Bacteria Modeling Report

for the West Fork San Jacinto River and Lake Creek Watershed Protection Plan

WEST FORK WATERSHEDS PARTNERSHIP

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November 29, 2017

This document was prepared by the Houston-Galveston Area Council for the stakeholders of the West Fork Watersheds Partnership, the Texas Commission on Environmental Quality (TCEQ), and the Galveston Bay Estuary Program (GBEP) of the TCEQ. This project is funded by a Clean Water Act Section 319(h) grant from the TCEQ and additional funding from GBEP.

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1.0 Introduction

To serve the development of a watershed protection plan (WPP) for the West Fork San Jacinto River (West Fork) and Lake Creek, and as part of an effort to characterize the Spring and Cypress Creek watersheds, the Houston-Galveston Area Council (H-GAC) conducted an effort to estimate the necessary reduction of fecal indicator bacteria[1] loads in project waterways, and the potential source loads of fecal waste in the corresponding watersheds. Load duration curves (LDCs) were used to establish the reduction 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 the mix potential fecal bacteria sources. The purpose of this effort was to set reduction targets and to evaluate the spatial distribution and relative prominence of individual sources and their potential cumulative impact. The results of these 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.

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 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 measure 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[2].

For the West Fork and Lake Creek WPP effort, the specific needs served by this modeling effort were to:

- Identify the flow conditions in which exceedances were occurring (LDCs);
- Determine reduction goals to ensure future water quality standard compliance (LDCs);

[1] Throughout this document and model results, references to "bacteria" should be taken to refer to *E. coli* as an indicator bacterium of fecal waste, or, in reference to loads, number of fecal bacteria as a representation of fecal waste.

[2] https://www3.epa.gov/region9/water/nonpoint/9elements-WtrshdPlan-EpaHndbk.pdf

- 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[3] (SELECT).

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

[3] More information about the modeling methodology can be reviewed in the modeling QAPP and Modeling Methodology report at http://westfork.weebly.com/project-documents.html.

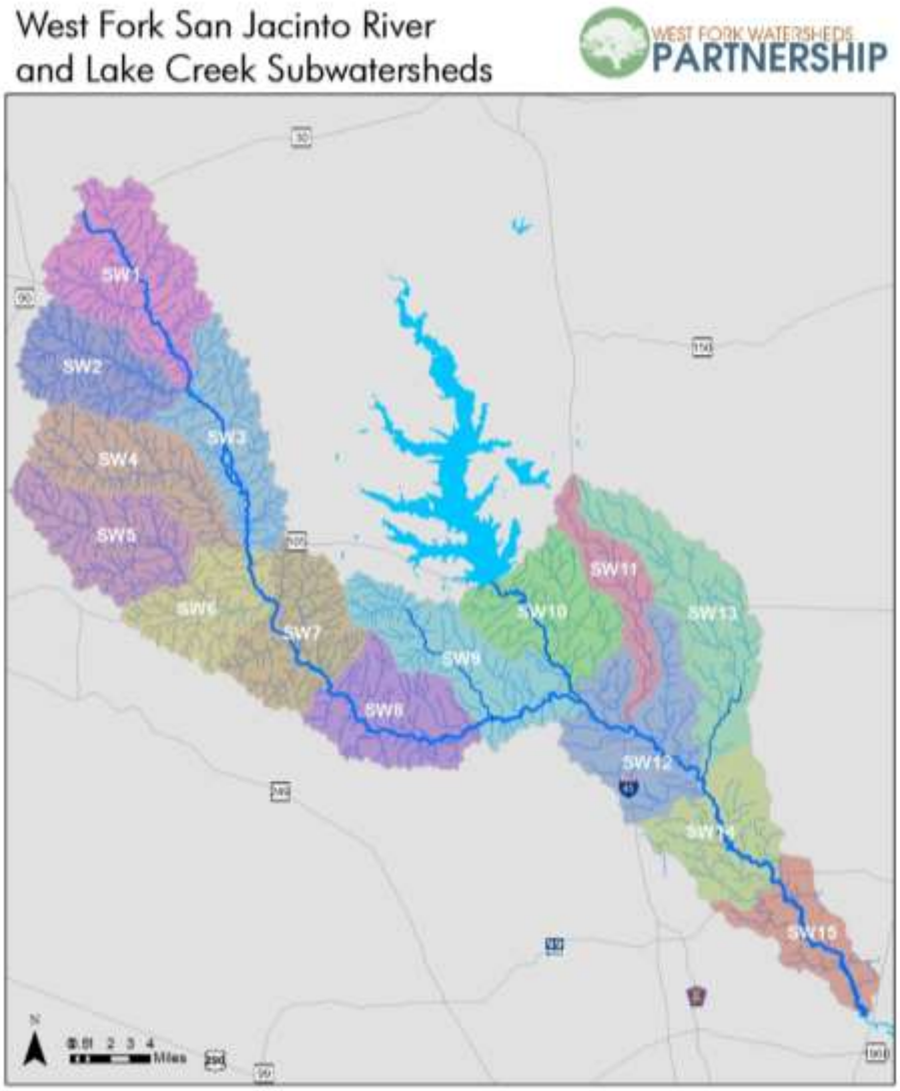

Figure 1- Project Area with Subwatersheds

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.

A key choice made early 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, 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, et al.), the degree of detail in these results is an incremental improvement in terms of support 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 conservative as possible, a modified approach to SELECT that accounts for high level consideration of transmission potential was implemented.

To account for concerns that 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. Additional disadvantages of using SELECT include the inability to fully represent wildlife contributions (due to lack of sufficient data), and a lack of any consideration of fate and transport of pollutants as they are acted on by biological and abiotic environment and forces as they move through the system. However, these disadvantages were not appreciable in a consideration of the project data needs and the intended use of the data[4].

A full explanation of the modeling selection process is included in the Modeling Methodology report for this project[5].

Analysis Design

The primary impetus for the WPP in the West Fork (Segment 1004) and Lake Creek (1015) are the water quality impairments and/or concerns listed for these segments[6]. The primary water quality issue identified as being of interest to this project are fecal waste and pathogens (as evidenced by elevated

[4] For example, lack of sufficient wildlife data is unlikely to impact BMP selection, and the modeling methodology's focus on using reduction targets from LDCs means fate and transport analysis is not necessary.
[5] A copy of which is available for review at http://westfork.weebly.com/project-documents.html.
[6] The source for impairment or concern status is the 2014 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 .

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;
- 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 USGS HUC 10 and 12 layers, adjusted to reflect conditions on the ground, to segregate tributaries, and to normalize subwatershed size. Specific implementations of the subwatershed delineation and resulting assessment area derivation is discussed in the modeling descriptions in Sections 4 and 5.

The overall intent for the design of the LDC analyses was to generate bacteria reduction targets at strategic locations in the project waterways. The end use of these targets was in their application to estimated source loads to generate reduction loads.

The design for the source load characterization with SELECT was based on identifying appropriate sources 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 2030 as the target year for compliance.

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

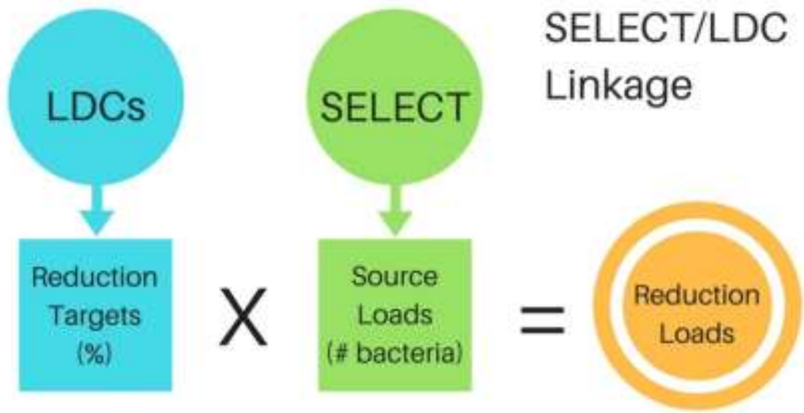

Figure 2 - SELECT/LDC Linkage

Greater 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 bacteria[8] concentrations, and establish the reduction targets needed to comply with the water quality standard.

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. Lastly, monitoring data for the contaminant of concern is multiplied by flows to produce a load duration curve, indicating 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 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

[8] As a freshwater system, all bacteria values are based on *E. coli* indicator bacteria.

exceedances, or in which contaminants exceed the allowable limit in all conditions, then a mix of point and nonpoint sources is likely.

Site Selection

Site selection for LDCs was based on support for a mix of considerations, including known water quality conditions[9], 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, and sanitary sewer overflow information, water quality in the project watersheds tends toward greater variability and higher rates of exceedance in the tributaries to the primary segments. Therefore, LDC locations were chosen to represent both the primary segments and assessed unclassified segments rather than having only one station per each watershed. A single station would not be representative of the variability of conditions based on the water quality review. This design allows for a greater degree of scrutiny of geographic variability of loads in the watershed, and an ability to more precisely target reductions. For example, a primary segment like Lake Creek (1015) may not show an impairment, but one of its unclassified segments (Mound Creek, 1015A) does. Evaluating both segments 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. The site selected to represent the main body of the West Fork is upstream of the final two subwatersheds of the system. However, the next downstream site is in the confluence with Lake Houston, and was not considered to be representative of end flows from the West Fork. Based on a review of water quality data, the current selected site (11243) is expected to be representative of conditions.

Long Term Assessment Considerations

To ensure long-term assessment and continued data, potential LDCs locations were drawn from existing Clean Rivers Program monitoring stations, which will provide ongoing data. The existing sites were found to be sufficient to characterize conditions in the waterways, as affirmed by the stakeholders. Sites were chosen in part to be able to match reductions to currently assessed segments.

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

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

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 proposed set of LDC locations, which were reviewed with stakeholders. Based on the feedback received, additional LDC locations were appended to the original proposal to provide more detailed information on Mound Creek (17937) and Crystal Creek (16635).

Based on these considerations, project staff conducted five LDC analyses, four of which would be used to generate load reduction targets[10]. The final LDC sites are indicated in Figure 3, and described in Table 1.

Table 1- LDC Locations

LDC Site	CRP Station	USGS Gauge	Assessed Area
Lake Creek	11367	NA[11]	Subwatersheds 1-8
Mound Creek	17937	NA	NA[12]
West Fork San Jacinto North	11251	08067650	NA[13]
West Fork San Jacinto South	11243	08068090	Subwatersheds 9,10,11,12,14,15
Crystal Creek	16635	NA	Subwatershed 13

[10] The first LDC, at station 11251, is intended to represent and evaluate boundary conditions, i.e. primarily the inflow from the Lake Conroe reservoir. Neither the water quality analysis nor LDC indicated any reduction was needed at this station.

[11] Stations 11367, 17937 and 16635 did not have continuous flow data specific to their waterways. Data was derived from implementing elements of SWAT to generate flow series.

[12] The Mound Creek subwatershed is part of a large modeled subwatershed, covered by station 11243. The LDC site is intended to provide guidance in siting BMPs for the Mound Creek area, which sees greater impairment than the rest of its subwatershed attainment area.

[13] This station represents boundary conditions from Lake Conroe, and is not specific to attainment modeling.

LDC Locations

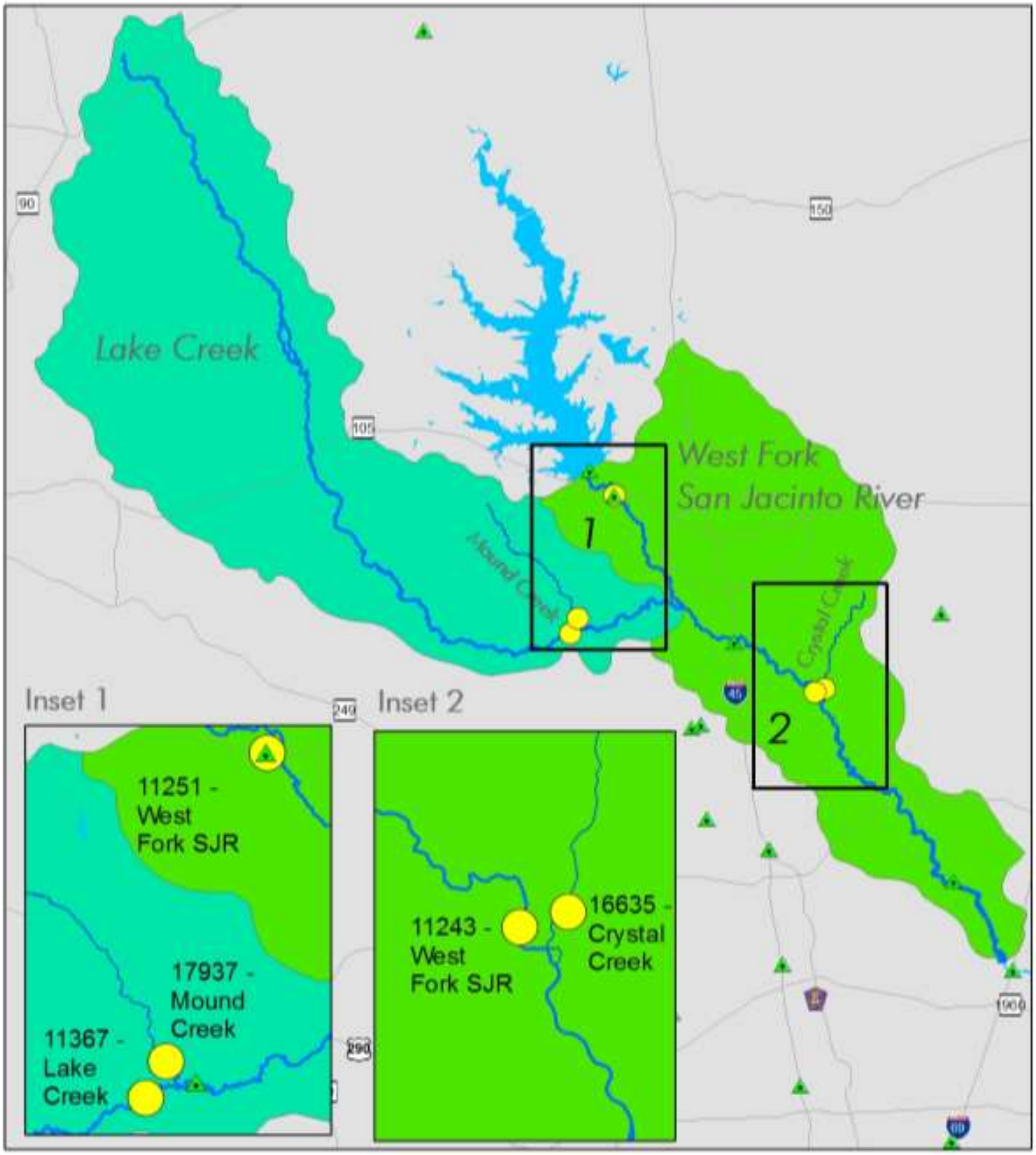

Figure 3 - LDC locations

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). The mainstem West Fork LDC sites (11251, 11243) had corresponding USGS gauges. However, the Lake Creek gauge did not have sufficient amount of flow data to generate a flow curve of similar quality. Additionally, no flow gauge is available for the Mound Creek or Crystal Creek LDC sites.

Project staff used existing flow data (grab samples from CRP monitoring events) and the SWAT model to generate extrapolated flow series sufficient to characterize these stations[14]. The modeled period included a 10-year time frame (2005-2015). Flow was generated based on best available spatial data using the same subwatershed delineations as used for the project in general.

Ambient Water Quality Data

Quality-assured ambient water quality results from CRP monitoring was available for all stations. Table 2 indicates the number of *E. coli* data points for each station. All stations had at least 7 years of data available (28+ data points), which is sufficient to develop the LDCs based on the data quality objectives of the project[15]. 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.

Table 2 - Number E. coli Samples by Station

LDC Location	Station	Number of *E. coli* Samples
Lake Creek	11367	34
Mound Creek	17937	30
West Fork San Jacinto North	11251	28
West Fork San Jacinto South	11243	45
Crystal Creek	16635	41

Subwatershed delineation is not quality-assured. While quality assured ambient water quality data was sufficient for all identified LDC sites, continuous flow data was not available at some locations. Project staff utilized elements of the Source Water Assessment Tool (SWAT) to generate flows for these locations.

[14] More information on the methodology employed to generate the flow data is discussed in the project Modeling QAPP, found at https://westfork.weebly.com/project-documents.html.
[15] Ibid.

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.

Station 11251 – West Fork San Jacinto River (North)

Station 11251 is located on the main channel of the West Fork (segment 1004) just downstream of the Lake Conroe dam, and generally represents the boundary conditions at the start of the West Fork system. There are inputs upstream of the station, but a review of potential sources with project partners and stakeholders, as well as relevant discharge monitoring reports from wastewater inputs, indicated inputs to the system were likely minimal. Due to the small amount of watershed represented by the upstream area from the station, the generally good water quality indicated at this station (and by this LDC), and the intent to treat this station as a starting/boundary condition, no specific reduction targets or related attainment area were developed for this LDC. For the purpose of assessing water quality attainment, the section of watershed upstream of 11251 is considered part of the attainment area represented at 11243, downstream.

The drainage area upstream is primarily riparian forest adjacent to the Lake Conroe dam, and some light development along a highway corridor. Figure 5 is the LDC for Station 11251, which indicates a few exceedances at varying flow conditions.

Despite occasional exceedances, the analysis of needed reductions in the five flow categories indicated no reduction was necessary (Table 3).

