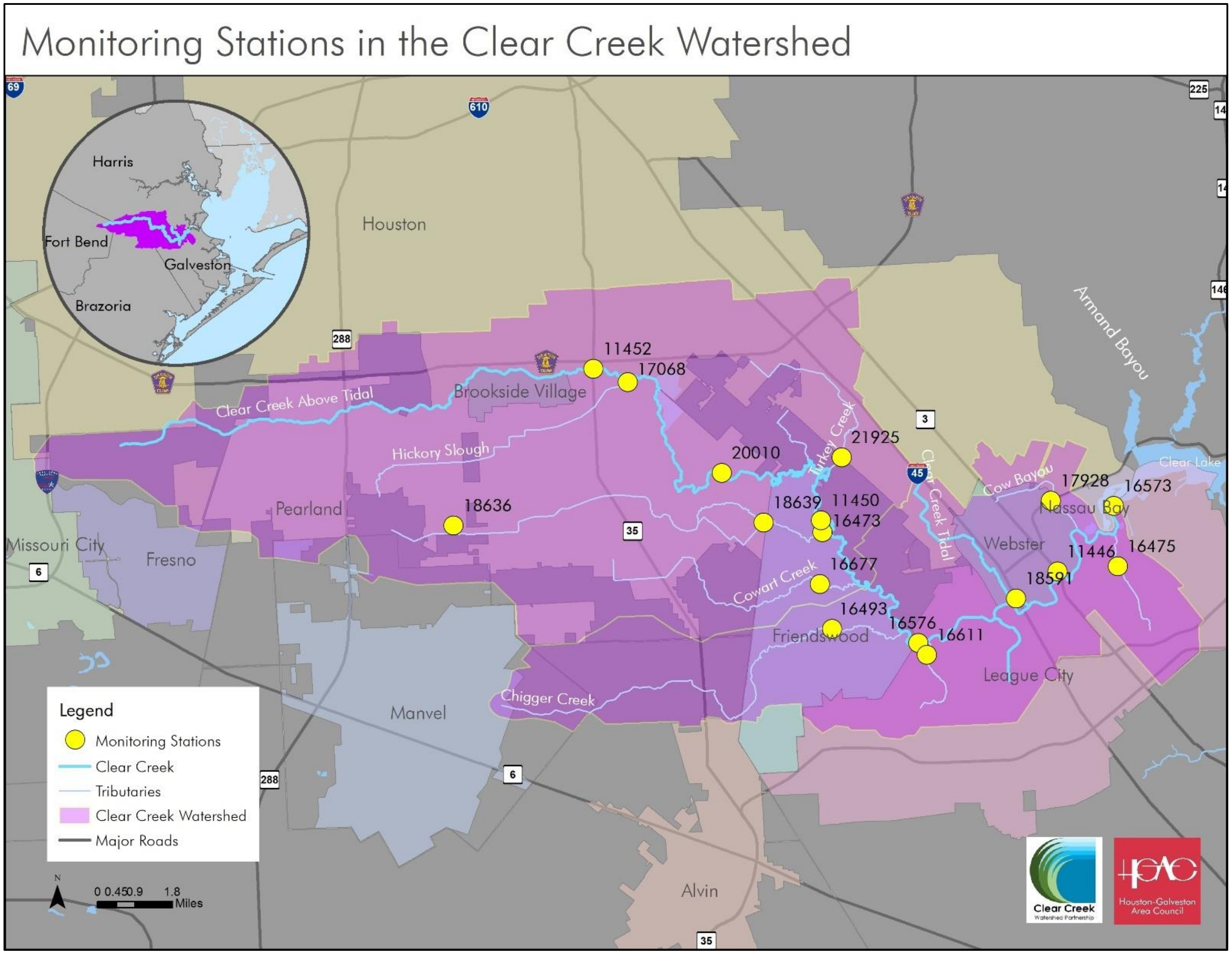

Figure 4 – Monitoring Stations in the Clear Creek Watershed

Data Development

Flow Data

LDCs require a sufficient amount of ambient water quality data, as well as flow data (with continuous flow data being preferable). Flow for all 15 of the Clear Creek LDC sites was developed from corresponding USGS gauges. There are two USGS stream gauges in the Clear Creek system:

- **08076997** – This Above Tidal gauge has actual flow measurements in cubic feet per second (cfs), and was used, after application of a direct drainage area ratio, to represent the relative area drained by each station. This gauge was also used for the tributaries in the Tidal segment, after application of both the drainage area ratio consideration and the tidal salinity regression and consideration.
- **08077600** – This Tidal segment gauge has only gauge height in feet (with a small subset of hourly cfs measurements). This data was converted into flow values by running a linear regression of recorded gauge height and observed cfs measurements. Continuous flow values were then interpolated from gauge heights, area ratios were applied, and tidal flows were considered, to represent flows at the main stem Tidal sites.

Flow for the tidal stations other than 18591, 18576, 18573, and 11446 were developed using a consideration of tidal impacts and volumes. Data from these gauges were used to develop the flow duration curves.

Ambient Water Quality Data

Quality-assured ambient water quality results from CRP monitoring were available for all 15 stations[12]. There were a sufficient number of *Escherichia coli* (*E. coli*) and DO data points for each station to develop LDCs. Most stations had at least 7 years of monitoring results from which to draw (between 30-40 fecal indicator bacteria samples each). Stations 16677, 18591, and 21925 had fewer results than the other stations, but there were no alternate stations available for these three tributaries. The data was sufficient to develop LDCs, regardless. For fecal indicator bacteria, both single sample and geomean values were evaluated against their respective criteria, but only geomean values were used in the process of assessing reductions for this modeling effort.

Both the requisite flow and constituent sample data was sufficient to develop LDCs for all locations and will likely continue to support future revisions and the adaptive management process of evaluating WPP success. DO LDCs were also developed in the same manner and are presented alongside the fecal bacteria LDCs. Some stations (11452, 20010) did not have sufficient data to develop DO LDCs.

[12] More information on the ambient water quality data for these and other stations, and other relevant quality data, can be found in the Water Quality Data Collection and Trends Report produced for this project, available at https://clearcreekpartnership.weebly.com/project-documents.html.

LDC Implementation

Flow curves and LDCs were generated for each of the target stations and reviewed internally and with project stakeholders. No appreciable issues were identified in the development process based on quality assurance review and feedback. The stations are presented in order from headwaters to the confluence with Clear Lake.

Station 11452 – Clear Creek at Telephone Road/SH 35 in South Houston

Station 11452 is the first station on the system and represents the headwaters and northern City of Pearland area. 20457 is located west of Highway 99 and represents the cumulative drainage of the upper third of the watershed and headwaters. The waterway is heavily modified as a drainage conveyance of small to moderate size, and flow and conditions are variable. The drainage area upstream is a mix of rural residential, suburban, and urban uses, and is influenced by the State Highway 8/Beltway 8 corridor directly to the north. Figure 5 shows general character of the monitoring site. Figure 6 is the LDCs for Station 11452. Table 2 indicates the fecal bacteria reduction and DO improvement percentages needed at this location.

The results indicate an appreciable need for fecal bacteria reduction across all higher flow conditions, which may indicate a primacy of nonpoint sources. Low flow conditions have greater assimilative capacity.

Figure 5 – Clear Creek at Station 11452

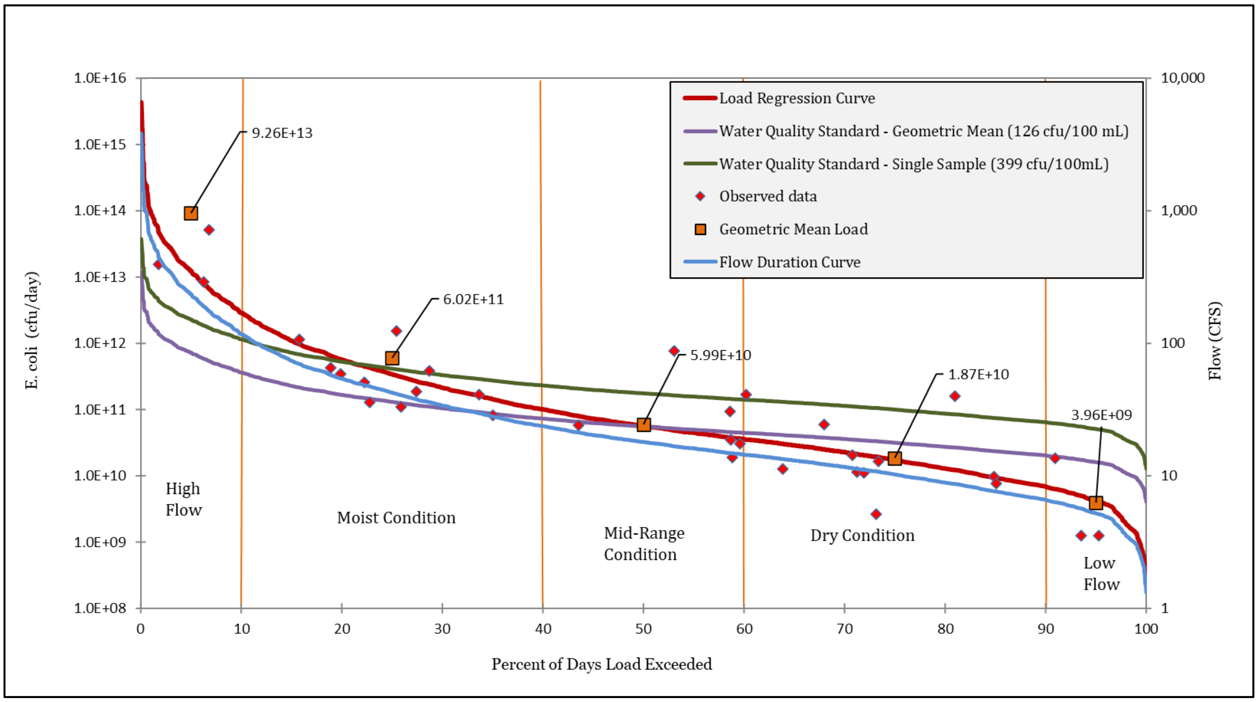

Figure 6 - Fecal Bacteria LDC for Station 11452

Table 2 - Flow-specific values for Station 11452

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean[13]
High Flows	0-10%	96%
Moist Conditions	10-40%	68%
Mid-Range Conditions	40-60%	4%
Dry Conditions	60-90%	-80%
Low Flows	90-100%	-309%

[13] Negative values indicate no reduction is necessary, and assimilative capacity may still exist. Reductions are represented by positive values.

Station 17068 – Hickory Slough at Robinson Drive in Pearland

Station 17068 is located at upstream of the confluence of Clear Creek and drains an area similar in character to Station 11452. The waterway itself is highly impacted by drainage from impervious areas and is a fairly small waterway up to the confluence. Figure 7 shows general character of the monitoring site. Figures 8 and 9 are the LDCs for the station. Table 3 indicates the fecal bacteria reduction and DO improvement percentages needed at this location.

Figure 7 – Hickory Slough at Station 17068

Results at this station indicate a range of conditions, with fecal bacteria reduction needed primarily in higher flow conditions, with some assimilative capacity in low flows. The results indicate that nonpoint sources as the likely leading cause of bacterial contamination. DO levels do not indicate a current need for improvement.

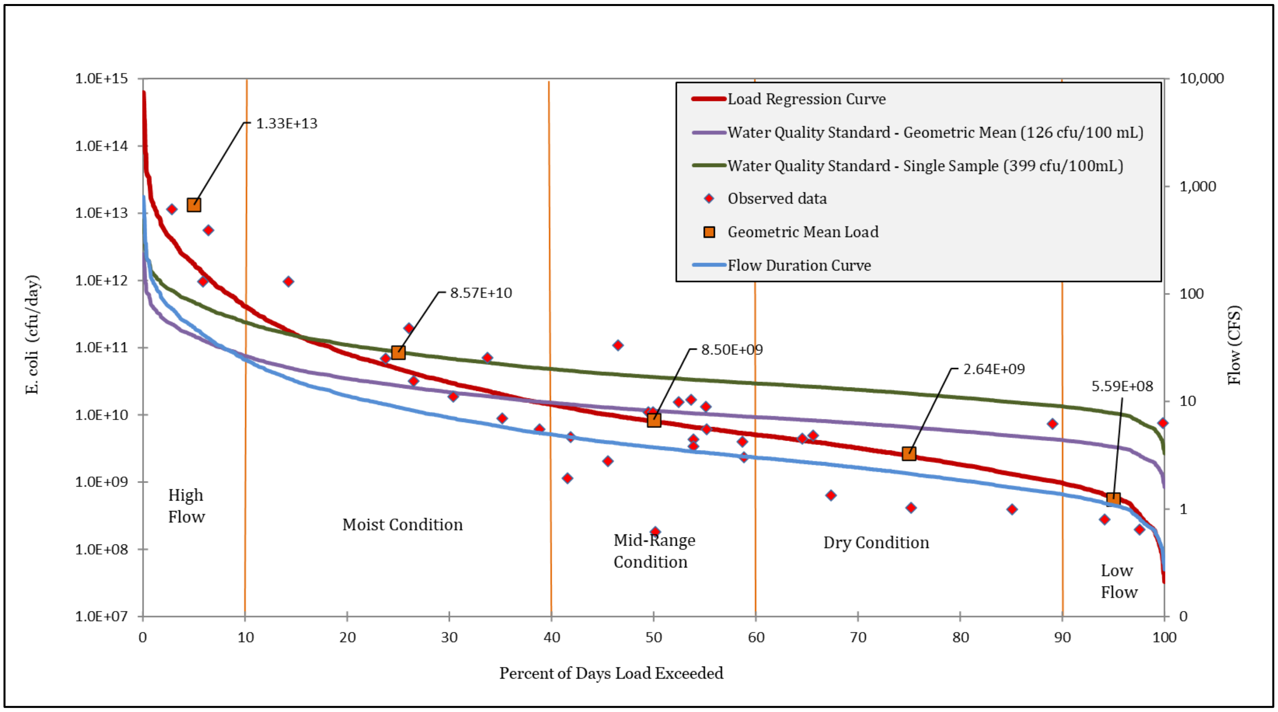

Figure 8 - Fecal Bacteria LDC for Station 17068

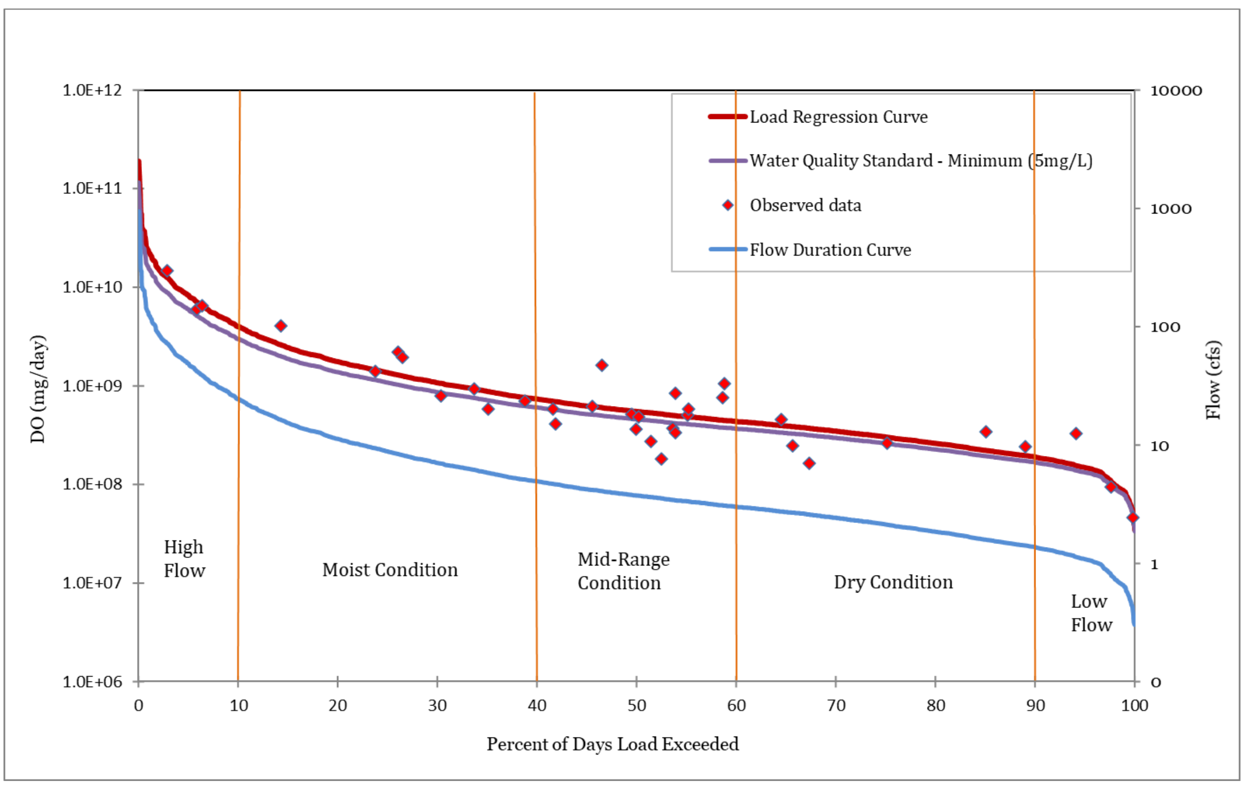

Figure 9 - DO LDC for Station 17068

Table 3 - LDC Results for Station 17068

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	95%	-40%
Moist Conditions	10-40%	53%	-26%
Mid-Range Conditions	40-60%	-41%	-20%
Dry Conditions	60-90%	-165%	-16%
Low Flows	90-100%	-502%	-11%

Station 20010 – Clear Creek Above Tidal at Yost Road Terminus in Pearland

Station 20010 is located upstream of the confluence of several tributaries and drains largely suburban areas. The riparian tree cover at this location is slightly denser, although the waterway has not expanded appreciably from station 11452. Figure 10 shows general character of the monitoring site. Figure 11 is the fecal bacteria LDC for Station 20010. Table 4 indicates the fecal bacteria reduction needed at this location.

The results show a similar pattern as upstream stations, with the greatest need for reduction in highest flows, and assimilative capacity in low flows, indicating likely nonpoint source origins for fecal waste pollution.

Figure 10 – Clear Creek at Station 20010

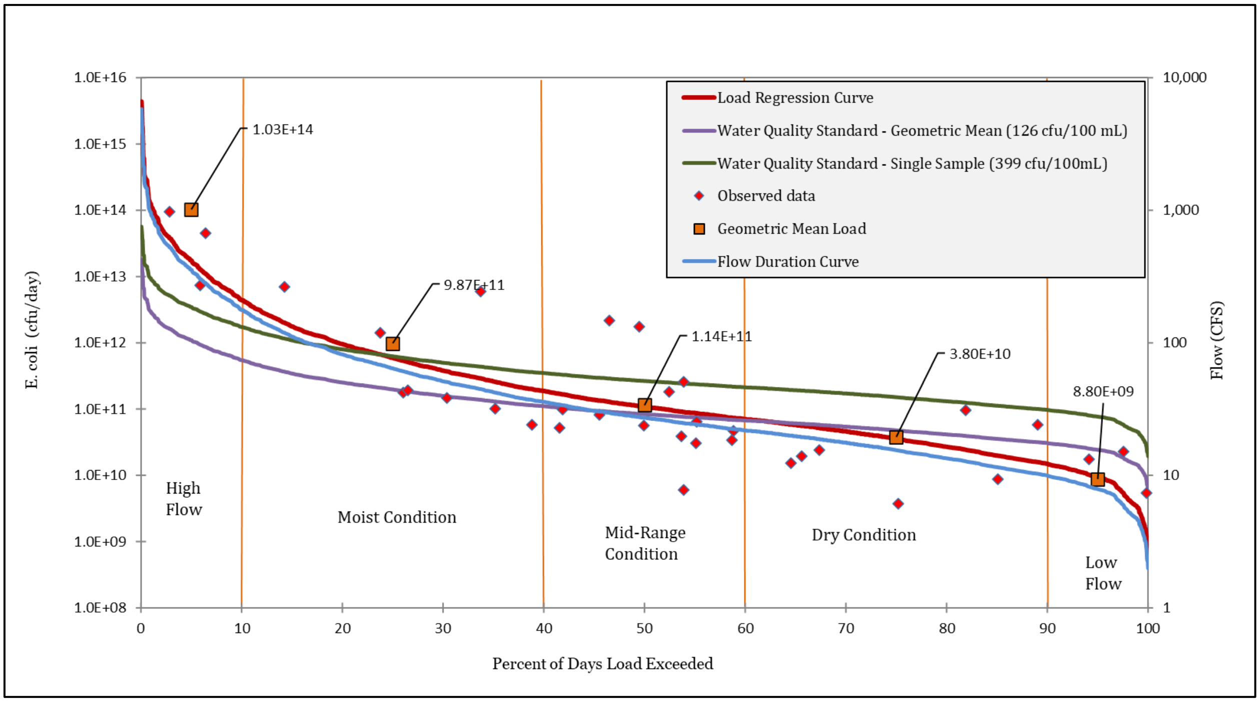

Figure 11 - Fecal Bacteria LDC for Station 20010

Table 4 - LDC Results for Station 20010

Flow category	**Percent Exceedance (of flow)**	**Fecal Bacteria Percent Reduction - Geomean**
High Flows	0-10%	96%
Moist Conditions	10-40%	71%
Mid-Range Conditions	40-60%	24%
Dry Conditions	60-90%	-33%
Low Flows	90-100%	-176%

Station 21925 – Turkey Creek at Beamer Road in Friendswood

Station 21925 is located just upstream of the confluence with the main stem of Clear Creek on Turkey Creek. Turkey Creek is heavily modified, in places channelized, as drainage for an area of the Beltway/State Highway 8 and I-45 transportation corridors and surrounding residential and commercial development. The waterway is heavily impacted by drainage flows, with steeper, less stable banks in some areas. Figure 12 shows the general character of the monitoring site. Figures 13 and 14 are the LDCs for the station. Table 5 indicates the fecal bacteria reduction and DO improvement percentages needed at this location.

Results at this station mirror prior stations, with highest fecal bacteria levels and lowest DO concentrations at highest flows.

Figure 12 - Turkey Creek at Station 21925

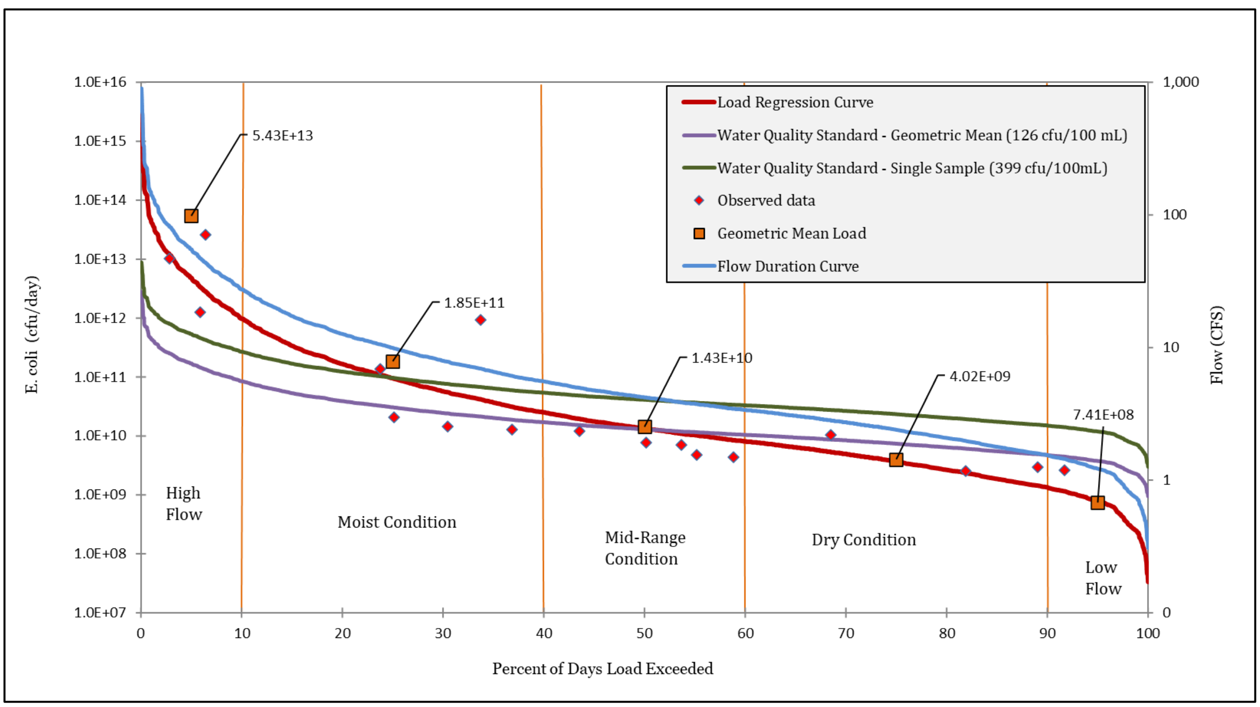

Figure 13 - Fecal Bacteria LDC for Station 21925

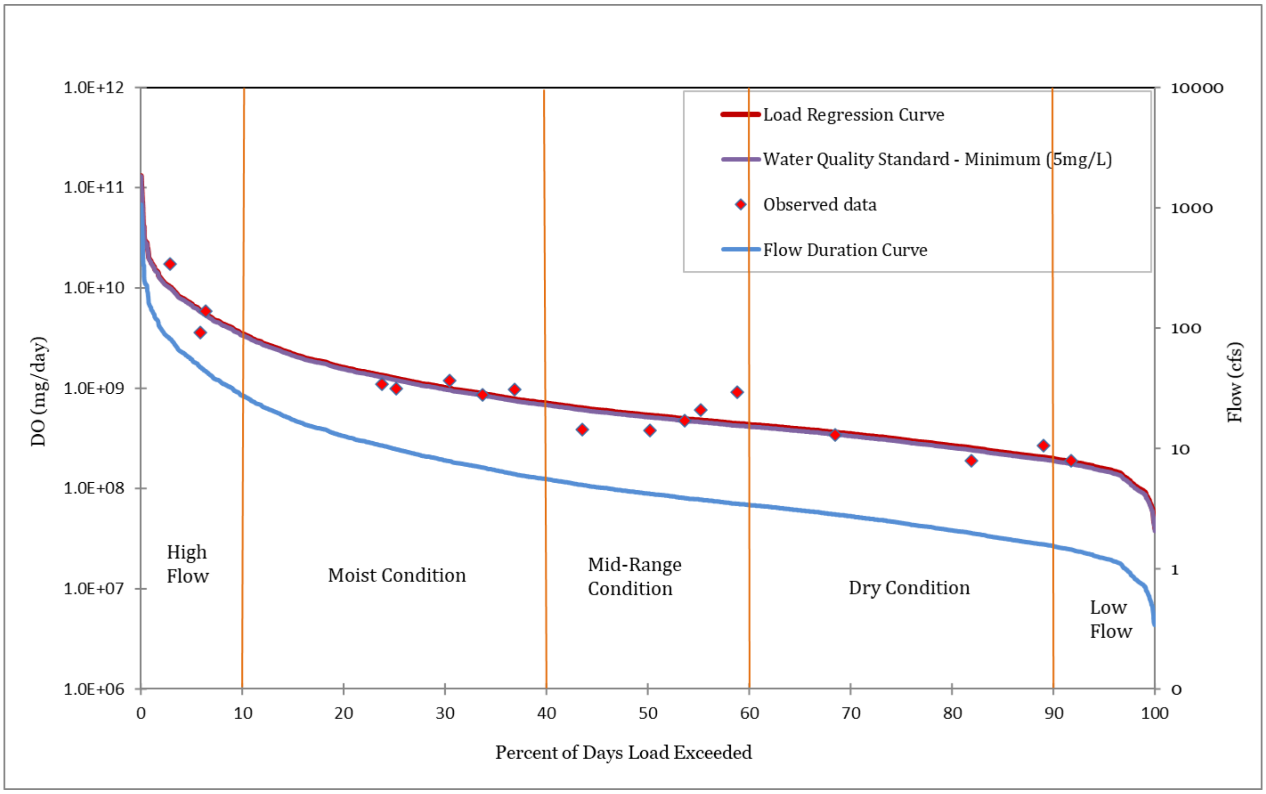

Figure 14 - DO LDC for Station 21925

Table 5 - LDC Results for Station 21925

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	98%	-3%
Moist Conditions	10-40%	75%	-4%
Mid-Range Conditions	40-60%	5%	-5%
Dry Conditions	60-90%	-97%	-5%
Low Flows	90-100%	-416%	-5%

Station 11450 – Clear Creek Above Tidal at FM 2351 near Friendswood

Station 11450 is located just upstream of the confluence of several larger tributary systems and passes through an area of denser riparian buffer along upstream parkland. However, the surrounding area is still relatively dense suburban and urban development. The waterway at this location has grown broader than at its upstream stations. Figure 15 shows the general character of the monitoring site. Figure 16 is the fecal bacteria LDC for the station. Table 6 indicates the fecal bacteria reduction needed at this location. Results at this station mirror prior stations, with highest fecal bacteria levels highest flows, although appreciable reduction is still required in midrange flows here.

