Navasota River Below Lake Limestone Watershed Protection Plan

Developed by the Navasota River Watershed Partnership

Texas Water Resources Institute TR-XXX

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Prepared for the Navasota River Watershed Partnership

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List of Acronyms

AU	Assessment Unit OR Animal Unit
AVMA	American Veterinary Medical Association
BMP	Best BMP
BOD-5	Five Day Biological Oxygen Demand
BRA	Brazos River Authority
BST	Bacterial Source Tracking
CFU	Colony Forming Unit
CP	Conservation Plan
CRP	Clean Rivers Program OR Conservation Reserve Program
CSP	Conservation Stewardship Program
CWA	Clean Water Act
DO	Dissolved Oxygen
DR	Designated Representative
EQIP	Environmental Quality Incentive Program
ERIC-RP	Enterobacterial Repetitive Intergenic Consensus Sequence Polymerase Chain Reaction and Ribosomal Deoxyribonucleic Acid Genetic Fingerprinting
ESRI	Environmental Systems Research Institute
FSA	Farm Service Agency
FDC	Flow Duration Curve
GIS	Geographic Information System
I-Plan	Implementation Plan
LCRA	Lower Colorado River Authority
LDC	Load Duration Curve
LULC	Land Use / Land Cover
MGD	Million Gallons Per Day
MS4	Municipal Separate Storm Sewer System
NRCS	Natural Resources Conservation Service
NASS	National Agriculture Statistics Survey
NPS	Nonpoint Source Pollution
OSSF	On-Site Sewage Facility
SEP	Supplemental Environmental Program
SWCD	Soil and Water Conservation District
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TPWD	Texas Parks and Wildlife Department
TSS	Total Suspended Solids
TSSWCB	Texas State Soil and Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWRI	Texas Water Resources Institute
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
WPP	Watershed Protection Plan
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Plant

Chapter 1 : Watershed Management

Watershed Definition and Impacts

A watershed is defined as the land area surrounding a waterbody that drains to a common waterway such as a stream, river or lake. Watersheds can vary greatly in size. Some may span a few miles while large watersheds can encompass several nations. Additionally, several smaller watersheds, called subwatersheds, can combine to form larger-scale watersheds. For example, the Navasota River watershed is a part of the larger Brazos River basin.

Natural processes and human activities that occur within a watershed have the potential to impact the overall water quality of the waterbody that the surrounding land drains to. With this in mind, the most effective way to address water quality issues for a waterbody is to examine natural processes and human activities occurring in watershed.

The Watershed Approach

The watershed approach is described as a "flexible framework for managing water resource quality and quantity within a specific drainage area or watershed". This framework includes engaging stakeholders to assist in making decisions in order to effectively manage the watershed using both sound science and technology (USEPA 2008). This approach includes the following principles:

- Focus on the geography of a watershed determined by hydrological boundaries rather than political boundaries;
- Assess water quality objectives using scientific data;
- Coordinate priorities and integrate solutions within a watershed; and,
- Establish diverse, well-integrated partnerships.

By utilizing the watershed approach, potential sources of pollution within a watershed can be addressed by watershed stakeholders, despite the fact that a watershed's boundaries often cross municipal, county and state boundaries. A watershed stakeholder is any individual or entity that lives, works or has an interest in a particular watershed or may be affected by decisions made for the watershed. Involving stakeholders is a critical component of effectively implementing a holistic approach for managing concerns for a watershed.

Navasota River Watershed Protection Planning Efforts

The Navasota River watershed protection plan (WPP) is the combined efforts of watershed stakeholders to describe water quality issues facing the watershed, define the causes of these issues, and establish a plan to address the sources of stress to the area's water quality. Local education and outreach formed the basis of this planning effort. Broad-based programming, including the Texas Watershed Steward and Texas Well Owners Network programs, was delivered in the watershed, and press releases were developed and delivered via local newspapers and radio outlets. Informational presentations were made at a number of meetings including:

- Commissioners Courts: Leon and Grimes counties
- Bedias Creek, Brazos County, Limestone-Falls, Navasota, and Robertson County soil and water conservation districts
- Local Texas A&M AgriLife Extension programs
- Local Master Gardener/Naturalist Programs
- Brazos River Clean Rivers Program stakeholder meeting

Additional meetings were held to raise awareness regarding planning efforts with City Water Superintendents or Wastewater Supervisors, County Judges and Commissioners, Designated Representatives (Septic System Inspectors), and Extension Agents.

In the fall of 2015, two public meetings were held to discuss current Navasota River water quality conditions and the WPP development process. Approximately 30 stakeholders participated in these discussions and identified the most effective means to engage the diverse group of stakeholders across the watershed. Some key stakeholders were unable to commit to routine meetings, so individual or small group meetings were used to better engage watershed stakeholders. Small workforces in many locations, the lack of a central meeting location in the watershed, and the inability for many stakeholders to travel to meetings precluded the use of organized work group or committee member meetings. Instead, a decentralized approach using feedback from individuals or small groups was condensed into consensus-based information and conveyed to those attending public meetings for additional feedback was utilized. This tactic is a non-traditional approach to WPP development; however, it afforded the inclusion of numerous stakeholders into the planning process that would not have been able to participate otherwise. Stakeholder types engaged throughout the watershed included:

- Landowners
- Business and industry representatives
- Agricultural producers
- City and County personnel
- Citizen groups
- Soil and water conservation districts

Using this method, WPP inputs were validated, management recommendations based on local needs were developed, and water quality and implementation targets were established. Consensus on these items was achieved by condensing information and delivering it back to stakeholders for review and additional comment.

Public meetings were held approximately quarterly during the WPP development process to facilitate discussion and reach consensus on WPP components. Meetings were held in College Station and Franklin on the same day (or close together) and covered identical material. All meetings were open to the public and advertised via email, news releases, website postings, and radio announcements. Technical information regarding water quality, potential management strategies, and goals to meet objectives were all discussed in these meetings. Feedback from each meeting was gathered and integrated into subsequent meetings for stakeholder consideration.

Stakeholder groups were provided technical guidance throughout the WPP development process by state and federal agencies. These individuals provided information on matters related to their jurisdictions or areas of expertise. Technical representatives included:

- Brazos River Authority (BRA)
- Texas A&M AgriLife Extension Service
- Texas Commission on Environmental Quality (TCEQ)
- Texas State Soil and Water Conservation Board (TSSWCB)
- Texas Water Resources Institute (TWRI)
- United States Department of Agriculture, Natural Resources Conservation Service (USDA - NRCS)

Chapter 2 : The Navasota River Watershed

Watershed Characteristics

The Navasota River Watershed is located in East-Central Texas and has a drainage area of 1,438,718 acres that contains parts of eight counties (Figure 2.1). The Navasota River is perennial and floods frequently after large rainfalls due in part to the predominately clay soils in the watershed that yield high runoff. In the upper part of the watershed, Lake Limestone causes a major hydrological divide which also affects downstream water quality. As the river enters the lake, sediment and many other water quality constituents begin to settle, while ultraviolet light kills numerous pathogens suspended in the water. This process improves water quality and yields cleaner water at the lake outlet than at its inlet. Despite this process, water's natural tendency is to transport sediment which can release pollutants in sediment such as *E. coli* (Frey et al. 2015). This WPP focuses specifically on the portion of the watershed below Lake Limestone which covers 1,006,330 acres and portions of six counties (Figure 2.2).