Station 11251

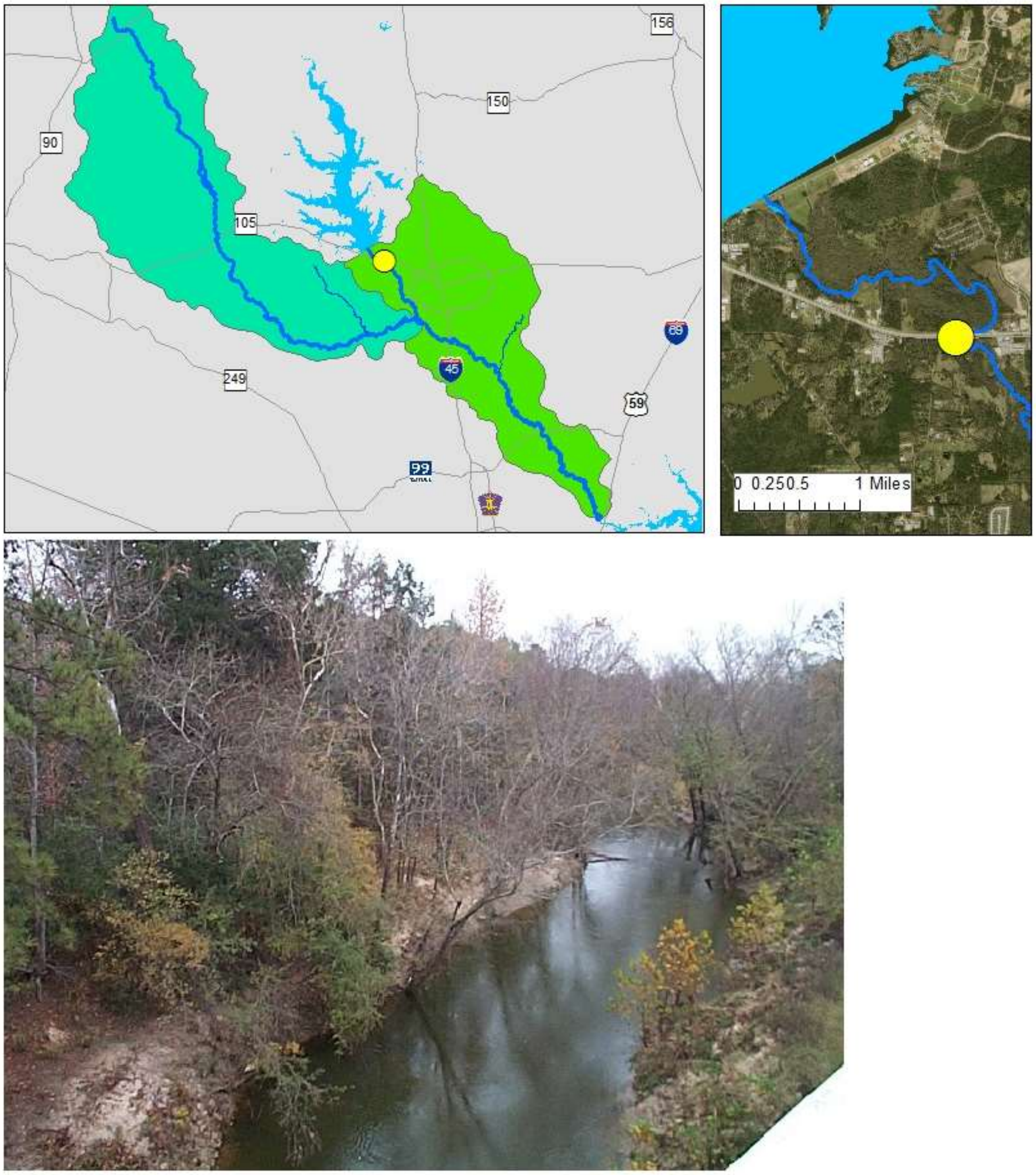

Figure 4 - LDC Site at Station 11251

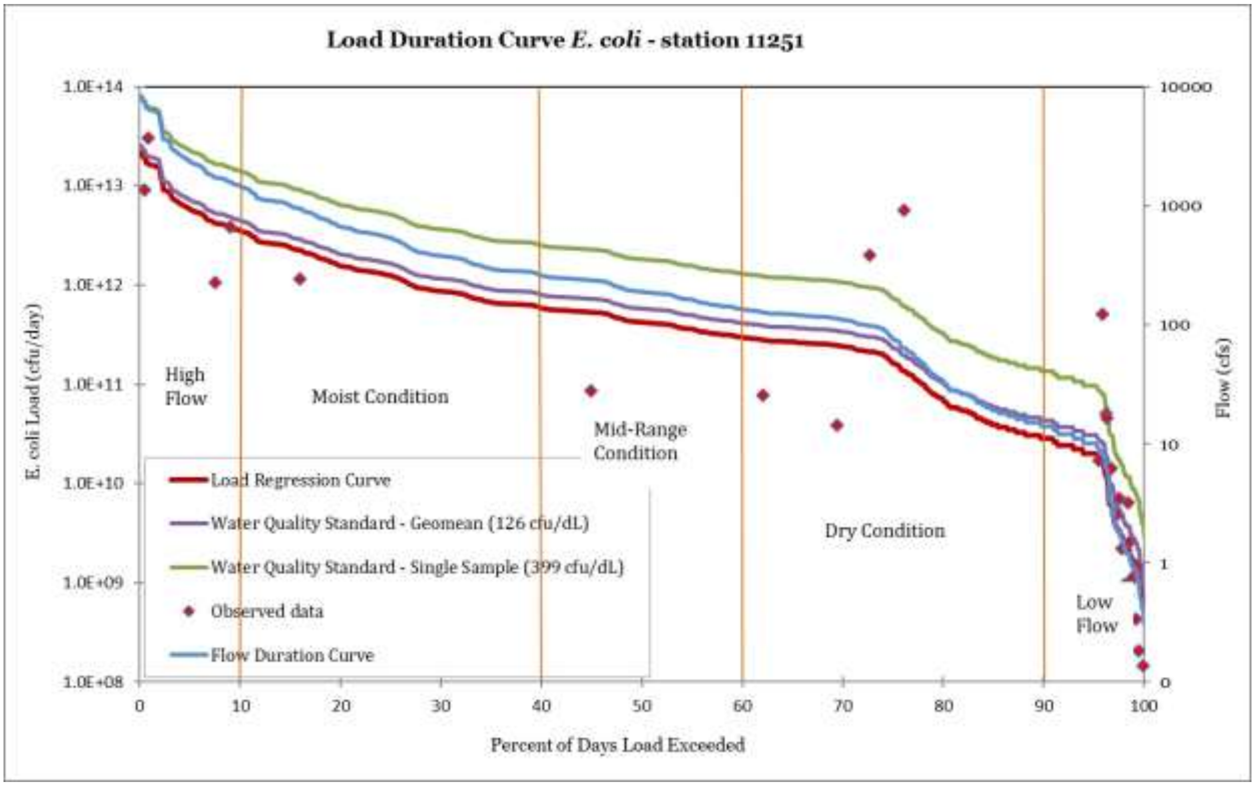

Figure 5 - LDC for Station 11251

Table 3 - Flow-specific values for LDC 11251

Flow category	Percent Exceedance (of flow)	Percent Reduction - Geomean[16]	Percent Reduction – Single Sample
High Flows	0-10%	-24	-292
Moist Conditions	10-40%	-31	-316
Mid-Range Conditions	40-60%	-37	-333
Dry Conditions	60-90%	-43	-353
Low Flows	90-100%	-57	-396

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

Station 11243 – West Fork San Jacinto River (South)

Station 11243 is located on the West Fork (segment 1004) just prior to the confluence with Crystal Creek, and is the most southerly project monitoring point on the West Fork system[17].

The watershed upstream of this station includes the influence of Lake Creek, tributaries from the urban area of Conroe, and other primary inputs to the system upstream of the confluence with Spring/Cypress Creeks to the south immediately prior to the Lake Houston confluence. A wide mix of land uses is represented, from dense urban environments, suburban development along transportation corridors, heavy commercial development along the I-45 corridor intersecting the watershed on a north-south tangent, as well as large areas of rural/undeveloped areas and the large riparian forests along the lower part of the watershed. Notable development of sand and gravel in the riparian corridor exists along the West Fork.

Figure 7 is the LDC for Station 11243, which indicates a range of conditions, with exceedances most pronounced in highest flow conditions. The analysis of needed reductions in the five flow categories indicated reductions were needed in the high flow and moist condition categories, but not in lower flow categories. This points in general to a predominance of nonpoint sources, but in such a large conglomerated system, it is hard to draw a direct relationship (Table 3). Nevertheless, between station 11251 and 11243 on the West Fork, bacteria source inputs are enough to create a reduction need, as indicated in Table 4.

[17] It should be noted that there is an appreciable amount of watershed downstream of this station. However, the next most southerly monitoring station is in the confluence of the West Fork and Lake Houston, in an area highly influenced by the Lake (Figure 6.) For the purpose of this project, it was not considered representative of the West Fork watershed in general. Additionally, the concentration of load (as demonstrated in Section 5) is closer to the upper, urban parts of the watershed, making this mid-length station more representative of the bacteria impairment. The lower aspect of the watershed includes more undisturbed riparian forest with limited crossings and access other than by boat. Therefore, while this report recognizes that it is not ideal to include downstream areas as part of the attainment area represented by LDC station 11251, the project staff and stakeholders felt it was better to take a conservative approach, erring on over-representing the upper part of the watershed. As a counterpoint to this level of uncertainty, the implementation decisions of the WPP will prioritize the subwatershed of this attainment area that indicate greater potential loads.

Station 11243

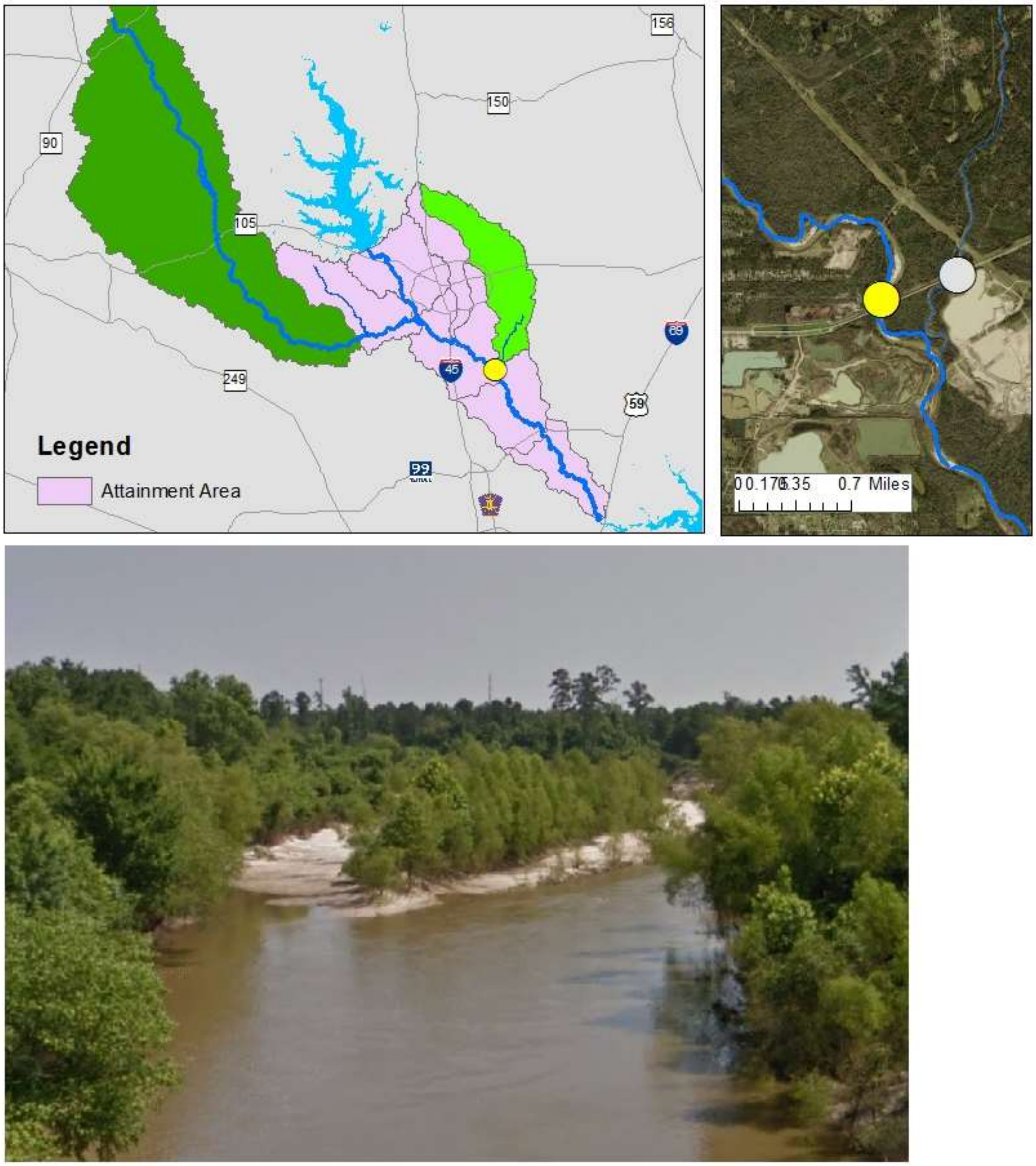

Figure 6 - LDC Site for Station 11243

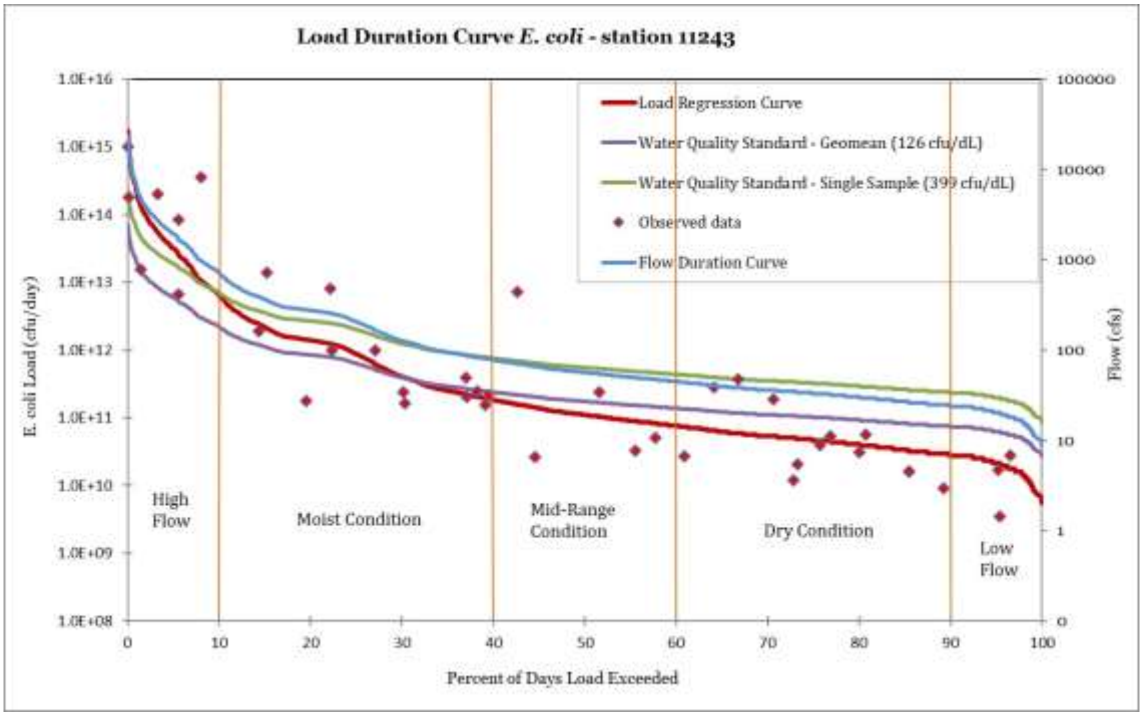

Figure 7 - LDC for Station 11243

Table 4- Flow-specific values for LDC site 11243

Flow category	Percent Exceedance (of flow)	Percent Reduction - Geomean	Percent Reduction – Single Sample
High Flows	0-10%	80	38
Moist Conditions	10-40%	20	-154
Mid-Range Conditions	40-60%	-57	-398
Dry Conditions	60-90%	-120	-597
Low Flows	90-100%	-211	-885

Station 16635 – Crystal Creek

Station 16635 is located toward the end of Crystal Creek (Segment 1004D), prior to its confluence with the West Fork. Crystal Creek drains an area ranging in a clockwise arc around the outskirts of Conroe, from north to southeast. Its headwaters include a mix of light residential, commercial and industrial areas, while its downstream areas have more undeveloped, forested land. In general, the tributary's watershed is lightly developed, although some larger industrial facilities are nearby (Figure 8).

Station 16635

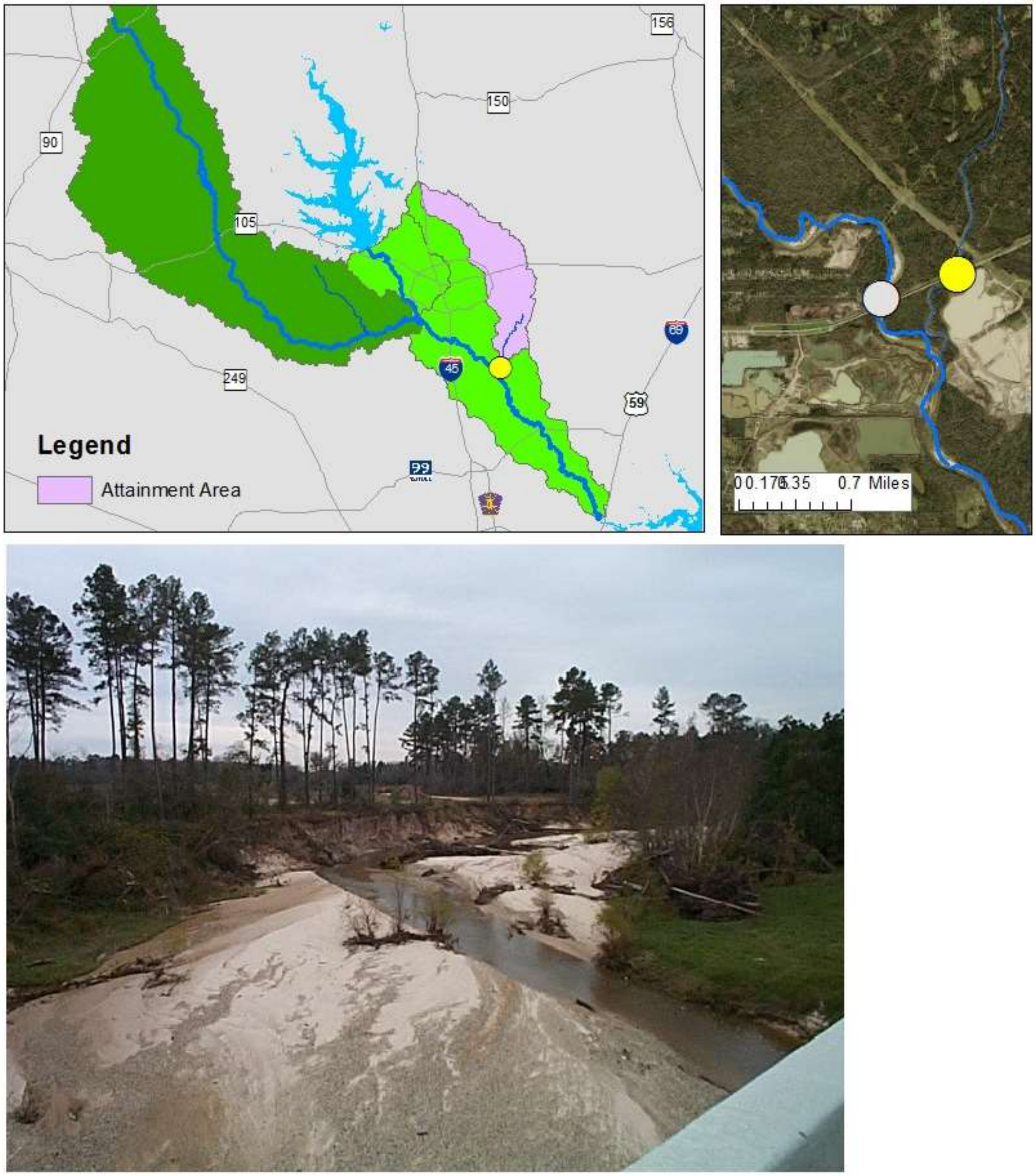

Figure 8 - LDC Site 16635

The LDC for station 16635 indicates that the waterway is generally in compliance with the water quality standard, with occasional exceedances. Only the highest flow category indicated a small need for reductions (Table 5.)

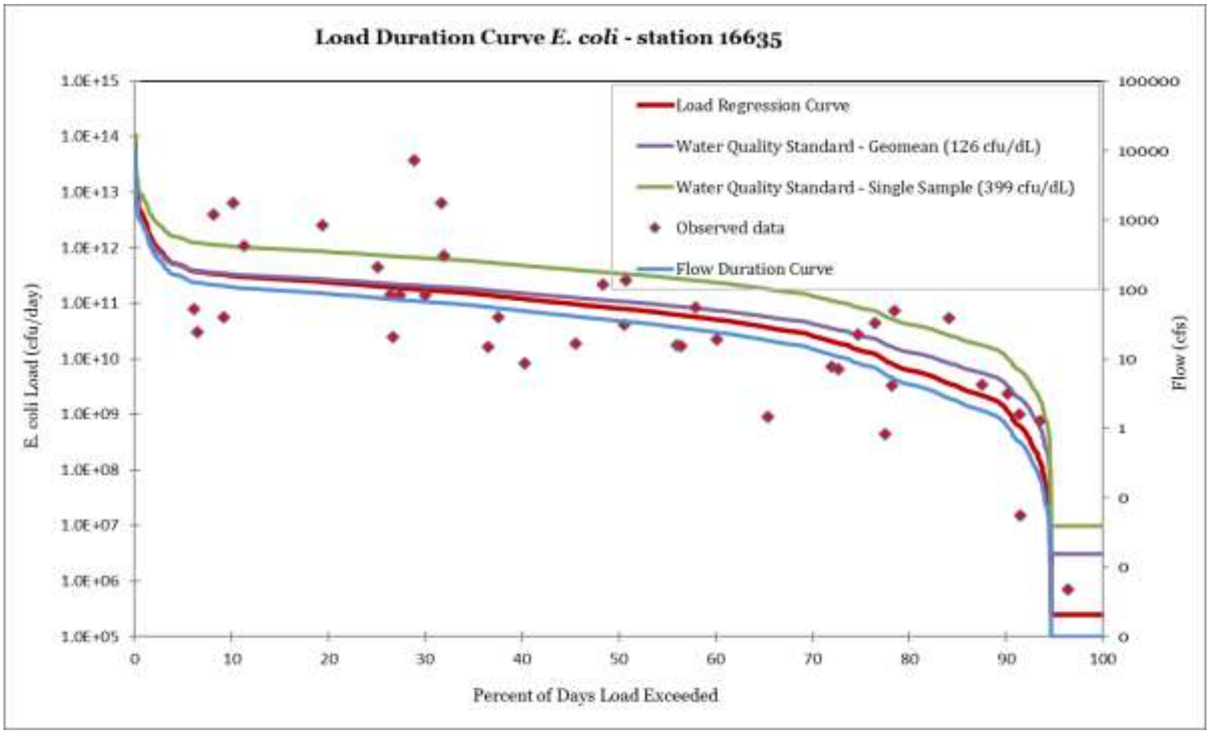

Figure 9 - LDC for station 16635

Table 5 - Flow-specific values for LDC station 16635

Flow category	Percent Exceedance (of flow)	Percent Reduction - Geomean	Percent Reduction – Single Sample
High Flows	0-10%	6	-199
Moist Conditions	10-40%	-15	-265
Mid-Range Conditions	40-60%	-35	-328
Dry Conditions	60-90%	-93	-510
Low Flows	90-100%	-740	-2560

Station 11367 – Lake Creek

Lake Creek (segment 1015) is the primary tributary to the West Fork system downstream of Lake Conroe and upstream of the confluence with Spring and Cypress Creek. A full segment in its own right, Lake Creek is characterized by a dramatic shift in land use between its rural/agricultural headwaters to the expanding suburban and exurban development in its downstream reaches. However, the most southerly monitoring station on the main stem is located prior to the confluence of Mound Creek (Segment 1015A). Therefore, the more developed areas of the Lake Creek segment are included in the station 11243 LDC site described previously, including the Mound Creek segment. The attainment area for Lake Creek proper, therefore, is primarily characterized by rural areas comprising agricultural and light residential uses (Figure 10).