Figure 15- Clear Creek Above Tidal at Station 11450

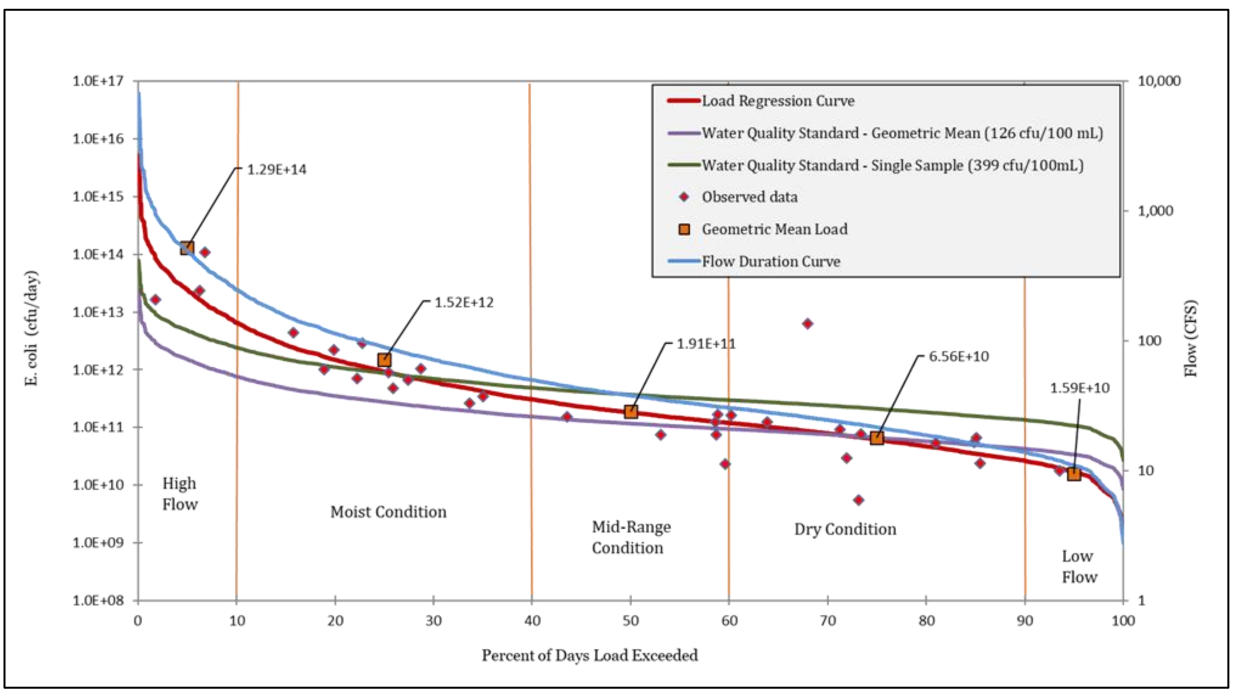

Figure 16 - Fecal Bacteria LDC for Station 11450

Table 6 - Fecal Bacteria LDC for Station 11450

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean
High Flows	0-10%	96%
Moist Conditions	10-40%	74%
Mid-Range Conditions	40-60%	36%
Dry Conditions	60-90%	-7%
Low Flows	90-100%	-113%

Station 16473 – Mary’s Creek at Mary’s Crossing in Friendswood

Station 6473 is located just upstream of the confluence with Clear Creek Above Tidal on Mary’s Creek. This station also includes the cumulative flow from Mary’s Creek Bypass (1102F), which can introduce flow upstream of this confluence in high rain events. Mary’s Creek is highly impacted by drainage flows. While the station is located adjacent to large open areas with moderate riparian cover, the stream banks indicate erosion in high flow events and much of the drainage area is developed land of varying density. Figure 17 shows the general character of the monitoring site. Figures 18 and 19 are the LDCs for the station. Table 7 indicates the fecal bacteria reduction needed at this location. Results at this station still show the highest need for fecal bacteria reduction at highest flows, but some degree of reduction is needed at all but the lowest flows. DO levels have good assimilative capacity in all flows.

Figure 17 - Mary's Creek at Station 16473

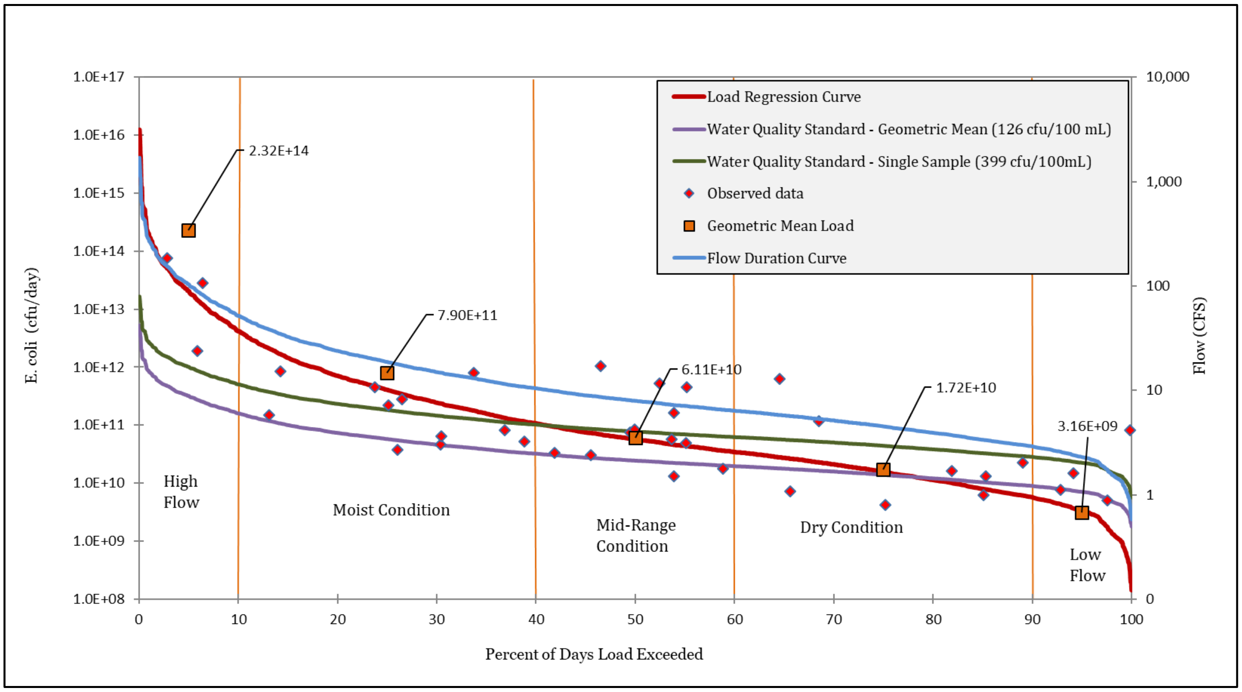

Figure 18 - Fecal Bacteria LDC for Station 16473

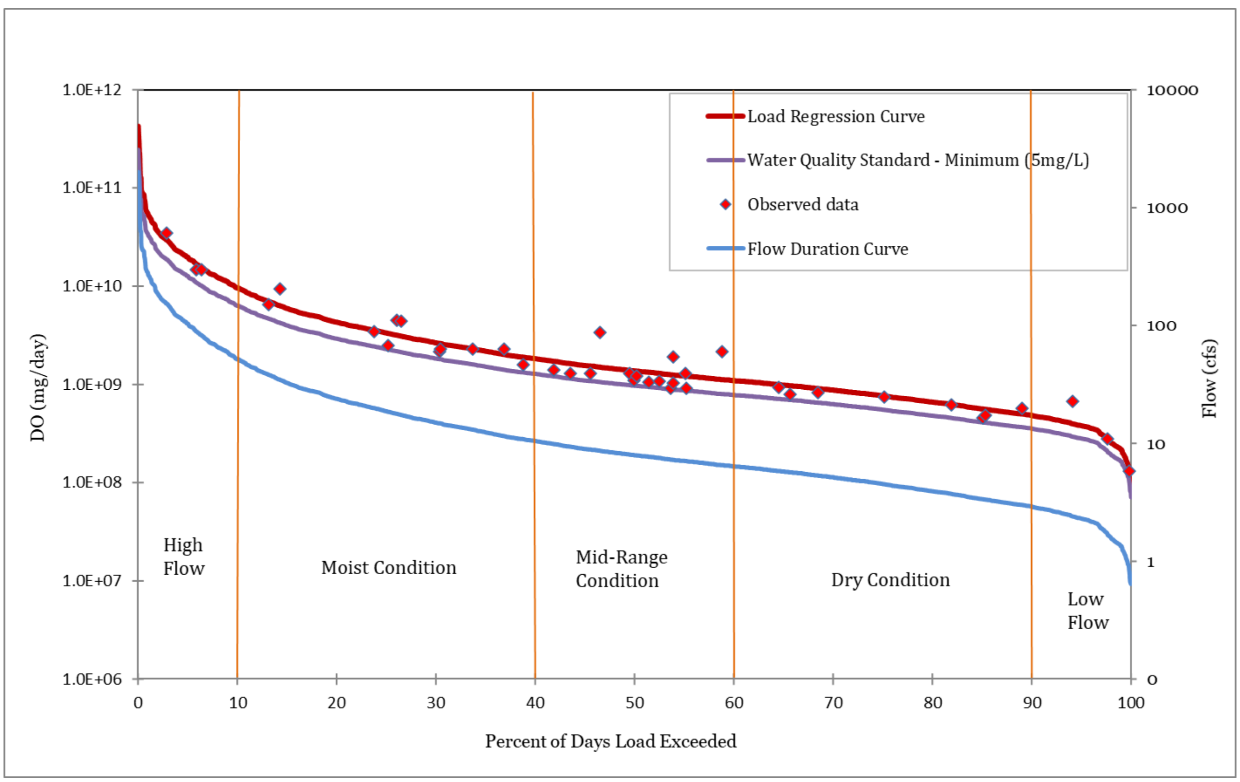

Figure 19 - DO LDC for Station 16473

Table 7 - LDC Results for Station 16473

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	99%	-56%
Moist Conditions	10-40%	89%	-46%
Mid-Range Conditions	40-60%	58%	-41%
Dry Conditions	60-90%	13%	-38%
Low Flows	90-100%	-128%	-34%

Station 16677 – Cowart's Creek at Castlewood Drive in Friendswood

Station 16677 is located just upstream of the confluence with Clear Creek Above Tidal on Cowart's Creek. Cowart's Creek drains an area that varies from undeveloped areas in its headwaters, agricultural production (including a poultry farm), and residential development. The waterway has appreciable riparian buffer area along much of its reach but has also been straightened and modified for use as drainage conveyance. Figure 20 shows the general character of the monitoring site. Figure 21 is the fecal bacteria LDC for the station. Table 8 indicates the fecal bacteria reduction needed at this location. Results at this station indicate similarity to other tributaries in the Above Tidal, exhibiting large reductions in fecal bacteria needed in highest flows, but appreciable assimilative capacity in low flows, a strong indicator of a nonpoint source origin for fecal contamination.

Figure 20 - Cowart's Creek at Station 16677

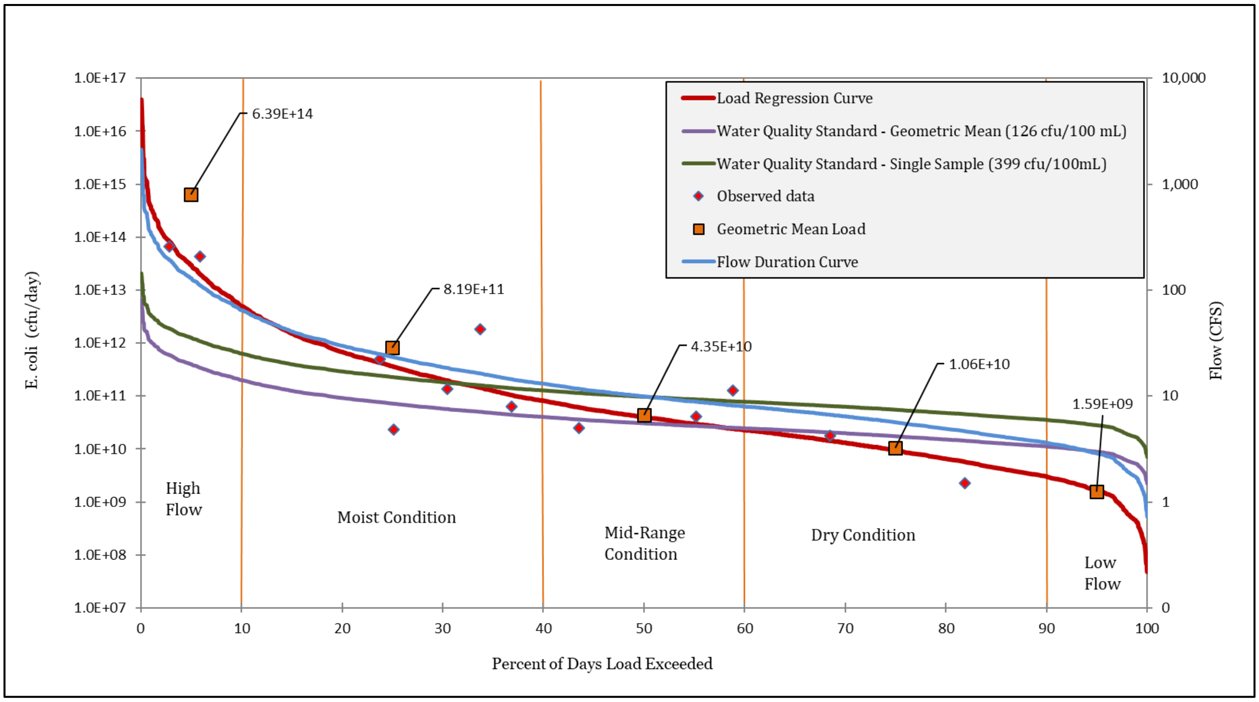

Figure 21 - Fecal Bacteria LDC for Station 16677

Table 8 - LDC Results for Station 16677

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean
High Flows	0-10%	100%
Moist Conditions	10-40%	86%
Mid-Range Conditions	40-60%	26%
Dry Conditions	60-90%	-79%
Low Flows	90-100%	-475%

Station 16493 – Chigger Creek at FM 528 in Friendswood

Station 16493 is located upstream of the confluence with Clear Creek Tidal on Chigger Creek. This is the first tidal station, representing a primarily freshwater tributary entering the system below the demarcation of the Above Tidal/Tidal boundary. The drainage area upstream of this station is varied, with its headwaters in undeveloped or lightly developed rural areas, but also including industrial/petrochemical land uses. The majority of its length is light residential development. The riparian buffer is fairly large, but the actual bed and banks of the waterway are maintained in a mowed and cleared state for drainage purposes. Figure 22 shows the general character of the monitoring site. Figure 23 is the fecal bacteria LDC for the station. Table 9 indicates the fecal bacteria reduction needed at this location. Results at this station indicate similarity to other tributaries in the Above Tidal, exhibiting large reductions in fecal bacteria needed in highest flows through midrange flows, but appreciable assimilative capacity in low flows, a strong indicator of a nonpoint source origin for fecal contamination.

Figure 22 - Chigger Creek at Station 16493

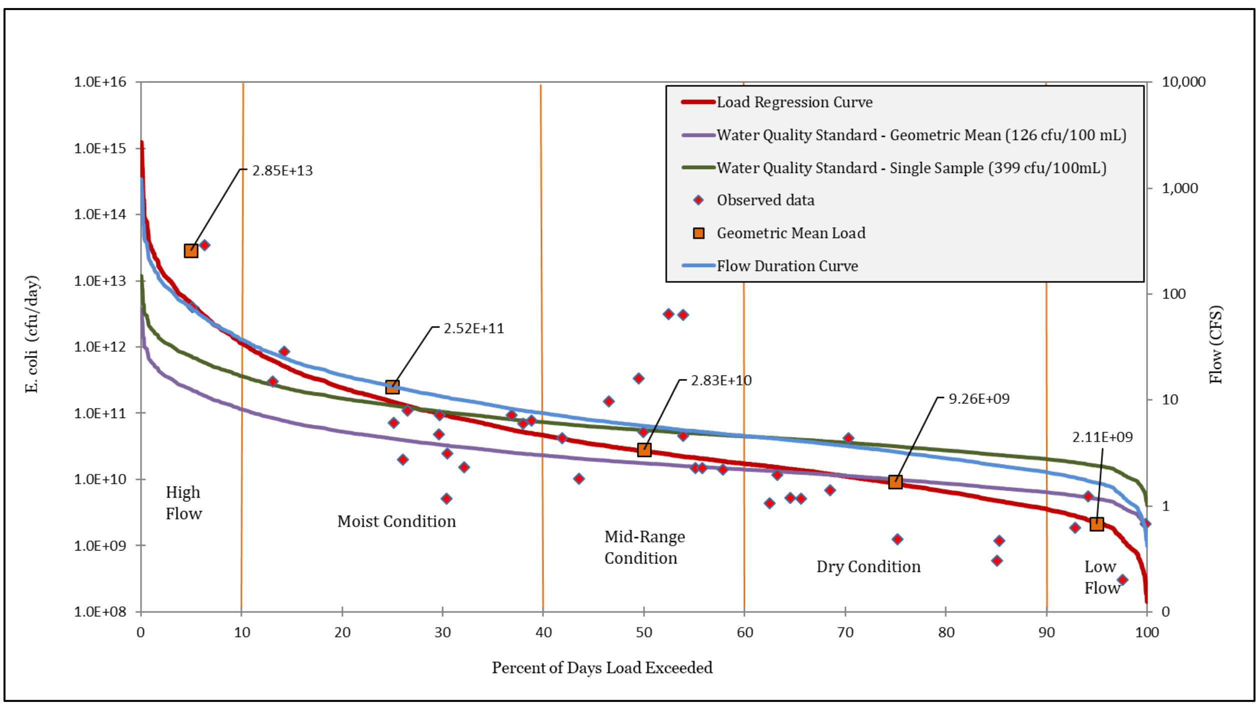

Figure 23 - Fecal Bacteria LDC for Station 16493

Table 9 - LDC Results for Station 16493

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean
High Flows	0-10%	97%
Moist Conditions	10-40%	76%
Mid-Range Conditions	40-60%	36%
Dry Conditions	60-90%	-14%
Low Flows	90-100%	-142%

Station 16576 – Clear Creek Tidal at Brookdale Drive in League City

Station 16576 is the first Tidal segment station on the main stem of Clear Creek, located downstream of the Chigger Creek confluence and upstream of the Magnolia Creek confluence, adjacent to parkland. This station represents the boundary conditions between the Above Tidal and Tidal segments, with the addition of the Chigger Creek flow and the cumulative impact of the Above Tidal segment watershed. The Tidal segment here has grown to be a broad waterway with little resemblance to the prior main stem site in the Above Tidal, with the introduction of several intervening tributary systems and tidal volumes. Figure 24 shows the general character of the monitoring site. Figures 25 and 26 are the LDCs for this station. Table 10 indicates the fecal bacteria reduction and DO improvement needed at this location. Results at this station reflect the changed character of the waterway, with bacteria reductions required across all flow conditions, but not peaking in higher flows. DO levels remain acceptable, but show a greater capacity in lower flows, with higher flows nearing the point where improvement would be required.

Figure 24 - Clear Creek Tidal at Station 16576

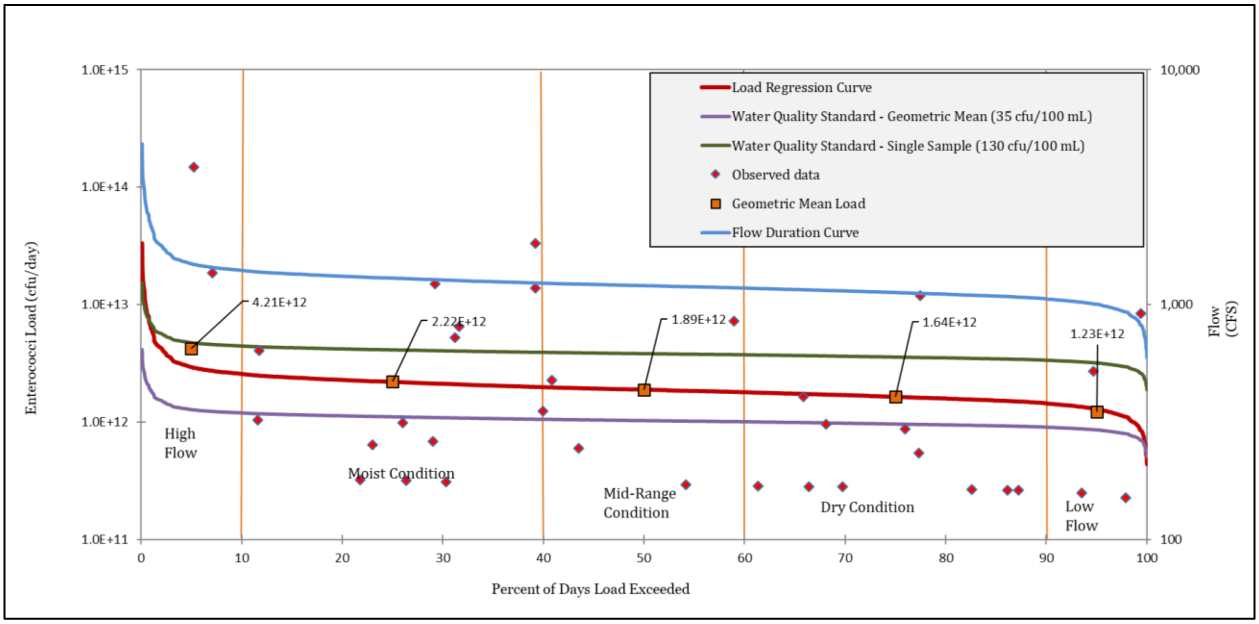

Figure 25 - Fecal Bacteria LDC for Station 16576

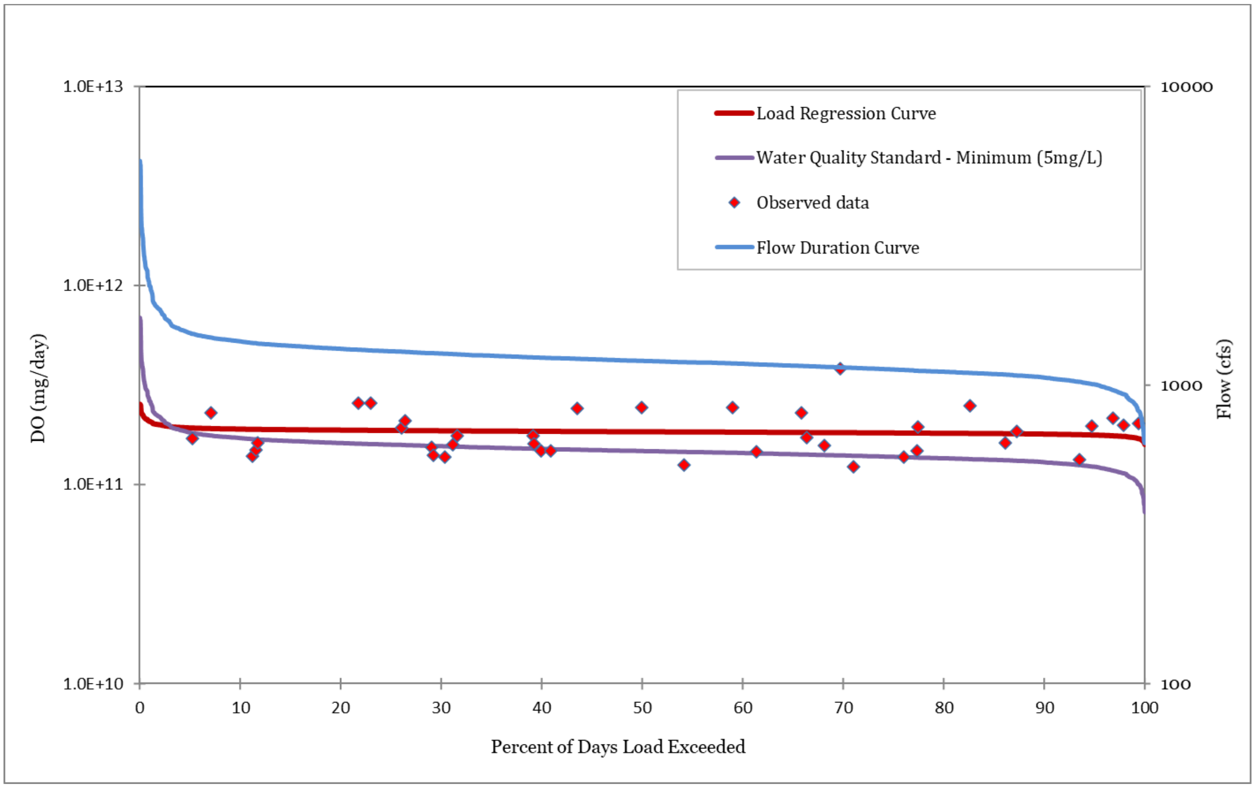

Figure 26 - DO LDC for Station 16576

Table 10 - LDC Results for Station 16576

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	62%	0%
Moist Conditions	10-40%	50%	-18%
Mid-Range Conditions	40-60%	45%	-25%
Dry Conditions	60-90%	41%	-32%
Low Flows	90-100%	32%	-49%

Station 16611 – Magnolia Creek at Bay Area Boulevard in League City

Station 16611 is located on Magnolia Creek upstream of the confluence with Clear Creek Tidal. Its drainage area is varied in land use, including light residential and commercial, large areas of riparian forest/buffer, and heavily modified drainage channels. Immediately downstream of the station, and potentially impacting levels in higher tides, is Lynn Gripon Park, which includes a dog park. Figure 27 shows the general character of the monitoring site. Figure 28 is the LDC for this station. Table 11 indicates the fecal bacteria reduction needed at this location. Results at this station require fecal bacteria reductions in all flow conditions. While reductions are greater in higher flows, these results point to a potential mix of sources, or potential chronic contamination from a nearby source.