Physical Characteristics

The watershed is mostly rural and consists of grass pastures, hay fields, and hardwood forests in bottomland and upland areas. Urbanization is not widespread and is largely confined to the Bryan/College Station area in Brazos County. The watershed is dominated by the Southern Post Oak Savanna (33b) ecoregion which consists of alternating bands of post oak woods and savannas or post oak woods that surround small prairie openings (Griffith et al., 2004). Portions of the Floodplains and Low Terraces, Southern Blackland, and San Antonio Prairie ecoregions also occur in the watershed. Soils in the watershed vary across the area and include very productive sands, silts, loams and clay. The watershed typically experiences 34 to 44 inches of rainfall annually with cool, wet winters and hot, dry sum-

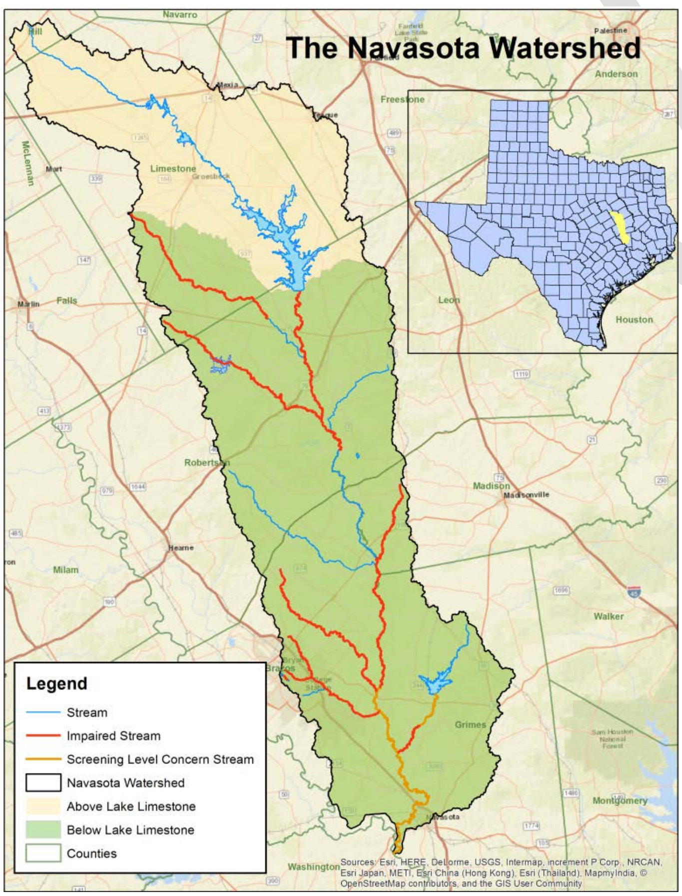


Figure 2.1 The Navasota Watershed in Texas and its divide above and below Lake Limestone

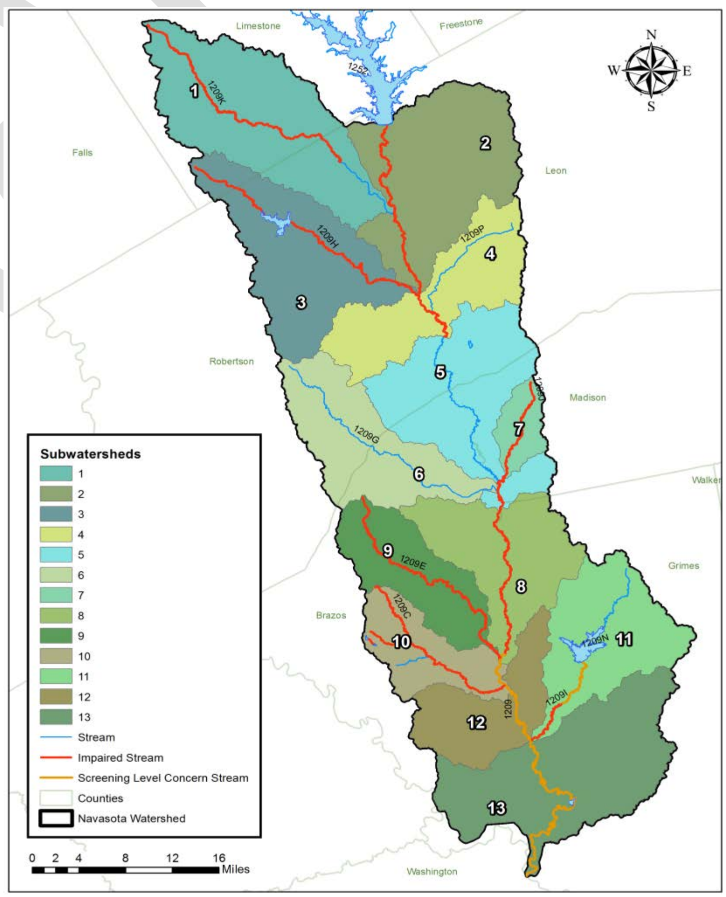


Figure 2.2 Navasota River Watershed Below Lake Limestone subwatershed delineated to aid management prioritizing

mers. These conditions, paired with good land management, result in a highly productive watershed that supports abundant livestock and wildlife.

Subwatersheds

Subwatersheds were created to better analyze the watershed and help identify key areas of interest. The watershed is divided into 13 hydrologically unique subwatersheds (Figure 2.).This will allow resources, time and funding to be directed to the areas that will have the highest impacts on water quality and expedite achievement of WPP goals.

Land Use/Land Cover

Watershed land use and land cover (LULC) is classified into nine categories (Figure 2.1). Dominant LULC categories are hay/pasture land (37.9%) and forests (24.8%) (Table 2.2). The LULC is also divided by subwatershed in Table 2.3. A detailed category description and the map development methods are described in Appendix B.

Population

The largest urban area in this watershed is Bryan/College Station. The remaining watershed area is sparsely populated. 2010 census block data was obtained for the entire watershed and a population density map was created (Figure 2.2). Of the six counties, Brazos County has the largest population per square mile and projected future population increase (Table 2.1).

Table 2.1 Population and population density in the watershed.