The LDC for 11367 (Figure 11 and Table 6) indicates similar results to the other stations, with modest reductions needed in the higher flow conditions, and infrequent exceedances in other flow categories. Assimilative capacity in moderate flow conditions is small, and additional downstream influence of Mound Creek and more developed areas near the confluence with the West Fork may create a greater need for reduction for the segment than is represented by the project attainment area upstream of 11367. However, long-term assessment sampling is conducted at this station, so this point is the baseline for evaluating implementation progress going forward. To balance the concerns of downstream areas being diluted by their inclusion in the site 11243 West Fork attainment area, a separate LDC was completed for Mound Creek, even though it does not have a separate attainment area.

Station 11367

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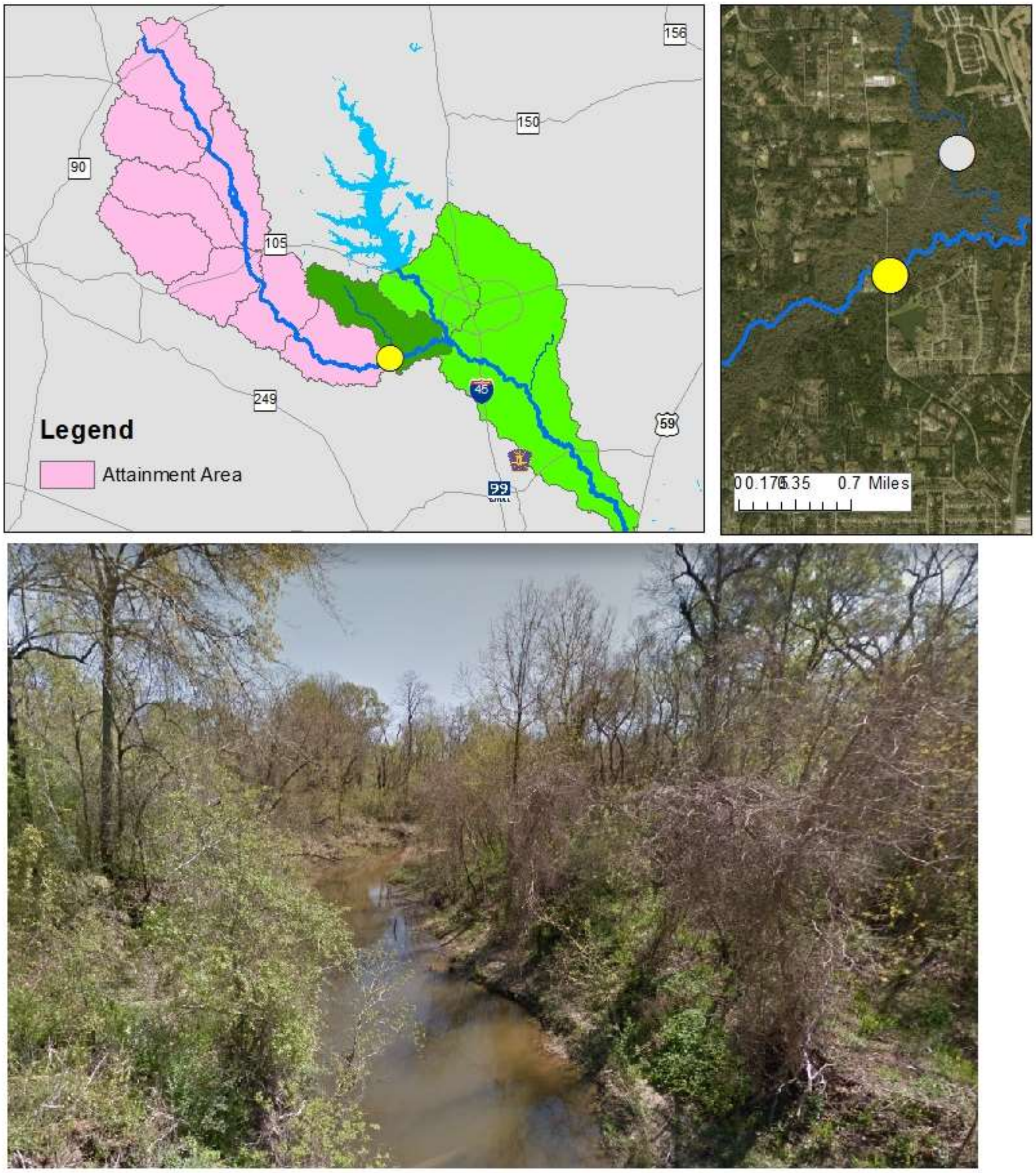

Figure 10- LDC Site 11367

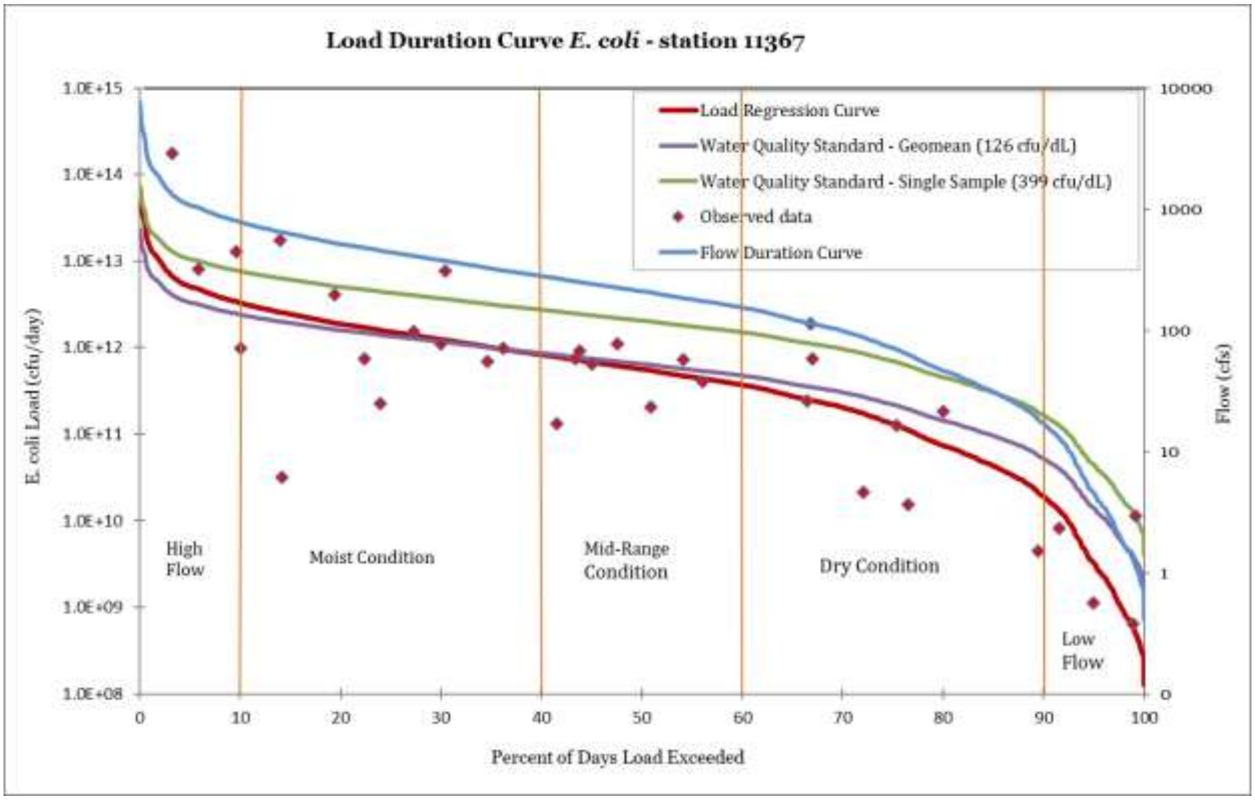

Figure 11 - LDC for Site 11367

Table 6- Flow-specific Values for LDC Station 11367

Flow category	Percent Exceedance (of flow)	Percent Reduction - Geomean	Percent Reduction – Single Sample
High Flows	0-10%	37	-98
Moist Conditions	10-40%	11	-182
Mid-Range Conditions	40-60%	-16	-266
Dry Conditions	60-90%	-78	-463
Low Flows	90-100%	-361	-1361

Station 17937 – Mound Creek

Mound Creek (segment 1015A) is the primary tributary of the Lake Creek system in the more developed southeastern reach. While Lake Creek is not listed for an impairment in the 2014 Texas Integrated Report of Surface Water Quality (Integrated Report), Mound Creek is. The stakeholders held that this is indicative of the water quality in the tributaries and lower reach where development has spread west on the major transportation corridors. Because the Mound Creek area is part of the larger attainment area that includes the West Fork proper and lower Lake Creek, it is unlikely that its internal impairment translates to a large impact to the two larger waterways into which its flow eventually enters. The disparity between monitoring locations and spatial variation in conditions led to the development of a separate LDC for Mound Creek. While the Mound Creek watershed was considered too small to be its own attainment area[18], the LDC is intended to highlight the need and scale for treating Mound Creek as a priority area. Hereafter, the Mound Creek LDC are will be referred to as the station 17937 priority area, in comparison with the other station attainment areas.

The drainage area for Mound Creek includes suburban/exurban development but also includes fairly broad riparian buffer forests and undeveloped areas along much of its length. Only near its confluence does it pass adjacent to larger developed areas and a golf course (Figure 12.)

The LDC for 17937 (Figure 13) highlights the importance of this watershed as a priority area. Unlike the rest of the project areas, which needed modest reductions, the Mound Creek LDC indicates reductions are necessary in all but the lowest flow categories (Table 7.) Additionally, these reductions are appreciably larger than in other waterways that were evaluated, including waterways of similar character and land uses like Crystal Creek.

[18] Project staff and stakeholders explored the potential to segregate Mound Creek, but the smallest existing hydrologic subdivisions for the area, the USGS HUC12s, were not granular enough (i.e. Mound Creek shares a subwatershed with other areas). When staff delineated a separate watershed for Mound Creek, the discrepancy between its size and the other project subwatersheds was detrimental to the aim to keep subwatershed size fairly uniform and comparable. The compromise proposed by project staff and accepted by stakeholders was to develop an LDC as an indicator of the scale of reductions necessary internal to Mound Creek, and then use that as a guide when siting BMPs in the subwatershed/attainment area in which it falls.

Station 17937

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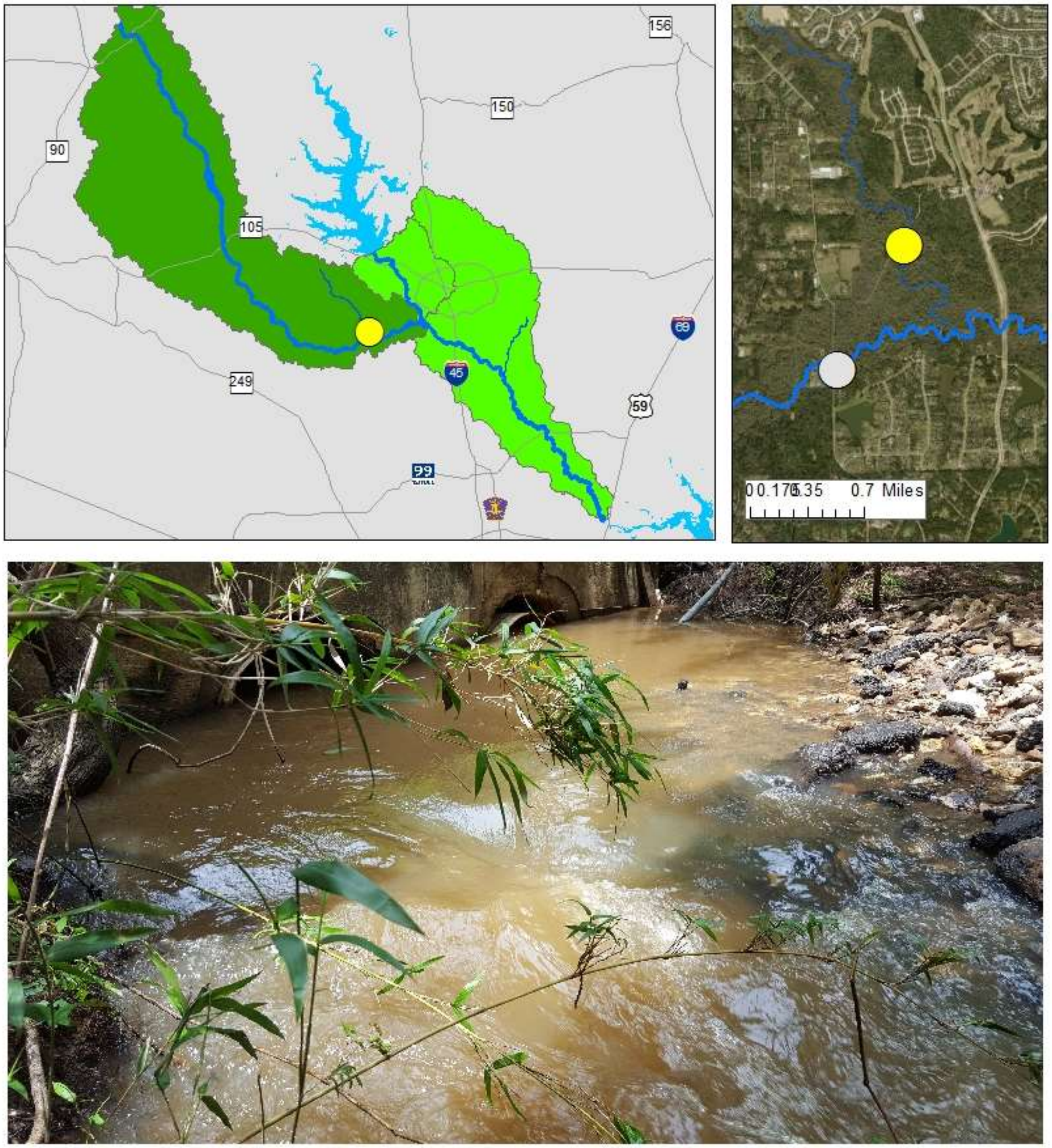

Figure 12 - LDC site for Station 17937

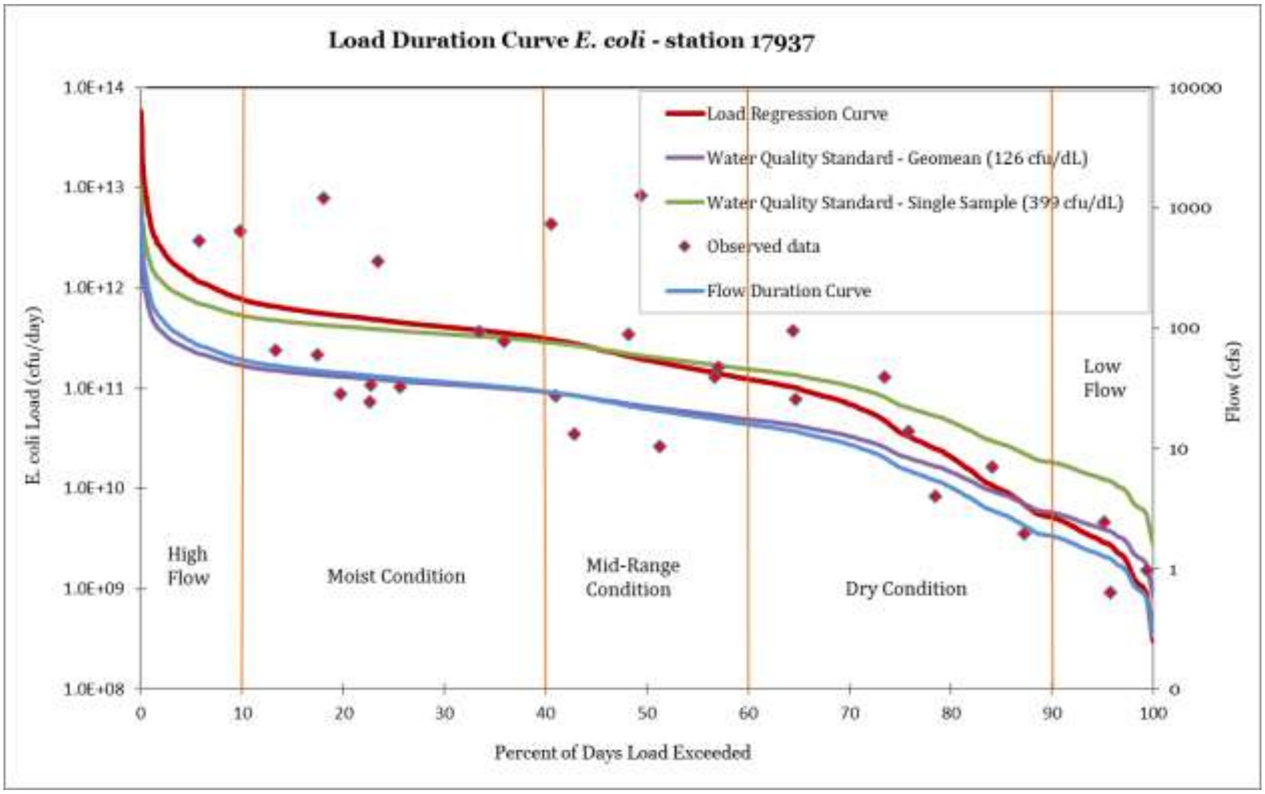

Figure 13 - LDC for station 17937

Table 7 - Flow-specific values for LDC site 17937

Flow category	Percent Exceedance (of flow)	Percent Reduction - Geomean	Percent Reduction – Single Sample
High Flows	0-10%	82	44
Moist Conditions	10-40%	74	19
Mid-Range Conditions	40-60%	66	-9
Dry Conditions	60-90%	36	-104
Low Flows	90-100%	-46	-361

LDC Summary and Bacteria Reduction Targets

The LDC modeling results were reviewed internally by project staff, and confirmed with stakeholders. After discussing the raw results of the initial round of LDCs, the Partnership decided to add the Mound Creek (17937) and Crystal Creek (16635) sites to provide a more detailed look at variability between different areas and different watershed types.