Figure 27 - Magnolia Creek at Station 16611

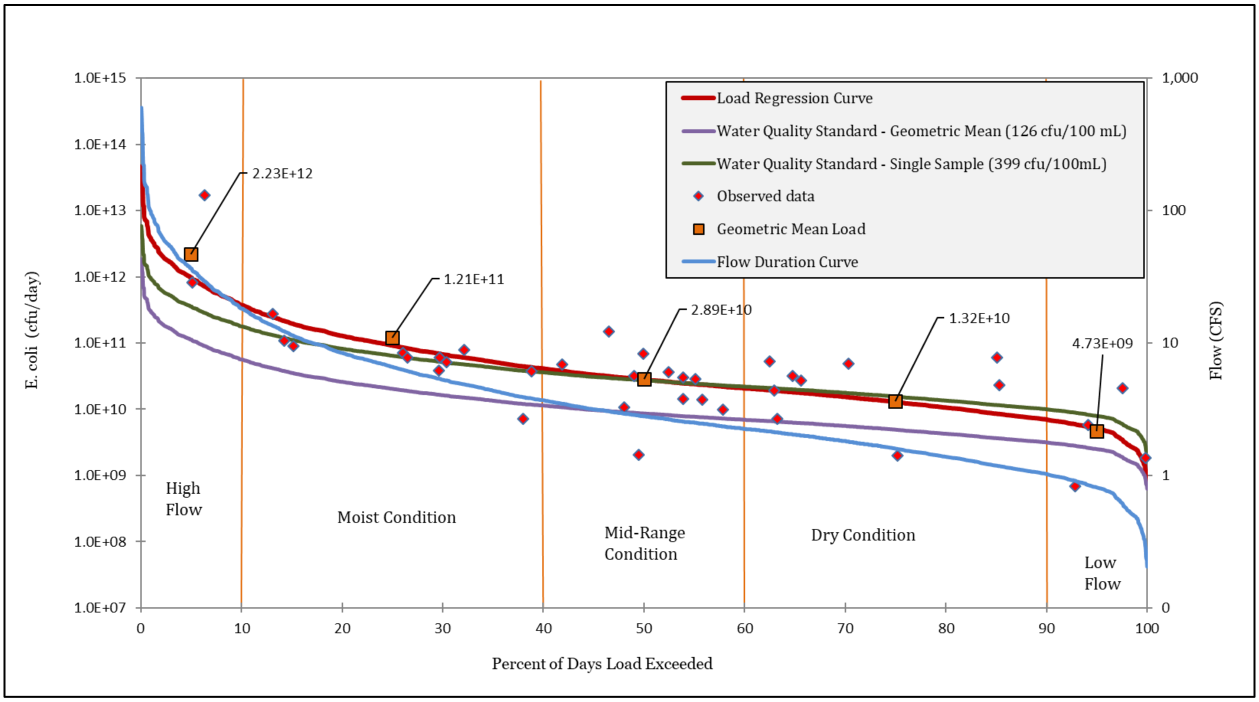

Figure 28 - Fecal Bacteria LDC for Station 16611

Table 11 - LDC Results for Station 16611

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean
High Flows	0-10%	89%
Moist Conditions	10-40%	79%
Mid-Range Conditions	40-60%	69%
Dry Conditions	60-90%	62%
Low Flows	90-100%	49%

Station 18591 – Unnamed Tributary at I-45 Corridor

Station 18591 is upstream of the confluence of the Unnamed Tributary and Clear Creek Tidal, directly downstream of a cemetery. The tributary is primarily a heavily modified drainage conveyance that serves the dense commercial areas of the I-45 corridor. Figure 29 shows the general character of the monitoring site. Figures 30 and 31 are the LDCs for this station. Table 12 indicates the fecal bacteria reduction and DO improvement needed at this location. Results at this station require moderate bacteria reductions in high to midrange conditions and show DO levels that decrease with flows. A greater degree of variation was expected based on the function the tributary plays as a drainage mechanism for a densely developed area and may suggest an area for further study.

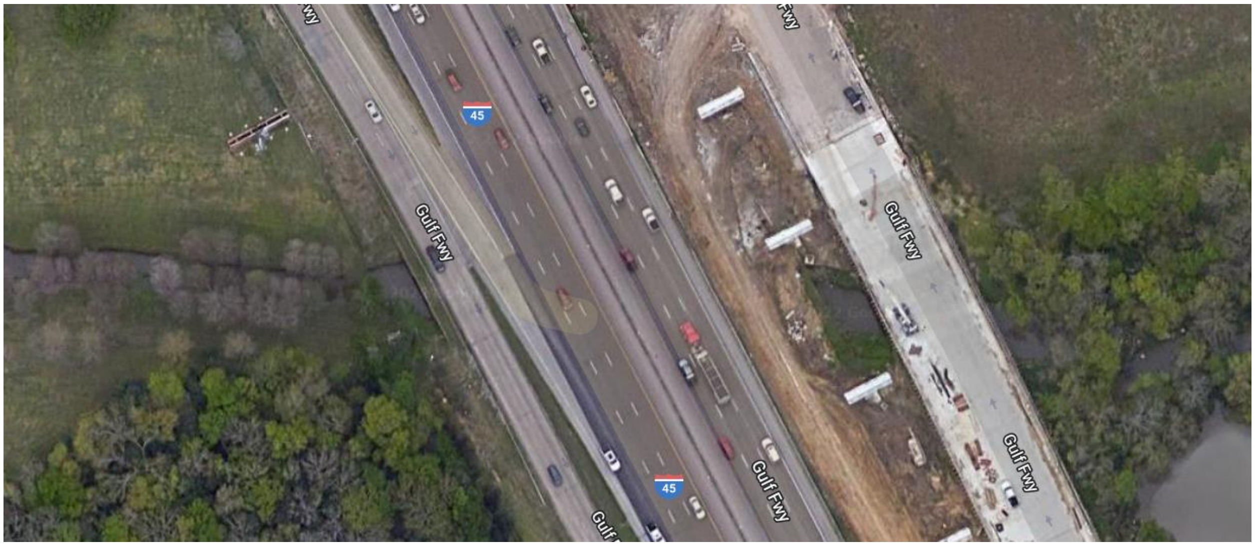

Figure 29 - Unnamed Tributary Passing Beneath I-45 at Station 18591

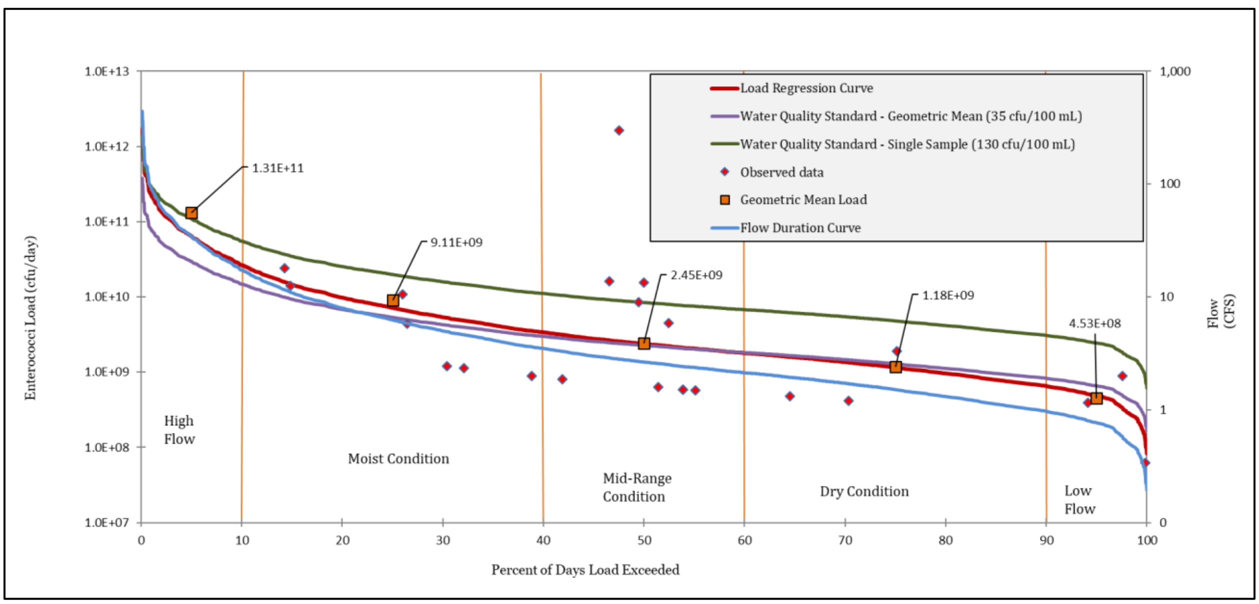

Figure 30 - Fecal Bacteria LDC for Station 18591

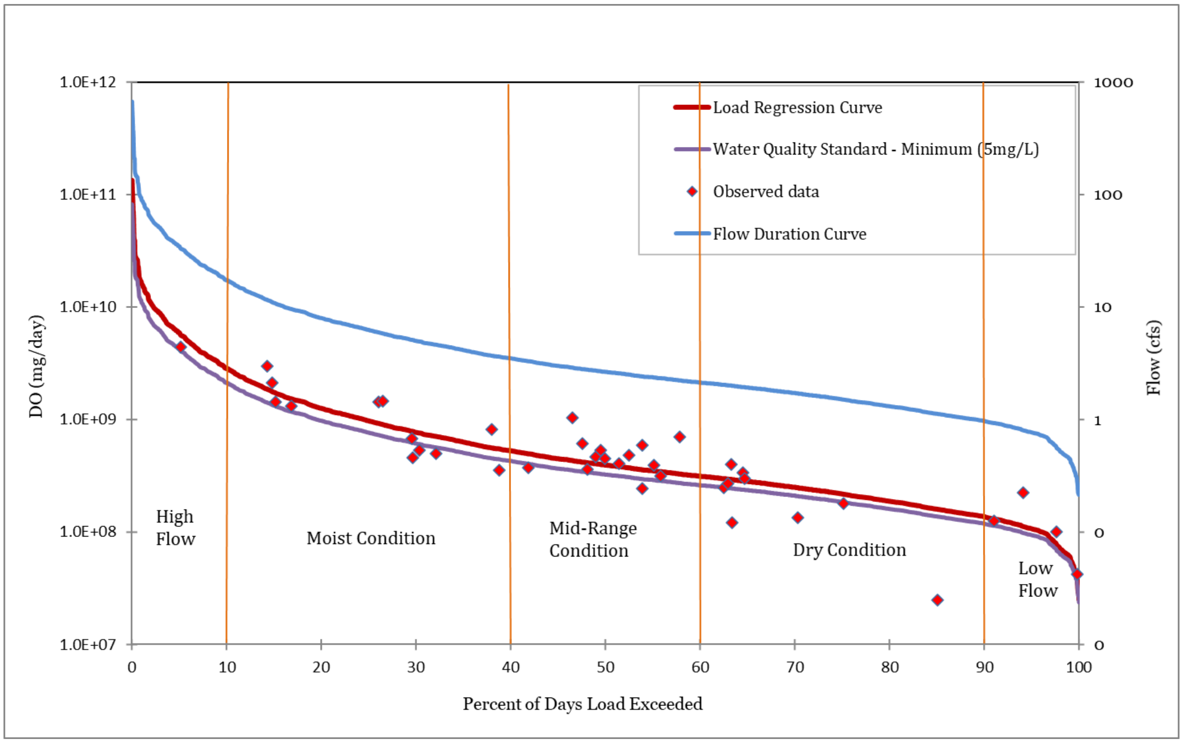

Figure 31 - DO LDC for Station 18591

Table 12 - LDC Results for Station 18591

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	56%	-40%
Moist Conditions	10-40%	27%	-28%
Mid-Range Conditions	40-60%	5%	-22%
Dry Conditions	60-90%	-12%	-18%
Low Flows	90-100%	-39%	-13%

Station 11446 – Clear Creek Tidal at State Highway 3

Station 11446 is the last Tidal segment station before the mainstem changes character into a series of connected broad lakes and other modifications along the main channel as it nears Clear Lake. The area contributing to this section of the creek is densely developed along the transportation corridors and includes areas of petrochemical storage and large undeveloped tracts adjacent to the creek. At this point, Clear Creek has become a broad and voluminous coastal waterway. Figure 32 shows the general character of the monitoring site. Figures 33 and 34 are the LDCs for this station. Table 13 indicates the fecal bacteria reduction and DO improvement needed at this location. Results at this station require bacteria reductions in all flow conditions, with substantial reductions needed in high to midrange flows. DO levels are relatively stable with no need for reduction, especially in higher flows. The results are relatively characteristic of a station near the end of a large system, in a place where flow (especially as buffered by tides) is more consistent than upland tributaries.

Figure 32 - Clear Creek Tidal at State Highway 3

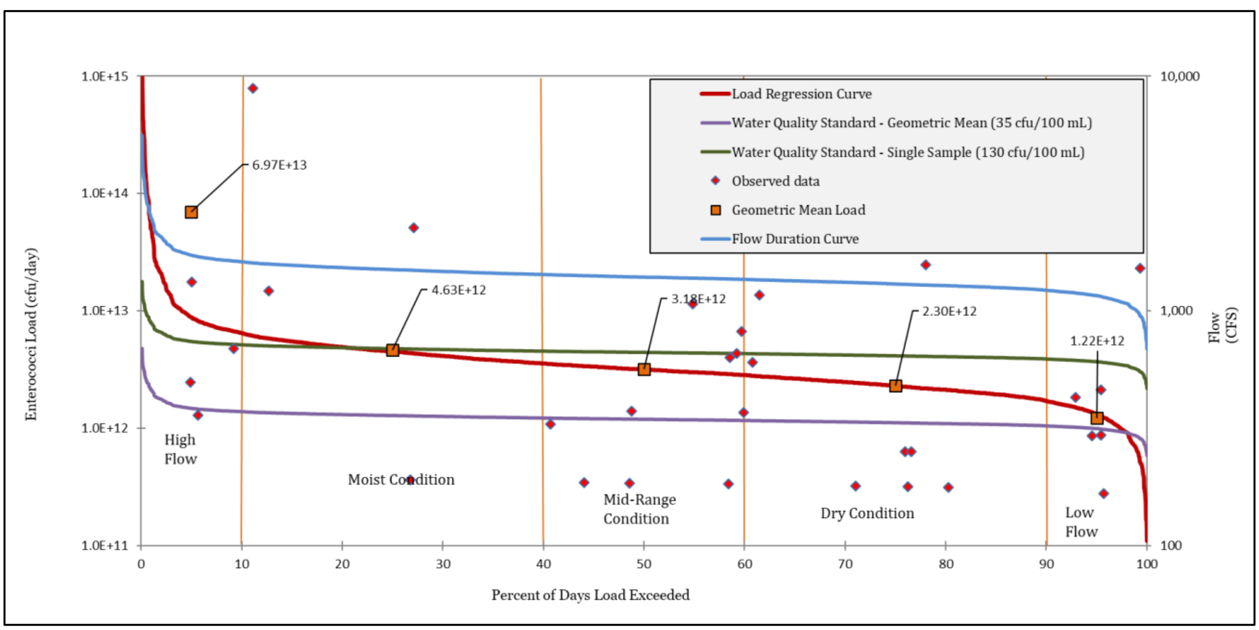

Figure 33 - Fecal Bacteria LDC for Station 11446

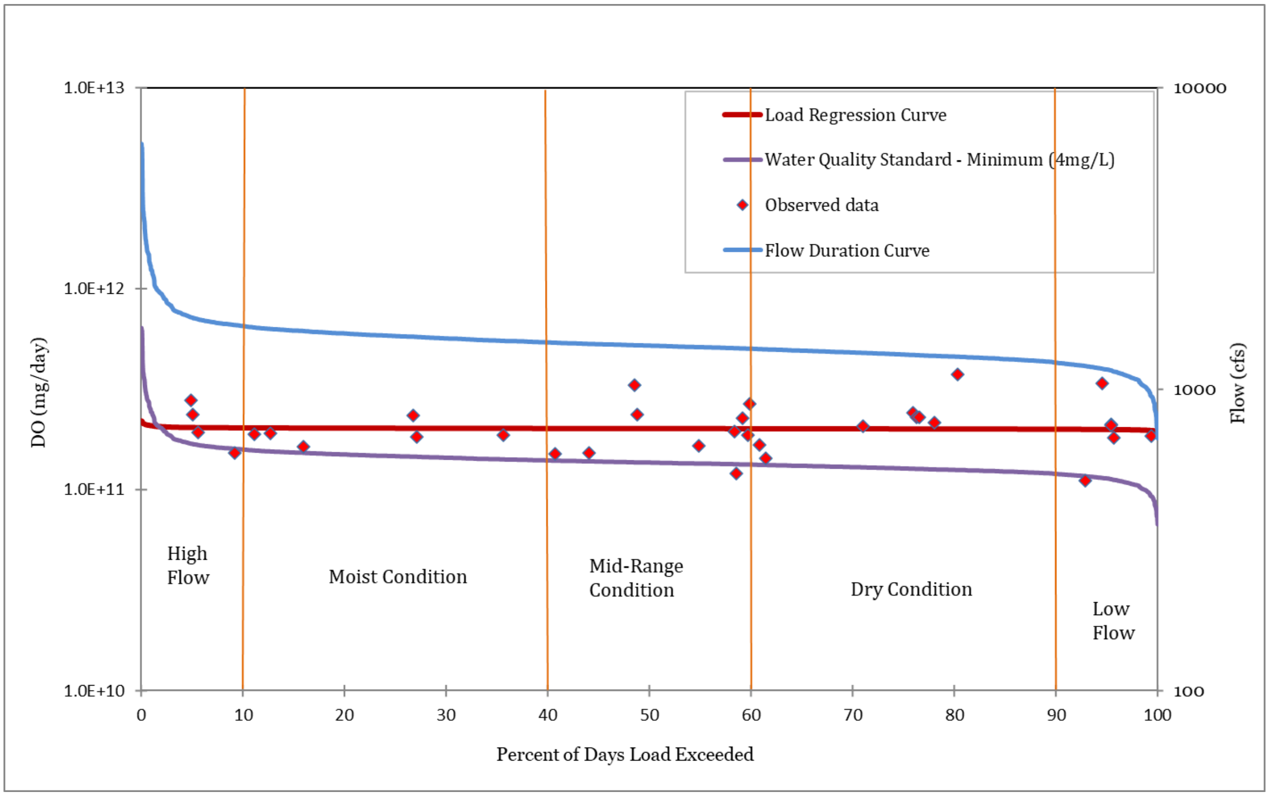

Figure 34 - DO LDC for Station 11446

Table 13 - LDC Results for Station 11446

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	95%	-13%
Moist Conditions	10-40%	72%	-37%
Mid-Range Conditions	40-60%	62%	-48%
Dry Conditions	60-90%	51%	-58%
Low Flows	90-100%	19%	-82%

Station 17928 – Cow Bayou at NASA Road 1

Station 17928 on Cow Bayou is upstream from the main stem of Clear Creek Tidal but represents the boundary between the bayou itself and the extended confluence of the Creek that pushes north from its main stem. The area drained by Cow Bayou is a mix of suburban residential, industrial, and commercial properties in this densely developed area, with significant impact from drainage. Some areas of NASA's Johnson Space Center drain to this tributary at or slightly past its confluence with Clear Creek Tidal. The upper reaches of the Bayou become tangled in interconnected drainage conveyances which may at times connect this tributary to the Horsepen Bayou system to the north. The majority of this system is modified to be a drainage conveyance with little riparian buffer or cover. Figure 35 shows the general character of the monitoring site. Figures 36 and 37 are the LDCs for this station. Table 14 indicates the fecal bacteria reduction and DO improvement needed at this location. Results at this station require significant bacteria reductions in all flow conditions. However, DO levels are generally in compliance.

Figure 35 - Cow Bayou at NASA Road 1

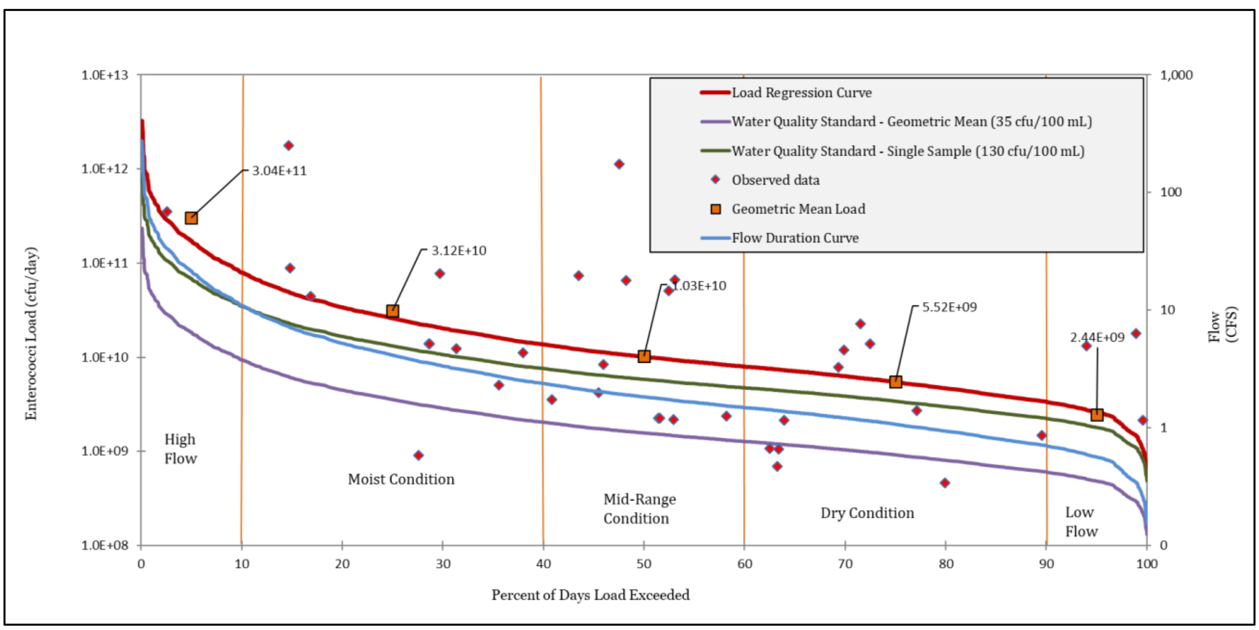

Figure 36 - Fecal Bacteria LDC for Station 17928

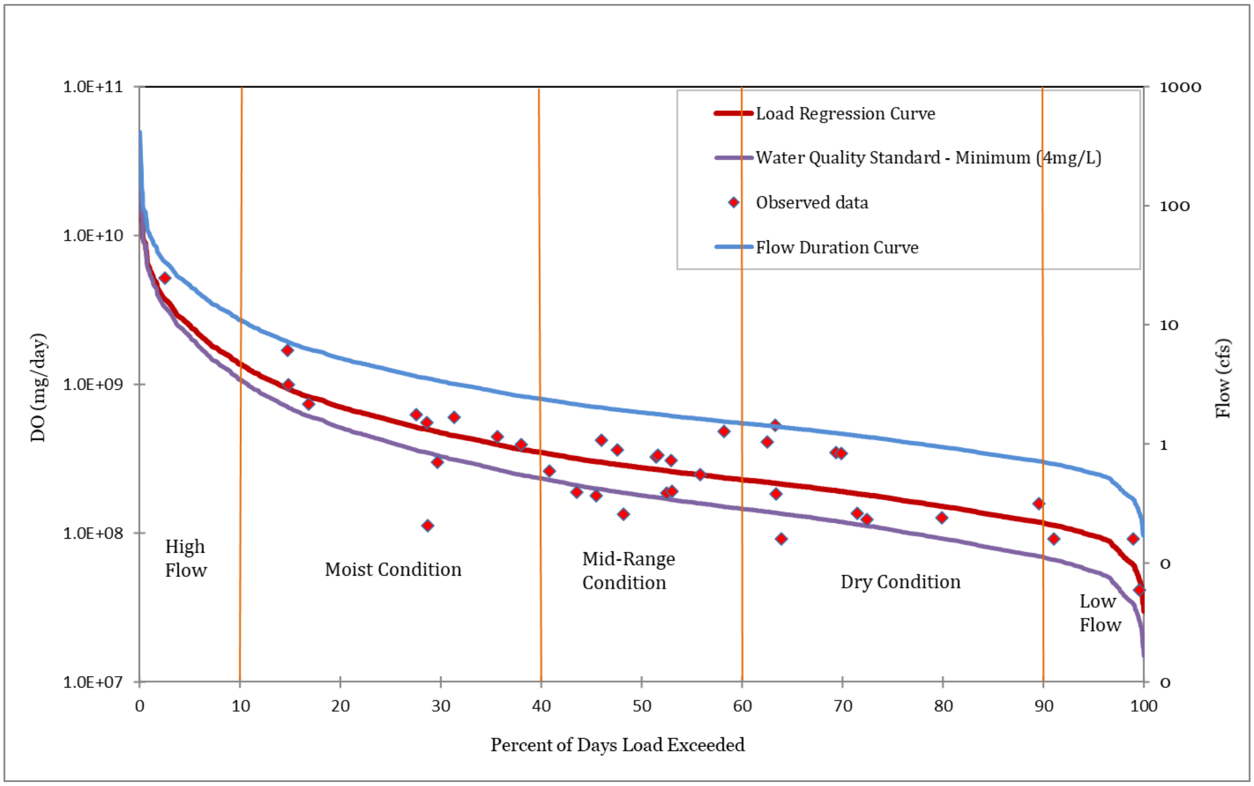

Figure 37 - DO LDC for Station 17928

Table 14 - LDC Results for Station 17928

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	90%	-17%
Moist Conditions	10-40%	86%	-40%
Mid-Range Conditions	40-60%	85%	-53%
Dry Conditions	60-90%	83%	-63%
Low Flows	90-100%	81%	-76%

Station 16475 – Robinson Bayou at FM 270 in League City

Station 16475 is appreciably upstream on Robinson Bayou, which comprises a mix of natural and conveyed drainage to Clear Creek tidal just upstream of its confluence with Clear Lake. The station is representative, however, of conditions on the bayou itself, as areas further downstream become indistinguishable from an arm of Clear Creek. The majority of the drainage network to the bayou is channelized conveyance of residential and commercial areas. Figure 38 shows the general character of the monitoring site. Figures 39 and 40 are the LDCs for this station. Table 15 indicates the fecal bacteria reduction and DO improvement needed at this location. Results at this station require significant bacteria reductions in all flow conditions. However, DO levels are generally in compliance and relatively stable. This is notable given that Robinson Bayou was assessed by TCEQ as having an impairment for DO grab minimums. In assessing the LDC, while DO is generally good throughout the flow categories, there were enough outliers to indicate times of high DO variability in the system.