County*	County Population in Watershed	Population Density Per Square Mile	Projected 50 year Percent (entire county)
Brazos	156,941	376.5	124 %
Grimes	11,170	34.5	48 %
Madison	1,419	20.2	44 %
Leon	5,235	21.3	47 %
Limestone	1,735	11.5	34 %
Robertson	4,540	12.4	62 %
TOTAL	181,040		

*not all county area is in the watershed

(Texas Water Development Board (TWDB) 2014); U.S. Census Bureau 2010)

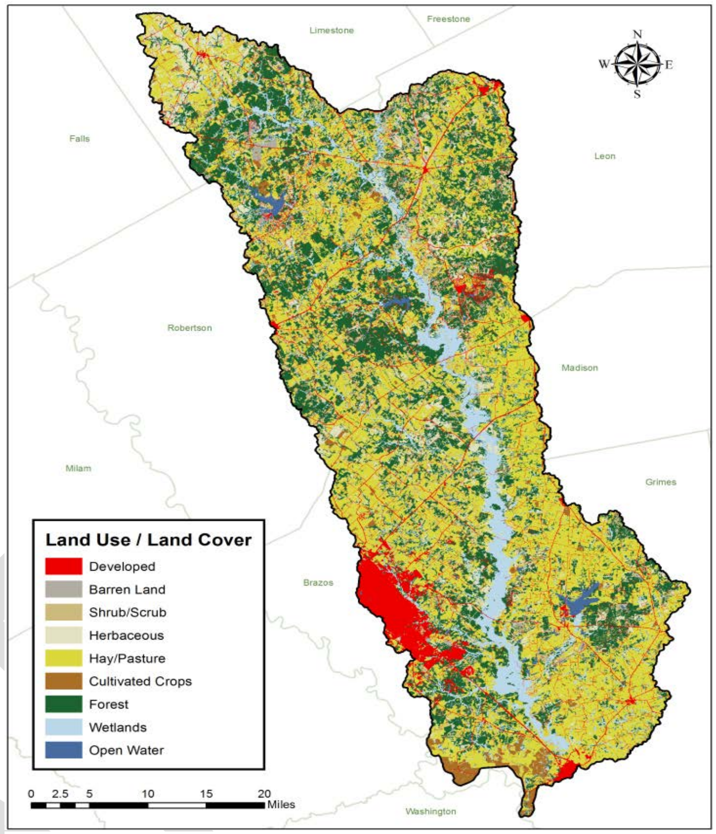


Figure 2.1 Land use / land cover (NLCD 2011)

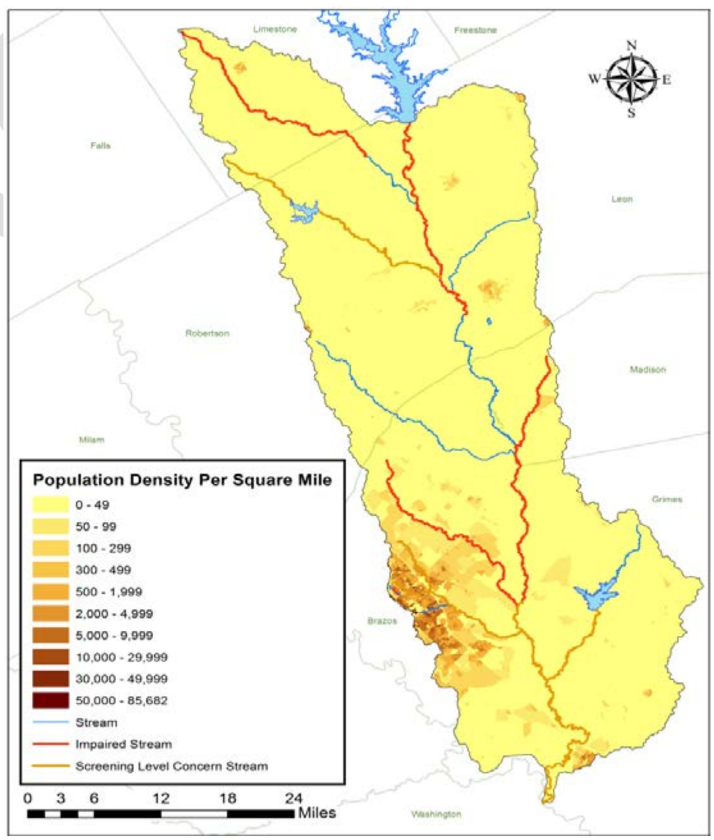


Figure 2.2 Population by census blocks (U.S. Census Bureau 2010)

Table 2.2 Acres of land use/land cover per county (NLCD 2011)

County	Acres & Percents of Land Use and Land Cover Categories																		Total Acres of County	
	Developed		Barren Land		Shrub/ Scrub		Herbaceous		Hay/ Pasture		Cultivated Crops		Forest		Wetlands		Open Water		Total Acres	Percent of Watershed
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Brazos	35,717	13.39	741	0.28	25,730	9.64	17,595	6.60	89,388	33.51	9,235	3.46	57,185	21.44	29,797	11.17	1,392	0.52	266,781	26.51
Grimes	12,841	6.21	1,008	0.49	11,663	5.64	11,596	5.60	111,274	53.78	2,518	1.22	34,134	16.5	17,260	8.34	4,621	2.23	206,915	20.56
Madison	1,768	3.93	57	0.13	3,104	6.91	2,418	5.38	25,821	57.46	29	0.06	6,055	13.47	5,448	12.12	239	0.53	44,940	4.47
Leon	11,287	7.18	3,219	2.05	23,108	14.71	15,436	9.83	48,473	30.86	249	0.16	47,091	29.98	7,157	4.56	1,076	0.69	157,096	15.61
Limestone	4,009	4.17	1,917	1.99	6,221	6.46	17,760	18.46	28,618	29.74	2,024	2.10	28,813	29.94	6,573	6.83	298	0.31	96,233	9.56
Robertson	11,745	5.01	2,575	1.10	23,246	9.92	16,312	6.96	78,153	33.35	5,167	2.20	76,269	32.54	17,538	7.48	3,361	1.43	234,366	23.29
Acres of Category in Watershed	77,367		9,517		93,072		81,117		381,727		19,222		249,547		83,773		10,987		1,006,330	
Percent of Category in Watershed	7.7		0.9		9.2		8.1		37.9		1.9		24.8		8.3		1.1			

Table 2.3 Acres of land use/land cover by subwatershed (NLCD 2011)