The results pointed to generally modest reductions in higher flow conditions, with the exception on the Mound Creek priority area, with its appreciable reductions across most conditions. The results presented interesting questions to answer during the SELECT analysis effort. While Mound Creek had some of the denser riparian cover and only moderate development, its reduction needs were in stark contrast to Crystal Creek, whose land uses and general character were relatively similar. Conversely, the West Fork attainment area, which receives flow from most of the denser urban area of Conroe, as well as the inputs from developing lower Lake Creek, showed an overall lower reduction need. The general hypothesis carried over into the discussion of sources and the linkage therewith, was that volume was a primary factor in assimilative capacity in this project area. More information on the linkage between the modeling efforts is discussed in Section 6.

The design for generating single target reductions for each attainment area[19] 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. For example, Station 11243 indicated a need for reductions in the two highest flow categories, but not in the other three. The most conservative approach would be to apply the greatest overall reduction to the watershed in general. The least conservative approach would be to average all flow conditions, thus diluting the reductions needed in the highest categories. The approach taken finds the flow weighted average of the two categories needing reduction, i.e. the conditions driving the impairment, and uses that as a reduction target. Table 8 represents the final bacteria target reductions for the modeled assessment areas and the Mound Creek priority area. Figure 14 represents the final attainment areas.

Table 8 - Final Bacteria Reduction Targets

Attainment Area	LDC Station	Weighted Average Bacteria Reduction Target (%)
West Fork and Lower Lake Creek	11243	35
Crystal Creek	16635	6
Lake Creek	11367	17.5
Mound Creek	*17937*	*60.4*

[19] As opposed to the modeled reduction values for each flow category.

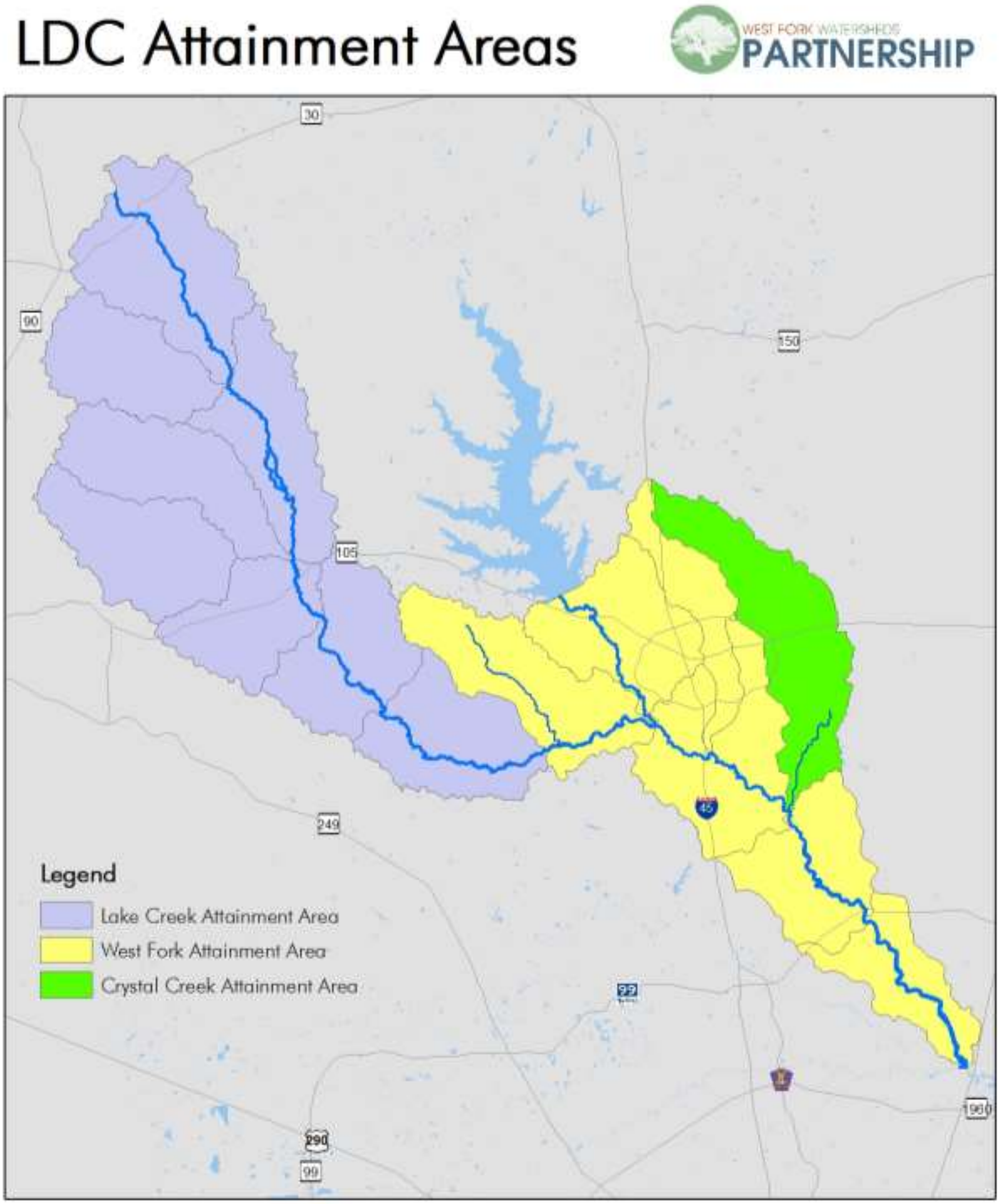

Figure 14 - LDC Attainment Areas

5.0 SELECT Analysis

Overview

The SELECT Model

The Spatially Explicit Load Enrichment Calculation Tool (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[20]. The intent of this tool is to estimate the total potential 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 bacteria load generated in a watershed (or subwatershed) based on land use/land cover, known source locations (WWTF outfall locations, OSSFs, etc.), literature assumptions about nonpoint sources (pet ownership rates, wildlife population statistics, etc.) and feedback from stakeholders. The potential source load[21] estimates are not intended to represent the amount of indicator bacteria actually transmitted to the water, as the model does not account for the natural processes that may reduce bacteria on its way to the water, or the relative proximity of sources to the waterway.

Analysis Design in the West Fork WPP 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 assumes all bacteria generated in a watershed equally. Loads generated 2 miles from a watershed 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

[20] 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.

[21] 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 fate and transport considerations.

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 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[22]. 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 watersheds of the West Fork are undergoing rapid developmental change. Current sources[23] are expected to expand in the future. Therefore, bacteria reductions based on current conditions would be inadequate to meet future needs. This implementation of SELECT uses regional demographic projection data to estimate future conditions through 2040

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

[23] References to "current" conditions refer to 2015 estimations, based on the available data at the time of the modeling effort.

in 5-year intervals[24]. Land use change is the primary driver for estimating changes in source contribution, and spatial distribution of loads[25].

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 was 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 15) 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).

[24] 2040 was chosen as a target year to coincide with the extent of the regional demographic model projections.
[25] 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/community/socioeconomic/2040-regional-growth-forecast/default.aspx) demographic model projections are widely used in the region and in similar WPPs, and thus considered the best available data for making these projections. Some wildlife sources have additional levels of uncertainty because the model assumes that change between land uses eliminates populations tied to the former land use. However, there is not adequate data or analytical approaches within the scope of this project to determine the potential that wildlife populations will change or consolidate. 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.

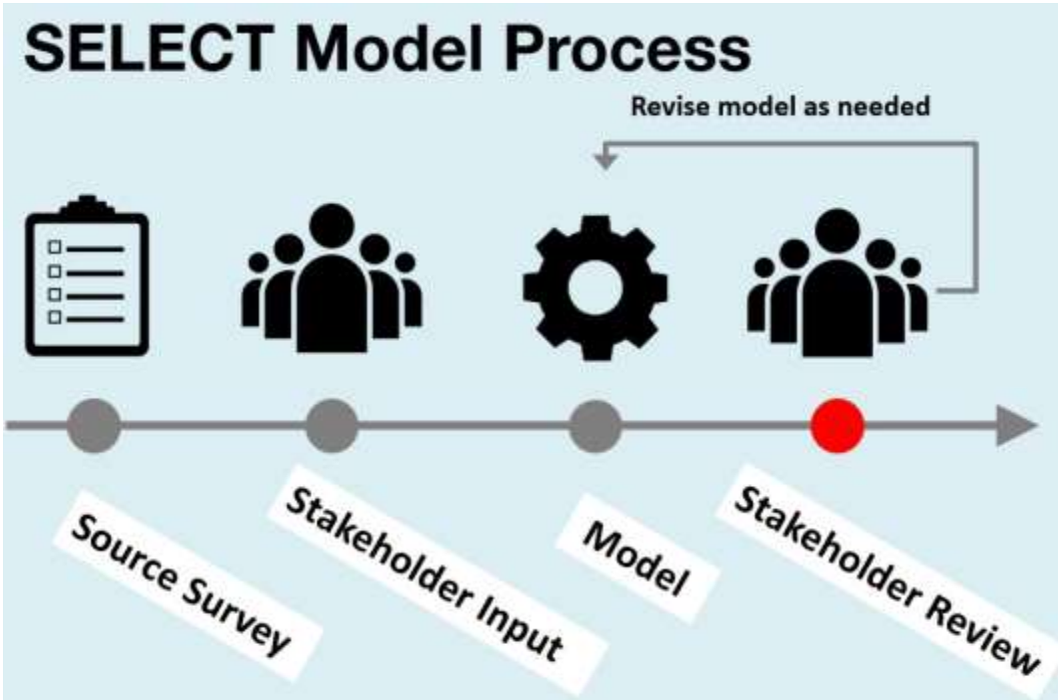

Figure 15 - SELECT Modeling Process

Source Survey

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 bacteria 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 bacteria sources in a watershed is discussed as being a source survey.

Source Survey
Characterizing fecal bacteria pollution in watersheds, and development of 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[26]:

- Known Source Characterization – Staff reviewed existing data to generate information on spatially located, (usually permitted) sources. The data sources included[27]:
    - WWTF spatial locations and discharge monitoring reports (TCEQ outfall locations and DMR records)
    - Permitted OSSF locations (H-GAC proprietary data compiled from local authorized agent data under 604(b) projects.)
    - 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 and Road Reconnaissance - Staff utilized aerial imagery, online map assets (Google Maps, Google Maps Streetview, Google Earth) 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
    - Small, unincorporated communities
    - Recreation use
- Staff also conducted ongoing road reconnaissance throughout the watershed specific to this task and as part of all activities in the watershed. Specific items noted or affirmed during road reconnaissance included:
    - Presence of deer in appreciable numbers in developed areas
    - Progress of development

[26] The cumulative results of these assessments are summarized in Table 9, and specific results are discussed in the subsections on each source later in this section.
[27] More information on data sources and quality objectives can be found in the project QAPP.

- Sign of feral hog activity in some areas
    - General character of observable agricultural activities.
- Stakeholder Feedback – Stakeholder engagement was a primary focus of the source survey. Local knowledge was a key aspect of understanding source composition in the area. Project staff engaged stakeholder consideration of sources through:
    - direct discussion of sources at Partnership meetings
    - direct discussion of sources at source-based Work Group meetings
    - 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, 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.

The results of the Source Survey are summarized by general category in Table 9. The estimated extent reflects preliminary understandings, rather than the modeled outcomes. 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 bacteria per day, using scientific notation[28].

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

Table 9- Bacteria Source Survey

Category	Source	Origin	Estimated Extent
Human Waste	OSSFs	Failing/improperly routed OSSFs	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	Moderate
	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[29]	Feral hogs	Runoff or direct deposition	Moderate
	Deer	Runoff or direct deposition	Minor to moderation (locally)
	Birds	Direct deposition	Not expected, no data.
	Bats	Direct deposition	Minor, no data.
	Other wildlife[30]	Runoff or direct deposition	No data.
Other Sources	Dogs (pets)	Runoff	Moderate
	Dogs (feral)	Runoff	Minor to moderate (locally)
	Cats (pets)	Runoff	Not expected
	Cats (feral)	Runoff	Not expected or minor
	Dumping	Runoff or direct deposition	Minor (locally)
	Sediment	Erosion or mining operations	NA[31]

[29] 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.

[30] 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).

[31] Significant mining operations and erosion is present in many places in the watershed. 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 bacteria, and are the prevailing wastewater solution for large areas of the watersheds, including new development. Montgomery County areas have seen rapid increases in OSSFs as larger lot development has pushed north from the greater Houston area. While OSSFs in the area are generally newer and more closely regulated than in some areas of the region, the ubiquitous use of OSSFs in the area and the inherently distributed maintenance for those system is a concern for future water quality as systems begin to age. Most of the systems in the watershed area are aerobic type, with some legacy septic tanks and other system types.

Permitted OSSF data was taken from existing spatial data compiled by H-GAC from authorized agents[32]. Assumptions for unpermitted OSSFs are based on a review of occupied parcels outside of sanitary sewer boundaries for which no permitted OSSF exists. It was assumed that these parcels contained an unpermitted OSSF. Loading rates are based on output from failing/improperly maintained systems. Project staff discussed failure rate with Montgomery County and the San Jacinto River Authority, the primary authorized agents for the area, as well as the Partnership and Human Waste work group. Based on the stakeholder knowledge of system status in the watershed, their experienced violation rates, and best professional judgement, a 15% 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 2040.

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. 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 not expand appreciably. 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 16 shows the current loading distributions for OSSFs in the watersheds. Figure 17 indicates the change in loading over time, through 2040. Table 10 indicates the actual OSSF source loading estimates by subwatershed.

[32] 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.

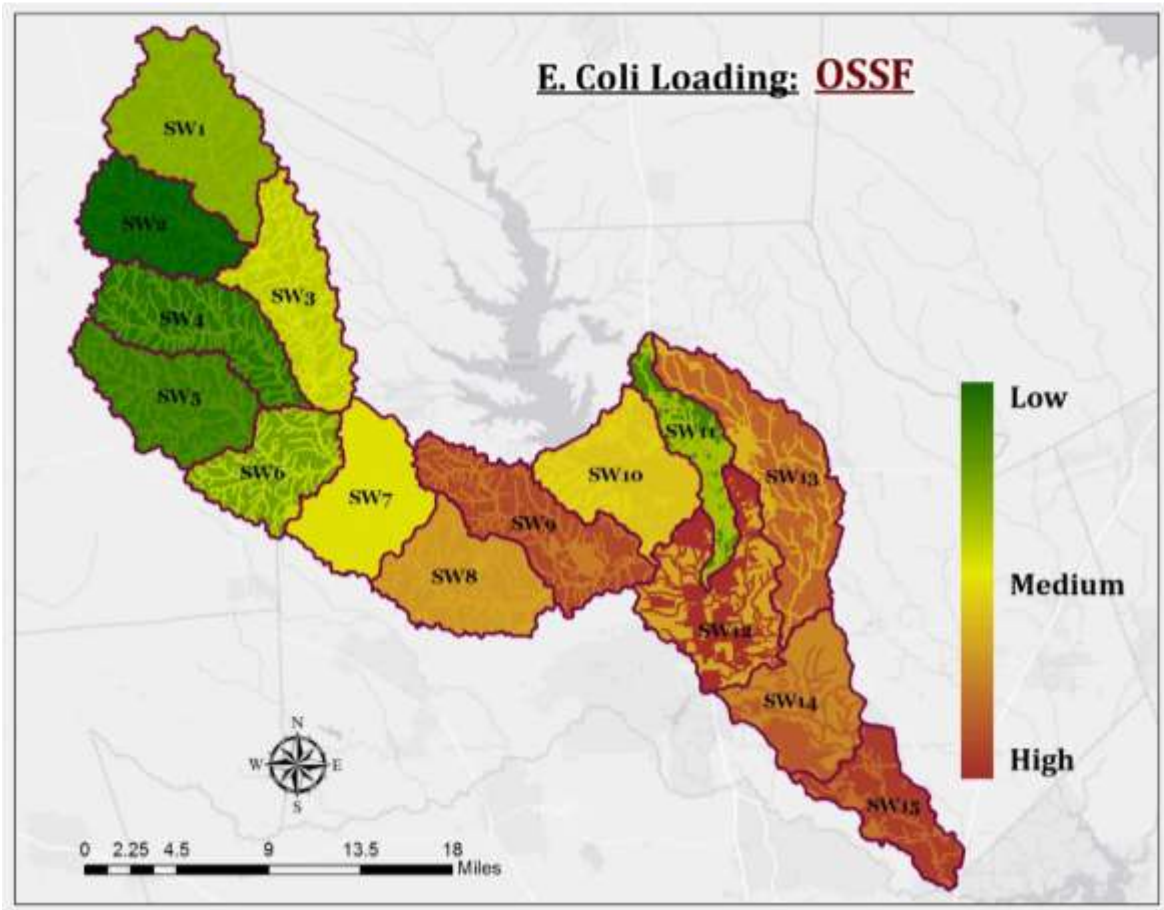

Figure 16 - Bacteria Loading from OSSFs, by Subwatershed

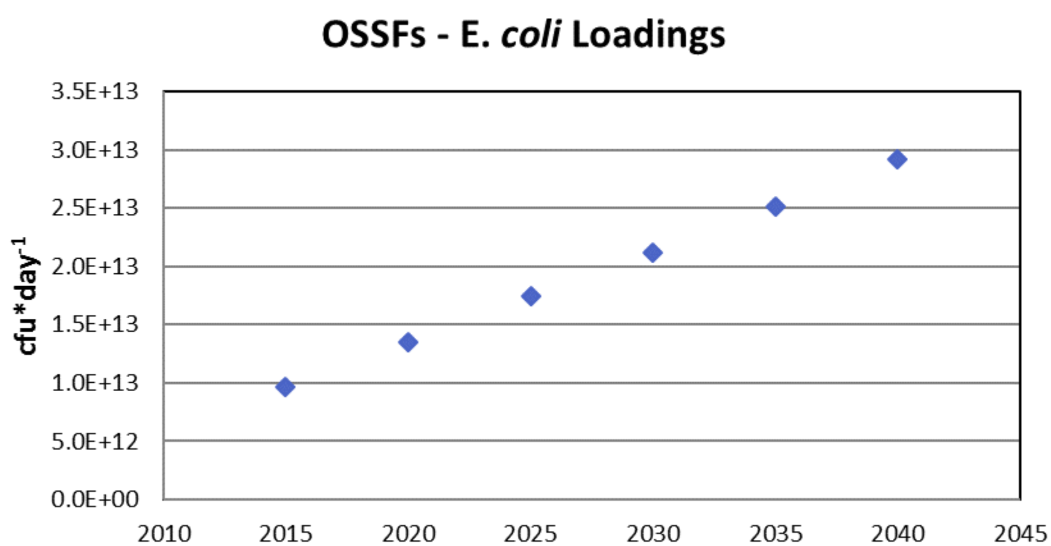

Figure 17 - Future Bacteria Loadings from OSSFs

Table 10 - Current Potential Bacteria Loads from OSSFs by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of OSSFs	Outside Buffer	395	127	568	208	226	372	929	3553
	Within Buffer	113	49	236	92	80	147	372	808
E. coli Loading	Outside Buffer	5.50E+10	1.77E+10	7.90E+10	2.89E+10	3.14E+10	5.18E+10	1.29E+11	4.94E+11
	Within Buffer	6.29E+10	2.73E+10	1.31E+11	5.12E+10	4.45E+10	8.18E+10	2.07E+11	4.50E+11
Subwatershed % of total load		1.0%	0.4%	1.9%	0.7%	0.7%	1.2%	3.0%	8.4%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of OSSFs	Outside Buffer	5329	1911	298	3209	4122	3604	6248	**31099**
	Within Buffer	992	503	133	3220	648	1112	1007	**9512**
E. coli Loading	Outside Buffer	7.41E+11	2.66E+11	4.15E+10	4.46E+11	5.73E+11	5.01E+11	8.69E+11	**4.33E+12**
	Within Buffer	5.52E+11	2.80E+11	7.40E+10	1.79E+12	3.61E+11	6.19E+11	5.60E+11	**5.29E+12**
Subwatershed % of total load		11.4%	4.8%	1.0%	19.8%	8.3%	9.9%	12.7%	**9.62E+12**

As indicated in Figure 17, OSSF loadings are expected to increase appreciably by 2040. The rapidly changing land uses of the watersheds, especially along the major transportation corridors, is driving the increase in systems. The somewhat unusual heavy reliance on OSSFs, including in master-planned and new suburban communities in Montgomery County, is a local factor influencing the large growth in systems. Balancing this increase, Montgomery County's robust approach to system management and enforcement is expected to continue to keep failure rates relatively low. High property values in many of the new development areas utilizing OSSFs is also expected to keep failure rates for aging systems partially in check.