Figure 38 - Robinson Bayou at Station 16475

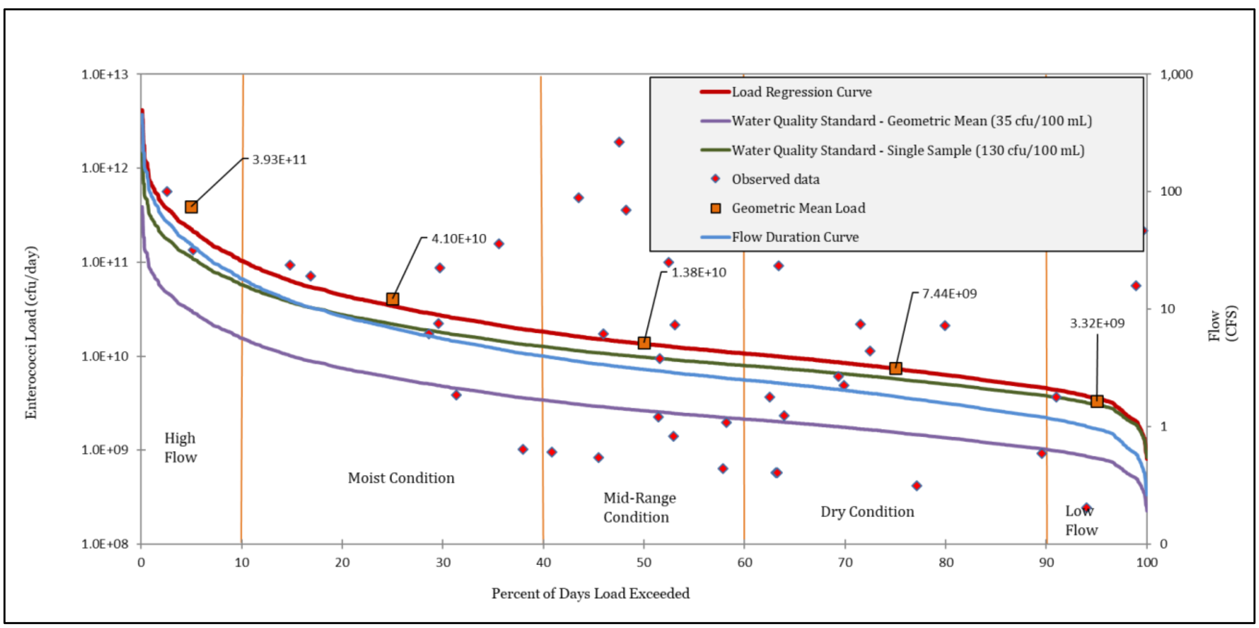

Figure 39 - Fecal Bacteria LDC for Station 16475

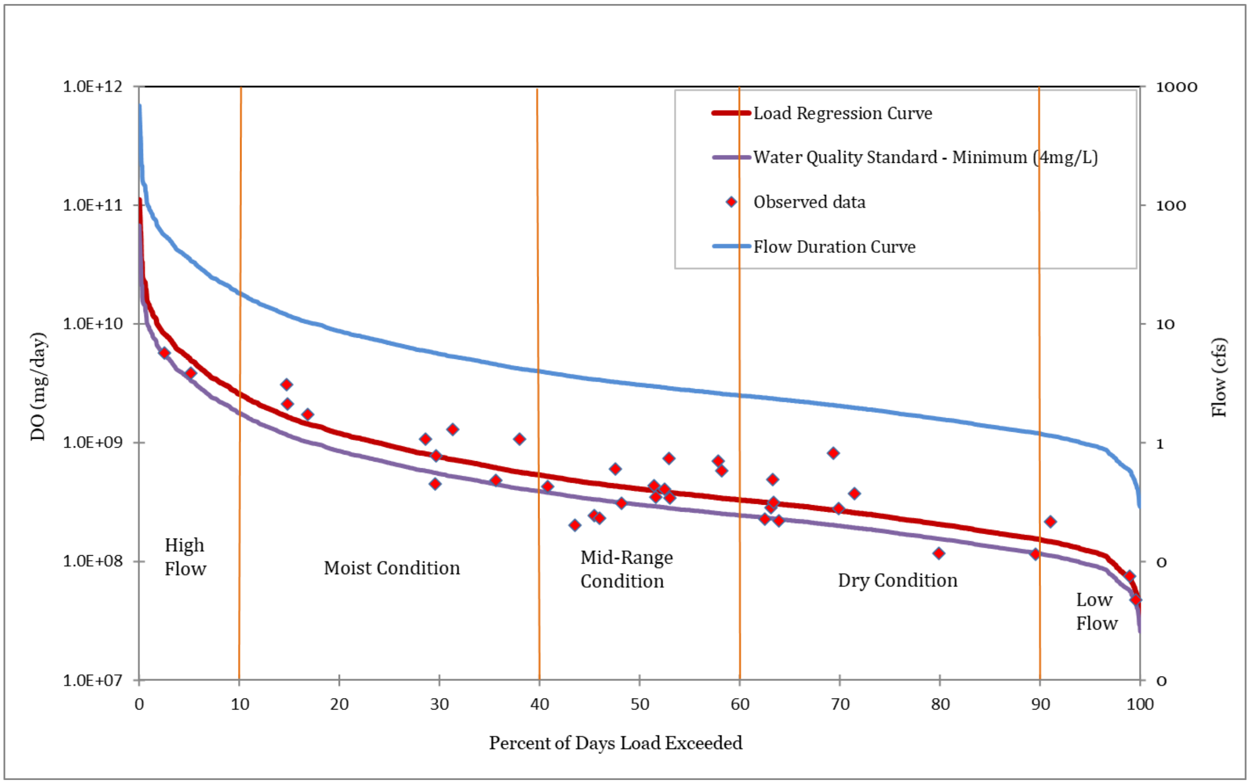

Figure 40 - DO LDC for Station 16475

Table 15 - LDC Results for Station 16475

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean	DO Improvement
High Flows	0-10%	87%	-49%
Moist Conditions	10-40%	83%	-40%
Mid-Range Conditions	40-60%	81%	-36%
Dry Conditions	60-90%	79%	-33%
Low Flows	90-100%	77%	-30%

Station 16573 – Clear Creek Tidal at the Clear Lake Confluence

Station 16573 represents the station closest to the TCEQ-designated terminus of the Clear Creek Tidal segment. At this point, the Creek is indistinguishable from the westernmost extent of Clear Lake. The extent to which this station is representative of the segment, versus the lake, was discussed by the stakeholders who decided not to use it as a measuring point for future progress. Figure 41 is the fecal bacteria LDC for this station, which is primarily intended as a comparison of the impacts of the confluence against the more representative stations upstream. Table 16 indicates the fecal bacteria reduction needed at this location. Results at this station appear characteristic of the confluence of a tributary system with a larger lake/bay. In highest flow conditions, the impact of the upstream body is clear with significant fecal bacteria reductions needed. However, in other flow conditions, the diluting effect of the lake system is apparent.

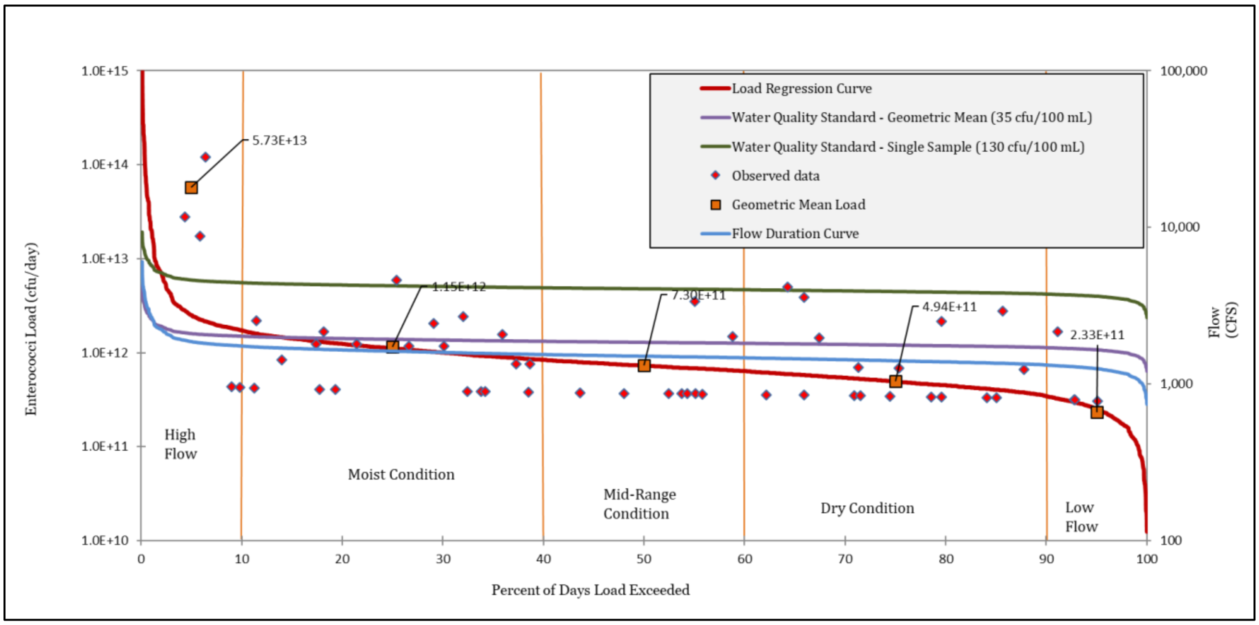

Figure 41 - Bacteria LDC for Station 16573

Table 16 - LDC Results for Station 16573

Flow category	Percent Exceedance (of flow)	Fecal Bacteria Percent Reduction - Geomean
High Flows	0-10%	92%
Moist Conditions	10-40%	-21%
Mid-Range Conditions	40-60%	-77%
Dry Conditions	60-90%	-144%
Low Flows	90-100%	-359%

LDC Summary and Fecal Bacteria Reduction Targets

The LDC modeling results were reviewed internally by project staff and with stakeholders. The Partnership considered the best interpretation of the data in the context of project decision-making.

Overall, the results indicated that fecal bacteria levels varied widely throughout the system. Stations in the tributaries and headwaters areas of the creek exhibited a stronger relationship between high flows and high fecal bacteria concentrations. However, as the creek broadened in the Tidal segment, bacteria levels were more consistently in excess of the standard, but with less variation between flow regimes. This is potentially an indication of the strong influence of nonpoint sources on an episodic basis in the former, and the cumulative impact of the sources in the watershed, as well as the more stable profile of a larger waterbody, in the latter. Regardless, it is clear that fecal bacteria contamination is consistent throughout the system, even as it may vary in extent and relationship to flow. While the results of the confluence station (16573) at the end of the system indicate that the impact on Clear Lake is likely as a source of chronic load in most conditions, but acute impact in high flow conditions, the generally higher levels in the Tidal segment pose a concern given its proximity to the most densely developed areas and potential recreational sites.

In the interpretation of the DO results it should be noted that even though many LDCs throughout the system indicated that DO levels did not require improvement in most if any flow categories, 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.

The results presented interesting questions to answer during the SELECT analysis effort. More information on the linkage between the modeling efforts is discussed in Section 6.

The design for generating single target reductions[14] for each subwatershed or group of subwatersheds was based on a compromise between the worst-case scenario (highest possible reduction need in any flow category, specific to each LDC station/attainment area) versus the least conservative approach (average reduction needed based on all flow conditions, general to each watershed). H-GAC proposed, and the stakeholders affirmed, a moderate approach in which reduction targets would be established based on a weighted average of the flow conditions in which reductions were needed, for each of the segments and their assessed tributaries.

- *Under this approach, a station that showed a need for reductions in its LDC during High, Moist, and Midrange conditions, but no reduction in Dry Conditions of Low Flows, would*

[14] As opposed to up to five modeled reduction values, representing one for each flow category.

establish a reduction target by finding the weighted average of the percent reductions for High, Moist, and Midrange conditions.

Table 7 represents the current single-number fecal bacteria percent reduction targets[15] for the modeled subwatersheds. No specific percentage improvement goals were developed for DO. In general, the most downstream station was chosen to be representative of a subwatershed area.

Table 17 - Fecal Bacteria Load Reduction Goals

LDC Station	Subwatersheds	Weighted Average Fecal Bacteria Reduction Target (%)
11452	1	51.3%
17068	2	63.5%
11450	3 (inclusive of 4)	65.0%
21925	5	55.0%
16473	6	57.9%
16677	7	68.3%
16493	8	66.2%
16611	9	69.9%
11446	10	60.7%
18591	11	24.5%
17928	12	84.8%
16475	13	81.2%

The range of values demonstrates the need for multiple points of consideration rather than a single, overall target for the watershed. The range also demonstrates that even weighted targets indicate most areas in the system need moderate to high levels of fecal bacteria reduction.

[15] These targets do not consider the potential impacts of upstream subwatersheds meeting their reduction targets (i.e., subwatershed 3 includes cumulative loads from subwatersheds 1,2, and 4, as may be affected by growth and decline during transport prior to reaching station 11450. Realistically, if the preceding subwatersheds made great strides in reducing fecal waste, subwatershed 3, downstream, should show a decrease because it no longer receives that cumulative load from upstream. However, the reduction target for subwatershed 3 does not assume prior targets were met, as a conservative approach.

5.0 SELECT Analysis

Overview

The SELECT Model

SELECT is a 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 fecal bacteria load in a watershed and to show the relative contributions of individual sources of fecal bacteria 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 fecal bacteria load generated in a watershed or subwatershed based on land use/land cover, known source locations (wastewater treatment facility (WWTF) outfall locations, onsite sewage facilities (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 fecal indicator bacteria actually transmitted to the water, as the model does not account for the natural processes that may reduce fecal bacteria on its way to the water, or the relative proximity of sources to the waterway.

Analysis Design in the Clear Creek SELECT Implementation

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 treats all fecal bacteria generated in a watershed equally. For example, loads generated two 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 which a particular source is generally located farther from the waterway, it may be overrepresented

[16] Additional information about SELECT can be found at http://ssl.tamu.edu/media/11291/select-aarin.pdf. Information about the specific implementation of SELECT utilized by this project can be found in the project modeling QAPP.

[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.

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 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 Clear Creek watershed is undergoing developmental change as areas in its headwaters and outlying aspects continue to be developed and redevelopment and infill occurs in its denser core. Current sources[19] are expected to expand in the future. Therefore, fecal bacteria reductions based on current conditions would be inadequate to meet future needs. This implementation of SELECT uses regional demographic projection data to estimate

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

[19] References to "current" conditions refer to 2021-2022 estimations, based on the available data at the time of the modeling effort.

future conditions through 2050 in 5-year intervals[20]. Land use change is the primary driver for estimating changes in source contribution and spatial distribution of loads[21].

- **Dual Indicators –** Using SELECT, source loads were generated in units of *E. coli.* For the purpose of Tidal reductions, the percent reduction developed in the LDC is assumed to be applicable to source loads regardless of whether the indicator is *E. coli* or Enterococcus, and thus can be applied to the *E. coli*-based source load.

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, 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 ultimate 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 LDC reduction percentages to generate source reduction loads (as discussed in Section 6).

The analysis design for this process (Figure 43) includes four primary steps: 1) development of a source survey using known locations/sources, suspected sources derived from projects in similar areas, and feedback from stakeholders; 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).

[20] 2050 was chosen as a target year to coincide with the extent of the regional demographic model projections at the time, and 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 are 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 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.

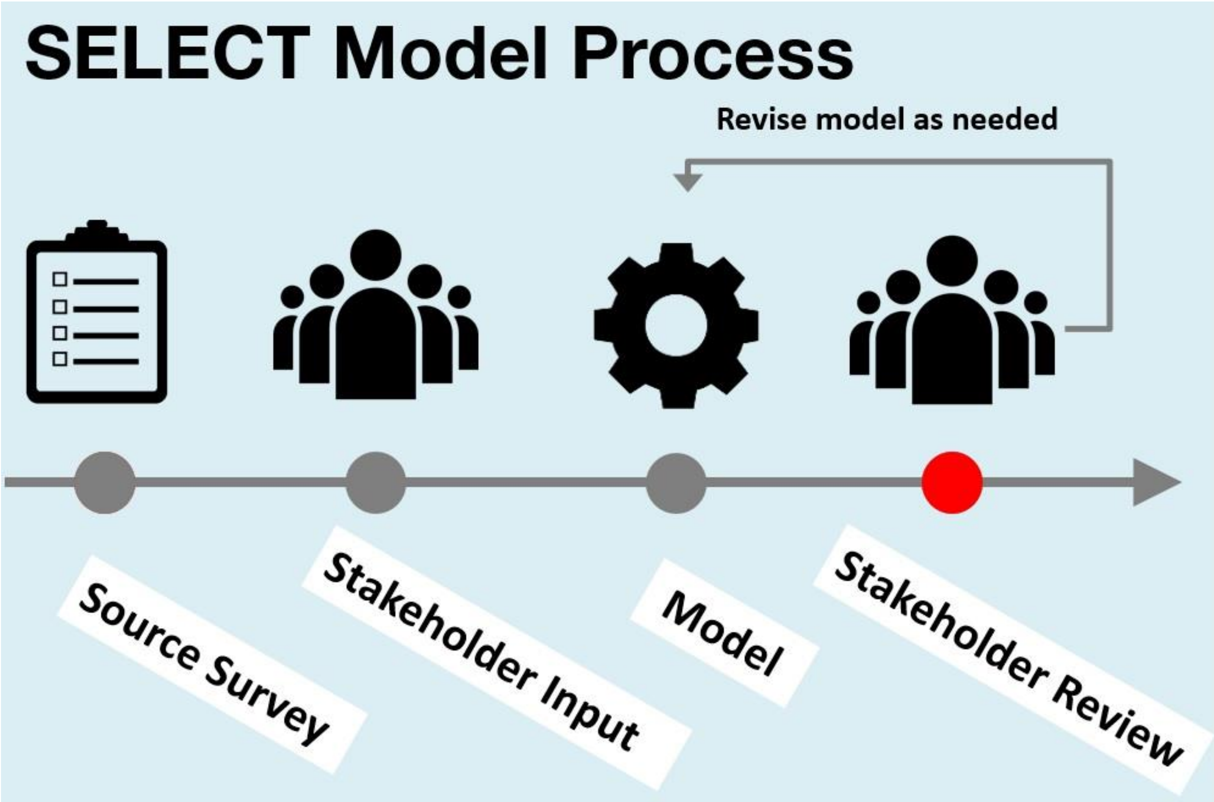

Figure 42 - SELECT Modeling Process

Source Survey

Fecal Bacteria Sources in Watersheds

All warm-blooded animals produce waste bearing fecal indicator bacteria, and thus are potential sources of contamination. *E. coli* is the indicator bacterium used to identify the presence of fecal waste in freshwater segments. The indicator bacteria are not necessarily themselves the source of potential health impacts; however, they signify the presence of fecal waste and the host of other pathogens it may contain. There is a wide array of potential fecal waste sources in the watersheds of the project area. SELECT analyses can consider all sources for which data could be feasibly obtained or produced, including cattle, sheep and goats, horses, OSSFs, WWTFs, dogs, feral hogs, deer, and other wildlife. The potential mix of sources in a watershed can vary greatly in both spatial and seasonal contexts. Determining the potential sources in a watershed is crucial to developing a SELECT analysis for the project area.

The preliminary process of identifying potential fecal bacteria sources in a watershed is discussed as being a source survey.

Source Survey

Characterizing fecal bacteria pollution in watersheds and developing SELECT analyses to estimate potential loading, requires a consideration of potential sources. In any watershed with a mix of land uses, fecal indicator bacteria can be produced by a broad mix of sources; this is especially true in a large, diverse set of watersheds like this project area. The existence and location of some sources are known from existing data, while many nonpoint sources need to be evaluated from a mix of land use analysis, imagery and road reconnaissance, and stakeholder feedback. Prior to developing the SELECT methodology, project staff completed the following assessments[22]:

- Known Source Characterization – Staff reviewed existing data to generate information on spatially located (usually permitted) sources. The data sources included[23]:
    - WWTF spatial locations and DMRs (TCEQ outfall locations and DMR records)
    - Permitted OSSF locations (H-GAC proprietary data compiled from local authorized agent data under 604(b) projects.)
    - Concentrated Animal Feeding Operations (CAFOs) (TCEQ CAFO locations and violations data from Central Registry records)
    - SSOs (TCEQ SSO database)
- Land Cover/Land Use 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 in the later SELECT implementation as the basis of populating diffuse sources whose assumptions were tied to specific land cover types.
- 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. Items derived from this analysis were:
    - Presence of horse stables
    - Recreation use
    - Developmental projects in the watershed
    - Specific commercial and industrial sites of interest noted
- 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:
    - Progress of development in undeveloped areas

[22] The cumulative results of these assessments are summarized in Table 8, and specific results are discussed in the subsections on each source later in this section.
[23] More information on data sources and quality objectives can be found in the project QAPP.

    - Sign of feral hog activity in some areas
    - Specific drainage mechanisms
    - 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
    - map exercises with small groups following Partnership meetings
    - one-on-one meetings with local stakeholders
    - one-on-one meetings with state and regional experts/agencies (e.g., TPWD, TSSWCB, et al.)

  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, etc.) 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 results of the Source Survey are summarized by general category in Table 18. The estimated extent reflects preliminary understandings, rather than the modeled outcomes or final stakeholder feedback. Note that these extents reflect current estimated status. Some sources may be expected to increase or decrease in the period assessed by this modeling effort.

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 fecal bacteria per day, using scientific notation[24].

[24] For example, 1.4E+12 is equivalent to 1.4×10^{12}, or 1.4 trillion. E+9 would be billions, E+6 millions, etc.

Table 18- Fecal Bacteria Source Survey

Category	Source	Origin	Estimated Extent
Human Waste	OSSFs	Failing/improperly routed OSSFs	Minor to moderate
	WWTFs	Improperly treated sewage from permitted outfalls	Minor
	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	Minor
	Horses	Runoff or direct deposition	Minor to moderate (locally)
	Sheep and Goats	Runoff or direct deposition	Minor
	CAFOs	Improper or improperly treated discharge from permitted facilities	Not expected.
	Pigs	Runoff	Minor
	Exotic animals	Runoff or direct deposition	Not expected to minor (locally).
Wildlife and Non-domestic animals[25]	Feral hogs	Runoff or direct deposition	Moderate
	Deer	Runoff or direct deposition	Minor to moderation (locally)
	Birds	Direct deposition	Minor, no formal data.
	Bats	Direct deposition	Minor, no data.
	Other wildlife[26]	Runoff or direct deposition	Moderate, no data
Other Sources	Dogs (pets)	Runoff	High
	Dogs (feral)	Runoff	Minor to moderate (locally)
	Cats (pets)	Runoff	Not expected
	Cats (feral)	Runoff	Minor to moderate (locally)
	Dumping	Runoff or direct deposition	Minor (locally)
	Sediment	Erosion or mining operations	NA[27]

[25] Even though feral hogs have established wild populations, they are not considered wildlife for all applicable purposed by the TPWD and other state agencies. The consideration of hogs in the same category as other wildlife should not be construed as suggesting they are viewed as wildlife by this modeling effort or WPP development project. The category solely reflects their status as being different than domestic animals.

[26] As noted previously and discussed in further detail in the wildlife section of the SELECT source characterizations, other wildlife is used here and henceforth as a means of designating all potential wildlife populations for which sufficient data does not exist and which could not specifically be assessed (unlike colonial birds and bat colonies). Stakeholder decisions regarding inclusions of an assumption for this source is discussed in greater detail in its corresponding section.