Sub-watershed	Acres & Percents of Land Use and Land Cover Categories																		Total Acres of Subwatershed	
	Developed		Barren Land		Shrub/ Scrub		Herbaceous		Hay/ Pasture		Cultivated Crops		Forest		Wetlands		Open Water		Total Acres	Percent of Watershed
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
1	5,297	4.46	2,251	1.90	8,223	6.93	19,904	16.77	37,941	31.96	2,654	2.24	32,891	27.70	9,218	7.76	344	0.29	118,722	11.80
2	6,732	6.21	2,711	2.50	15,340	14.16	9,931	9.17	37,025	34.17	659	0.61	29,978	27.67	5,325	4.91	641	0.59	108,342	10.77
3	5,077	5.27	1,322	1.37	8,522	8.85	7,204	7.48	32,804	34.07	2,336	2.43	31,703	32.93	5,132	5.33	2,176	2.26	96,276	9.57
4	4,149	5.65	979	1.33	8,489	11.56	6,933	9.45	16,968	23.12	669	0.91	29,961	40.82	4,137	5.64	1,119	1.52	73,405	7.29
5	5,451	5.59	297	0.30	10,318	10.58	7,358	7.54	33,969	34.83	412	0.42	24,555	25.17	14,448	14.81	730	0.75	97,538	9.69
6	2,916	3.78	373	0.48	10,073	13.06	8,187	10.61	28,436	36.86	1,113	1.44	22,162	28.73	3,716	4.82	174	0.23	77,150	7.67
7	784	4.69	27	0.16	965	5.78	143	0.86	11,844	70.88	0	0.00	2,081	12.45	793	4.75	73	0.43	16,710	1.66
8	3,005	4.01	39	0.05	6,094	8.14	6,142	8.20	32,233	43.04	704	0.94	13,684	18.27	12,614	16.84	378	0.50	74,893	7.44
9	3,605	6.39	36	0.06	5,866	10.40	3,443	6.10	29,734	52.72	1,026	1.82	10,374	18.39	2,110	3.74	208	0.37	56,402	5.60
10	20,987	48.16	80	0.18	2,946	6.76	1,281	2.94	6,669	15.3	253	0.58	6,483	14.88	4,718	10.83	159	0.36	43,577	4.33
11	4,361	5.76	633	0.84	5,584	7.37	4,703	6.21	35,761	47.20	409	0.54	17,390	22.95	3,538	4.67	3,383	4.47	75,764	7.53
12	7,789	14.90	568	1.09	4,125	7.89	2,206	4.22	15,307	29.29	35	0.07	13,354	25.55	8,106	15.51	770	1.47	52,260	5.19
13	7,215	6.26	202	0.17	6,526	5.66	3,683	3.19	63,037	54.67	8,953	7.77	14,932	12.95	9,916	8.60	834	0.72	115,297	11.46
Acres of Category Watershed	77,367		9,517		93,072		81,117		381,727		19,222		249,547		83,773		10,987		1,006,330	
Percent of Category Watershed	7.7		0.9		9.2		8.1		37.9		1.9		24.8		8.3		1.1			

Water Resources

Surface Water

Surface water is abundant throughout the watershed. Lake Limestone, Gibbons Creek Reservoir and the Twin Oaks Reservoir represent the largest surface water resources. Lake Limestone was impounded in 1978 when the Sterling C. Robertson dam was completed. Lake Limestone lies mainly in Limestone County, and has a total capacity of 203,780 acre-feet and a surface area of approximately 12,486 acres (TWDB 2016a). Gibbons Creek is a tributary of the Navasota River. Gibbons Creek Reservoir was officially impounded in 1981, and can store 26,171 acre-feet of water within its 2,576 acres (TWDB 2016b). Twin Oaks Reservoir is located on Duck Creek, a tributary of the Navasota River, and was officially completed in 1982. It has a total capacity of 30,319 acre-feet and covers 2,330 acres (TWDB 2016c). Numerous smaller reservoirs and stock ponds also exist in the watershed. In total, they cover approximately 10,987 acres downstream of Lake Limestone. Creeks and streams are common across the watershed. Of these, 11 are named and assessed by the State; however, many more exist.

Groundwater

Several major and minor aquifers are present within the watershed. Major aquifers include the Carrizo-Wilcox and Gulf Coast Aquifers. The Carrizo-Wilcox Aquifer extends from Louisiana to Mexico and runs adjacent to the Gulf Coast Aquifer. It reaches 3,000 feet in thickness, but the average saturated thickness of the sands is approximately 670 feet (TWDB 2016d). Quality ranges from fresh to slightly saline and from hard to soft depending on location within the aquifer. The Carrizo-Wilcox Aquifer provides drinking water for many watershed residents, particularly those in the Bryan/College Station area. The Gulf Coast Aquifer parallels the coast and also extends from Louisiana to Mexico. The maximum thickness is about 1,300 feet, with 1,000 feet being the average saturated thickness. Its quality within the watershed is generally good due primarily to distance from the coast (TWDB 2016e). Minor aquifers including the Yegua Jackson, Sparta, Queen City and Brazos River Alluvium are also present in the watershed and provide important water resources for irrigation, livestock watering and potable uses.

Chapter 3 : Water Quality

Water is monitored in Texas to ensure that its quality supports designated uses defined in the Texas Water Code. Designated uses and associated standards are developed by TCEQ to fulfill requirements of the Clean Water Act (CWA), which addresses toxins and pollution in waterways and establishes a foundation for water quality standards. It requires states to set standards that: (1) maintain and restore biological integrity in the waters, (2) protect fish, wildlife, and recreation in and on the water (must be fishable/swimmable), and (3) consider the use and value of state waters for public supplies, wildlife, recreation, agricultural, and industrial purposes. Each state creates their own water quality standards that are approved by the USEPA and allow these goals to be maintained.

The CWA (33 USC § 1251.303) administered by USEPA (40 CFR § 130.7), requires states to develop a list that describes all waterbodies that are impaired and are not within established water quality standards (commonly called the 303(d) List). In addition, the states are required to develop total maximum daily loads (TMDL) or other acceptable strategies to restore water quality for impaired waterbodies not meeting the standards (40 CFR § 130.7). A TMDL is a budget that sets the maximum pollutant loading capacity of the waterbody and the reduction needed for the waterbody to meet applicable standards. It establishes the maximum allowable pollutant loads in a waterbody from point and nonpoint pollution sources and is used to reduce pollution by allocating this established maximum load among the pollution sources (USEPA 1991). Another option is the development of a locally created WPP. Stakeholders are encouraged to address causes of impairments and threats to water quality and are given decision-making power to establish WPP goals. WPPs provide a long-term restoration plan with strategies that ultimately attain water quality standards or protect unimpaired waters.

Waterbody Assessments

TCEQ conducts waterbody assessments biennially; usually on even numbered years. The report is titled *Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) List* (referred to as the *Texas Integrated Report*). The most recent iteration of this report was published in 2014 and considered water quality data collected between December 1, 2005 and November 30, 2012. This is more than two years prior to the start of efforts to develop this WPP.

Table 3.1 Monitoring stations for the Navasota WPP (LCRA 2015)

Segment	Station ID	Station Name	Collected by	Frequency	Parameters*
1209_01	11873	Navasota River at SH 6	BRA	Quarterly	F, B, C
1209_02	11875	Navasota River at SH 30	BRA / TWRI	Quarterly / Twice Monthly	F, B, C / F, B, C, FL
1209_03	16398	Navasota River at CR 162	TWRI	Twice Monthly	F, B, C, FL
1209_05	11877	Navasota River at US 79	BRA / TWRI	Quarterly / Twice Monthly	F, B, C, FL / F, B, C, FL
1209C	11785	Carter's Creek at Bird Pond Rd	BRA	Quarterly	F, B, FL
1209I_02	18800	Gibbons Creek East at FM 244	BRA	Quarterly	F, B, C

* F = field: Includes pH, DO, specific conductance, and temperature
B = bacteria: refers to *E. coli* in this case
C = conventional: includes nutrients, minerals, and particulate matter
FL = flow