WWTFs

Permitted wastewater utilities primarily serve the core urban areas in the watershed, including the City of Conroe and many of the core suburban areas. There are 51 WWTF outfalls in the WPP area, representing 49 unique WWTFs[33]. Only four of the plants are industrial, the rest are domestic. The plants range in size from 10 MGD to discharges less than 0.01 MGD. DMR data indicates exceedances of permit limits for bacteria are not common, and do not show a strong relationship to season or plant size.

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[34]. To estimate loadings, the total permitted flows for each subwatershed were multiplied by the 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 proportional to projected household increase within the existing service area boundary.

Table 11 indicates the actual WWTF source loading estimates by subwatershed. Figure 18 shows the current loading distributions for WWTFs in the watersheds. Figure 19 indicates the change in loading over time, through 2040.

Table 11 - WWTF Outfalls and Loadings, by Subwatershed

Subwatershed	Outfalls	Loading
1	1	1.19E+07
2	0	0.00E+00
3	0	0.00E+00
4	0	0.00E+00
5	1	5.96E+07
6	0	0.00E+00
7	1	4.77E+08
8	7	7.06E+09

Subwatershed	Outfalls	Loading
9	5	3.53E+09
10	5	2.79E+10
11	0	0.00E+00
12	12	1.60E+10
13	7	4.37E+09
14	7	9.99E+09
15	5	1.14E+10
Total	**10**	**8.08E+10**

[33] 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.
[34] 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.

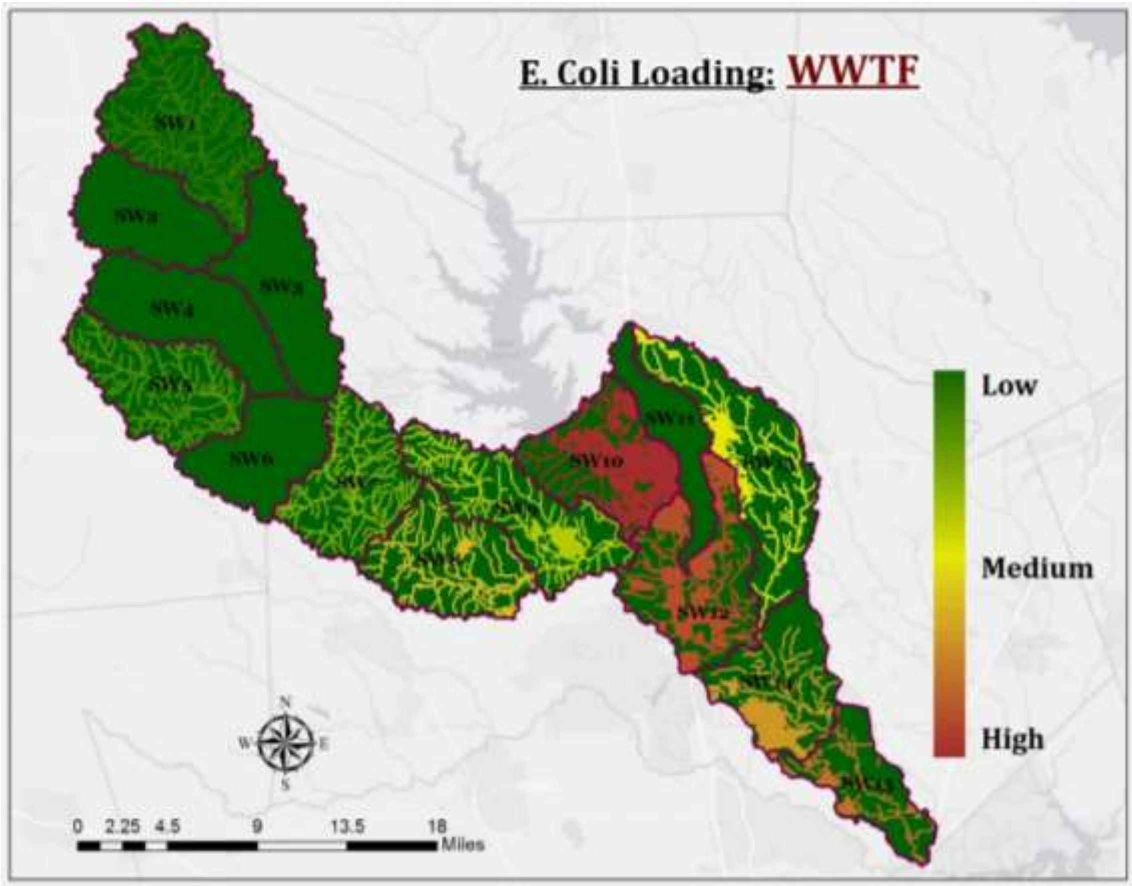

Figure 18- Bacteria Loadings from WWTFs, by Subwatershed

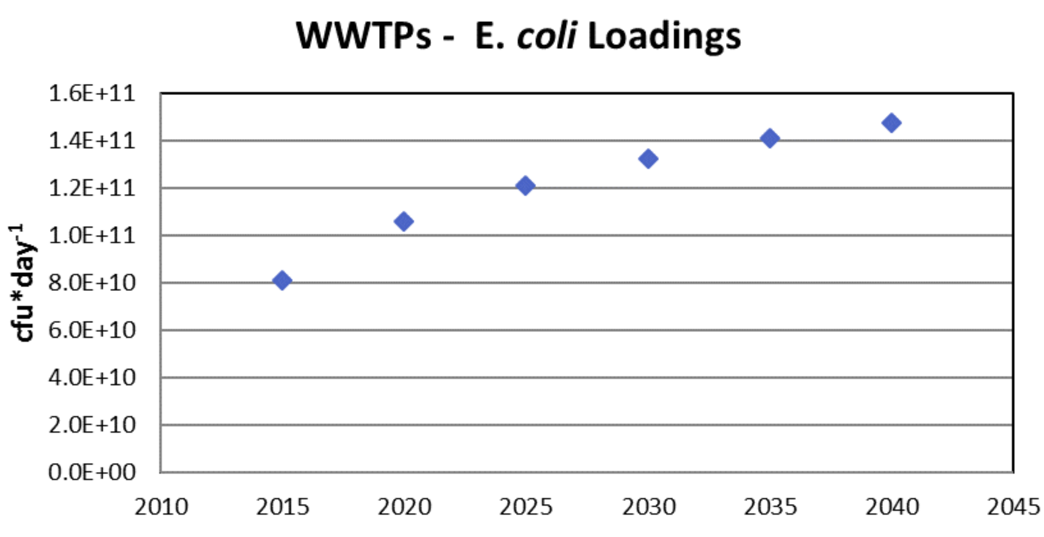

Figure 19 - Future Bacteria Loadings from WWTFs

WWTF flows and loadings increase through 2040, but they remain a minor contributor to overall potential loading.

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, 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[35].

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. All SSOs related to a WWTF and receiving stream segment in the watershed area[36] were used to characterize this source. Loading values were based on a consideration of the causes identified for SSOs in the watershed, which were primarily dilute (rainwater charger releases) or moderate. Concentrations of bacteria can vary greatly based on the composition of sewage at the time of the SSO. EPA literature values[37] 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 stems from their (usually) episodic nature. SSOs in the watershed areas were not generally found to be chronic loads, but rather, episodic in nature. Therefore, their acute 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 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 use the latter approach. The intent was to focus on any identified problem areas as localized, acute sources to prioritize for remediation in the WPP. Figure 20 shows the current loading distributions for SSOs in the watersheds. Figure 21 indicates the change in loading over time, through 2040.

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[35] More information on the character and distribution of SSOs is available in the project Water Quality Data Collection and Trends Analysis Report at https://westfork.weebly.com/project-documents.html

[36] While collection systems can straddle boundaries, and WWTFs outside the watershed may have systems partially within it, staff review of spatial distribution of plants in the surrounding area did not lead to an expectation that this was the case in this project area.

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

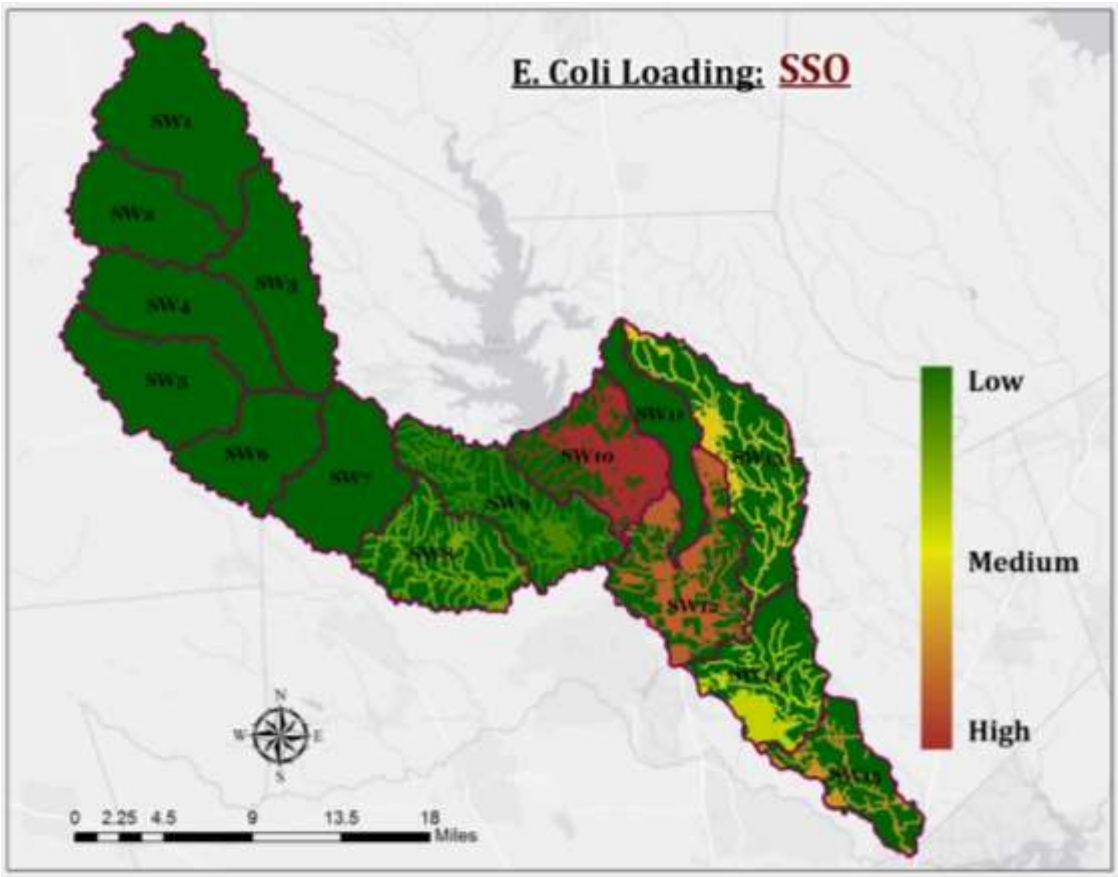

Figure 20 - Bacteria Loading from SSOs, by Subwatershed

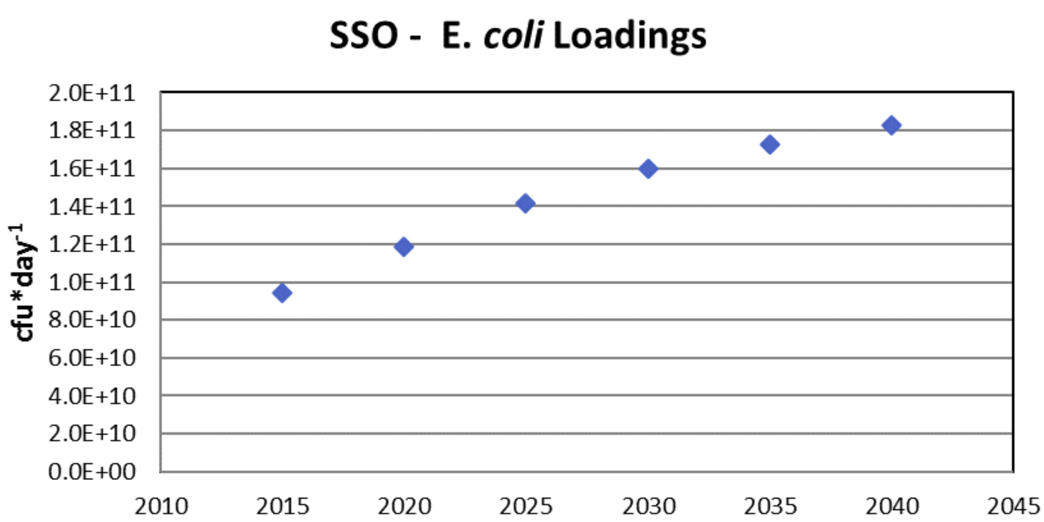

Figure 21 - Future Bacteria Loadings from SSOs

Table 12 indicates the actual SSO source loading estimates by subwatershed.

Table 12 – Current Potential Bacteria Loadings from SSOs, by Subwatershed

Subwatershed	SSOs	Load
SW1	0	0.00E+00
SW2	0	0.00E+00
SW3	0	0.00E+00
SW4	0	0.00E+00
SW5	0	0.00E+00
SW6	0	0.00E+00
SW7	0	0.00E+00
SW8	8	6.95E+08
SW9	5	2.02E+08
SW10	28	7.71E+10
SW11	0	0.00E+00
SW12	20	5.60E+09
SW13	10	3.12E+09
SW14	7	2.59E+09
SW15	17	4.93E+09
Total	**95**	**9.42E+10**

As shown in Figure 21, while SSOs are currently a minor source of 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; 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).

Cattle

Cattle production has been historically present in the more rural areas of the watersheds, and is currently concentrated in areas such as the northern and western reaches of Lake Creek. Cattle populations for the watershed were based on the latest (2012) 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 the counties. The ratio of each county's portion of the watershed's acreage in appropriate land cover types to that of the respective county as a whole was generated. This ratio was then applied to county cattle populations, such that a number of cattle proportional to the size of the watershed acreage in that county was established. This approach ensures that the density of cattle in a county's applicable land cover acreage (grassland and pasture/hay) was the same as the density in the watershed's applicable land use acreage. The initial cattle populations were expected to be overly high by project staff. The 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 the Soil and Water Conservation Districts for each county, and with the topical work group for agriculture. In general, the feedback from these groups was in line with the project's staff's expectations. The stakeholders identified two key factors they felt drove the overestimation; the sizeable negative impact of the 2011 drought on herd size (which was not well reflected in the 2012 NASS data) and the impact of developmental pressure on land value.

Based on their feedback, cattle numbers were reduced in each subwatershed based on the information and local knowledge specific to that watershed. In meetings with SWCDs, Board members worked with staff on calculations based on known herds in given subwatersheds to determine rough reduction values. In most cases, this process yielded results close to their initial percent reduction estimates. The reductions ranged from 50-75%[38] showing the sizeable impact of drought and development on agricultural production. The greater reductions in the Conroe area are in part driven by overestimation by the model due to ambiguous land cover along the developmental fringe. There are no CAFOs in the watershed.

Cattle bacteria loads were then derived for milestones at every five years starting with current (2015) conditions. Figure 16 shows the current loading distributions for cattle in the watersheds. Table 10

[38] Cattle were reduced by 75% for urban subwatersheds 10,11, and 12; 60% for 1,2,4, and 5; and 50% for all others.

indicates the actual cattle source loading estimates by subwatershed. Figure 17 indicates the change in loading over time, through 2040[39].

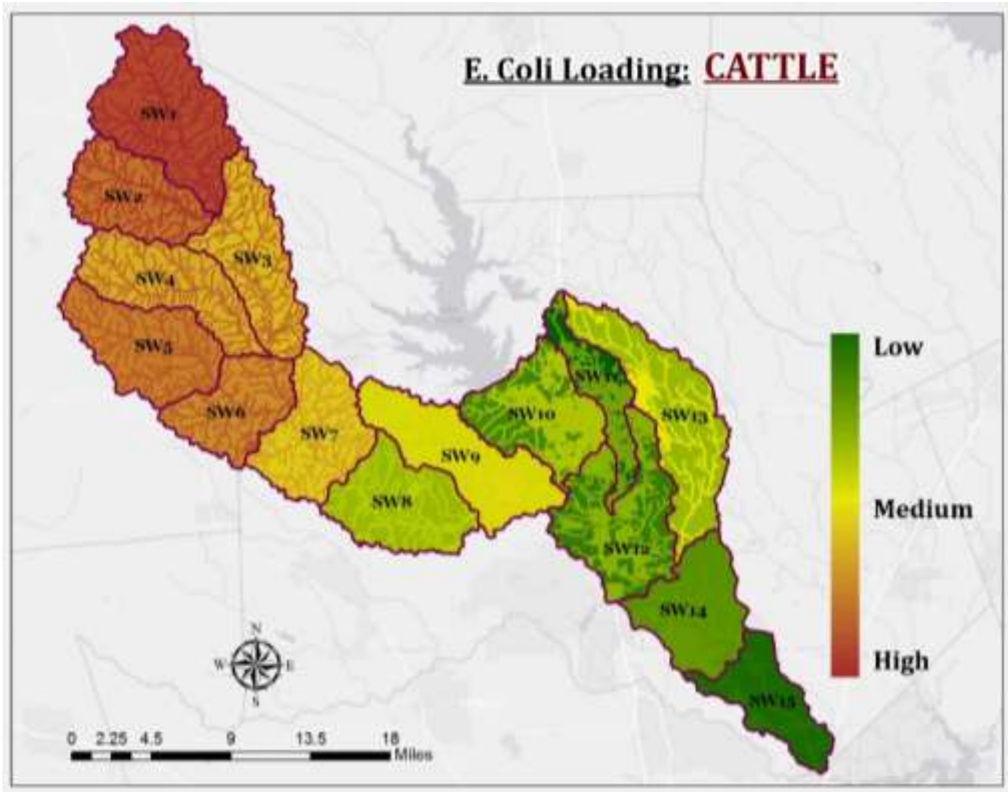

Figure 22 - Bacteria Loadings from Cattle, by Subwatershed

[39] Variation in color between subwatersheds shows relative (rather than absolute) loading differential between subwatersheds. Similarly-colored sections should not be compared between source maps. Color variation within subwatersheds represents the higher loading coefficient in the riparian buffer. While not indicated in the summary graph Figure 16, future conditions were developed for each subwatershed individually.