[27] While not a source of bacteria per se, suspended sediment in the water act to decrease bacteria die-off from insolation, etc.

OSSFs

Failing or improperly maintained OSSFs can be significant sources of fecal bacteria and are a legacy wastewater solution for less developed or rural areas of the watershed. Some new development uses OSSFs for its primary treatment, but much of the current or proposed development in the remaining outlying areas of the watershed rely on centralized wastewater. While OSSFs in the area are generally more closely regulated than in some areas of the region, the inherently distributed maintenance for those systems is a concern for future water quality as systems continue to age. Systems in this area are a mix of traditional septic systems and other treatment technologies, primarily aerobic systems.

Permitted OSSF data were taken from existing spatial data compiled by H-GAC from authorized agents[28]. Assumptions for unpermitted OSSFs are based on a review of household data projections outside of sanitary sewer boundaries for which no permitted OSSF exists. It was assumed that occupied parcels outside service areas without permitted OSSF contained an unpermitted OSSF. Loading rates are based on output from failing/improperly maintained systems. Project staff discussed failure rate with authorized agents for the area, as well as the Partnership and Human Waste work groups. Based on the stakeholder knowledge of system status in the watershed, their experienced violation rates, and best professional judgement, a 10% failure rate was used for all system types and ages. Stakeholders did not feel further division of failure rates was possible given their knowledge and existing data. Future load projections are based on an increase of systems and system load proportional to increases in households outside the existing service area boundaries for sewer utilities, in five-year increments through 2050.

Some uncertainty exists due to the insufficiency of data concerning both permitted and unpermitted systems. H-GAC's permitted system spatial dataset is not inclusive of all records obtained from authorized agents in the region, although Harris County's records are well documented. In some cases, issues with the data or inability to geocode a record means that records are excluded even if permitted. Additionally, the deductive analysis that identifies unpermitted system locations is intended to represent potential locations rather than known unpermitted systems. During the project, local authorized agents and knowledgeable partners were asked to review maps of known and suspected OSSF locations. No appreciable changes were recommended. It is also assumed that failure rates will stay constant and that service area boundaries will expand based on projected development. While boundaries may change, there is no feasible way to predict spatially where this will occur. The stakeholders reviewed and confirmed the assumptions and estimates.

Figure 44 shows the current loading distributions for OSSFs in the watersheds, relative to each subwatershed's contribution[29]. Figure 45 indicates the change in loading over time, through 2050. Table 19 indicates the actual OSSF source loading estimates by subwatershed.

---

[28] Data is collected under a 604(b) agreement between H-GAC and TCEQ, and quality assured under the auspices of that contract. Use of this acquired data is detailed in the project modeling QAPP for this project.

[29] Throughout this section, it should be noted that these loading maps use color to indicate relative loading for each. They are not necessarily comparable to degree of color exhibited on maps for other sources. Actual loading estimates for comparison are given in their respective tables.

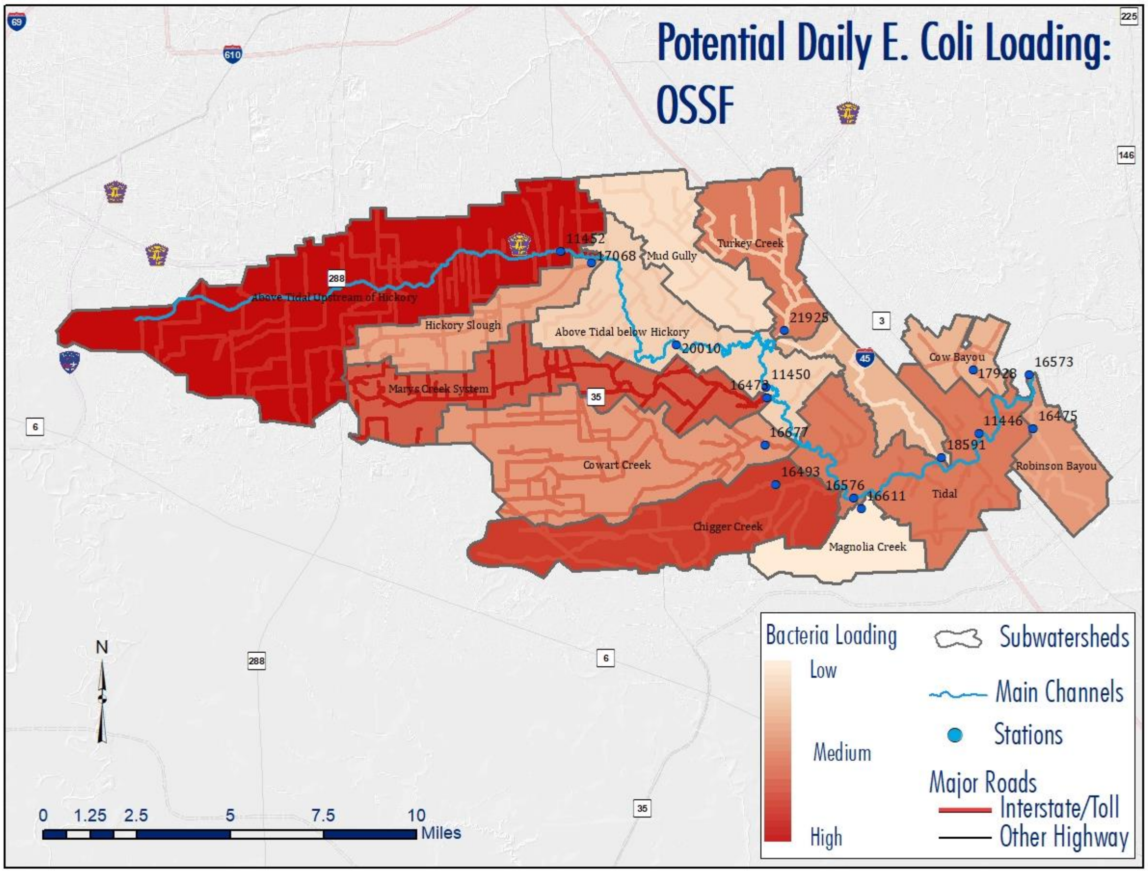

Figure 43 - Fecal Bacteria Loading from OSSFs, by Subwatershed

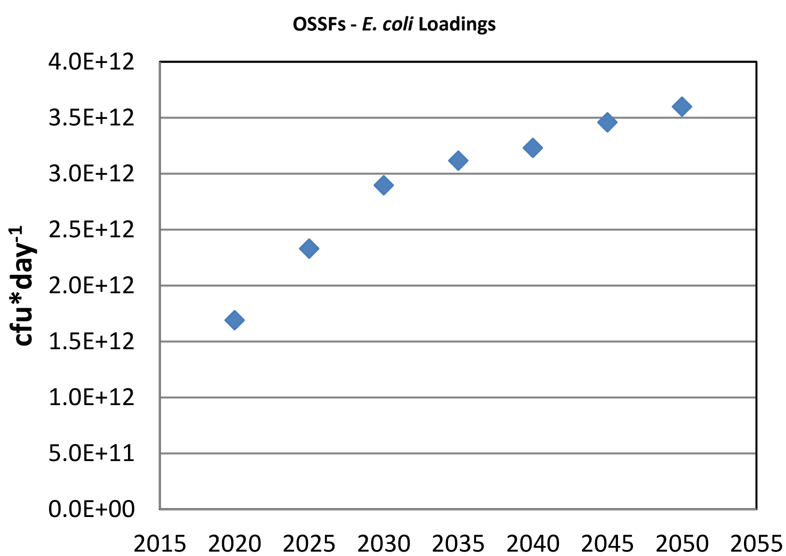

Figure 44 - Future Source Loads from OSSFs

Table 19 - Current Source Loads for OSSFs, in E. coli

Subwatershed	Location Category	Number of OSSFs	Average Daily Load, in *E. coli*
SW1	Out Buffer	2976	2.76E+11
	Within Buffer	478	1.77E+11
SW2	Out Buffer	452	4.19E+10
	Within Buffer	139	5.16E+10
SW3	Out Buffer	59	5.51E+09
	Within Buffer	56	2.08E+10
SW4	Out Buffer	43	4.03E+09
	Within Buffer	16	5.80E+09
SW5	Out Buffer	585	5.43E+10
	Within Buffer	72	2.68E+10
SW6	Out Buffer	1096	1.02E+11
	Within Buffer	723	2.68E+11
SW7	Out Buffer	483	4.48E+10
	Within Buffer	157	5.81E+10
SW8	Out Buffer	1242	1.15E+11
	Within Buffer	286	1.06E+11
SW9	Out Buffer	0	0.00E+00
	Within Buffer	0	0.00E+00
SW10	Out Buffer	583	5.41E+10
	Within Buffer	205	7.61E+10
SW11	Out Buffer	393	3.65E+10
	Within Buffer	14	5.12E+09
SW12	Out Buffer	305	2.83E+10
	Within Buffer	122	4.51E+10
SW13	Out Buffer	477	4.43E+10
	Within Buffer	116	4.29E+10
TOTAL	Out Buffer	8694	8.06E+11
	Within Buffer	2383	8.84E+11
	Total	**11077**	**1.69E+12**

As indicated in Figure 45, OSSF loadings are expected to continue to increase through 2050, with the addition of households in undeveloped areas, outside of wastewater service areas. For the sake of this analysis, areas outside known or planned wastewater service areas were assumed to be reliant on OSSFs. However, additional sewage system development in these areas in the future may reduce the number of OSSFs in new development. While OSSFs are not routinely inspected, new systems must be permitted and have regular maintenance. A 10% failure rate is currently being used for all years, based on stakeholder feedback, although the stakeholders indicated that this be checked regularly as some systems continue to age. An increase in assumed failure rate may be necessary if on the ground conditions warrant.

WWTFs

Permitted wastewater utilities in a variety of sizes serve populations throughout the watershed. Much of the watershed is inside city limits, municipal utility districts (MUDs), or other districts where the primary form of sewage treatment is via centralized sewage systems. There are 20 WWTF outfalls in the WPP area (representing 19 unique WWTFs[30]). Only one of the plants (representing two outfalls) is industrial, the rest are domestic. The plants range in size from 12 million gallons a day (MGD) to 0.012 MGD. Of these facilities, all 19 have DMR data that was included in the modeling. The DMR data indicates exceedances of permit limits for fecal bacteria are not common, and do not show a strong relationship to season or plant size[31].

WWTFs were not expected to be a large source of loading based on previous review of DMR data and stakeholder feedback. WWTFs always have the risk of being acute, localized sources of note, but no evidence or feedback was received that would indicate any specific, chronic problems of a size that might impact loading estimates[32]. To estimate loadings, the total permitted flows for each subwatershed were multiplied by the fecal indicator bacteria standard. While most plants discharged well below the standard, this approach was chosen by the stakeholders to ensure a conservative estimate of potential WWTP impact. This is intended to account for times of exceedance and variation of conditions throughout a daily cycle. Loads were applied at the buffer area loading rate to reflect direct outfalls. For future projections, discharges were assumed to be at or below the standard. Future flows were increased proportionally to projected household increase within the existing service area boundaries.

[30] More information on the distribution, character, and DMR records for these plants is included in the project's Water Quality Data Collection and Trends Analysis Report at www.clearcreekpartnership.weebly.com.
[31] The data reviewed and modeled here is for permitted discharges. For discussion of sanitary sewer overflows, please refer to the and the Water Quality Data Collection and Trends Analysis report at
[32] Feedback regarding localized issues was taken into consideration for the focus of BMPs in implementing the plan but did not rise to the level of potential impacts to loading numbers, as special cases were episodic and localized.

Table 20 indicates the actual WWTF source loading estimates by subwatershed. Figure 45 indicates the change in loading over time, through 2040. Figure 46 shows the current loading distributions for WWTFs in the watersheds.

Table 20 – WWTFs and Loadings by Subwatershed

Subwatershed	WWTFs	Daily Average Load (in *E. coli)*
1	4	7.36E+09
2	1	7.43E+07
3	2	8.30E+09
4	1	8.45E+09
5	1	8.77E+09
6	3	8.29E+09
7	2	1.33E+08
8	0	0.00E+00
9	1	3.40E+09
10	4	3.38E+10
11	0	0.00E+00
12	0	0.00E+00
13	0	0.00E+00
Total	**19**	**7.86E+10**

WWTF flows and loadings increase slightly through 2050, but they remain a minor contributor to overall potential loading. Currently, areas outside existing service area boundaries and known or planned developments are assumed to be served by OSSFs, including future development. Depending on the extent to which development includes centralized sanitary sewer, OSSF numbers may need to be reduced.

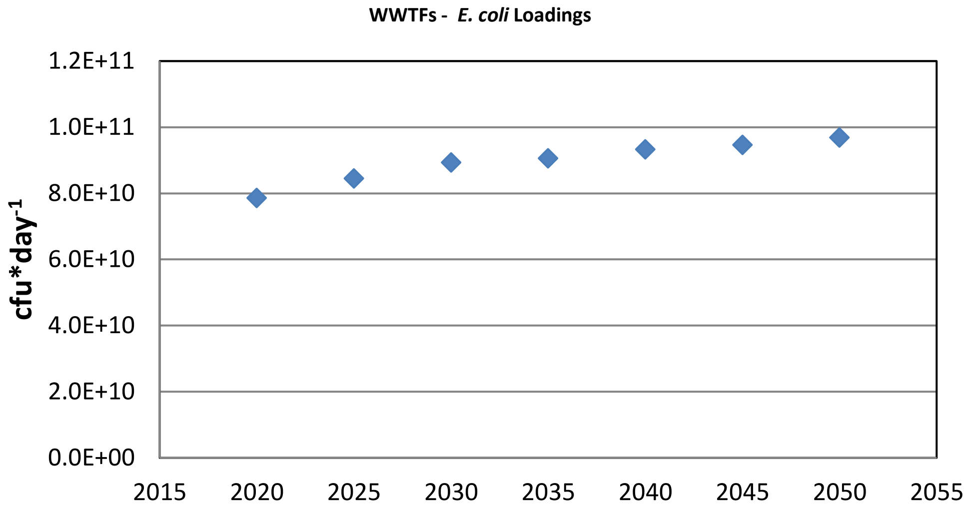

Figure 45 - Future Fecal Bacteria Loadings from WWTFs

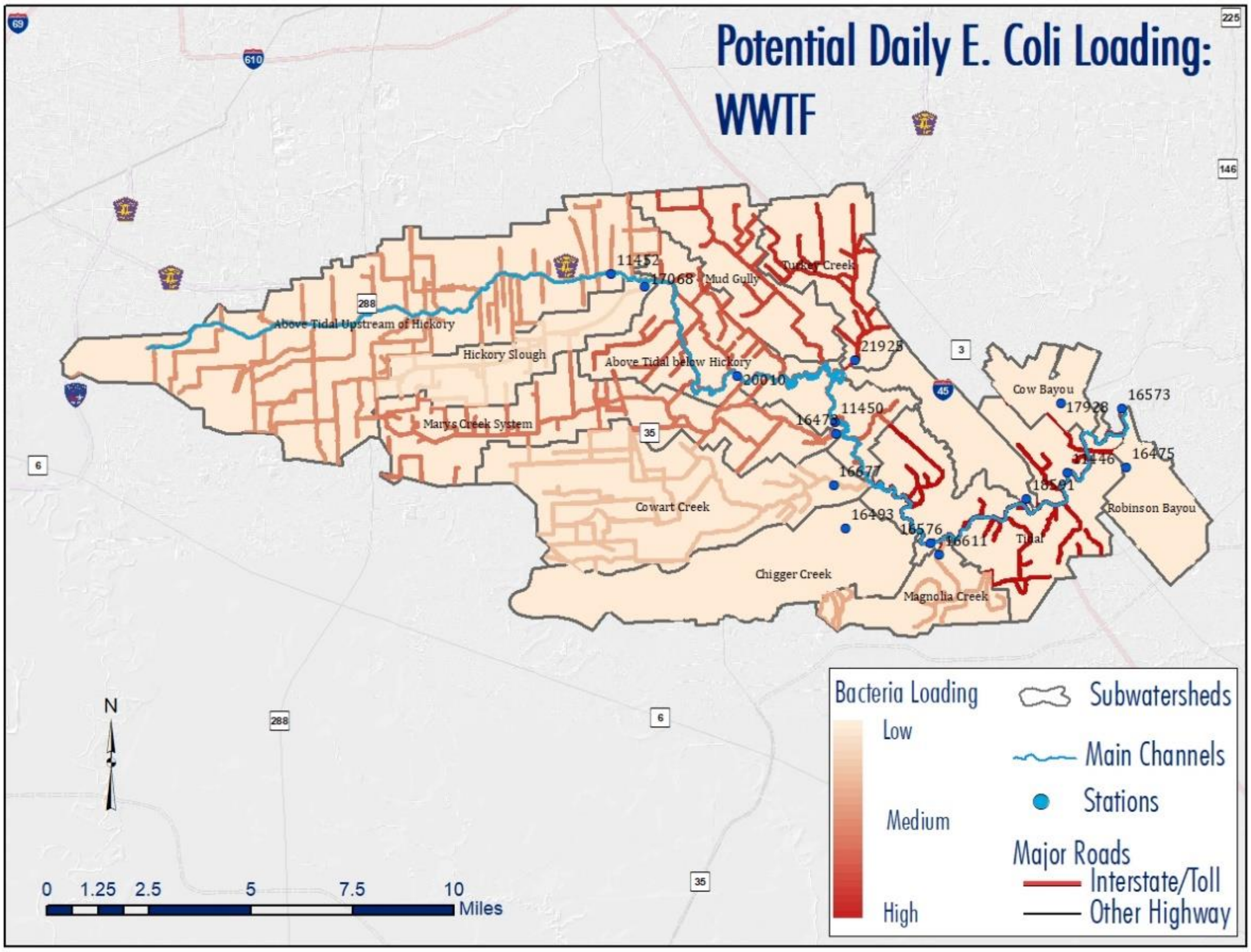

Figure 46 - Daily E. coli loading from WWTFs

Stakeholders noted that age of wastewater systems in the watershed varied greatly, with newer development in the Pearland and Friendswood areas, and older development in the aspects of the watershed in Harris County and in older areas of Galveston County.

Cattle

Cattle production has been historically present in parts of the watershed, and its remnants are currently concentrated primarily in the undeveloped and rural areas in the headwaters and southern portions of the watershed. Developmental pressure, weather events (e.g., the 2011 drought), and other market forces have led to a marked decline in agricultural production in general in the Clear Creek Watershed. Initial estimates of cattle populations for the watershed were based on the latest (2017) livestock census data from the USDA's National Agricultural Statistics Service (NASS). Because the data for cattle is not specific to the watershed area, cattle were assumed to be equally distributed throughout applicable land cover (grassland and pasture/hay) in each county. H-GAC generated the ratio of each county's portion of the watershed's acreage in appropriate land cover types to the acreage of the entire county. This ratio was then applied to county cattle populations, to establish the number of cattle proportional to the size of the watershed acreage in that county . This approach ensures that the density of cattle in a county's applicable land cover acreage was the same as the density in the watershed's applicable land use acreage. The initial cattle populations were expected to be overly high by project staff. The assumed overestimation was based primarily on the model treating appropriate land cover as being under production for cattle, even if it may be fallow. These data were reviewed with the stakeholders and with the topical work group for agriculture. In general, the feedback from these groups was that cattle populations were more accurate than expected based on known herds and activity. There are no CAFOs in the watershed.

Cattle fecal bacteria loads were then derived for milestones at every five years starting with current conditions. Table 21 indicates the actual cattle source loading estimates by subwatershed. Figure 47 indicates the change in loading over time, through 2050. Figure 48 shows the current loading distributions for cattle in the watersheds.

As indicated in Figure 47, cattle production and presence in the watersheds is expected to continue to decrease, leading to a corresponding decrease in potential fecal bacteria load. Primary forces behind this change in the model are change of land cover to developed areas, but stakeholder feedback also indicated that rising land value and changing conditions ahead of growth were also pressures on cattle production. Additionally, market forces and the result of past weather events unrelated to development are exerting negative pressure on production in the watershed.

Table 21 - Current Potential Fecal Bacteria Loads from Cattle, by Subwatershed

Subwatershed	Location Category	Number of Cattle	Average Daily Load, in *E. coli*
SW1	Out Buffer	396	2.67E+11
	Within Buffer	73	1.98E+11
SW2	Out Buffer	31	2.10E+10
	Within Buffer	10	2.81E+10
SW3	Out Buffer	12	8.36E+09
	Within Buffer	7	1.98E+10
SW4	Out Buffer	2	1.02E+09
	Within Buffer	1	2.30E+09
SW5	Out Buffer	63	4.25E+10
	Within Buffer	13	3.62E+10
SW6	Out Buffer	32	2.15E+10
	Within Buffer	9	2.55E+10
SW7	Out Buffer	430	2.90E+11
	Within Buffer	179	4.84E+11
SW8	Out Buffer	459	3.10E+11
	Within Buffer	115	3.12E+11
SW9	Out Buffer	73	4.92E+10
	Within Buffer	14	3.67E+10
SW10	Out Buffer	65	4.39E+10
	Within Buffer	10	2.61E+10
SW11	Out Buffer	47	3.20E+10
	Within Buffer	11	2.85E+10
SW12	Out Buffer	20	1.35E+10
	Within Buffer	0	9.86E+06
SW13	Out Buffer	16	1.09E+10
	Within Buffer	2	6.63E+09
TOTAL	Out Buffer	1646	1.11E+12
	Within Buffer	444	1.20E+12
	Total	**2090**	**2.31E+12**

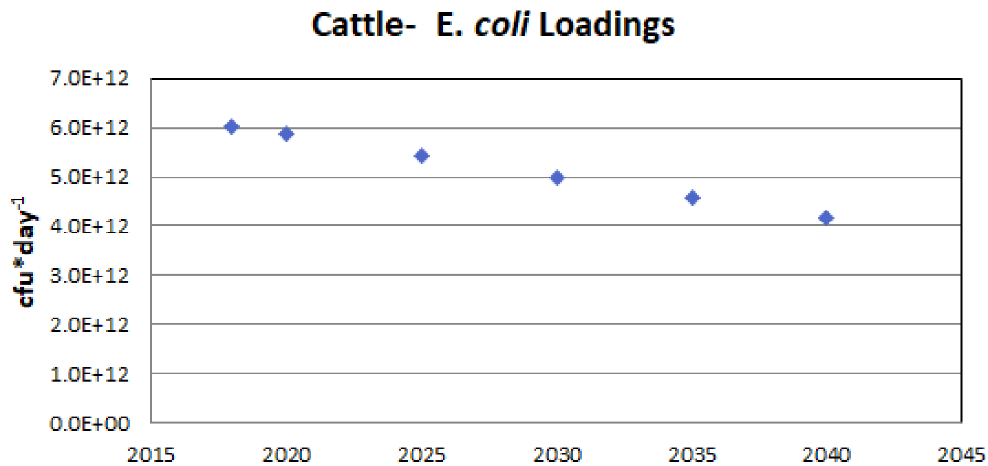

Figure 47 - Future Fecal Bacteria Loads from Cattle

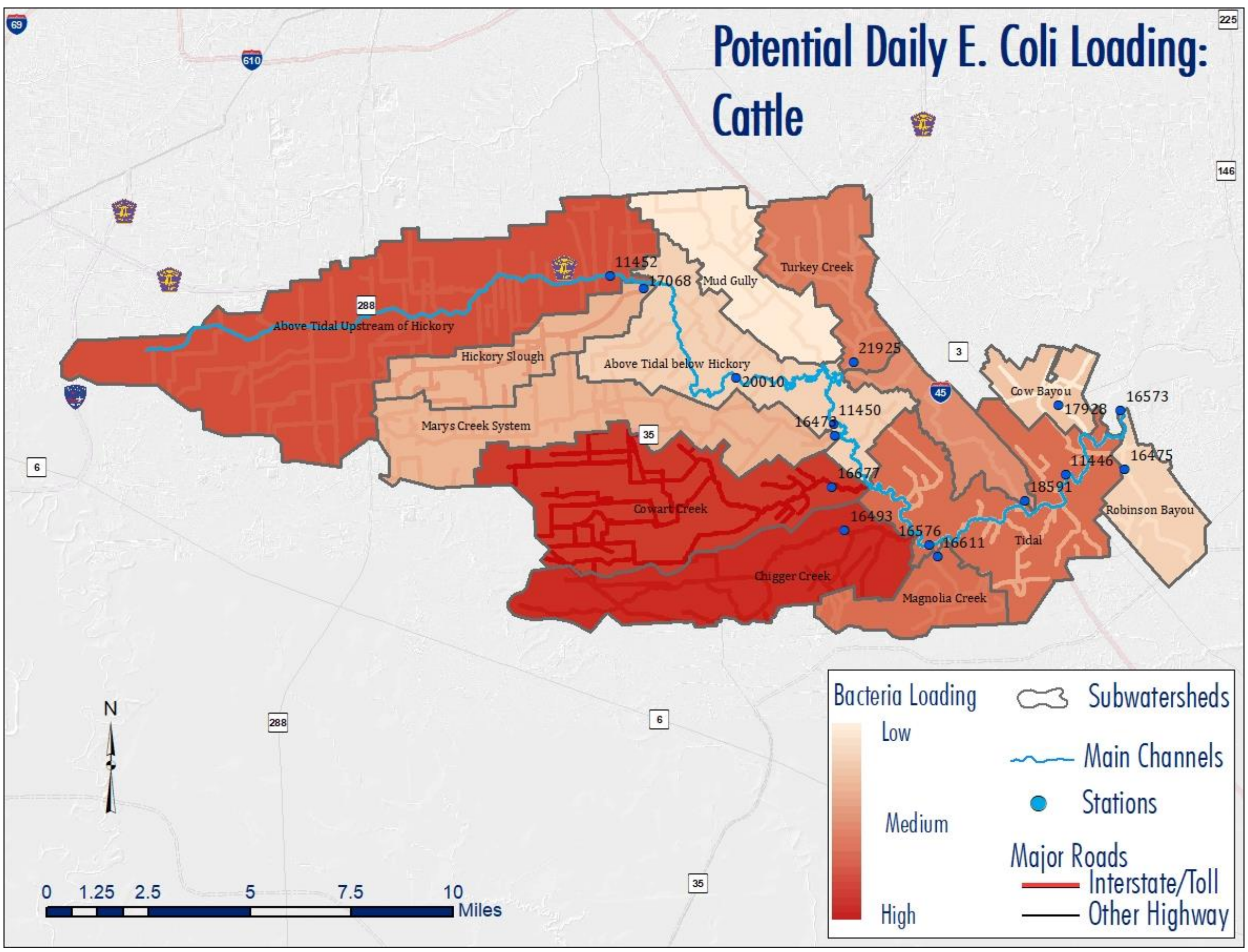

Figure 48 - Fecal Bacteria Loadings from Cattle, by Subwatershed

Horses

Unlike cattle populations in the watershed, horses have straddled the divide between rural areas and suburban/exurban development. Horse populations are found in both traditional rural settings and in less densely developed areas, where recreational[33] horse ownership was noted. Primary modes of ownership include traditional rural populations accompanying existing agricultural operations, and large acreage home sites which may have one or a small number of horses, and boarded horses in stabling operations. Based on stakeholder feedback there were no known problem operations or specific areas of concern.