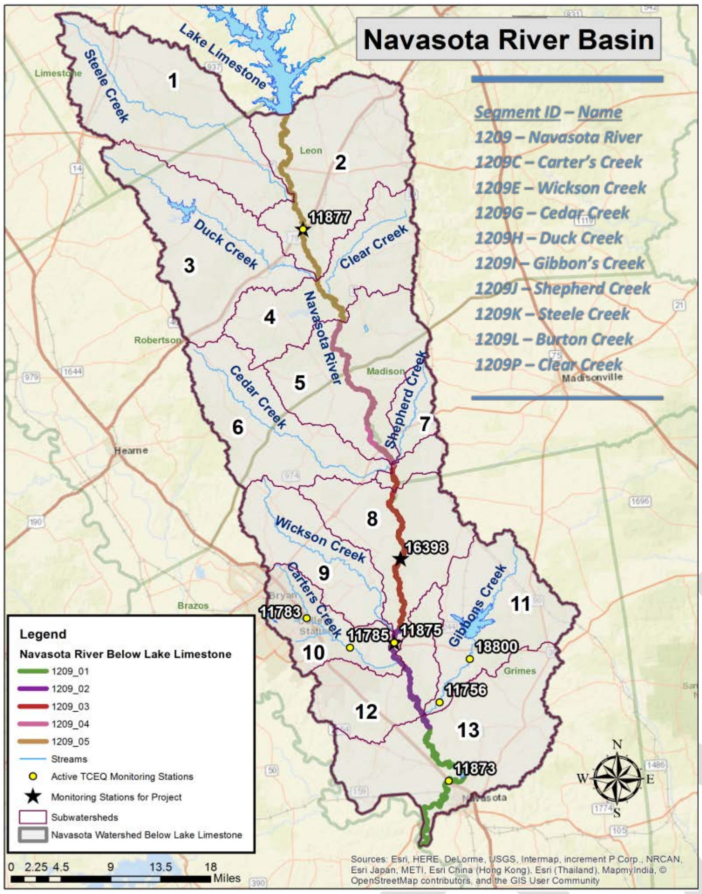


Figure 3.1 Navasota River assessment units and monitoring station locations

Each waterbody assessed in the state of Texas has a segment identification number (ID) which is further divided into assessment units (AU). For example, the Navasota River is segment 1209, and has five AUs designated 1209_01 through 1209_05 (Figure 3.1). Monitoring stations are located on most AUs and allow independent water quality analysis for each AU in a segment. Assessments are conducted using the most recent seven years of data available. At least 10 data points are required for all water quality parameters except bacteria. It requires a minimum of 20 samples. TCEQ may also consider data outside of the assessment period if necessary and appropriate. Actively monitored stations within the watershed provide the bulk of assessment data (Table 3.1; Figure 3.1). These assessments result in waterbodies being added to or removed from the 303(d) List.

Texas Surface Water Quality Standards (TSWQS)

Water quality standards are established to define a waterbody's ability to support its designated uses which may include: aquatic life use (fish, shellfish, and wildlife protection and propagation), primary contact recreation (swimming), public water supply, and fish consumption. Water quality indicators for these uses include dissolved oxygen (DO) (aquatic life use), *E. coli* (primary contact recreation), pH, temperature, total dissolved solids, sulfate and chloride (general uses) (Table 3.2), and a variety of toxins (fish consumption and public water supply) (TCEQ 2015b).

Table 3.2 Measured water quality parameters, standards, and assessment criteria for the Navasota River (TCEQ 2015c)

Parameter	Standard Screening Level	Criteria*
DO	5.0/3.0 mg/L	# exceed > 10%/min
E. coli	126 cfu	Geometric mean
pH	6.5 - 9.0	Average within range
TDS	600 mg/L	Average
Chloride	140 mg/L	Average
Sulfate	100 mg/L	Average
Water Temperature	33.9 °C	Average

Dissolved Oxygen

DO is an important indicator of water quality. It determines a waterbody's ability to support and maintain aquatic life. High DO levels are a sign of good water quality. Low DO levels inhibit aquatic life use and may indicate limited aeration, excessive temperature, or excess nutrient loads. Most freshwater perennial streams should maintain a 24-hour DO average of 5.0 mg/L and a 3.0 mg/L minimum for aquatic life use (TCEQ 2015b). These thresholds are evaluated primarily during an index period and critical period that span from March 15 to October 15 and from July 1 to September 30 respectively. These periods represent warm months when low stream flow, maximum temperatures, and minimum DO levels typically occur. Half of the samples used for assessment must be from the index period, while a quarter must be collected during the critical period. DO criteria are not supported when greater than 10% of samples do not attain established criteria (TCEQ 2015b).

Bacteria

Bacteria standards for primary contact recreation are applied to all fresh waterbodies in the state unless site specific standards have been developed. The standard is a geometric mean of 126 colony forming units (cfu)/100 mL of *E. coli* from at least 20 samples (30 TAC §307.7). At this level, the risk to someone engaging in contact recreation (swimming, diving, wading by children) to contract a gastrointestinal illness that may or may not include fever is 36 individuals out of 1,000 (USEPA 2012). *E. coli* concentrations meeting or better than this standard do not necessarily ensure that no risk of illness exists nor do concentrations above this level indicate that a person will get sick.

Nutrients

Nutrient standards have not been set in Texas; however, screening levels are set at the 85th percentile for parameters from similar waterbodies. If more than 20% of samples from a waterbody exceed the screening level, that waterbody is on average experiencing pollutant concentrations higher than 85% of the streams in Texas and is considered to have an elevated nutrient concentration concern. Ammonia, nitrate, total phosphorus and chlorophyll-a screening levels are applicable in the watershed (Table 3.3).

Table 3.3 Nutrient screening levels for the Navasota River

Parameter	Standard Screening Level	Criteria
Ammonia Nitrogen (NH_3-N)	0.33 mg/L	> 20% exceedance
Nitrate Nitrogen (NO_3-N)	1.95 mg/L	> 20% exceedance
Chlorophyll-a	14.1 µg/L	> 20% exceedance
Total Phosphorus (TP)	0.69 mg/L	> 20% Exceedance

(TCEQ 2015b; TCEQ 2015c)

Other Measurements

Other parameters are often recorded to assess general water quality including water temperature, pH, total dissolved solids (TDS), chloride, and sulfate. TDS measures the amount of dissolved ions in the water (such as chloride, sulfate, and other salts) and is a measure that generally indicates the ability of water to support aquatic life and public water supply uses. The maximum average TDS concentration allowed for the Navasota River is 600 mg/L. TDS is commonly related to specific conductance by multiplying TDS by 0.65. Therefore, specific conductance should not exceed 923.08 microsiemens per centimeter (µS/cm) (TCEQ 2015b). This conversion is done primarily due to the ease of measuring specific conductance compared to TDS. Chloride and sulfate standards are established as 140 and 100 mg/L respectively. Each of these constituents are forms of salts which can be detrimental to aquatic life and public water supply uses at excessive levels.

Temperature and pH are important parameters regarding aquatic life uses and public water supply. Acidity is measured using pH (potential hydrogen) and should be between 6.5 and 9 for most waters in Texas. Temperature thresholds are also in place to ensure that water temperatures do not increase to levels detrimental to aquatic life and to mitigate chemical reaction rates. This affects DO concentrations and the toxicity of some chemical compounds in water to aquatic life.