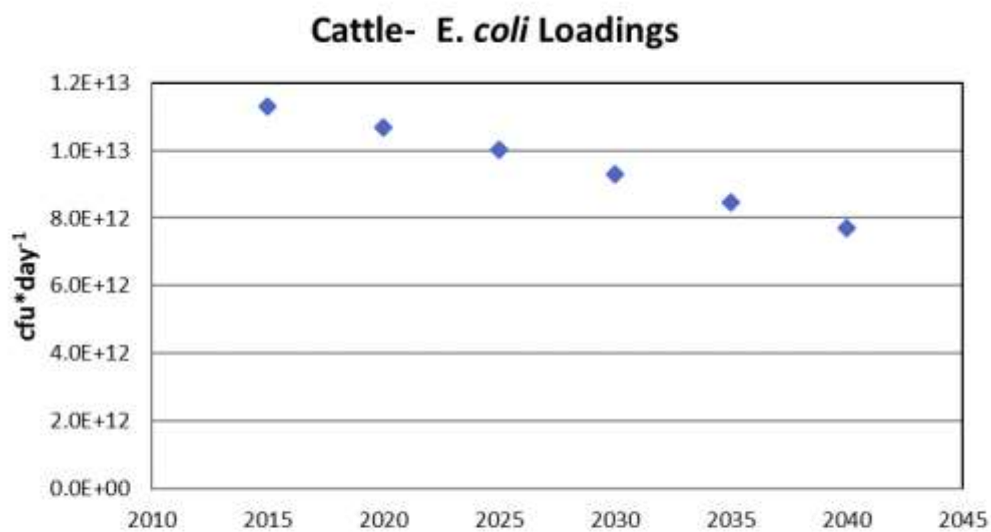

Figure 23 - Future Bacteria Loads from Cattle

Table 13 - Current Potential Bacteria Loads from Cattle, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Cattle	Outside Buffer	1224	903	518	707	893	817	493	173
	Within Buffer	490	368	258	260	303	303	198	70
E. coli Loading	Outside Buffer	8.26E+11	6.10E+11	3.50E+11	4.77E+11	6.03E+11	5.51E+11	3.33E+11	1.17E+11
	Within Buffer	1.32E+12	9.93E+11	6.98E+11	7.02E+11	8.19E+11	8.17E+11	5.34E+11	1.88E+11
Subwatershed portion of total load		19.0%	14.2%	9.3%	10.4%	12.6%	12.1%	7.7%	2.7%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Cattle	Outside Buffer	312	44	4	25	172	74	8	**6,368**
	Within Buffer	106	56	32	35	81	30	4	**2,594**
E. coli Loading	Outside Buffer	2.11E+11	3.00E+10	2.76E+09	1.69E+10	1.16E+11	5.03E+10	5.08E+09	**4.30E+12**
	Within Buffer	2.85E+11	1.51E+11	8.54E+10	9.45E+10	2.20E+11	8.06E+10	1.16E+10	**7.00E+12**
Subwatershed % of total load		4.4%	1.6%	0.8%	1.0%	3.0%	1.2%	0.1%	**1.13E+13**

As indicated in Figure 23, cattle production and presence in the watersheds is expected to continue to decrease, leading to a corresponding decrease in potential 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.

Horses

Unlike cattle populations in the watershed, horses have straddled the divide between rural areas and suburban/exurban development. Dense horse populations are primarily limited to a few stabling operations. Primary modes of ownership include traditional rural populations accompanying existing agricultural operations, and "ranchette" style home sites which may have one or a small number of horses. 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 (SWCDs, etc.), and then with the work group and Partnership. Based on feedback from the SWCDs, and affirmed by stakeholders, reductions ranging from 50-60% were made to horse populations by subwatershed[40].

Horse bacteria loads were then derived for milestones at every five years starting with current conditions. Figure 24 shows the current loading distributions for horses in the watersheds. Table 14 indicates the actual horse source loading estimates by subwatershed. Figure 25 indicates the change in loading over time, through 2040.

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.

[40] Horse populations were reduced by 60% for subwatersheds 1,2,4,5, and 6, and 50% for all other subwatersheds.

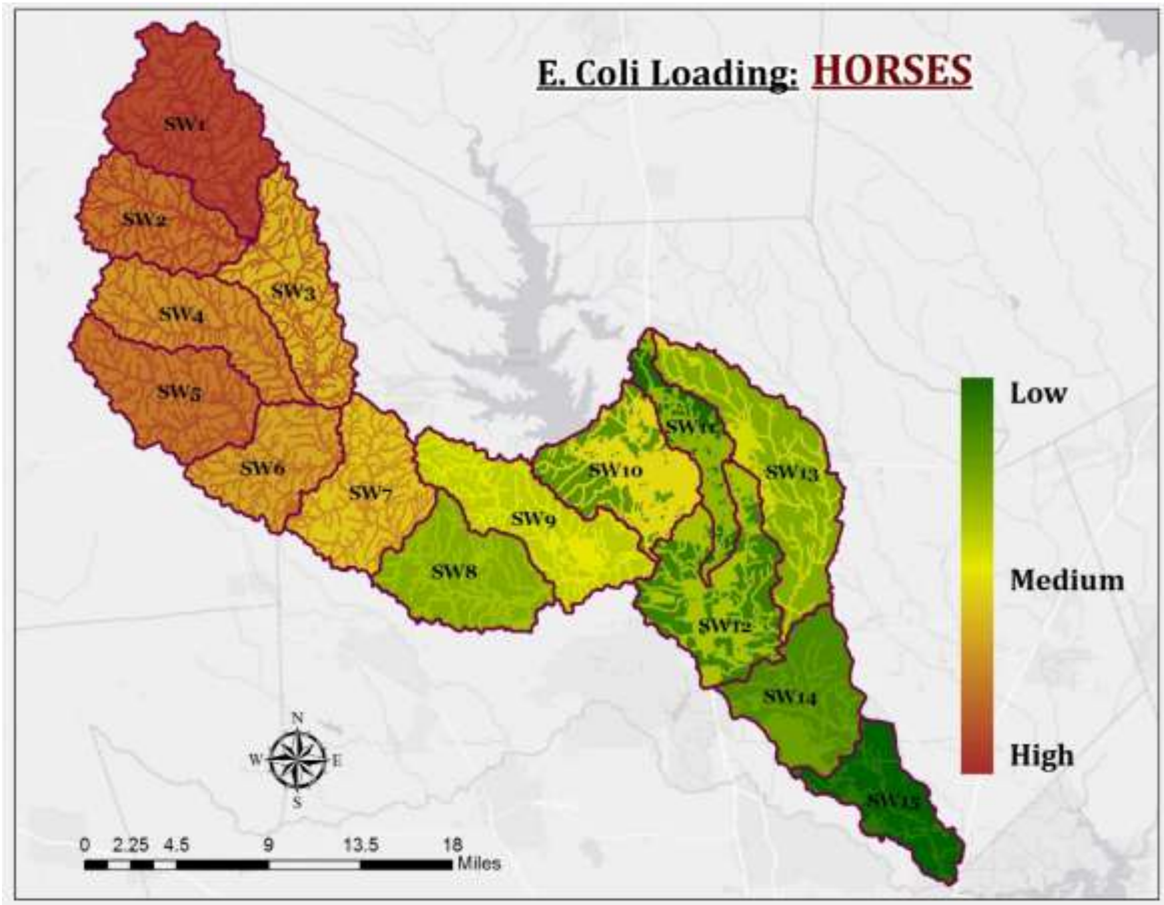

Figure 24 - Bacteria Loading from Horses, by Subwatershed

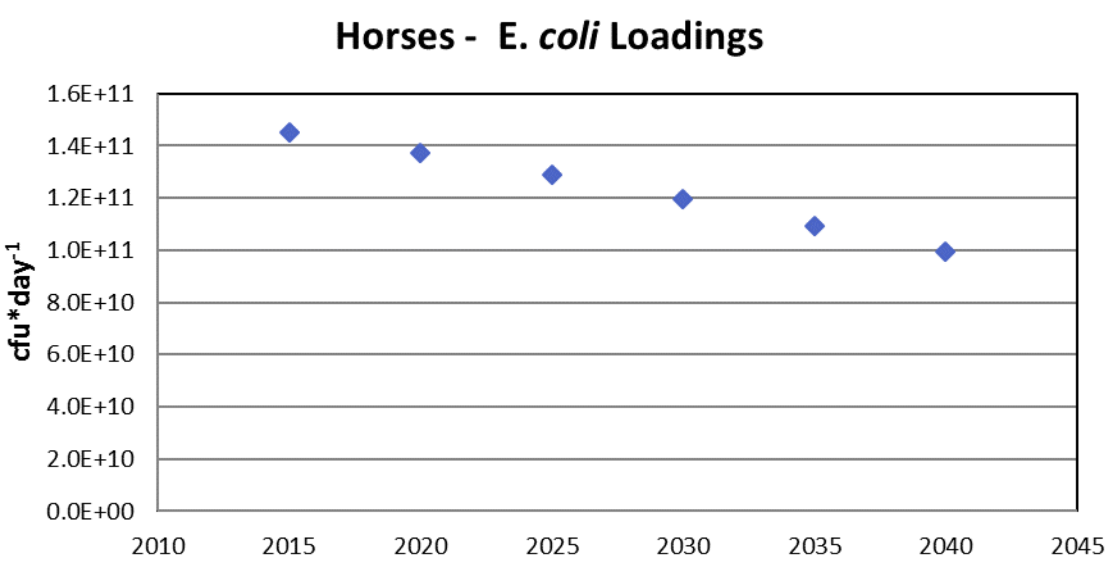

Figure 25 - Future Bacteria Loadings from Horses

Table 14 – Current Potential Bacteria Loadings from Horses, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Horses	Outside Buffer	200	148	85	116	146	107	81	28
	Within Buffer	80	60	42	42	50	40	32	11
E. coli Loading	Outside Buffer	1.05E+10	7.75E+09	4.44E+09	6.07E+09	7.66E+09	5.61E+09	4.23E+09	1.48E+09
	Within Buffer	1.68E+10	1.26E+10	8.87E+09	8.92E+09	1.04E+10	8.31E+09	6.79E+09	2.39E+09
Subwatershed % of total load		11.8%	8.8%	5.8%	6.5%	7.8%	6.0%	4.8%	1.7%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Horses	Outside Buffer	51	15	4	8	28	12	1	**1,028**
	Within Buffer	17	18	32	11	13	5	1	**455**
E. coli Loading	Outside Buffer	2.68E+09	7.62E+08	2.76E+09	4.30E+08	1.48E+09	6.39E+08	6.45E+07	**5.65E+10**
	Within Buffer	3.62E+09	3.83E+09	8.54E+10	2.40E+09	2.79E+09	1.02E+09	1.47E+08	**1.74E+11**
Subwatershed % of total load		2.7%	2.0%	38.2%	1.2%	1.8%	0.7%	0.1%	**2.31E+11**

Sheep and Goats

Sheep and goat populations represent a smaller portion of the livestock in the watershed, but still retain a presence in rural areas. 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, and similar reductions were made.

Sheep and goat bacteria loads were then derived for milestones at every five years starting with current conditions. Figure 26 shows the current loading distributions for sheep and goats in the watersheds. Table 15 indicates the actual sheep and goat source loading estimates by subwatershed. Figure 27 indicates the change in loading over time, through 2040.

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.

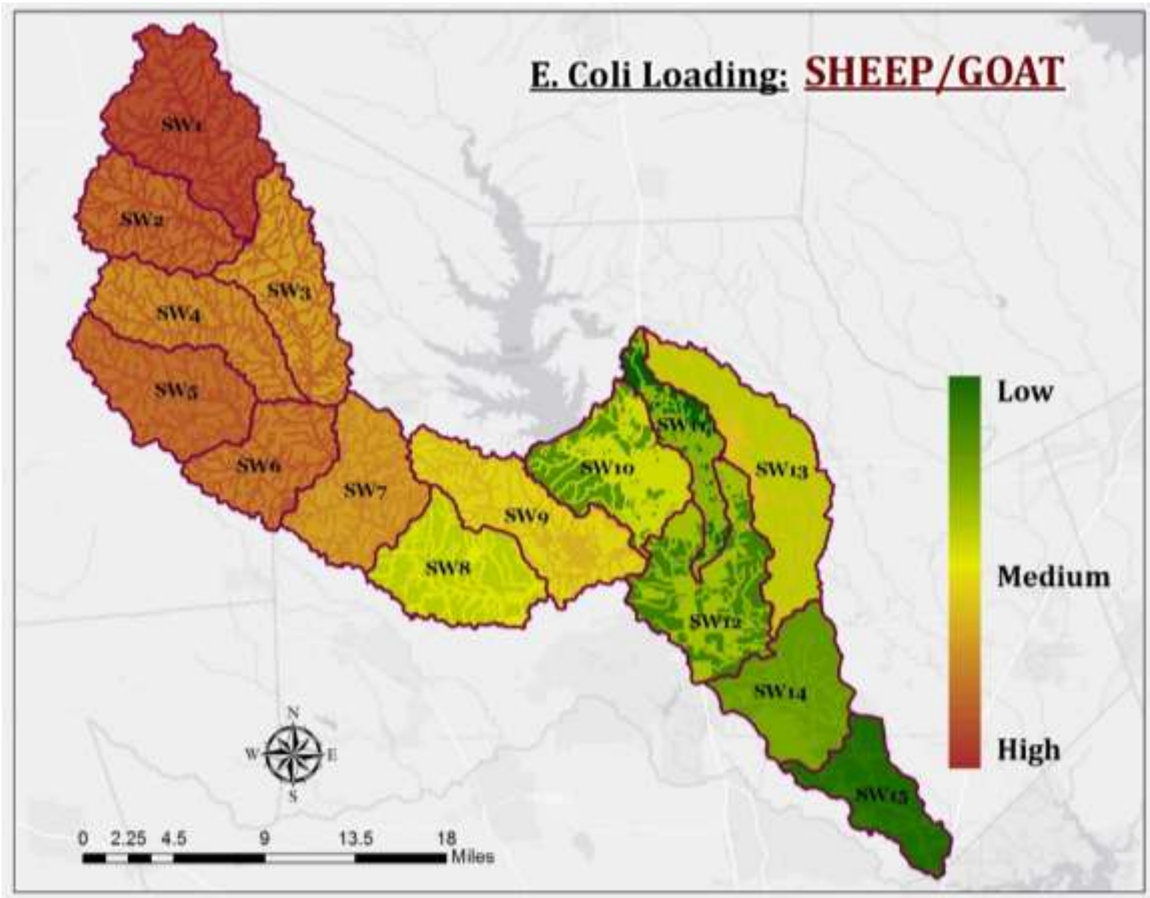

Figure 26 - Bacteria Loadings from Sheep and Goats, by Subwatershed

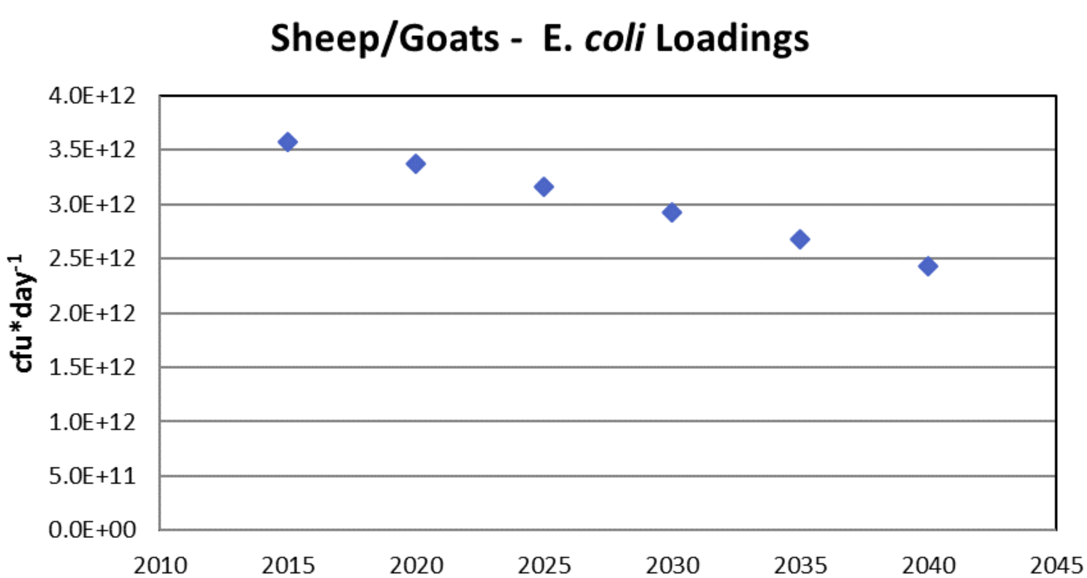

Figure 27 - Future Bacteria Loadings from Sheep and Goats

Table 15 – Current Potential Bacteria Loadings from Sheep and Goats, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Sheep and Goats	Outside Buffer	116	86	49	67	85	77	47	16
	Within Buffer	46	35	24	25	29	29	19	7
E. coli Loading	Outside Buffer	2.61E+11	1.92E+11	1.10E+11	1.51E+11	1.90E+11	1.74E+11	1.05E+11	3.69E+10
	Within Buffer	4.18E+11	3.13E+11	2.20E+11	2.22E+11	2.59E+11	2.58E+11	1.69E+11	5.94E+10
Subwatershed % of total load		19.0%	14.2%	9.3%	10.4%	12.6%	12.1%	7.7%	2.7%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Sheep and Goats	Outside Buffer	30	4	0	2	16	7	1	**603**
	Within Buffer	10	5	3	3	8	3	0	**246**
E. coli Loading	Outside Buffer	6.65E+10	9.46E+09	8.71E+08	5.33E+09	3.67E+10	1.59E+10	1.60E+09	**1.36E+12**
	Within Buffer	9.00E+10	4.76E+10	2.70E+10	2.98E+10	6.93E+10	2.55E+10	3.66E+09	**2.21E+12**
Subwatershed % of total load		4.4%	1.6%	0.8%	1.0%	3.0%	1.2%	0.1%	**3.57E+12**

Feral Hogs

Feral hogs (*Sus scrofa* and related hybrids) are a pressing invasive species issues throughout the Houston-Galveston region, 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 dense riparian forests in much of the project area's watershed (especially downstream of I45 on the West Fork, and in forested areas of Lake Creek and Mound Creek) 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 AgriLife were used as initial assumptions.

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[41] 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 bacteria loads were derived for milestones at every five years starting with current conditions. Figure 28 shows the current loading distributions for sheep and goats in the watersheds. Table 16 indicates the actual sheep and goat source loading estimates by subwatershed. Figure 29 indicates the change in loading over time, through 2040.

Future conditions reflect a 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.