Horse populations were derived using the same methodology as cattle populations, using proportional numbers of county NASS data populations. As with cattle, horse population estimates were first reviewed internally by project staff, then with local experts, and then with the work group and Partnership.

Horse fecal bacteria loads were then derived for milestones at every five years starting with current conditions. Figure 49 indicates the change in loading over time, through 2050. Table 22 indicates the actual horse source loading estimates by subwatershed. Figure 50 shows the current loading distributions for horses in the watersheds. As with cattle and other livestock, horse populations are expected to decline as development pushes further into rural areas. However, the extent of reduction is expected to be somewhat less as exurban acreage developments continue to support small horse populations.

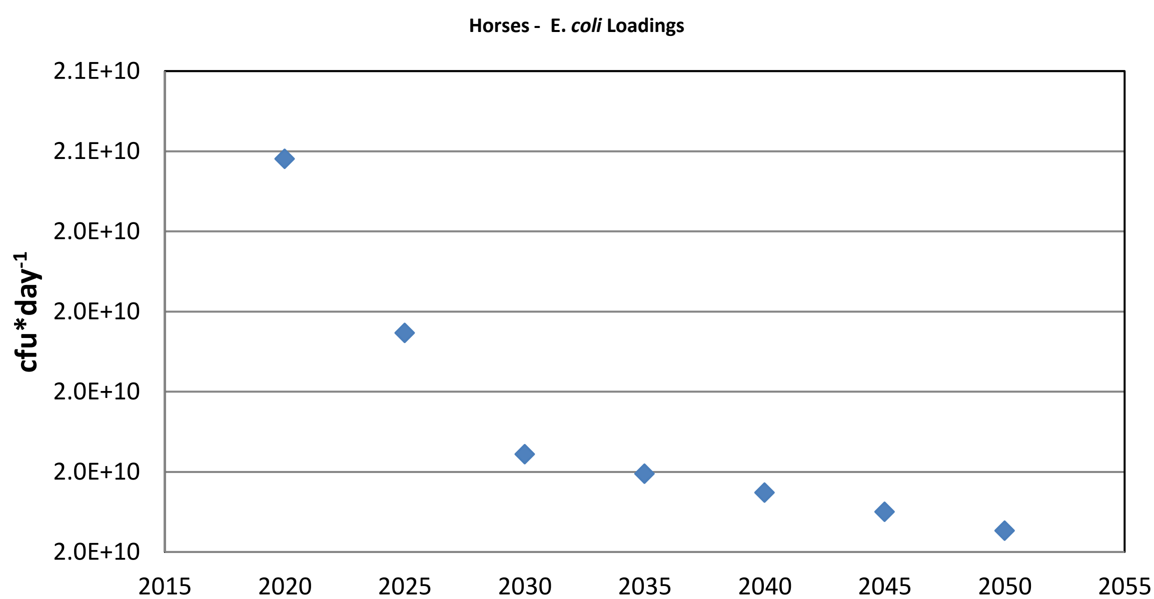

Figure 49 - Future Fecal Bacteria Loadings from Horses

[33] "Recreational" is used here in comparison to horses that are part of an agricultural operation or property.

Table 22 - Current Potential Fecal Bacteria Loadings from Horses, by Subwatershed

Subwatershed	Location Category	Number of Horses	Average Daily Load, in *E. coli*
SW1	Out Buffer	45	2.37E+09
	Within Buffer	8	1.76E+09
SW2	Out Buffer	4	1.87E+08
	Within Buffer	1	2.50E+08
SW3	Out Buffer	1	7.44E+07
	Within Buffer	1	1.76E+08
SW4	Out Buffer	0	9.07E+06
	Within Buffer	0	2.05E+07
SW5	Out Buffer	7	3.78E+08
	Within Buffer	2	3.22E+08
SW6	Out Buffer	4	1.91E+08
	Within Buffer	1	2.26E+08
SW7	Out Buffer	49	2.58E+09
	Within Buffer	20	4.30E+09
SW8	Out Buffer	52	2.75E+09
	Within Buffer	13	2.77E+09
SW9	Out Buffer	8	4.38E+08
	Within Buffer	2	3.26E+08
SW10	Out Buffer	7	3.90E+08
	Within Buffer	1	2.32E+08
SW11	Out Buffer	5	2.85E+08
	Within Buffer	1	2.53E+08
SW12	Out Buffer	2	1.20E+08
	Within Buffer	0	8.77E+04
SW13	Out Buffer	2	9.65E+07
	Within Buffer	0	5.90E+07
TOTAL	Out Buffer	186	9.88E+09
	Within Buffer	50	1.07E+10
	Total	**236**	**2.06E+10**

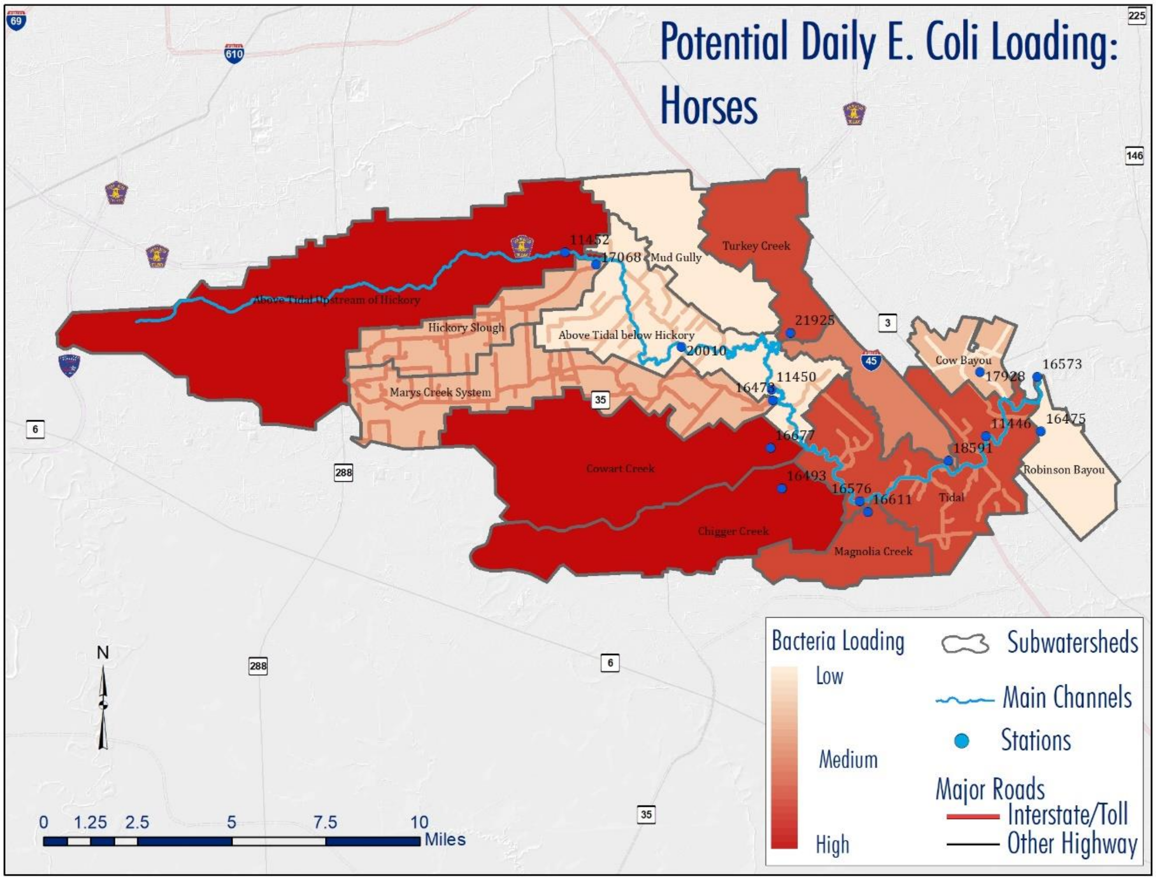

Figure 50 – Fecal Bacteria Loading from Horses, by Subwatershed

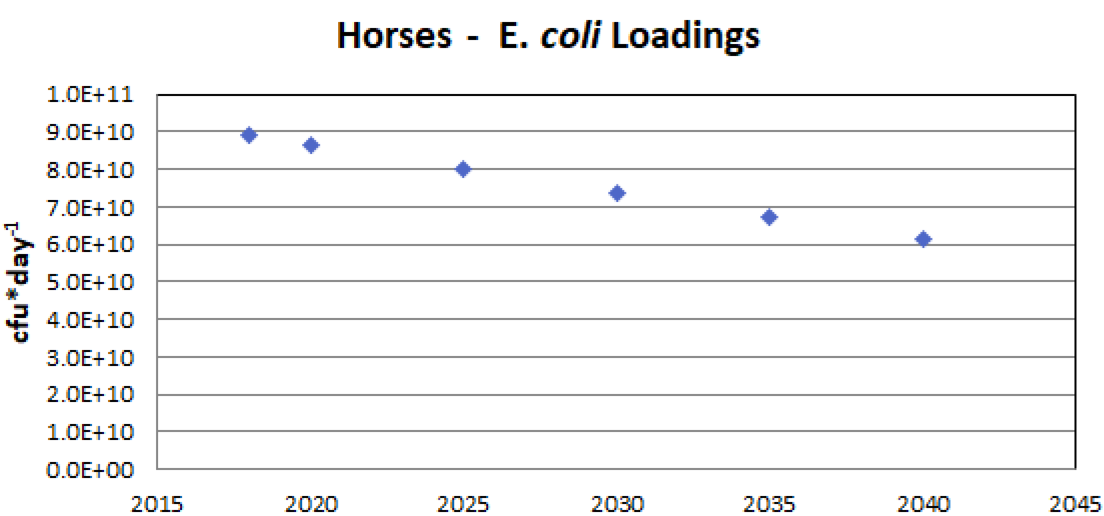

Figure 51 – Future Fecal Bacteria Loadings from Horses

Sheep and Goats

Sheep and goat populations represent a smaller portion of the livestock in the watershed, but still retain a small presence in rural areas. Stakeholders indicated that there were no known large/dense operations or known problem areas in the watershed.

Sheep and goat populations are estimated together because the base NASS data lumps them into a single statistic. Stakeholders indicated they did not expect this conglomeration of populations to pose any significant issue for load estimation in the project area. Populations and loads for current and future conditions were estimated in the same manner as was described for cattle and horses. Assessment and revision of the initial population estimates was conducted concurrently with other livestock, but no specific need for reductions was identified.

Sheep and goat fecal bacteria loads were then derived for milestones at every five years starting with current conditions. Figure 52 shows the current loading distributions for sheep and goats in the watersheds. Table 23 indicates the actual sheep and goat source loading estimates by subwatershed. Figure 53 indicates the change in loading over time, through 2050.

Future projections indicate that sheep and goat populations will decline with other livestock, but without the same residual presence in exurban areas that horses are likely to experience.

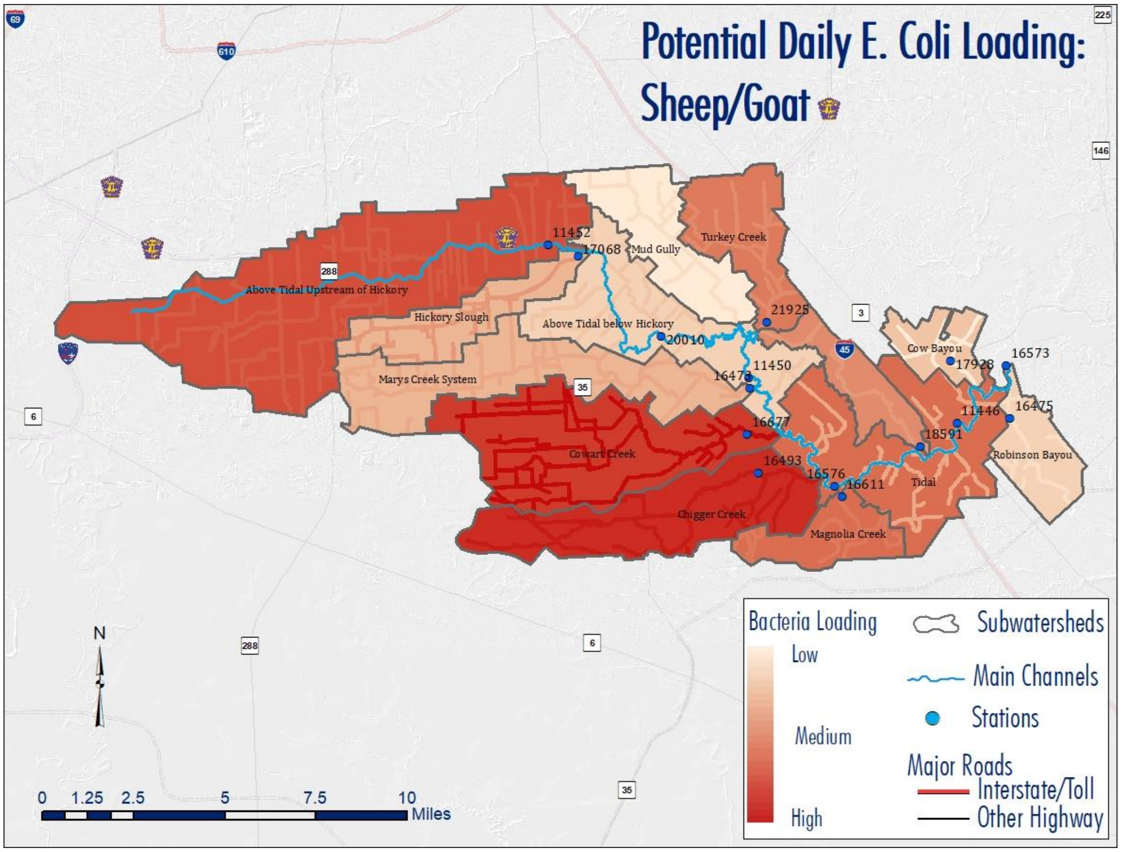

Figure 52 – Fecal Bacteria Loadings from Sheep and Goats, by Subwatershed

Table 23 - Current Potential Fecal Bacteria Loadings from Sheep and Goats, by Subwatershed

Subwatershed	Location Category	Number of Sheep and Goats	Average Daily Load, in *E. coli*
SW1	Out Buffer	38	8.59E+10
	Within Buffer	7	6.38E+10
SW2	Out Buffer	3	6.76E+09
	Within Buffer	1	9.03E+09
SW3	Out Buffer	1	2.69E+09
	Within Buffer	1	6.36E+09
SW4	Out Buffer	0	3.28E+08
	Within Buffer	0	7.40E+08
SW5	Out Buffer	6	1.37E+10
	Within Buffer	1	1.16E+10
SW6	Out Buffer	3	6.91E+09

	Within Buffer	1	8.19E+09
SW7	Out Buffer	41	9.33E+10
	Within Buffer	17	1.56E+11
SW8	Out Buffer	44	9.96E+10
	Within Buffer	11	1.00E+11
SW9	Out Buffer	7	1.58E+10
	Within Buffer	1	1.18E+10
SW10	Out Buffer	6	1.41E+10
	Within Buffer	1	8.38E+09
SW11	Out Buffer	5	1.03E+10
	Within Buffer	1	9.16E+09
SW12	Out Buffer	2	4.33E+09
	Within Buffer	0	3.17E+06
SW13	Out Buffer	2	3.49E+09
	Within Buffer	0	2.13E+09
TOTAL	Out Buffer	158	3.57E+11
	Within Buffer	42	3.87E+11
	Total	**200**	**7.44E+11**

Table 24 – Current Potential Fecal Bacteria Loadings from Sheep and Goats, by Subwatershed

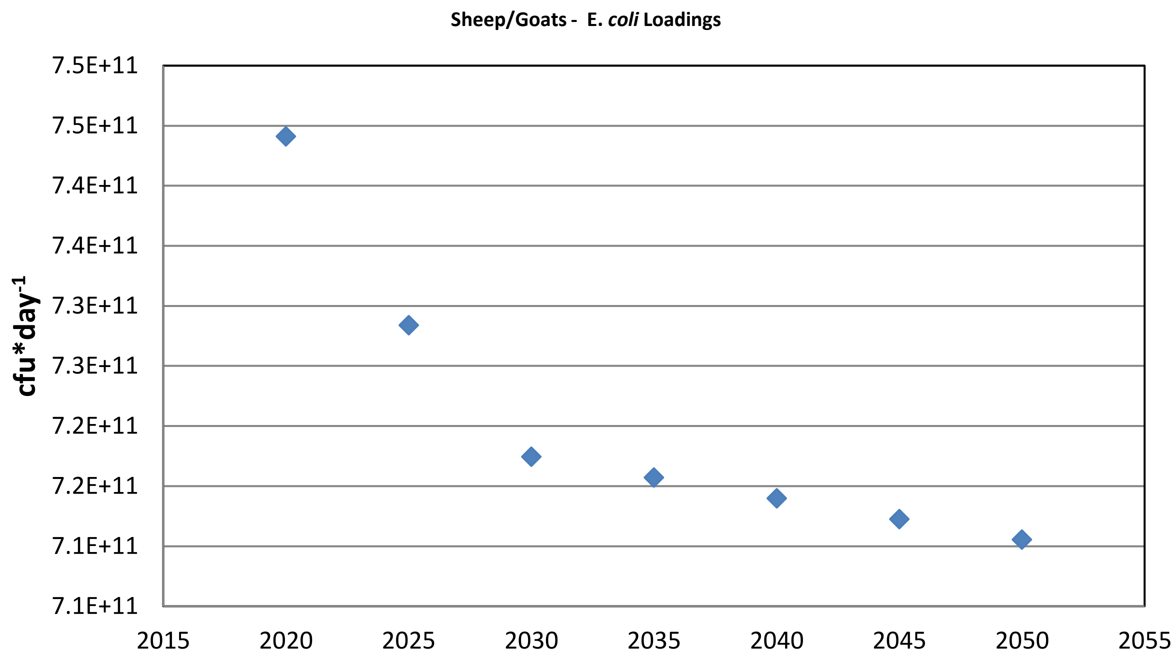

Figure 53 - Future Fecal Bacteria Loadings from Sheep and Goats

Feral Hogs

Feral hogs (*Sus scrofa* and related hybrids) are a pressing invasive species issue throughout the Houston-Galveston region in general, and specifically within the project area. Adaptable, fertile, and aggressively omnivorous, their populations are responsible for significant damage to agricultural production, wildlife and habitat, and human landscapes. Hogs can transmit diseases dangerous to humans, pets, and domestic livestock, and can generate large volumes of waste where they concentrate. The riparian corridors adjacent to food resources serve as transportation corridors and shelter for hogs, who then roam adjacent areas to feed. Feedback from stakeholders indicated that feral hogs were a persistent issue in the watershed, but anecdotal reports on extent of hog presence and damage differed significantly, even within the same areas. No specific study of hog populations in the area exists, so literature values from Texas A&M AgriLife Extension (AgriLife) were used as initial assumptions. Based on accounts from landowners at the edge of the developed areas, hogs were a persistent issue, but no rapid change in populations was noticed in the last 5 years.

Hogs were populated in all land cover types in the watershed except developed and open water areas. Densities were assigned based on AgriLife literature values[34] and experience in previous WPP efforts, as affirmed by project stakeholders. Two hogs per square mile were populated in bare land, cultivated, and pasture/hay cover types, and 2.45 hogs were populated in grasslands, forest, shrublands, and wetland areas. While hogs are known to congregate around water bodies to wallow, to use as transport, and as shelter, they also range widely into surrounding areas to feed. Therefore, no specific weighting was given to presence inside the buffer other than the standard buffer weighting used in this implementation of SELECT. Future projections were based on land cover change, with loss of hog population as developed areas increased.

Feral hog fecal bacteria loads were derived for milestones at every five years starting with current conditions. Figure 54 indicates the change in loading over time, through 2050. Table 25 indicates the actual feral hog loading estimates by subwatershed. Figure 55 shows the current loading distributions for feral hogs in the watersheds.

Future conditions reflect a slight reduction in hog populations and loading. As noted previously, the model cannot account for concentration of displaced hog populations in surrounding areas, nor can it project populations dynamics without adding an assumption. Project staff and stakeholders did not have literature values or defensible means to suggest a potentially increasing feral hog population based on population increase rather than habitat expansion. Therefore, the modeled projections should be taken to be conservative, as feral hog populations across the state have demonstrated a tendency toward population growth and adaptability to changing developmental conditions.

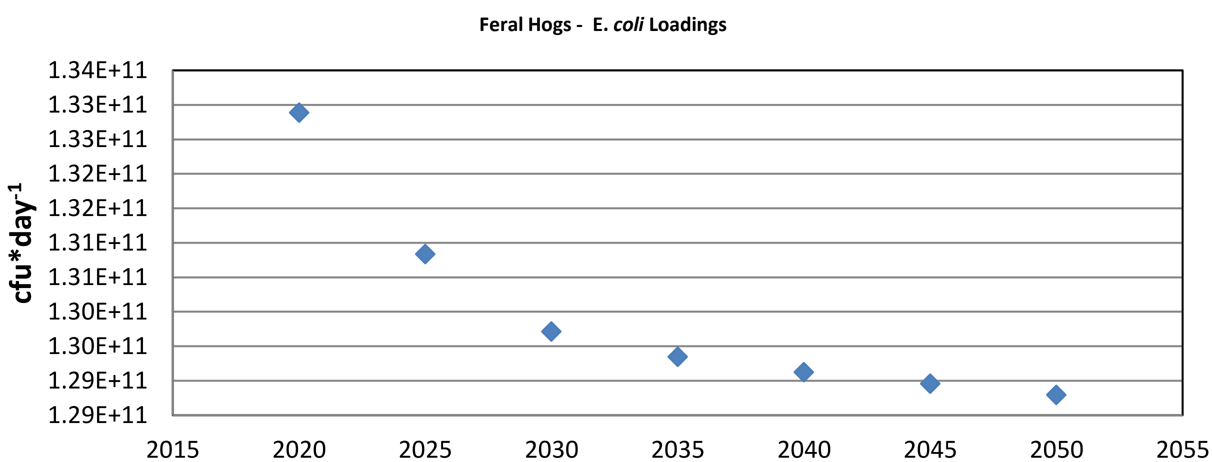

Figure 54 - Future Fecal Bacteria Loads from Feral Hogs

[34] From numbers in https://cdn.agrilifetoday.tamu.edu/wp-content/uploads/2019/10/sp-472.pdf and http://feralhogs.tamu.edu/files/2011/05/FeralHogFactSheet.pdf.

Table 25 - Current Potential Fecal Bacteria Loadings for Feral Hogs, by Subwatershed

Subwatershed	Location Category	Number of Feral Hogs	Average Daily Load, in *E. coli*
SW1	Out Buffer	15	1.65E+10
	Within Buffer	4	1.62E+10
SW2	Out Buffer	1	1.55E+09
	Within Buffer	0	1.97E+09
SW3	Out Buffer	3	3.03E+09
	Within Buffer	2	7.75E+09
SW4	Out Buffer	1	8.14E+08
	Within Buffer	0	7.14E+08
SW5	Out Buffer	3	2.91E+09
	Within Buffer	1	4.65E+09
SW6	Out Buffer	1	1.16E+09
	Within Buffer	0	1.68E+09
SW7	Out Buffer	9	9.83E+09
	Within Buffer	4	1.64E+10
SW8	Out Buffer	10	1.11E+10
	Within Buffer	3	1.33E+10
SW9	Out Buffer	3	2.80E+09
	Within Buffer	1	2.77E+09
SW10	Out Buffer	3	3.87E+09
	Within Buffer	2	7.30E+09
SW11	Out Buffer	2	2.25E+09
	Within Buffer	0	1.91E+09
SW12	Out Buffer	0	4.39E+08
	Within Buffer	0	4.61E+08
SW13	Out Buffer	1	6.74E+08
	Within Buffer	0	8.33E+08
TOTAL	Out Buffer	52	5.70E+10
	Within Buffer	17	7.59E+10
	Total	**69**	**1.33E+11**

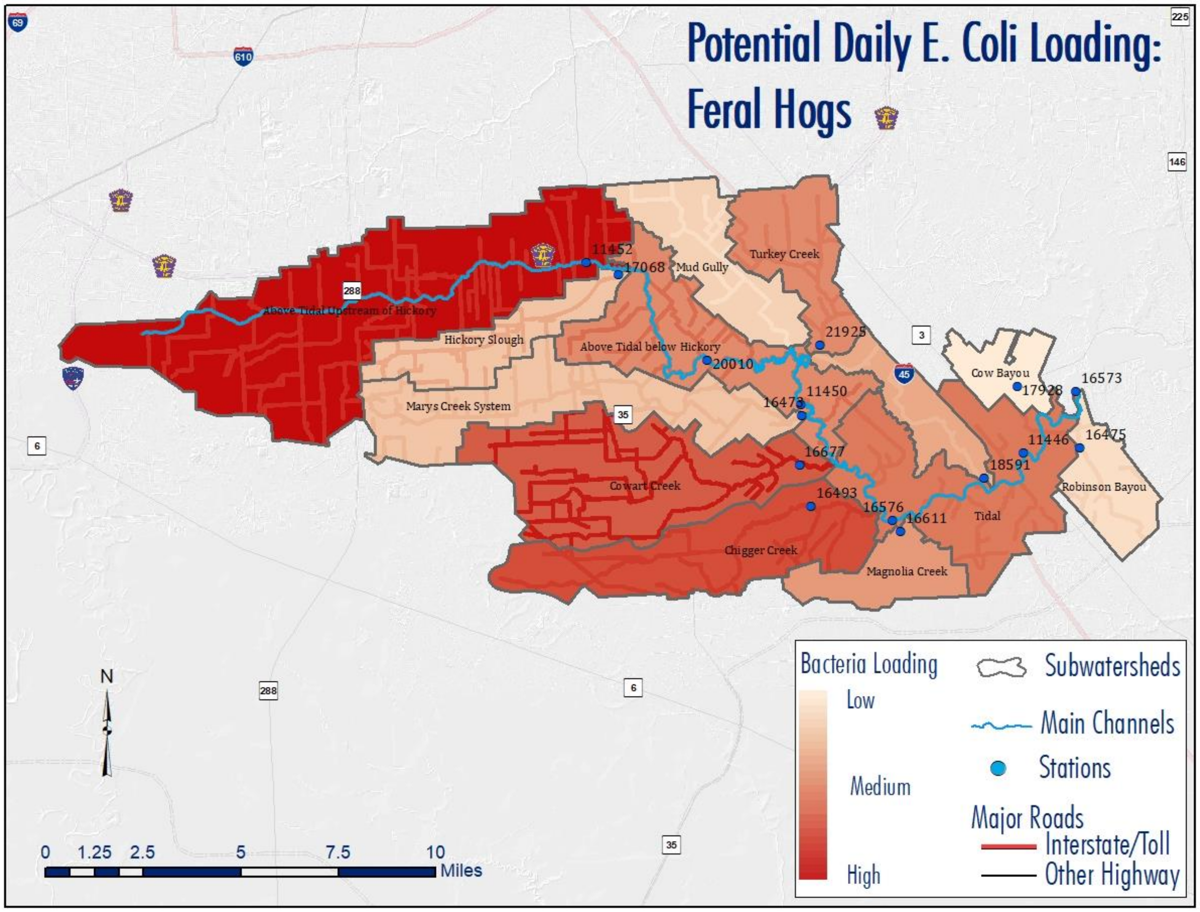

Figure 55 – Fecal Bacteria Loadings from Feral Hogs, by Subwatershed

Dogs

Domestic and feral dog populations are a significant contributor to fecal bacteria contamination in the greater Houston region, especially in dense developed areas. Unlike cats or other pet species, dog waste is often deposited outside instead of collected in litter boxes or other waste receptacles. Despite local and regional efforts to promote dog waste reduction, feedback from the stakeholders indicated that many owners did not pick up after their dogs.