Segment Impairments and Concerns

When water quality measurements for a waterbody segment do not meet established criteria (Table 3.2), they are considered impaired and unable to support one or more of their designated uses. According to the *2014 Texas Integrated Report*, the document where waterbody impairments are listed, the Navasota River watershed has eight segments with bacterial impairments and two depressed DO impairments (Figure 3.2; Table 3.4).

If more than 20% of water quality measurements exceed designated screening levels, a screening level concern for that parameter exists. In the watershed, there are 11 waterbody segments with concerns for elevated nutrients and chlorophyll-a, depressed DO, or elevated bacteria (Table 3.5; Figure 3.4)

Table 3.5 Waterbody impairments in the watershed and the data used to determine its listing

303(d) Waterbody Impairments

*Parameter**	*Category***	*Mean Assessed*	*Criteria†*
Bacteria	**5b**		
1209E_01	Wickson Creek	313.66	126.00
1209H_01	Duck Creek	397.77	126.00
1209H_02	Duck Creek	317.13	126.00
1209I_01	Gibbons Creek	168.27	126.00
1209J_01	Shepherd Creek	426.85	126.00
1209K_02	Steele Creek	218.40	126.00
Bacteria	**5c**		
1209_03	Navasota River Below Lake Limestone	91.35	126.00
1209_05	Navasota River Below Lake Limestone	148.59	126.00
Depressed DO	**5c**		
1209H_01	Duck Creek	2.67	> 3.00
1209H_02	Duck Creek	2.50	> 3.00
Bacteria	**4a**		
1209C_01	Carter's Creek	465.60	126.00
1209D_01	Country Club Branch	722.84	126.00
1209L_01	Burton Creek	666.43	126.00

(TCEQ 2015c; TCEQ 2015d)

*Parameter or water quality indicator that does not meet the established standard.
** The category shows the current water quality and management status on the listed waterbodies. Category 5 states that the waterbody does not meet established standards for at least one of its designated uses due to pollutants.
Subcategories (taken directly from TCEQ 2015e):
5a: "TMDLs are underway, scheduled, or will be scheduled for one or more parameters"
5b: "A review of the standards for one or more parameters will be conducted before a management strategy is selected, including a possible revision to the water quality standards."
5c: "Additional data or information will be collected and/or evaluated for one or more parameters before a management strategy is selected."
Category 4 states that the "standard is not supported for one or more designated uses but does not require the development of a TMDL" because:
4a: "All TMDLs have been completed and approved by EPA"
† The value that sample data is compared against to determine impairment or concern. For DO, the criteria > 3.00 means that the sample minimum must be above 3.00. The remaining criteria show the maximum allowable value.

Table 3.4 Segments that are listed with one or more screening level concerns in the watershed

Waterbody Screening Level Concerns

*Parameter**	*Segment*	*Mean Exceed‡*	*Criteria†*
Bacteria			
1209I_02	Gibbons Creek	137.16	126.00
Depressed DO			
1209_01	Navasota River Below Lake Limestone	4.36	> 5.00
1209_02	Navasota River Below Lake Limestone	4.04	> 5.00
1209H_01	Duck Creek	3.38	> 5.00
1209H_02	Duck Creek	2.98	> 5.00
1209I_01	Gibbons Creek	1.98	> 3.00††
Nitrate			
1209_01	Navasota River Below Lake Limestone	5.62	1.95
1209C_01	Carters Creek	13.72	1.95
1209L_01	Burton Creek	12.20	1.95
Total Phosphorus			
1209_01	Navasota river Below Lake Limestone	1.50	0.69
1209C_01	Carters Creek	2.84	0.69
Chlorophyll-a			
1209C_01	Carters Creek	25.42	14.10

(TCEQ 2015c; TCEQ 2015e)

*Parameter or water quality indicator that does not meet the established standard.
‡ The mean of the samples that exceeded the criteria for the parameter. This is not an average of all samples, only the average of samples that exceeded the criteria. This mean does not influence listing. Rather the percent exceedance does as described in the nutrient section above.
† The value that sample data is compared against to determine impairment or concern. The criteria > 5.00 states that samples that are < 5 will be labeled as exceeding the criteria. The # of exceeded samples (samples whose values are less than 5) must be greater than 10% of the total samples assessed to be labeled as concerned or impaired must be mean of the samples must be above 5.00. The remaining criteria show the maximum allowable value.
†† The minimum DO for this segment is 2.00 while the grab average is 3.00. Both the average and minimum screening levels have concerns.

TMDLs in the Watershed

In 2008, TCEQ initiated efforts to develop TMDLs on Burton Creek, Carters Creek, and Country Club Branch (Segments 1209L, 1209C, 1209D respectively). Each of these waterbodies were impaired for elevated bacteria concentrations. TMDLs were developed and adopted in August 2012 (TCEQ 2012a). In association with these TMDLs, a TMDL Implementation Plan (I-Plan) was also developed that outlines management strategies and control actions that will be taken to address bacteria loading in the watershed. The I-Plan was also adopted in August 2012 (TCEQ 2012b) and the management measures and control actions are integrated into this WPP.