[41] http://feralhogs.tamu.edu/files/2011/05/FeralHogFactSheet.pdf

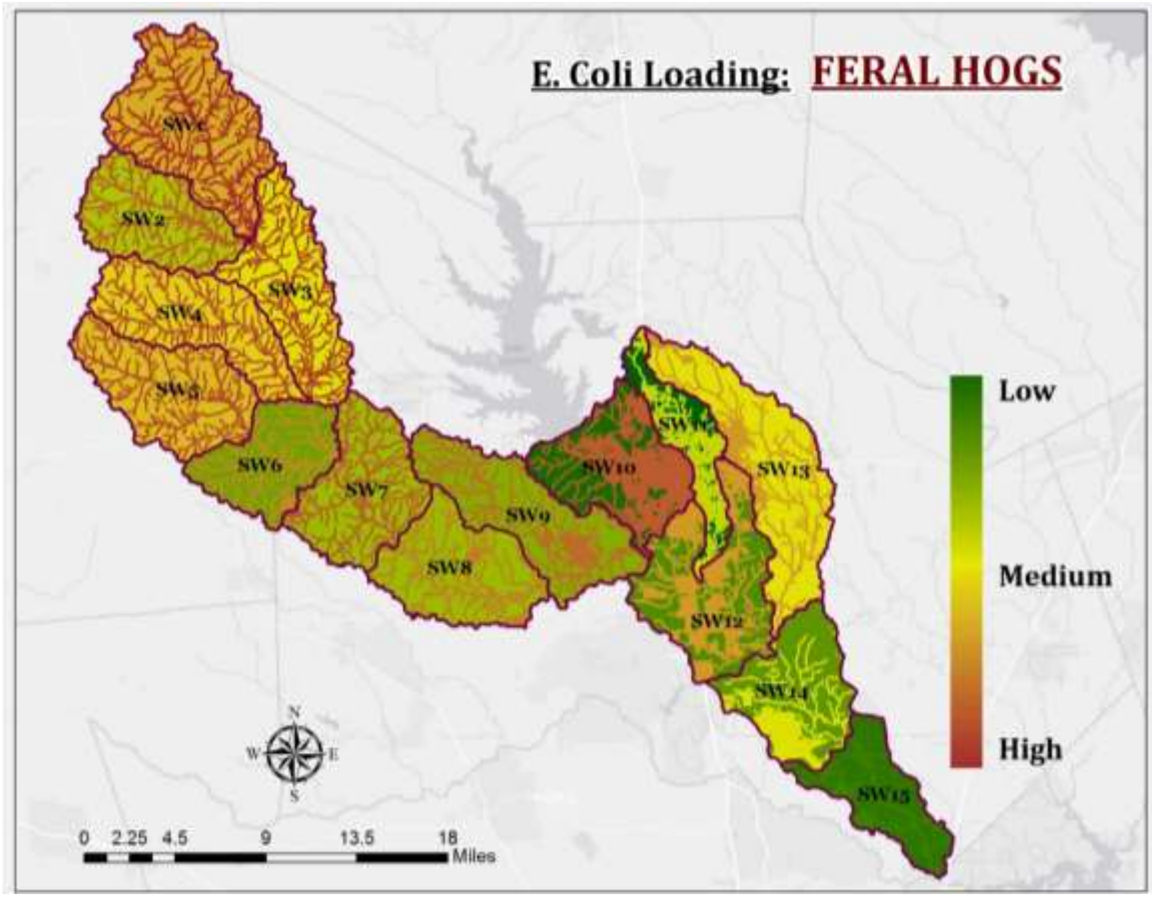

Figure 28 - Bacteria Loadings from Feral Hogs, by Subwatershed

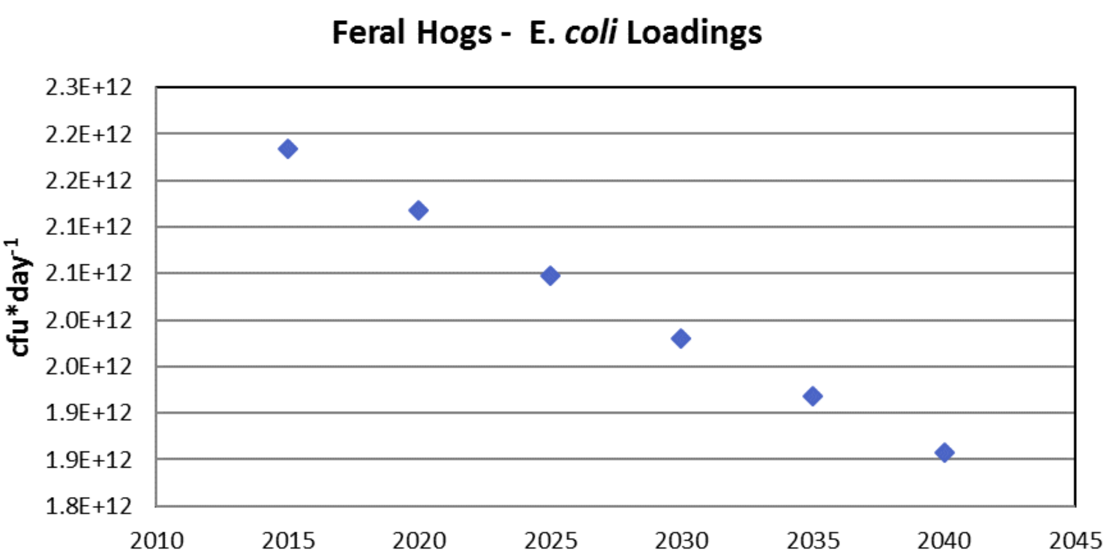

Figure 29 - Future Bacteria Loads from Feral Hogs

Table 16- Current Potential Bacteria Loadings for Feral Hogs, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Feral Hogs	Outside Buffer	70	47	51	55	57	39	45	45
	Within Buffer	38	24	28	26	28	20	26	22
E. coli Loading	Outside Buffer	7.74E+10	5.24E+10	5.68E+10	6.09E+10	6.33E+10	4.37E+10	4.97E+10	4.98E+10
	Within Buffer	1.69E+11	1.07E+11	1.25E+11	1.17E+11	1.24E+11	9.11E+10	1.14E+11	9.78E+10
Subwatershed % of total load		11.3%	7.3%	8.3%	8.2%	8.6%	6.2%	7.5%	6.8%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Feral Hogs	Outside Buffer	42	23	13	34	53	35	24	**633**
	Within Buffer	23	24	12	20	20	13	8	**333**
E. coli Loading	Outside Buffer	4.63E+10	2.58E+10	1.46E+10	3.84E+10	5.92E+10	3.90E+10	2.71E+10	**7.05E+11**
	Within Buffer	1.01E+11	1.07E+11	5.39E+10	8.98E+10	9.03E+10	5.67E+10	3.66E+10	**1.48E+12**
Subwatershed % of total load		6.7%	6.1%	3.1%	5.9%	6.8%	4.4%	2.9%	**2.18E+12**

Dogs

Domestic and feral dog populations are a significant contributor to 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 (AMVA)[42] 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 2012 statistical data for Texas. Stakeholders expressed concern that apartment ownership may not match home ownership rates, and the high number of apartment households might skew the estimation of dog populations. Project staff conducted a study of 12 apartment complexes in urban and suburban areas, and determined that there was an average of 0.5 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, mostly either in less dense rural areas where their waste was not a primary issue, or in the denser urban core of Conroe. No specific data existed or reasonable literature value was found that was applicable to this area/situation. Since the estimation of apartment density could potential 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 bacteria from dog waste continues to increase through 2040. There was no stakeholder expectation that dog ownership rates would be significantly different in the future.

Dog bacteria loads were derived for milestones at every five years starting with current conditions. Figure 30 shows the current loading distributions for dogs in the watersheds. Table 17 indicates the actual dog source loading estimates by subwatershed. Figure 31 indicates the change in loading over time, through 2040.

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

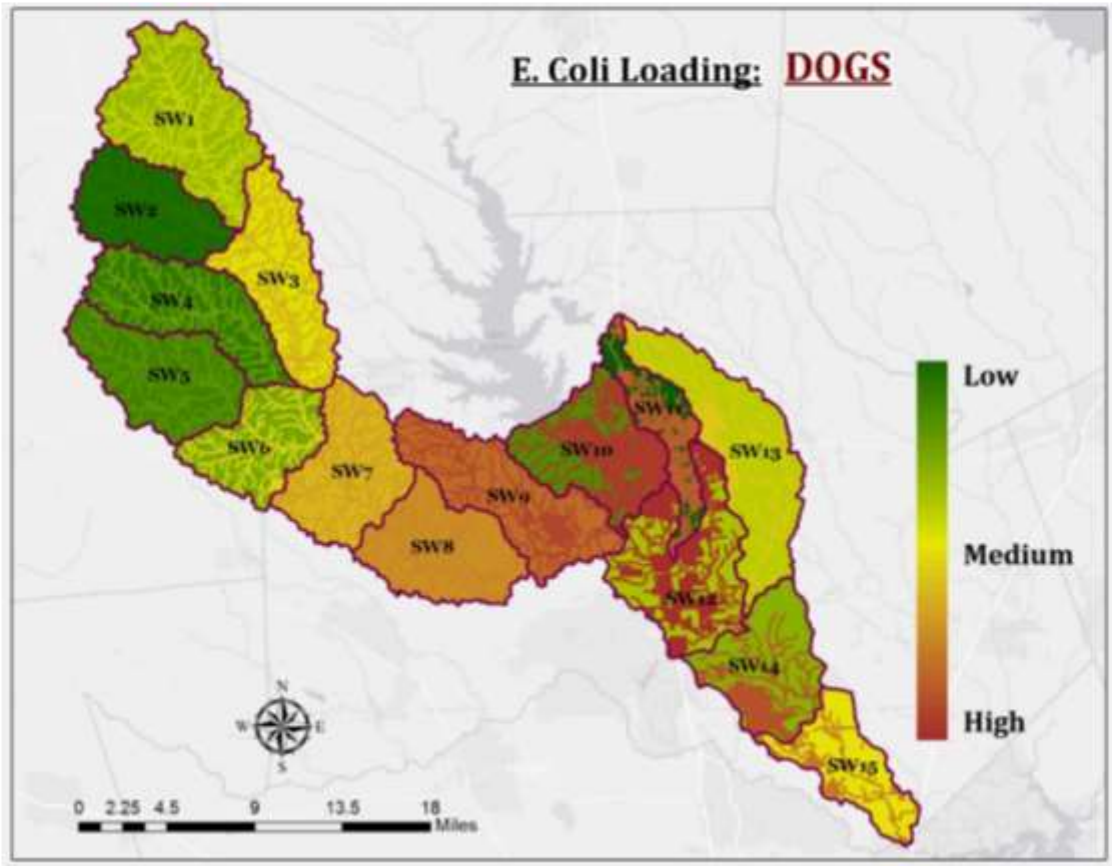

Figure 30 - Bacteria Loadings from Dogs, by Subwatershed

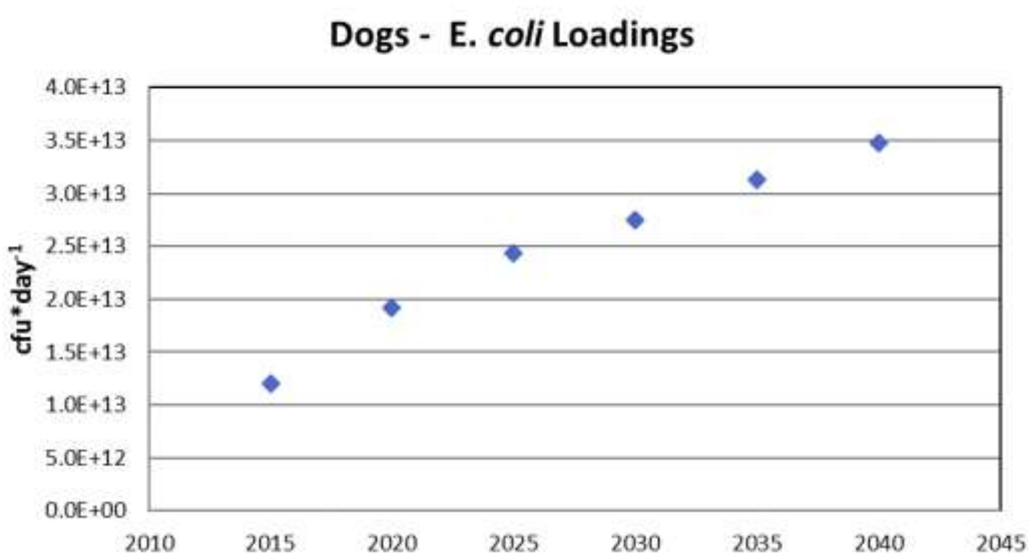

Figure 31 - Future Bacteria Loadings from Dogs

Table 17 – Current Potential Bacteria Loadings from Dogs, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Dogs	Outside Buffer	198	64	284	104	113	186	470	896
	Within Buffer	57	25	118	46	40	87	220	245
E. coli Loading	Outside Buffer	1.23E+11	3.97E+10	1.78E+11	6.50E+10	7.06E+10	1.16E+11	2.94E+11	5.60E+11
	Within Buffer	1.41E+11	6.13E+10	2.95E+11	1.15E+11	1.00E+11	2.16E+11	5.50E+11	6.13E+11
Subwatershed % of total load		2.2%	0.8%	3.9%	1.5%	1.4%	2.8%	7.0%	9.8%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Dogs	Outside Buffer	1340	1190	429	2064	2103	1895	3126	**14458**
	Within Buffer	353	5758	3388	7993	1007	3486	2597	**25417**
E. coli Loading	Outside Buffer	8.37E+11	7.43E+10	2.68E+10	1.29E+11	1.31E+11	1.18E+11	1.95E+11	**2.96E+12**
	Within Buffer	8.83E+11	1.44E+12	8.47E+11	2.00E+12	2.52E+11	8.72E+11	6.49E+11	**9.03E+12**
Subwatershed % of total load		14.3%	12.6%	7.3%	17.7%	3.2%	8.3%	7.0%	**1.20E+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.).

The starting point for estimating deer populations is the use of density projections derived from TPWD's Resource Management Unit 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 light 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 bacteria loads were derived for milestones at every five years starting with current conditions. Figure 30 shows the current loading distributions for deer in the watersheds. Table 17 indicates the actual deer source loading estimates by subwatershed. Figure 31 indicates the change in loading over time, through 2040.

The adaptation of deer to developed environments led to only minor fluctuations in deer populations as development converts natural habitat.

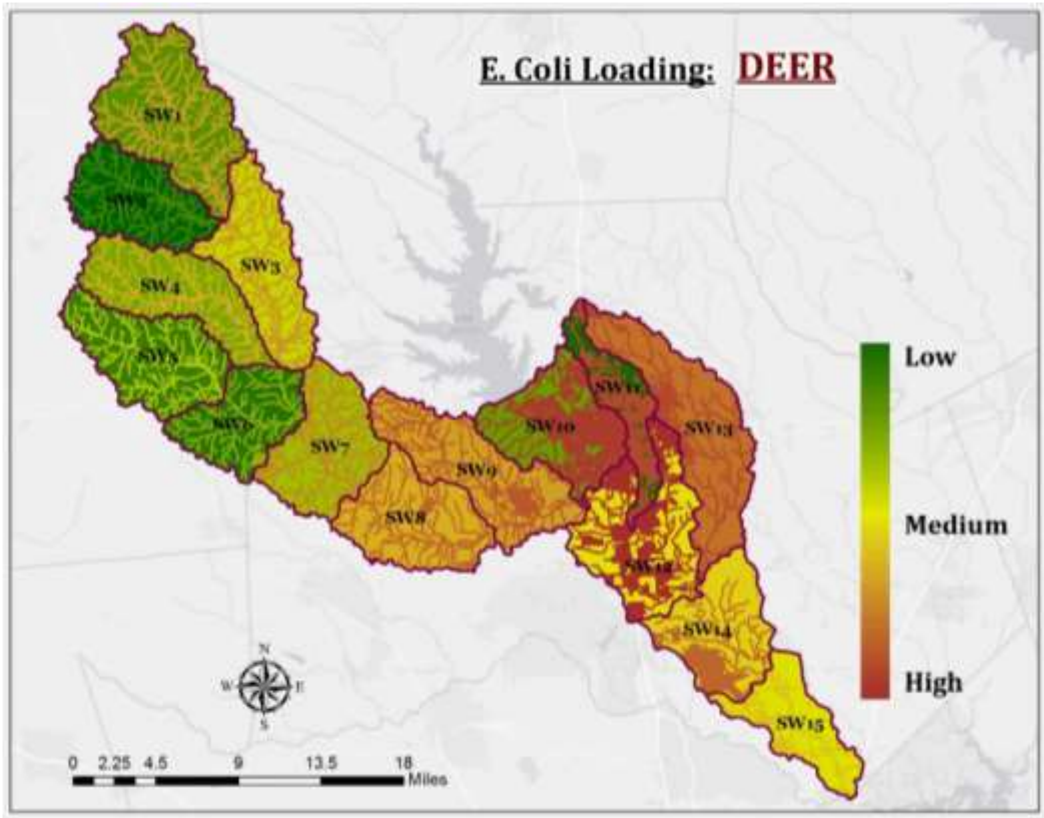

Figure 32 - Bacteria Loadings from Deer, by Subwatershed

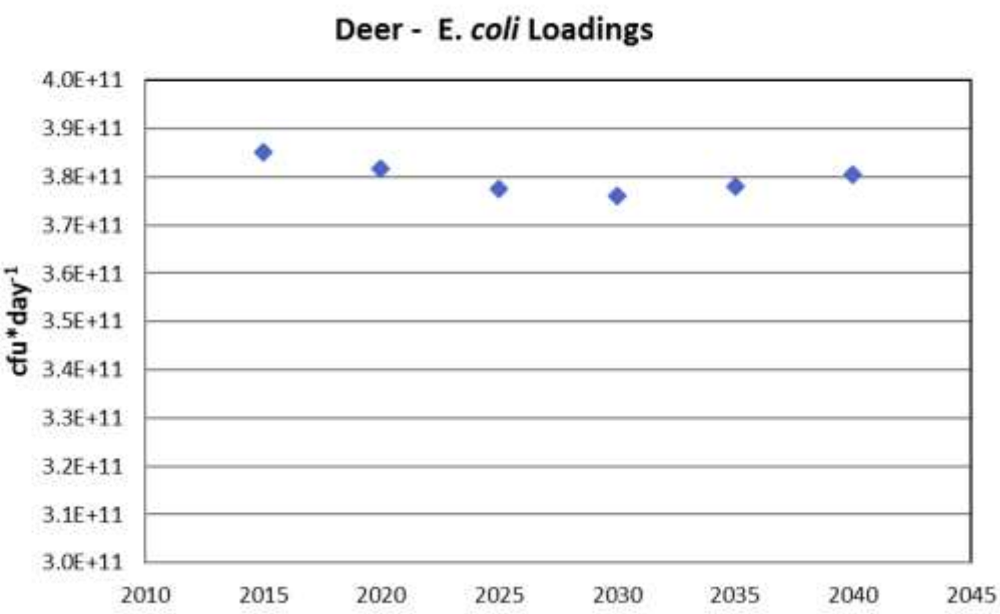

Figure 33 - Future Bacteria Loadings from Deer

Table 18 - Current Potential Bacteria Loadings from Deer, by Subwatershed

		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
# of Deer	Outside Buffer	127	62	193	157	103	85	186	274
	Within Buffer	71	30	84	68	48	42	93	106
E. coli Loading	Outside Buffer	5.57E+09	2.70E+09	8.46E+09	6.85E+09	4.49E+09	3.70E+09	8.12E+09	1.20E+10
	Within Buffer	1.25E+10	5.28E+09	1.47E+10	1.18E+10	8.34E+09	7.32E+09	1.64E+10	1.86E+10
Subwatershed % of total load		4.7%	2.1%	6.0%	4.9%	3.3%	2.9%	6.4%	7.9%

		SW9	SW10	SW11	SW12	SW13	SW14	SW15	**Total**
# of Deer	Outside Buffer	291	148	80	219	380	222	207	**2733**
	Within Buffer	125	200	132	214	133	106	65	**1518**
E. coli Loading	Outside Buffer	1.27E+10	6.46E+09	3.51E+09	9.56E+09	1.66E+10	9.73E+09	9.07E+09	**1.20E+11**
	Within Buffer	2.19E+10	3.51E+10	2.31E+10	3.74E+10	2.32E+10	1.85E+10	1.14E+10	**2.66E+11**
Subwatershed % of total load		9.0%	10.8%	6.9%	12.2%	10.4%	7.3%	5.3%	**3.85E+11**

Other Sources

The sources described previously make up the loading estimates for the SELECT analyses, but do not represent the totality of sources identified by stakeholders in the watershed. Other potential sources, and the reasons for not including them in the estimates are elaborated upon here. In general, sources which are not included in the SELECT estimates are still potential targets of intervention as part of the WPP, especially on a localized scale.

Human Waste – Direct Discharges

Stakeholders discussed the presence of some homeless individuals in some areas, and some small "colonias" areas which may not have wastewater solutions. 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.

Domestic Swine

Stakeholders and data did not indicate that domestic swine were an appreciable source in the watershed.

Exotic Animals

Stakeholders identified some exotic animal operations in the watershed, but in small numbers of expected populations. No quality-assured data or other reasonable source existed to characterize these animals as a source. The operations were not known to be an issue, and the potential populations were too small to be sources of concern.

Birds

Bird populations in the region can vary greatly by season. Large migratory populations pass through the Houston area as part of the great Central Flyway migration path. However, these populations are transient, staying for days or weeks during tow yearly migration seasons. Migratory waterfowl represent longer-term populations, especially in coastal marshes. However, no significant migratory waterfowl presence of any significant concentration is known in the watershed. Previous WPP efforts have evaluated the potential impact of waterfowl in terms of duration, potential 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 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. Additionally, no reasonable solutions were identified with project partners that were feasible and acceptable to stakeholders (due in no small part to their status as protected wildlife under the Migratory Bird Treaty Act and other regulations). Contributions from swallow colonies may be contributing to general background levels of bacteria, but were not a focus of this assessment for the reasons presented. Colonial waterbirds (e.g. heron rookeries) have also been identified under other WPP efforts as potential sources when they occur in sufficient density or size. No such large colonial nesting sites are known within the watershed. 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.

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. As with other wildlife sources, no likely solutions exist, making the uncertainty of their load somewhat moot.

Other Wildlife

The greatest degree of uncertainty in the SELECT analyses comes from the inability to accurately predict the contributions of other mammalian wildlife (in addition to birds and bats, as discussed, and exclusive of feral hogs and deer). 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. Recent bacteria source tracking analyses have indicated that wildlife contributions may be more significant than previously assumed, especially in undeveloped areas. A large portion of the Lake Creek Watershed and portions of the West Fork Watershed are good habitat areas for these and other species. Stakeholders elected to move forward with SELECT modeling with the understanding that this source would be underrepresented. To balance this concern, stakeholders and project staff recommended that the WPP include efforts to further characterize this source in conjunction with other efforts, and to identify any problem areas that may need local attention. The protected status of wildlife and lack of many feasible BMPs limits the ability to deal with these sources in watershed projects.