Pet ownership rates are the key to characterizing load in the SELECT analysis. Other WPP projects have used national averages established by the American Veterinary Medical Association (AVMA)[35] or other industry groups, ranging from 0.6 to 1 dog per household. The current assumption proposed by staff was 0.6 dogs per household based on the AMVA's statistical data for Texas. Apartment ownership rates

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

do not always match home ownership rates, and the high number of apartment households in the watershed might skew the estimation of dog populations. Project staff conducted a study of six apartment complexes in urban and suburban areas and determined that there was an average of approximately 0.48 dogs per household based on property manager estimations. This estimate was close enough to the standard 0.6 dogs per household, assuming there was an undetermined level of tenant underreporting of dog ownership based on property manager feedback, that the stakeholders felt a separate rate for apartment households was not needed. Based on stakeholder feedback, feral dog populations were not widespread. No specific data existed, or reasonable literature value was found that was applicable to this area/situation. Since the estimation of apartment density could potentially have some overestimation, and because feral populations were not considered an appreciable source, the stakeholders affirmed the project team's proposal to use 0.6 dogs per household as a uniform assumption. Specific measures to target each population will be developed under the WPP, but for the sake of the model, dog waste is tied to the 0.6 assumption.

Future dog populations were derived from household growth projections, using 0.6 as a static assumption of density for all time periods. As with other sources related to household growth, the relative contribution of fecal bacteria from dog waste continues to increase through 2050. There was no stakeholder expectation that dog ownership rates would be significantly different in the future. One novel consideration for this project was the rate of pet waste bag usage. Based on the apartment survey, stakeholder reports, and a survey of parks in the area, there is an appreciable level of pet waste station infrastructure and usage. Because pet waste bags effectively remove waste from the ecosystem, the stakeholders felt that reduction in load needed to be considered. Reports of usage differed widely, with the most reported use in denser areas. A conservative assumption of a 30% reduction in pet was applied to account for waste bags. Stakeholders elected to not increase this percentage in the baseline projections for future years, although they indicated that this would likely occur as bag use increased.

Dog fecal bacteria loads were derived for milestones at every five years starting with current conditions. Figure 57 shows the current loading distributions for dogs in the watersheds. Figure 58 indicates the change in loading over time, through 2050. Table 26 indicates the actual dog source loading estimates by subwatershed.

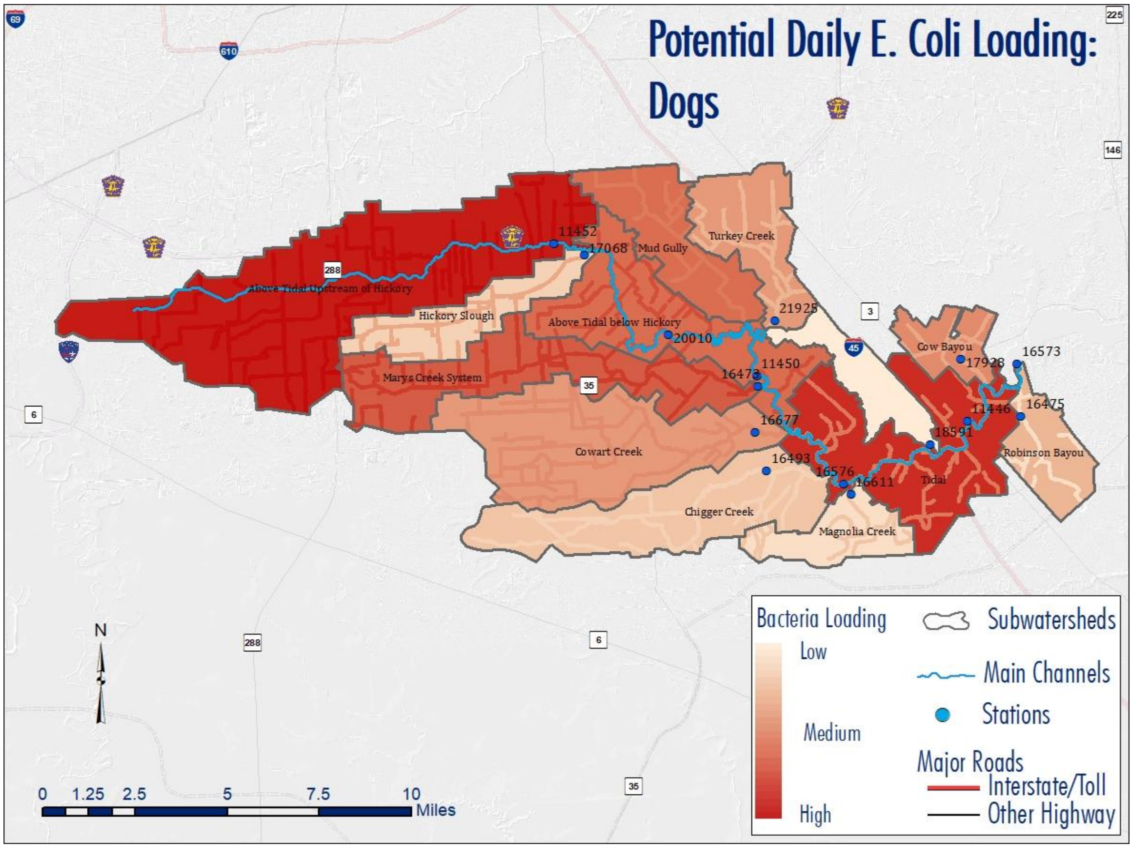

Figure 56 - Fecal Bacteria Loadings from Dogs, by Subwatershed

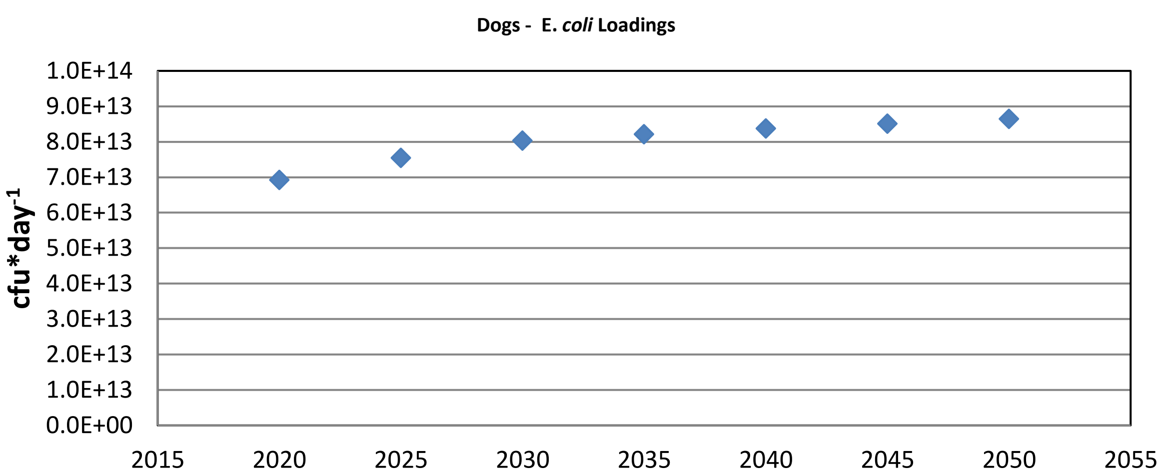

Figure 57 - Current Potential Fecal Bacteria Loadings for Dogs, by Subwatershed[36]

[36] Load estimates reflect the 20% reduction for pet waste bag usage.

Table 26 - Current Potential Fecal Bacteria Loadings for Dogs, by Subwatershed

Subwatershed	Location Category	Number of Dogs	Average Daily Load, in *E. coli*
SW1	Out Buffer	12683	4.44E+12
	Within Buffer	4034	5.65E+12
SW2	Out Buffer	2412	8.47E+11
	Within Buffer	848	1.19E+12
SW3	Out Buffer	7343	2.57E+12
	Within Buffer	2178	3.05E+12
SW4	Out Buffer	7864	2.75E+12
	Within Buffer	1247	1.74E+12
SW5	Out Buffer	4428	1.55E+12
	Within Buffer	813	1.14E+12
SW6	Out Buffer	8388	2.93E+12
	Within Buffer	2373	3.33E+12
SW7	Out Buffer	3903	1.37E+12
	Within Buffer	1146	1.60E+12
SW8	Out Buffer	3222	1.13E+12
	Within Buffer	647	9.03E+11
SW9	Out Buffer	2259	7.91E+11
	Within Buffer	649	9.10E+11
SW10	Out Buffer	9562	3.35E+12
	Within Buffer	1649	2.31E+12
SW11	Out Buffer	590	2.07E+11
	Within Buffer	40	5.58E+10
SW12	Out Buffer	4445	1.55E+12
	Within Buffer	898	1.26E+12
SW13	Out Buffer	3279	1.15E+12
	Within Buffer	484	6.78E+11
TOTAL	Out Buffer	70378	2.46E+13
	Within Buffer	17007	2.38E+13
	Total	**87385**	**4.84E+13**

Deer

White-tailed deer (deer) are one of the most common large mammals in the watershed areas. Wooded areas and open grasslands in the rural and undeveloped areas of the watershed provide abundant natural habitat. Because deer are among a handful of species that adapt well to the fringe of human development, large lot suburban and exurban development and even open areas in urban neighborhoods can provide alternative habitat. Based on discussions with TPWD staff, local stakeholder feedback, and land cover analysis, deer populations are widespread in the project area to the point of bordering on nuisances in some areas (urban golf courses, etc.). This mirrors findings in other area watersheds.

The starting point for estimating deer populations is the use of density projections derived from TPWD's Resource Management Unit (RMU) data for deer in this ecoregion. Deer were populated in appropriate land cover types in the model, primarily forested areas and open spaces. The RMU density is then applied to these acreages to determine deer populations. Future deer populations are tied to land cover change. As with feral hogs, there is no assumption made of population dynamics other than removal as habitat is removed. Similarly, there is no assumption of concentration to a carrying capacity as habitat is lost. Deer in developed habitat are removed from projections.

Stakeholder review of preliminary assumptions indicated that there were significant deer populations in lightly developed areas, and these acreages were populated in the next run of the model. The stakeholders affirmed the revised numbers based on anecdotal experiences and best professional judgement.

Deer fecal bacteria loads were derived for milestones at every five years starting with current conditions. Figure 58 shows the current loading distributions for deer in the watersheds. Table 27 indicates the actual deer source loading estimates by subwatershed. Figure 59 indicates the change in loading over time, through 2050.

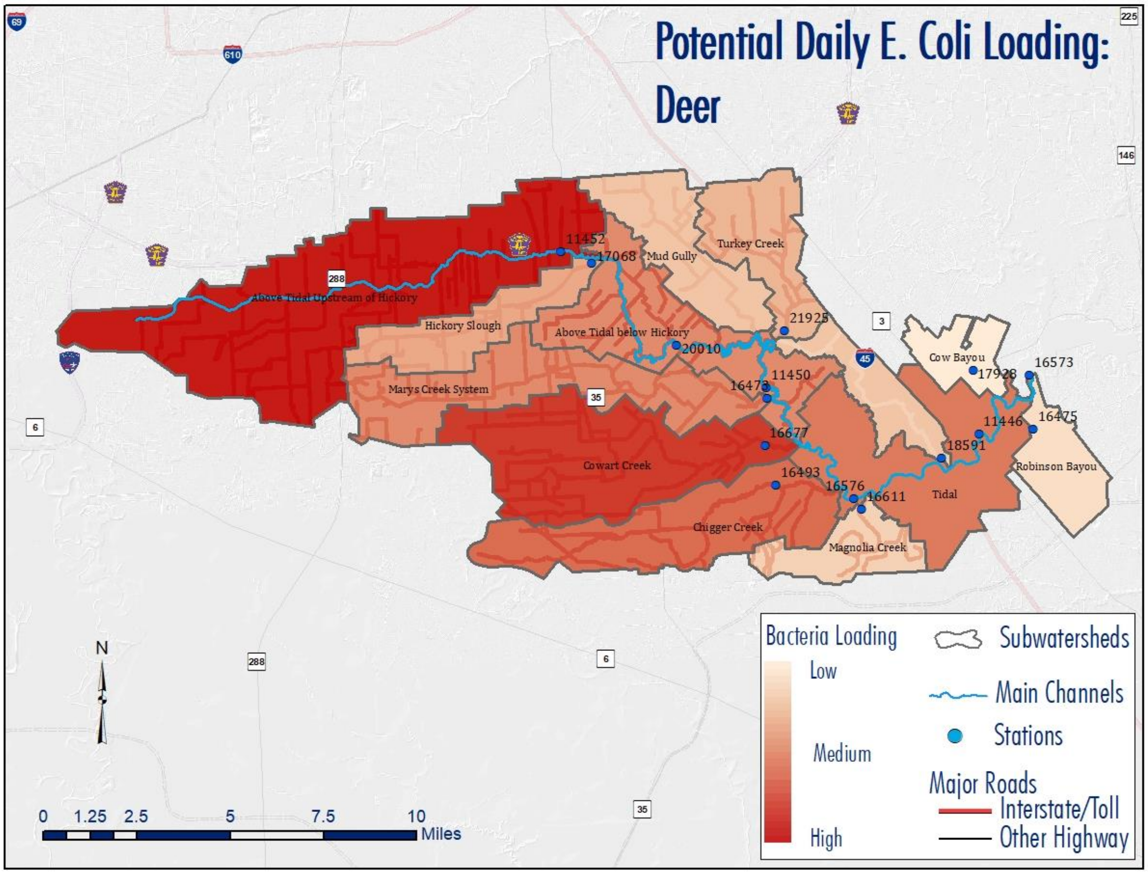

Figure 58 - Fecal Bacteria Loadings from Deer, by Subwatershed

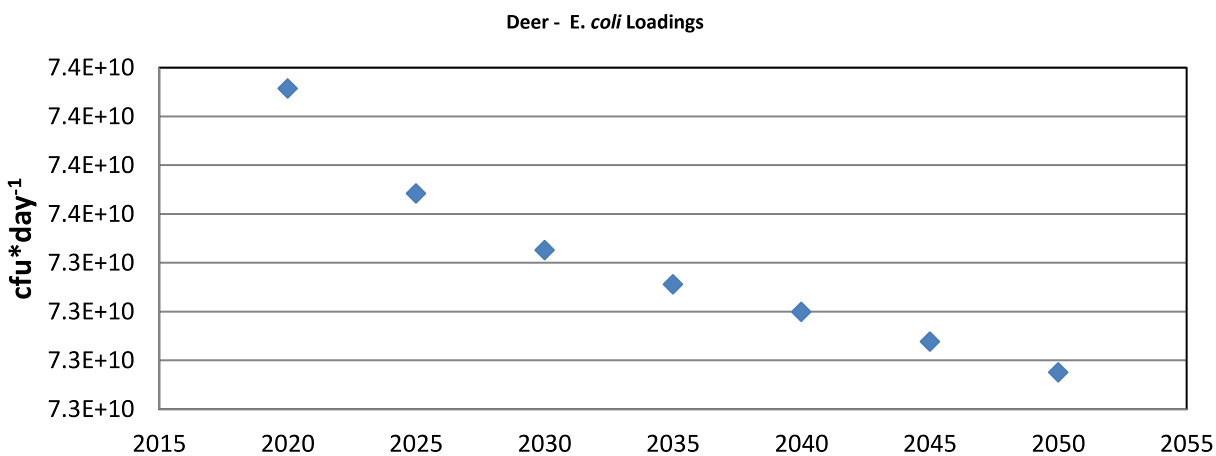

Figure 59 - Future Fecal Bacteria Loadings from Deer

Table 27 - Current Potential Fecal Bacteria Loadings for Deer, by Subwatershed

Subwatershed	Location Category	Number of Deer	Average Daily Load, in *E. coli*
SW1	Out Buffer	177	7.76E+09
	Within Buffer	54	9.50E+09
SW2	Out Buffer	32	1.42E+09
	Within Buffer	12	2.12E+09
SW3	Out Buffer	60	2.61E+09
	Within Buffer	25	4.32E+09
SW4	Out Buffer	27	1.17E+09
	Within Buffer	8	1.32E+09
SW5	Out Buffer	30	1.33E+09
	Within Buffer	10	1.68E+09
SW6	Out Buffer	59	2.58E+09
	Within Buffer	23	4.07E+09
SW7	Out Buffer	111	4.86E+09
	Within Buffer	39	6.91E+09
SW8	Out Buffer	90	3.94E+09
	Within Buffer	26	4.49E+09
SW9	Out Buffer	24	1.04E+09
	Within Buffer	8	1.38E+09
SW10	Out Buffer	67	2.94E+09
	Within Buffer	17	2.91E+09
SW11	Out Buffer	25	1.08E+09
	Within Buffer	6	1.07E+09
SW12	Out Buffer	10	4.48E+08
	Within Buffer	4	7.71E+08
SW13	Out Buffer	24	1.04E+09
	Within Buffer	6	1.00E+09
TOTAL	Out Buffer	736	3.22E+10
	Within Buffer	238	4.15E+10
	Total	**974**	**7.38E+10**

Other Wildlife

The primary missing element discussed by the stakeholders was the impact of wildlife other than deer, including some large animals like coyotes, but inclusive of all other non-modeled warm-blooded wildlife (rodents, wild cats, wild canines, other mammals, birds, etc.).

Prior projects in the area have not specifically addressed this source other than to recognize it may be appreciable, and to consider the context of limited potential means to address it. A limited fecal bacteria source tracking (BST) effort at one location close to the end of the Tidal segment[37] offered some insights into non-domestic animal contributions, showing upwards of 47% of the samples analyzed were broadly wildlife, of which 29% were non-avian, and 18% were avian. Another 31% of the samples were unidentified. While this data points to a strong contribution from wildlife, the effort was linked to a single site, over a single year, using an indicator (*E. coli)* not used for tidal systems. No equivalent data exists for other stations in the watershed. The great deal of uncertainty about the applicability of this data did not fit the data quality objectives of this project. However, it provides a snapshot of a potentially greater than expected wildlife contribution.

Additionally, stakeholders provided anecdotal information on various species of interest in both rural and urban areas. There was general concern that not including the load from other wildlife in some form might produce a less defensible estimation. In review of the source tracking information from the TWRI study and other studies from more rural watersheds[38] in the state it was clear that wildlife contributions were appreciable and not well represented by just deer and feral hogs. Without source tracking data for this area, and allowing for a greater degree of development, the stakeholders considered ways to apply results from other Texas watersheds to Clear Creek. To ensure that the estimate was conservative and reflected the developmental character of the area, other wildlife was assumed to be equivalent to 20% of the total load for the watershed. The value was generated by finding the total for all other sources, assuming that total to represent 80% of the actual total, and then considering the remaining 20% to be other wildlife. The stakeholders also felt that the extent of urban wildlife known in the watershed suggested that this load should be applied to all subwatersheds, rather than just rural areas. While the initial load was derived from the current year projections, the load estimate was kept as a constant across future projections, rather than increasing as a set percentage of each milestone year's total. This is intended to reflect a constant or declining wildlife population even as human sources increase. The stakeholders noted that additional research, including potential future source tracking, would be

---

[37] Monitoring was conducted by the Texas Water Resources Institute as part of their report, *Bacterial Source Tracking (BST) on Tributaries of Trinity and Galveston Bays* (August 2020), available online at https://twri.tamu.edu/media/5472/tr-528.pdf.

[38] 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); analysis conducted for the Lampasas and Leon Rivers showed similar results (https://oaktrust.library.tamu.edu/handle/1969.1/149197).

valuable to give this estimation greater precision. The other wildlife values are reflected in the final load estimation tables of this report.

Other Sources

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 intervention 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% other wildlife load estimate.

Human Waste – Direct Discharges

Stakeholders discussed the presence of some homeless individuals in some areas. Based on feedback from the work group and Partnership, the populations represented by the groups were not found to be large enough to have appreciable impact.

Land Deposition of Sewage Sludge

There were no anecdotal or official reports of sludge application violations or known issues with manure spreading identified by the stakeholders or other partners. Potential impacts would likely be dealt with as part of traditional agricultural BMPs (Water Quality Management Plans (WQMPs), etc.).

Concentrated Animal Feeding Operations

There are no CAFOs in the WPP project area.

Birds

Bird populations in the region can vary greatly by season. Large migratory populations pass through the Houston area as part of the Central Flyway migratory path. However, these populations are transient, staying for days or weeks during two yearly migration seasons. Migratory waterfowl represent longer-term populations, especially in coastal marshes. However, significant migratory waterfowl presence in the watershed has been in long-term decline.

Previous WPP efforts have evaluated the potential impact of waterfowl in terms of duration, potential fecal bacteria load/waste load, and other considerations, and found them to not be significant sources to be modeled. Colonial nesting birds have been identified in other WPP projects as sources of fecal bacteria load. Swallows and other similar colonial birds do have nest sites on some bridges throughout the watershed. However, no reasonable data, estimation, or methodology for assessing their populations exists, and no anecdotal account of significant populations exist.

Birds of potential concern identified in the stakeholder discussions include domestic exotics (e.g., Muscovy ducks) in parks and other detention facilities. However, no reasonable data exists to characterize this source or to suggest they would be either appreciable in impact or likely to contribute greatly to health risk. The limited BST evidence indicated avian wildlife may make up an appreciable portion of the load (18%), but the lack of individualized source data for this watershed relegates their potential load to be included assumptions for the Other Wildlife category.

Bats

Bats are present throughout the watershed project area, but there are no known large nesting sites of a size or density likely to represent a source of concern.

Other Wildlife

Anecdotal reports from stakeholders, known area species, and observed species during field reconnaissance indicate coyote, rabbit, skunk, many rodent species, nutria, beaver, raccoon, opossum, armadillo, and other common mammals are present in the watershed in appreciable numbers. However, little data exists to characterize their contributions. Their contributions cannot be individually assessed but are considered to be part of the 20% other wildlife load.

Cats

Domestic cat ownership general revolves around an indoor model in developed areas, in which cat feces are restricted to litter boxes, unlike dog waste which is more likely to be deposited outdoors. Therefore, cat loads were not estimated separately as part of this project. Feral cats, however, can be a local source when found in sufficiently dense urban populations. Project staff worked with local stakeholders to review potential data sources and anecdotal reports on feral cat populations. However, no literature values or data appropriate under project data quality objectives were located. In a review of other regional WPPs, feral cat populations were generally included as part of diffuse urban stormwater and were not specifically highlighted as significant sources. As with other sources not specifically modeled, feral cats may still be a focus of implementation efforts dependent on stakeholder decisions. While not wildlife, it is expected that their load is represented to some degree by the 10% other wildlife load. Some local governments have specifically targeted feral cat populations.

Dumping

In discussions with stakeholders, illegal dumping was not identified as a widespread issue. Some localized problem areas were identified, but there were no significant accounts of waste dumping that would add appreciably to fecal bacteria levels. The primary focus of dumping concerns was trash and other aesthetic and regulatory issues. Some specific sites were identified but not particularly strongly associated with fecal waste.

Sediment

Sand and gravel mining operations are common in the riparian corridors of the area watersheds but are less common on much of Clear Creek. However, there are a few small operations in the watershed. Mining operations are not a source of fecal bacteria, so no modeled estimation can be completed. In some areas, runoff from new development is notable during high runoff events. Excess sediment is common in the waterways, which can provide shelter for fecal bacteria and decrease insolation that may lead to die-off in the water column, can impact DO levels, and can have pronounced hydrologic impacts on flow. These effects are already an aspect of the in-stream conditions described under the LDCs, in that recorded fecal bacteria levels reflect the end product of these ambient factors as well as other fate and transport aspects Excess sediment introduced into the channel can foster the survival of fecal bacteria from other sources, making it an indirect source for fecal bacteria that might have otherwise not survived. The considerations regarding sediment will be dealt with in the WPP.