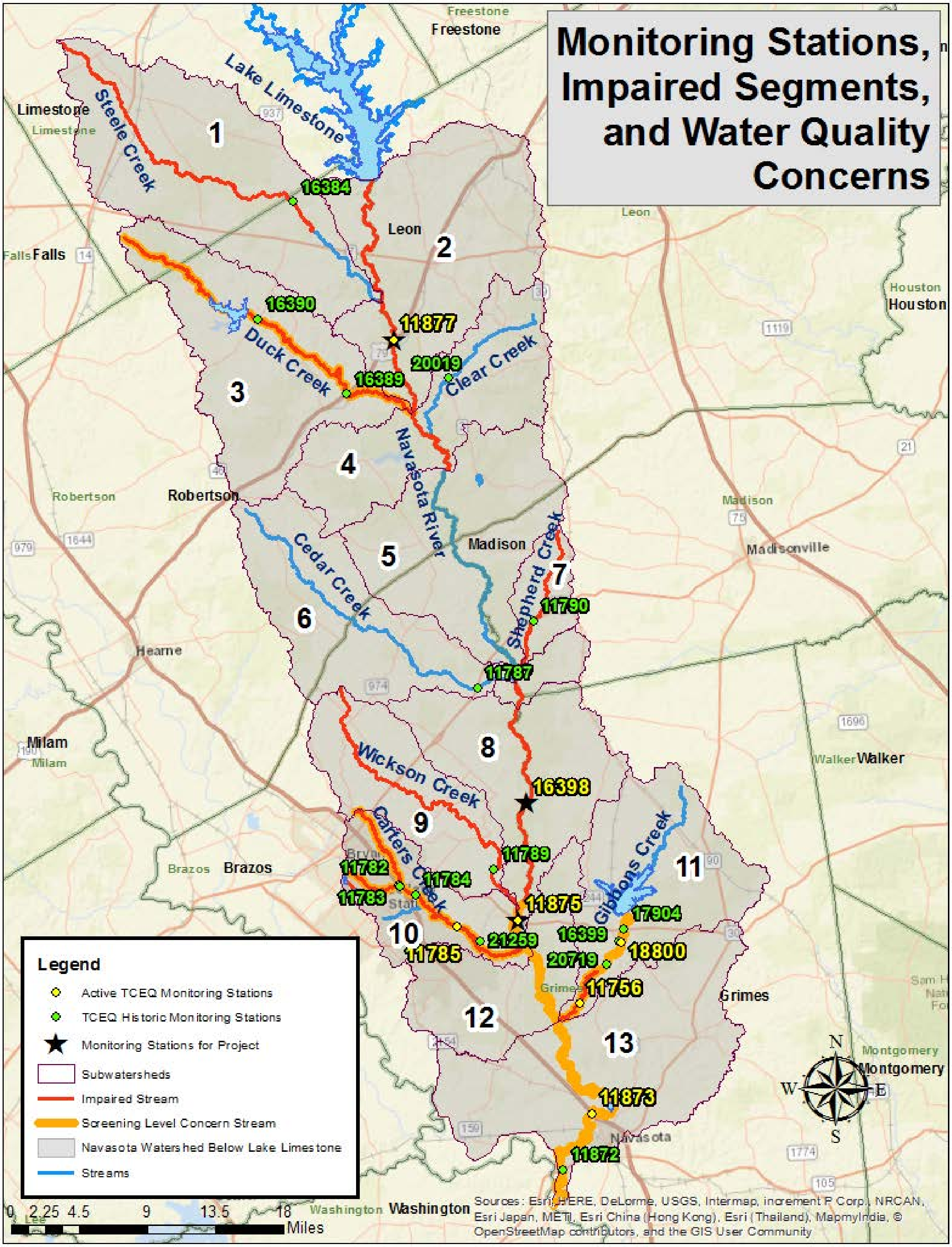


Figure 3.2 Monitoring stations, impaired segments, and water quality concerns in the watershed below Lake Limestone

Chapter 4 : Potential Sources of Pollution

Pollution is categorized as either a point or nonpoint source of pollution. Point sources enter receiving waters at identifiable locations, such as a pipe. Nonpoint sources are anything that is not a point source and enters the waterbody by runoff moving over and/or through the ground. Potential pollution sources in the watershed were identified through stakeholder input, watershed surveys, project partners, and watershed monitoring (Table 4.1).

Point Source Pollution

Wastewater Treatment Facilities (WWTFs)

There are currently eight operating WWTFs in the watershed (Figure 4.1). The cities of Bryan and College Station generate the majority of wastewater while Navasota, Anderson, Marquez, and Thornton generate much smaller wastewater volumes. Generally, measured E. coli concentrations in discharge waters are below the state standard; however, exceedances have occurred (Table 4.2). Discussions with WWTF operators indicate that stormwater inflow and infiltration into the conveyance system and the WWTF during rain events is the most common cause of effluent being discharged with *E. coli* concentrations higher in excess of their permits. With the exception of the Navasota WWTF, the WWTF outfalls are upstream of active monitoring stations allowing their influences on instream contribution to be accounted for during routine water quality measurements.

Table 4.1 Summary of potential pollution sources in the watershed below Lake Limestone

Pollutant Source	Pollutant Type	Potential Cause	Potential Impact
WWTFs	Bacteria Nutrients	System overload from large storm events Conveyance system failures due to age, illicit connections, etc.	Untreated wastewater may enter watershed or waterbodies
Residential OSSFs	Bacteria Nutrients	System failure due to age System not properly designed for site specific conditions Improper function from lack of maintenance / sludge removal Illegal discharge of untreated wastewater	Improperly treated wastewater is applied at or near soil surface; may runoff into waterbodies.
Urban Runoff	Bacteria Nutrients	Stormwater runoff from lawns, parking lots, dog parks, etc. - Improper application of fertilizers - Improper disposal of pet waste	Stormwater drains quickly and routes water directly to creek or river
Pets	Bacteria Nutrients	Fecal matter not properly disposed of Lack of dog owner education regarding effects of proper disposal	Bacteria and nutrients enter waterbody through runoff
Livestock	Bacteria Nutrients	Excessive runoff from pastures due to over-grazing Manure transport in runoff Direct fecal deposition to streams Riparian area disturbance and degradation	Deposited directly into waterbody or may enter during runoff events
Poultry	Bacteria Nutrients	Land application of poultry litter Outdoor storage of poultry litter before application	May wash into waterbody during runoff events
Wildlife	Bacteria Nutrients	Manure transport in runoff Direct fecal deposition to streams Riparian area disturbance and degradation	Deposited directly into waterbody or enters during runoff events
Illegal Dumping	Bacteria Nutrients	Disposal of trash and animal carcasses in or near waterbody	Direct or indirect contamination of waterbody

Table 4.2 Municipal WWTFs and their historic and current compliance status (USEPA 2015)

Facility Name	Receiving Stream	Flow (MGD)		Bacteria (cfu/100 mL)		Number of Quarters in Violation for exceedance from 07/2013 – 06/2016††
		Permitted	Reported (3-year avg.)†	Permitted (Daily Average)	Reported (3-year avg.)†	
City of Thornton	Tributary of Steele Creek (1209K_02)	0.041	0.017	126	5*	**9** (9 TSS)
City of Marquez	Bushy Creek to the Navasota River (1209_05)	0.04	0.020	126	44.93	**9** (7 pH, 6 *E.coli* for daily avgs., 2 *E.coli* for single grabs, 2 BOD_5, 1 DO)
City of Bryan: Burton Creek	Burton Creek to Carters Creek (1209C)	8.0	4.700	120	18.39	**3** (2 reporting, 1 Mercury)
City of College Station: Carter's Creek	Carters Creek (1209C)	9.5	6.092	120	47.55	**10** (8 *E. coli*, 4 flow, 1 reporting)
City of College Station: Carter Lake	Carters Creek (1209C)	0.0045	0.0027	120	2.28**	**6** (3 flow, 1 DO, 2 BOD_5, 3 TSS, 1 pH)
City of College Station: Lick Creek	Lick Creek to Navasota River (1209_02)	2.0	1.171	126	40.71	**10** (3 ammonia, 5 *E. coli*, 1 report-ing)
City of Anderson	Tributary of Navasota River (1209_01)	0.065	0.008	126	65.44	**9** (4 *E. coli*, 2 TSS, 1 pH, 1 BOD_5, 2 DO)
City of Navasota	Tributary of Navasota River (1209_01)	1.8	0.637	126	4.07	6 (3 *E. coli*, 2 BOD_5)

† 3-year average from 07/01/2013 – 06/30/2016. *E. coli* avg. is the geometric mean.
†† There can be multiple violations for different parameters within a quarter violation period.
*data collection only occurred between 12/31/2014 – 12/31/2015
**data collection began on 07/31/2014