Cats

Domestic cat ownership general revolves around an indoor model in developed areas, in which cat feces is restricted to litter boxes, unlike dog waste which is more likely to be deposited outdoors. Therefore, cat loads were not estimated 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 was 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.

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.

Sediment

Sand and gravel mining operations are common in the riparian corridors of the watersheds, primarily on the main channels of the West Fork and Lake Creek. Excess sediment is common in the waterways, which can provide shelter for bacteria and decrease insolation that may lead to die-off in the water column. These effects are already an aspect of the in-stream conditions described under the LDCs, in that recorded bacteria levels reflect these ambient factors as well as other fate and transport aspects. Mining operations are not a source of bacteria, so no estimation can be completed. Excess sediment introduced into the channel can foster the survival of bacteria from other sources, making it an indirect source for bacteria that might have otherwise not survived. The considerations regarding sediment will be dealt with in the WPP.

Summary of Results

The SELECT analyses indicated a mix of sources rather than one or two primary contributors. Figure 34 shows the relative spatial distribution of current total potential load by subwatershed. Table 19 indicates the estimated current potential loads for all sources. Figure 35 shows the change in total load between 2015 and 2040. Table 20 shows the estimated potential load for each milestone year, by source. Figure 36 shows the relative change in source contributions between current and future conditions.

Absent a concerted effort to address bacteria sources, the projections indicate that total bacteria loads in the watershed will continue to increase between 2015 and 2040. Between current conditions and those projected for 2040, the mix of sources shifts appreciably away from some of the legacy agricultural activity toward a predominance of sources associated with human development.

Table 19 - Bacteria Loadings by Source and Subwatershed

Subwatershed	OSSFs	WWTF	SSOs	Dogs	Cattle	Horses	Sheep/Goats	Deer	Feral Hogs	Total Daily Loading
SW1	1.18E+11	2.38E+07	0.00E+00	3.18E+11	2.15E+12	2.73E+10	6.79E+11	1.81E+10	2.46E+11	**3.56E+12**
SW2	4.49E+10	0.00E+00	0.00E+00	1.21E+11	1.60E+12	2.04E+10	5.06E+11	7.98E+09	1.60E+11	**2.46E+12**
SW3	2.10E+11	0.00E+00	0.00E+00	5.67E+11	1.05E+12	1.33E+10	3.31E+11	2.31E+10	1.82E+11	**2.37E+12**
SW4	8.01E+10	0.00E+00	0.00E+00	2.16E+11	1.18E+12	1.50E+10	3.72E+11	1.87E+10	1.78E+11	**2.06E+12**
SW5	7.60E+10	1.19E+08	0.00E+00	2.05E+11	1.42E+12	1.81E+10	4.49E+11	1.28E+10	1.87E+11	**2.37E+12**
SW6	1.34E+11	0.00E+00	0.00E+00	3.99E+11	1.37E+12	1.39E+10	4.32E+11	1.10E+10	1.35E+11	**2.49E+12**
SW7	3.36E+11	9.54E+08	0.00E+00	1.01E+12	8.67E+11	1.10E+10	2.74E+11	2.45E+10	1.64E+11	**2.69E+12**
SW8	9.44E+11	1.41E+10	6.95E+08	1.41E+12	3.05E+11	3.87E+09	9.62E+10	3.06E+10	1.48E+11	**2.95E+12**
SW9	1.29E+12	7.06E+09	2.02E+08	2.06E+12	4.96E+11	6.30E+09	1.56E+11	3.46E+10	1.47E+11	**4.20E+12**
SW10	5.46E+11	5.57E+10	7.71E+10	1.82E+12	1.81E+11	4.59E+09	5.70E+10	4.15E+10	1.32E+11	**2.91E+12**
SW11	1.15E+11	0.00E+00	0.00E+00	1.05E+12	8.81E+10	2.24E+09	2.78E+10	2.66E+10	6.85E+10	**1.38E+12**
SW12	2.24E+12	3.20E+10	5.60E+09	2.55E+12	1.11E+11	2.83E+09	3.52E+10	4.70E+10	1.28E+11	**5.15E+12**
SW13	9.34E+11	8.73E+09	3.12E+09	4.60E+11	3.36E+11	4.27E+09	1.06E+11	3.99E+10	1.49E+11	**2.04E+12**
SW14	1.12E+12	2.00E+10	2.59E+09	1.19E+12	1.31E+11	1.66E+09	4.13E+10	2.82E+10	9.57E+10	**2.63E+12**
SW15	1.43E+12	2.29E+10	4.93E+09	1.01E+12	1.67E+10	2.12E+08	5.26E+09	2.05E+10	6.38E+10	**2.58E+12**
TOTAL	**9.60E+12**	**1.60E+11**	**9.40E+10**	**1.40E+13**	**1.10E+13**	**1.40E+11**	**3.60E+12**	**3.90E+11**	**2.20E+12**	**4.20E+13**
% of Total	**22.9%**	**0.4%**	**0.2%**	**33.3%**	**26.2%**	**0.3%**	**8.6%**	**0.9%**	**5.2%**	**100.0%**

Table 20 - Bacteria Loadings by Source for all Milestone Years

Category	Source	2015	2020	2025	2030	2035	2040
Human Waste	OSSFs	9.6E+12	1.3E+13	1.7E+13	2.1E+13	2.5E+13	2.9E+13
	WWTFs	1.6E+11	2.1E+11	2.4E+11	2.6E+11	2.8E+11	3.0E+11
	SSOs	9.4E+10	1.2E+11	1.4E+11	1.6E+11	1.7E+11	1.8E+11
Pets	Dogs	1.4E+13	2.3E+13	2.9E+13	3.3E+13	3.8E+13	4.2E+13
Livestock	Cattle	1.1E+13	1.1E+13	1.0E+13	9.3E+12	8.5E+12	7.7E+12
	Horses	1.4E+11	1.4E+11	1.3E+11	1.2E+11	1.1E+11	1.0E+11
	Sheep/Goats	3.6E+12	3.4E+12	3.2E+12	2.9E+12	2.7E+12	2.4E+12
Wildlife and Feral Hogs	Deer	3.9E+11	3.8E+11	3.8E+11	3.8E+11	3.8E+11	3.8E+11
	Feral Hogs	2.6E+12	2.5E+12	2.4E+12	2.4E+12	2.3E+12	2.2E+12
Total		**4.2E+13**	**5.4E+13**	**6.2E+13**	**7.0E+13**	**7.7E+13**	**8.4E+13**

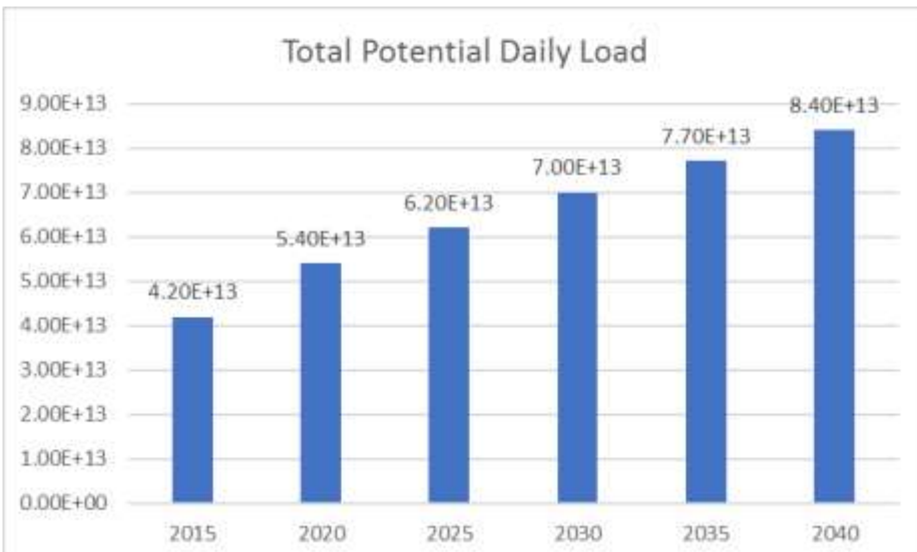

Figure 34- Total Potential Daily Load, 2015-2040

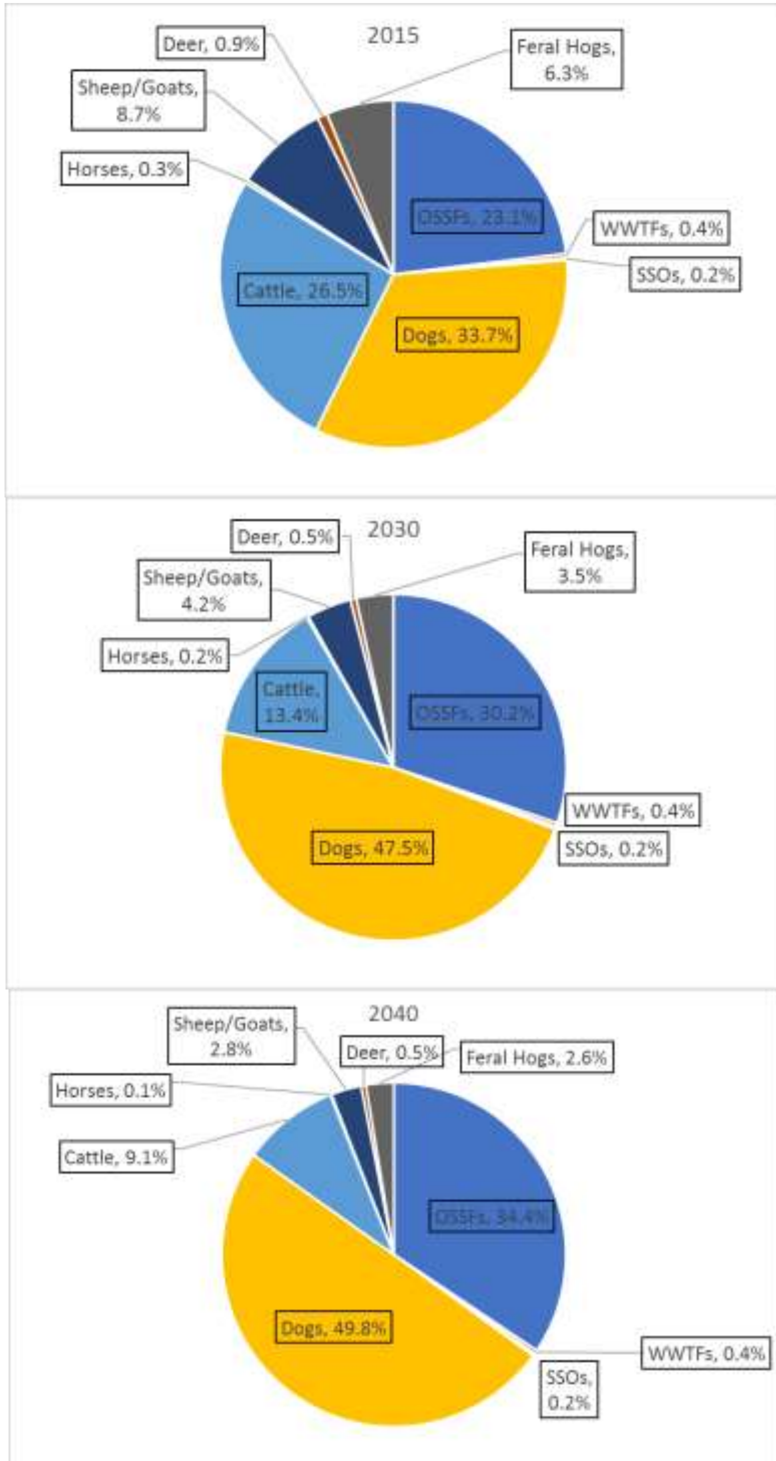

Figure 35 - Change in Source Contribution over Time

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 established in Section 6, and the final results were affirmed by the stakeholders after two rounds of feedback and revision. In general, the results indicated a varying level of reduction needed through the project area, and a shifting mix of sources over the planning period. 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.

Model Linkage

SELECT was used to generate potential source loads and characterize the source profile. The % 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 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; 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; and 5) the generally dense nature of drainage tributaries in the watershed (i.e. resembling "natural" systems of many small tributaries leading to larger tributaries, and then to main channels as opposed to watersheds with heavy channel modification) lends itself to a more consistent transmittal of loads to instream areas. While this approach includes a level of uncertainty because of excluded factors (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 rapidly changing 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. 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.)

Bacteria Reduction Targets

With the model linkage established, calculating 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 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 milestones dates between 2015 and 2040. 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 the amount of future growth projected for the watershed. A 5-year plan would not adequately address the appreciable increase in loads through 2040, whereas a more long-term plan would have to rely on less certain predictions[43]. Project staff proposed 2030 as a compromise, allowing a long-term focus to account for watershed change, while focusing on meaningful interim action. For a WPP approved in 2018/2019, this would represent a 11-12-year plan life. The stakeholders affirmed this proposal.

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 watersheds of the project area are varied in terms of reduction need and developmental character. Therefore, project staff proposed three attainment areas (Figure 14), each with their own specific reduction goals. The three attainment areas are: 1) Lake Creek upstream of Mound Creek; 2) Lake Creek downstream of Mound Creek and the West Fork upstream of Crystal Creek; and 3) Crystal Creek. The stakeholders affirmed this approach, with the understanding that through adaptive management, additional targets may be added if needed (e.g. breaking out Mound Creek, or Stewart's Creek from the second attainment area).

[43] 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 mix of sources present in the watershed, and the shift of relative contribution through 2040, posed a challenge for allocating how reduction targets would be met. Stakeholders considered several options, including: 1) targeting all sources proportional to their contribution (e.g. if in 2030 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 2030). Project staff proposed the first option, with the understanding that the WPP would stress opportunistic implementation and that short-term efforts may focus on sources that are currently pressing (e.g., livestock) even if they are not as significant in the 2030 projections. The proportional allocation was modeled for the whole watershed, subwatersheds, and attainment area groupings, with the proposed allocations to focus on the attainment areas. Stakeholders affirmed the proposal.

Based on these decisions, project staff generated reduction targets for each attainment area, subwatershed, and source. Table 8 in section 4 indicates the overall reduction targets for each of the attainment areas. Table 21 represents the linkage of the reduction target percentages to the source loadings to generate the target source load reductions for current and 2030 milestones years.

Tables 22 summarizes the allocation of reduction loads by source for each of the three attainment areas.

Table 21 - Current and 2030 Source Load Reduction Targets

Attainment Area	Subwatersheds	LDC Reduction (current)	Current Source Load[44]	Current Source Load Reduction Target	Incremental load 2015-2030[45]	2030 Source Load Reduction Target[46]
Lake Creek above Mound Creek	1,2,3,4,5,6,7,8	17.5%	2.1E+13	3.7E+12	4.1E+12	7.8E+12
Lake Creek below Mound Creek and the West Fork above Crystal Creek	9,10,11,12,14, 15	35%	1.9E+13	6.6E+12	2.2E+13	2.8E+13
Crystal Creek	13	6%	2.0E+12	1.2E+11	1.6E+12	1.8E+12

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

[45] The incremental load represents the difference between the 2030 load and the 2015 load. See footnote 46 for explanation of its use in generating 2030 source reduction load target.

[46] The 2030 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 2015 and 2030 is added to whatever existing reduction load exists in 2015. 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 2030.

Table 22 - Current Source Reduction Loads by Source and Attainment Area

		OSSFs	WWTFs	SSOs	Dogs	Cattle	Horses	Sheep/ Goats	Deer	Feral Hogs	Total
Lake Creek Above Mound Creek	Source Load	1.9E+12	1.5E+10	6.9E+08	4.2E+12	9.9E+12	1.2E+11	3.1E+12	1.5E+11	1.4E+12	2.1E+13
	% Total Load	9.3%	0.1%	0.0%	20.3%	47.4%	0.6%	15.0%	0.7%	6.7%	100.0%
	Reduction Load	3.4E+11	2.7E+09	1.2E+08	7.4E+11	1.7E+12	2.2E+10	5.5E+11	2.6E+10	2.4E+11	3.7E+12
Lake Creek Below Mound Creek and West Fork Above Crystal Creek	Source Load	6.7E+12	1.4E+11	9.0E+10	9.7E+12	1.0E+12	1.8E+10	3.2E+11	2.0E+11	6.4E+11	1.9E+13
	% Total Load	35.8%	0.7%	0.5%	51.4%	5.4%	0.1%	1.7%	1.1%	3.4%	100.0%
	Reduction Load	2.4E+12	4.8E+10	3.2E+10	3.4E+12	3.6E+11	6.2E+09	1.1E+11	6.9E+10	2.2E+11	6.6E+12
Crystal Creek	Source Load	9.3E+11	8.7E+09	3.1E+09	4.6E+11	3.4E+11	4.3E+09	1.1E+11	4.0E+10	1.5E+11	2.0E+12
	% Total Load	45.8%	0.4%	0.2%	22.5%	16.5%	0.2%	5.2%	2.0%	7.3%	100.0%
	Reduction Load	5.6E+10	5.2E+08	1.9E+08	2.8E+10	2.0E+10	2.6E+08	6.4E+09	2.4E+09	9.0E+09	1.2E+11

Implications of Findings

The findings of the bacteria modeling efforts for Lake Creek and the West Fork reinforce the image of watersheds in transition. Driven by the general growth of the Houston area, and pushing outward from transportation corridors, the project area has seen significant growth in recent decades, and will continue to do so in coming years. Developmental changes will reduce legacy agricultural sources in many areas. The loss of load from agricultural activities will be outweighed by the increases of sources derived from developed areas.

The increasing loads highlight the need for intervention through the WPP and other means. Current water quality issues will be compounded by future loads, leading to degrading water quality through the planning period absent any effort to the contrary.

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

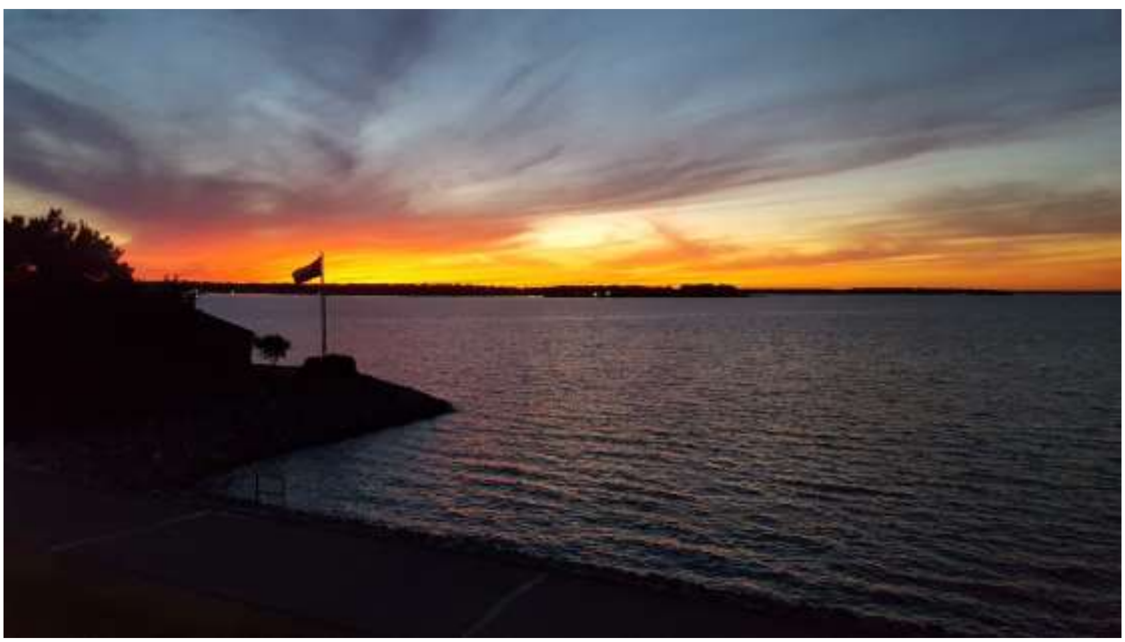

Figure 36 - West Fork Source Water in Lake Conroe