SSOs

Overflows from sanitary sewer collection systems can introduce large volumes of untreated sewage in short times. At best, they are acute, episodic sources. However, in areas with aging or improperly maintained infrastructure, they can be a chronic source of human fecal waste. Unlike treated wastes discharged by WWTFs, fecal bacteria levels in SSOs are often many orders of magnitude greater. SSOs can result from a variety of causes, including human error in system operation, infiltration of rainwater into sewer pipes during storm events, power failures at lift stations, or blockages in pipes[39].

Records of SSOs within the watersheds were derived from five years of TCEQ data. A fundamental level of uncertainty exists because the data relies on reporting and records from permitted utilities as well as TCEQ staff. The number, type, duration, and volume of SSOs in the data may not fully describe the level of SSO activity in the watershed for several logistical reasons[40]. All SSOs related to a WWTF and receiving stream segment in the watershed area[41] were used to characterize this source. Loading values were based on a consideration of the causes identified for SSOs in the watershed, of which over a third were primarily dilute (rainwater charger releases) or moderate. Concentrations of fecal bacteria can vary greatly based on the composition of sewage at the time of the SSO. EPA literature values[42] were used to identify likely concentrations in SSOs based on the breakout of SSO causes reported. The moderate concentration value was chosen as most representative. Future loads were generated by increasing SSOs proportionately to increases in households within the service areas.

The primary question on how to calculate SSOs and integrate them into other source loading estimates stems from their (usually) episodic nature. SSOs in the watershed areas were not generally found to be chronic loads, but rather, acute. Therefore, their live loading is high, but much of the time there is no loading. The stakeholders of the Partnership, local partners, and the work group considered the question of how to estimate SSO flows. The most conservative approach would be to take the highest potential loading and use it as a daily value. However, this would grossly overstate the loading on any given day from SSOs. However, the stakeholders had concerns that using an average of all SSO flow over

---

[39] More information on the character and distribution of SSOs is available in the project Water Quality Data Collection and Trends Analysis Report at www.clearcreekpartnership.weebly.com.

[40] E.g., SSOs may not be discovered until they have been discharging for an unknown period of time, estimates of volume may be hard to determine based on field conditions, etc.

[41] Collection systems can straddle watershed boundaries, and WWTFs outside the watershed may have systems partially within it. However, without spatially explicit data on SSO locations, SSOs from systems discharging outside the watershed could not be included.

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

time (i.e., treating the SSOs as a chronic load averaged over the year to produce a daily load value) would underestimate the impact of SSOs. Because of the documented nature of SSOs in the project area, the stakeholders elected to remove SSOs from the load calculation entirely and treat them as a separate item that was given high priority regardless of its relative contribution. The intent was to focus on any identified problem areas as localized, acute sources to prioritize for remediation in the WPP.

While SSOs are currently a minor source of load as an average daily load, they grow with population and development. Additional factors like the potential for increase in the rate of SSOs as systems age could not be extrapolated from known data. Comparison of older and newer systems did not produce any statistically significant differences, primarily due to the small data sets. While SSOs may not be a primary source, the stakeholders felt it was important to include them and highlight them because, 1) they are human waste sources, and thus have higher potential pathogenic impact[43]; 2) their peak volumes and concentrations are underrepresented here; and 3) they can be pronounced localized sources in areas where direct human contact is more likely (developed areas).

Summary of Results

The SELECT analyses indicated a mix of sources, but with a few primary contributors for the watershed overall. However, most importantly for stakeholder decision-making, the mix of sources projected for the future, and the spatial distribution of those sources shows marked differences in different areas of the watershed. The approaches of reducing pet waste to reflect waste bag usage, and the inclusion of a 20% load for other wildlife were included to reflect best professional judgement, trends in state and regional load estimation under other projects, and stakeholder feedback and decision-making. While neither is modeled under traditional approaches, uncertainty in their estimation should be balanced by the far greater uncertainty inherent in not addressing these issues. The focus on a conservative implementation of these approaches draws a balance between addressing them but remaining as defensible as possible.

Table 28 indicates the estimated current potential loads for all sources. Table 29 shows the estimated potential load for each milestone year, by source. Figure 60 shows the change in total load between 2020 and 2050. Figures 61 and 62 show the relative change in source contributions between current and future conditions, respectively.

[43] Quantitative microbial risk assessment studies, including work in the Leon River (*Gitter, Anna Caitlin (2016). Application of Quantitative Microbial Risk Assessment and Bacterial Source Tracking to Assess the Associated Human Health Risks from Multiple Fecal Sources During Recreational Exposure in the Leon River Watershed. Master's thesis, Texas A & M University.* Available electronically from 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.

Absent a concerted effort to address fecal bacteria sources, the projections indicate that total fecal bacteria load in the watershed will continue to increase through 2050, as well as the target date of 2035. Between current conditions and those projected for 2050, the mix of sources shifts away from some of the legacy agricultural activity toward a growing predominance of sources associated with developed areas.

Table 28 - Current Fecal Bacteria Daily Average Loadings by Source and Subwatershed

Subwatershed	OSSF	WWTFs	Dogs	Cattle	Horses	Sheep and Goats	Deer	Feral Hogs	Other Wildlife	Total Daily Load in *E. coli*
SW1	4.53E+11	7.36E+09	1.01E+13	4.65E+11	4.14E+09	1.5E+11	1.73E+10	3.27E+10	2.80E+12	**1.40E+13**
SW2	9.35E+10	74340198	2.03E+12	4.91E+10	4.37E+08	1.58E+10	3.54E+09	3.52E+09	5.49E+11	**2.75E+12**
SW3	2.63E+10	8.3E+09	5.62E+12	2.81E+10	2.5E+08	9.05E+09	6.93E+09	1.08E+10	1.43E+12	**7.14E+12**
SW4	9.83E+09	8.45E+09	4.5E+12	3.32E+09	29538490	1.07E+09	2.49E+09	1.53E+09	1.13E+12	**5.66E+12**
SW5	8.1E+10	8.77E+09	2.69E+12	7.87E+10	7E+08	2.53E+10	3.01E+09	7.56E+09	7.23E+11	**3.62E+12**
SW6	3.7E+11	8.29E+09	6.26E+12	4.69E+10	4.18E+08	1.51E+10	6.65E+09	2.84E+09	1.68E+12	**8.39E+12**
SW7	1.03E+11	1.33E+08	2.97E+12	7.74E+11	6.88E+09	2.49E+11	1.18E+10	2.62E+10	1.04E+12	**5.18E+12**
SW8	2.21E+11	0	2.03E+12	6.21E+11	5.53E+09	2E+11	8.43E+09	2.44E+10	7.78E+11	**3.89E+12**
SW9	0	3.4E+09	1.7E+12	8.59E+10	7.64E+08	2.76E+10	2.42E+09	5.57E+09	4.56E+11	**2.28E+12**
SW10	1.3E+11	3.38E+10	5.66E+12	6.99E+10	6.22E+08	2.25E+10	5.85E+09	1.12E+10	1.48E+12	**7.41E+12**
SW11	4.16E+10	0	2.62E+11	6.05E+10	5.38E+08	1.95E+10	2.14E+09	4.16E+09	9.76E+10	**4.88E+11**
SW12	7.34E+10	0	2.81E+12	1.35E+10	1.2E+08	4.33E+09	1.22E+09	9.01E+08	7.27E+11	**3.63E+12**
SW13	8.72E+10	0	1.83E+12	1.75E+10	1.56E+08	5.62E+09	2.04E+09	1.51E+09	4.85E+11	**2.42E+12**
Total	**1.69E+12**	**7.86E+10**	**4.84E+13**	**2.31E+12**	**2.06E+10**	**7.44E+11**	**7.38E+10**	**1.33E+11**	**1.34E+13**	**6.69E+13**
Percent of Total Load	**2.53%**	**0.12%**	**72.44%**	**3.46%**	**0.03%**	**1.11%**	**0.11%**	**0.20%**	**20.0%**	**100.0%**

Table 29 – Daily Average Fecal Bacteria Loadings by Source for all Milestone Years

Category	Source	2020	2025	2030	2035	2040	2045	2050
Human Waste	OSSFs	1.69E+12	2.33E+12	2.9E+12	3.12E+12	3.23E+12	3.46E+12	3.6E+12
	WWTFs	7.86E+10	8.45E+10	8.94E+10	9.06E+10	9.33E+10	9.47E+10	9.69E+10
Pets	Dogs	4.84E+13	5.29E+13	5.62E+13	5.75E+13	5.86E+13	5.96E+13	6.05E+13
Livestock	Cattle	2.31E+12	2.26E+12	2.23E+12	2.23E+12	2.22E+12	2.21E+12	2.21E+12
	Horses	2.06E+10	2.01E+10	1.98E+10	1.98E+10	1.97E+10	1.97E+10	1.97E+10
	Sheep / Goats	7.44E+11	7.28E+11	7.17E+11	7.16E+11	7.14E+11	7.12E+11	7.11E+11
Wildlife and Feral Hogs	Deer	7.38E+10	7.35E+10	7.34E+10	7.34E+10	7.33E+10	7.32E+10	7.32E+10
	Feral Hogs	1.33E+11	1.31E+11	1.3E+11	1.29E+11	1.29E+11	1.29E+11	1.29E+11
	Other Wildlife	1.34E+13	1.34E+13	1.34E+13	1.34E+13	1.34E+13	1.34E+13	1.34E+13
Total		**6.69E+13**	**7.18E+13**	**7.57E+13**	**7.73E+13**	**7.84E+13**	**7.96E+13**	**8.07E+13**

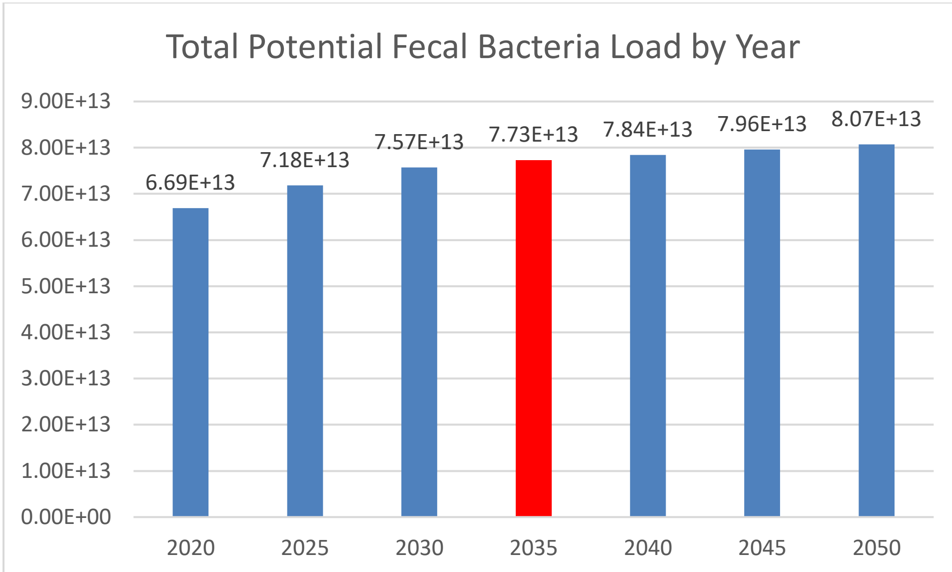

Figure 60 - Total Potential Daily Load, 2020-2050

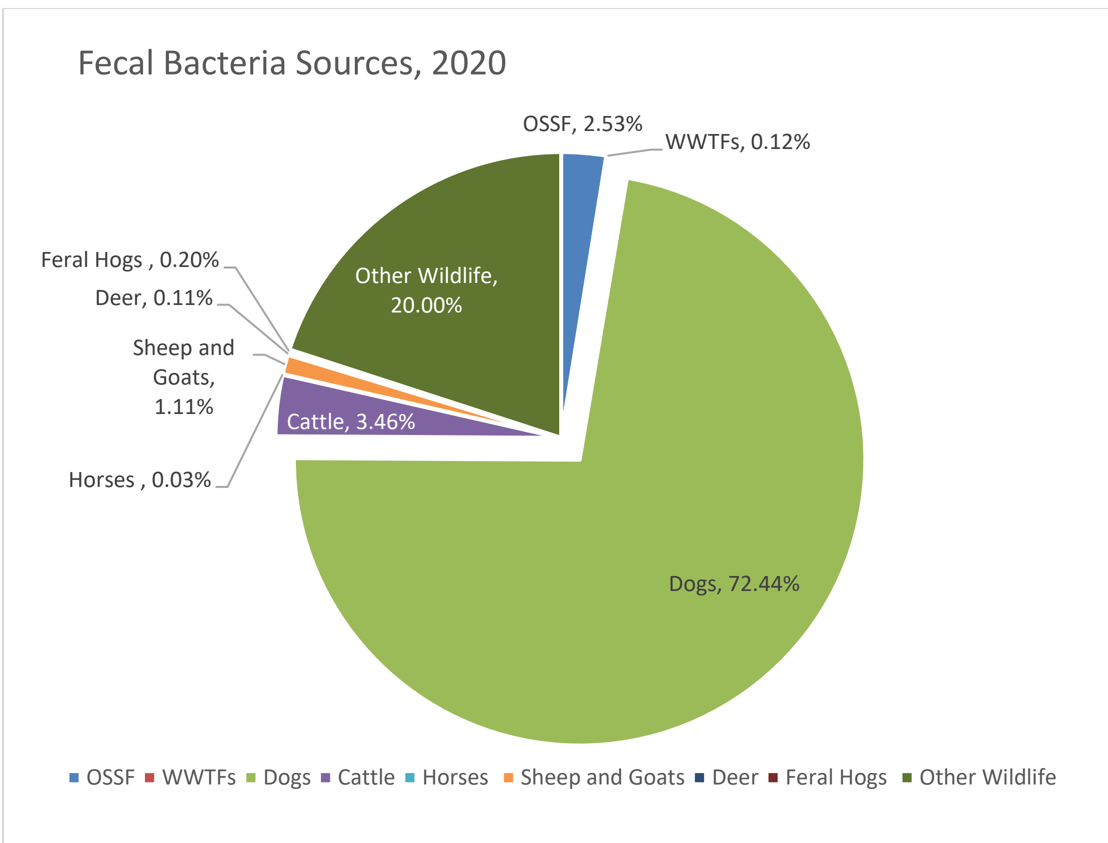

Figure 61 - Fecal Bacteria Source Profile, 2020

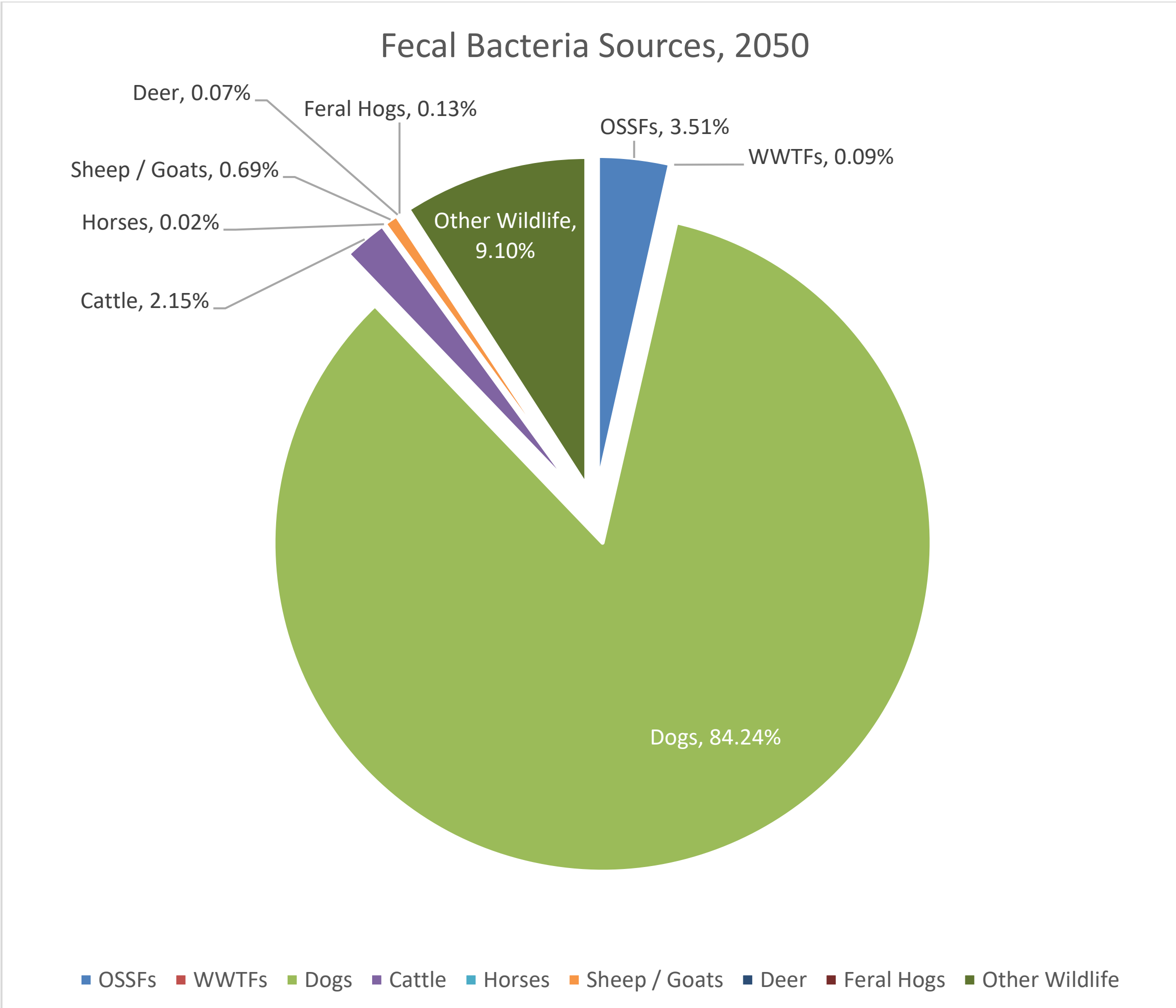

Figure 62 - Fecal Bacteria Source Profile, 2050

6.0 Outcomes and Implications of the Analyses

Overview of Outcomes

The implementation of the LDCs and SELECT analyses were able to address the project needs regarding fecal waste pollution established in Section 6, and the final results were affirmed by the stakeholders after an extended round of feedback and revision. In general, the results indicated a varying level of reduction needed through the project area, and a slightly shifting mix of sources over the planning period, but with dog waste dominating the source mix. Stakeholder feedback was a primary deciding factor for source review, assumption development, model development, and revision of results. However, in all cases, stakeholders relied on best available data as a starting point, with anecdotal evidence being used primarily to shape understanding of conditions and refine aspects of the analyses to best fit local conditions. The final step in the modeling effort was to link the reduction targets established in the LDC analyses to the source loads generated in the SELECT analyses to create source load reduction targets. This modeling project utilized some novel approaches in its SELECT phase (e.g., overall other wildlife assumption, reduction of dog waste due to pet waste bag usage) based on extensive consideration with stakeholders. We consider these to be the most defensible options for reducing uncertainty and in the spirit of previous conversations regarding the balance of modeling to the project need. Stakeholders felt strongly that additional microbial source tracking data, especially at key locations in the watershed and for priority sources (human, dogs), would greatly benefit the understanding of the relationship between source load and instream concentrations.

While DO was not identified as having numeric improvement goals at each individual LDC site, it should be noted that the results may not completely account for full daily or seasonal variability of DO levels. However, this is buffered to some degree by the focus on multi-benefit solutions already expressed by the stakeholders. As with similar WPPs, many of the potential solutions for the Clear Creek WPP will likely address elevated nutrients while addressing fecal waste, and thus positively impact the extent of precursors to low DO conditions. Additionally, while DO modeling was not conducted for this project, stakeholders are not enjoined in any way from implementing solutions that would improve DO.

Model Linkage

SELECT was used to generate potential source loads and characterize the source profile. The percent reduction targets developed under the LDCs were applied directly to the source loads to generate the source load reduction targets. This process was developed with H-GAC and TCEQ project staff and reviewed and accepted by the stakeholders. No granular fate and transport modeling was completed for this project. Instead, the linkage relies on the assumption of a linear relationship between source loads and instream conditions. The percent reduction from the LDCs, rather than absolute number of fecal bacteria to reduce, is used for the linkage. While real world conditions may not always follow a true linear relationship, there were several factors that help reduce the uncertainty for this model approach: 1) the implementation of a buffer for this SELECT analysis helped to conceptually account for the fate and transport of source loads outside the riparian areas; 2) the level of precision provided by further fate and transport modeling was expected to be beyond the level of information needed for the decisions facing the stakeholders; 3) this approach mirrors other WPP efforts in the state and region; and 4) the focus on accessible, efficient modeling based on decision-making needs was established between H-GAC, TCEQ, and the stakeholders at the start of the project. While this approach includes a level of uncertainty because of factors the models do not consider (die-off and regrowth, filtration, etc. as part of transmittal of runoff from source to stream), the primary use of the outcomes will be to guide implementation. In a densely populated watershed, for a project life of over a decade, and with implementation likely to be adapted as things progress, the outcomes were sufficient to set the general source reduction goals. Additional fate and transport modeling would add precision to estimates but would not likely be of much additional benefit to the stakeholders in their preliminary selection of BMPs, etc., and would still be subject to the same underlying level of uncertainty in source estimation. The estimation of future reductions was based on including any increase in load to the current conditions' reduction (i.e., assuming assimilative capacity of the waterway was an average constant).

Fecal Bacteria Reduction Targets

With the model linkage established, calculating fecal bacteria reduction targets required that the stakeholders consider three other primary questions: 1) what milestone year would reduction targets be based on; 2) would targets be watershed wide, or specific to certain areas; and 3) how would reductions be spread out among the fecal bacteria sources?

Milestone Year

WPPs typically are written for a 5-15-year basis. The existing projections developed during the SELECT analyses allowed the stakeholders to target any of the five-year milestone dates between 2020 and 2050. However, the further out the projections went, the greater the uncertainty. In deciding on a target milestone year, the stakeholders balanced the need to set near term, achievable goals within a period of relative certainty, and the need to account for future growth projected for the watershed. A 5-year plan would not adequately address the appreciable increase in loads through 2050, whereas a more long-term plan would have to rely on less certain predictions[44]. Project staff proposed 2035 as a compromise, allowing a long-term focus to account for watershed change, while focusing on meaningful interim action. For a WPP approved in 2023, this would represent a 12-year plan life.

Target Areas

The LDC sites were intended as the focus of long-term attainment; ongoing CRP data would form the bulk of water quality monitoring to determine WPP effectiveness. As noted in the SELECT and LDC analyses, the areas of the project watershed are varied in terms of reduction need and developmental character. Therefore, project staff developed reduction goals for each subwatershed (with the exception of subwatershed 4, which is included in subwatershed 3.) The broken-out reductions in Table 30 reflect the assessed tributaries areas segments of the system. In development of the WPP itself, the stakeholders may wish to further group these subwatershed into broader attainment areas of similar character, as has been done in other projects.

---

[44] This should not be taken to indicate a failure of the modeling methodology, but a reflection of the potential for unaccountable change the further out a model is used to predict conditions.

Allocating Reductions

The fairly stable mix of sources present in the watershed, even with a slight shift of relative contribution through 2050, provided several options on deciding how best to meet reduction targets by allocating the reduction amounts among various sources. Stakeholders considered several options, including: 1) targeting all sources proportional to their contribution (e.g., if in 2035 source X made up 30% of the total load, then 30% of the reduction value would be met by addressing that source.); 2) allocating reduction subjectively based on potential solutions; and 3) allocating reduction based on current relative contribution (rather than 2035). The stakeholders will decide on a final approach as part of the development of the WPP.

Based on these considerations, project staff generated reduction targets for each subwatershed. Table 20 indicates the overall reduction targets for each of the attainment areas and the linkage of the reduction target percentages to the source loadings to generate the target source load reductions for current and 2035 milestone years.

Table 30 - Source Load Reduction Targets by Subwatershed

Subwatershed(s)	LDC Reduction (current)	Current Source Load	Current Source Load Reduction Target	Incremental load 2020-2035[45]	2035 Source Load Reduction Target[46]
1	51.30%	1.40E+13	7.19E+12	3.36E+12	1.06E+13
2	63.50%	2.75E+12	1.74E+12	-8.93E+10	1.66E+12
3,4	65.00%	2.43E+12[47]	1.58E+12	4.90E+11	2.07E+12
5	55.00%	3.62E+12	1.99E+12	-3.04E+09	1.99E+12
6	57.90%	8.39E+12	4.85E+12	-1.70E+11	4.69E+12
7	68.30%	5.18E+12	3.54E+12	2.76E+12	6.30E+12
8	66.20%	3.89E+12	2.58E+12	2.64E+12	5.22E+12
9	69.90%	2.28E+12	1.59E+12	5.75E+11	2.17E+12

[45] The incremental load represents the difference between the 2035 load and the 2020 load. See the next footnote for explanation of its use in generating 2035 source reduction load target.

[46] The 2035 reduction target is generated by through the equation $C_r+(F_l-C_l)$; where C_r= current source reduction load, F_l = future total source load, and C_l = current total source load. In essence, the incremental load generated between 2020 and 2035 is added to whatever existing reduction load exists in 2020. This approach is used because LDCs cannot estimate future reduction percentages, and because it is assumed the waterway will not have additional assimilative capacity in 2035.

[47] Current source load is generated by summing the source loads for the subwatersheds within the attainment area.

10	60.70%	7.41E+12	4.50E+12	3.41E+11	4.84E+12
11	24.50%	4.88E+11	1.20E+11	4.93E+11	6.13E+11
12	84.80%	3.63E+12	3.08E+12	-1.54E+11	2.93E+12
13	81.20%	2.42E+12	1.97E+12	1.54E+11	2.12E+12

Implications of Findings

The findings of the fecal bacteria modeling efforts for Clear Creek reinforce the image of a developed watershed with some remaining rural, agricultural, and undeveloped areas rapidly transitioning to developed land use. 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. Developmental changes will reduce legacy agricultural sources in some areas, especially the Headwaters attainment area. The loss of load from agricultural activities will be outweighed by the increases of sources derived from developed areas. Regardless, the Clear Creek system remains a popular recreational area and tributary to the economic powerhouse of Galveston Bay. As such, its water quality has a tangible impact on the communities of the area.

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, although there was a strong preference for future microbial source tracking data. Further refinement of results may be needed in the future in light of changing conditions. While fecal bacteria source tracking was 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.

Figure 63 - Paddling Launch Area on Clear Creek