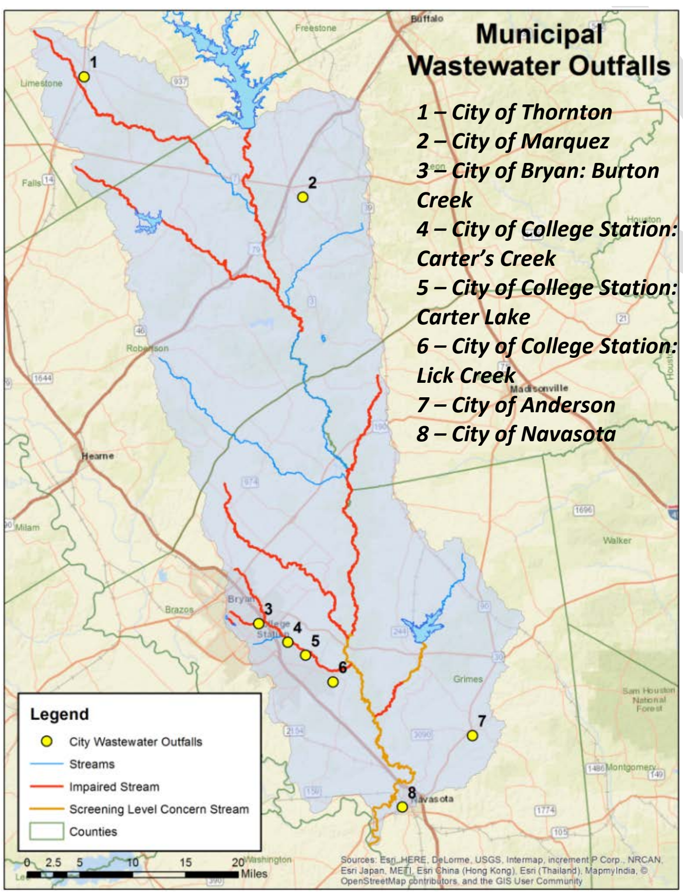


Figure 4.1 Municipal WWTF outfalls (TCEQ 2015a)

Nonpoint Pollution Sources

On-Site Sewage Facilities (OSSFs)

On-site sewage facilities (OSSFs) are common in the watershed, but the exact number of systems, their locations, ages, types, and functional status are unavailable. To estimate the number of systems and approximate their locations, an approach using 911 address points, 2010 census data, and recent aerial imagery was used to estimate the number of OSSFs (Gregory et al., 2013) (Appendix C). This method produced an estimate of 17,149 OSSFs within the watershed.

Many factors affect OSSF performance (Table 4.1). Adsorption field soil properties affect the ability of conventional OSSFs to treat wastewater by percolation. Soil suitability rankings developed by the NRCS to evaluate soil's ability to treat wastewater based on soil characteristics such as topography, saturated hydraulic conductivity, depth to the water table, ponding, flooding effects, and more (NRCS 2015). Soil suitability ratings are divided into three categories: not limited, somewhat limited, and very limited. Soil suitability dictates the type of OSSF required to properly treat wastewater. If not properly designed, installed, or maintained, OSSFs in somewhat or very limited soils pose an increased risk of failure. Approximately 56% of the watershed's soils are considered very limited, 10.5% are somewhat limited and 32.3% are not limited (Figure 4.2).

OSSF density can also affect overall treatment performance. If the systems installed are not appropriately designed, soil treatment capacity may be exceeded and lead to widespread OSSF failure (USEPA 2003). High OSSF density is not common in the watershed since each county has minimum acreage restrictions in place. Several areas in the watershed do have higher OSSF densities than surrounding areas and may increase the risk of OSSF failures and subsequent water quality effects (Figure 4.2).

Proximity to streams is important for determining OSSF's potential impact on water quality. The closer a potentially failing system is to a stream, the more likely it can impact water quality. In the watershed, only 16 OSSFs are estimated to be within 50 yards of a named waterbody and 37 OSSFs are expected within 100 yards (Figure 4.2).

Improper maintenance due to lack of homeowner knowledge is also responsible for some OSSF failures. Many owners do not understand proper OSSF function or environmental effects of improperly maintained systems. According to County Designated Representatives (DRs) and other stakeholders, about 1,747 (10.3%) of the 17,149 OSSFs estimated in the watershed are not functioning properly (see calculation in Appendix D).

Pets and Urban Runoff

Fecal matter from dogs and other urban animals can be a source of *E. coli* and nutrient pollution transported by urban runoff. The American Veterinary Medical Association (AVMA) estimates 0.584 dogs per household (AVMA 2015). This estimate multiplied by the number of households recorded in the 2010 Census was used to estimate the watershed dog population (Table 4.3). Fertilizer application can also be a source of nutrients in runoff if they are improperly applied. Runoff from urban areas is increased by impervious cover and can adversely affect water quality.

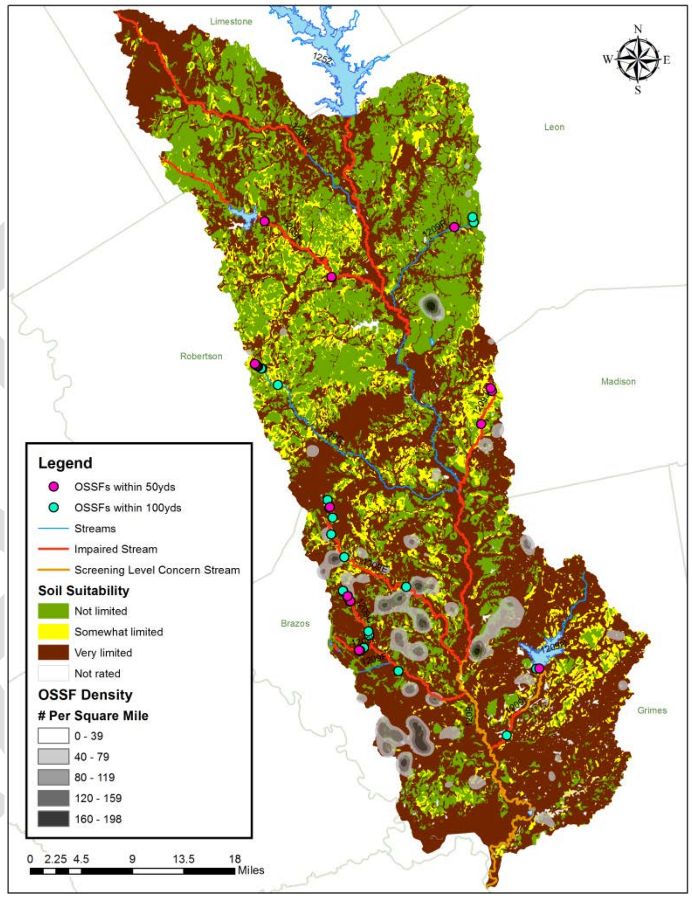


Figure 4.2 Soil suitability ratings, proximities of OSSFs to named streams, and OSSF density in the watershed (NRCS 2015)

Table 4.3 Estimated dog population in the watershed (AVMA 2012; U.S. Census Bureau 2010)

County	Households*	Estimated Dog Population
Brazos	50,616	29,559
Grimes	3,582	2,092
Limestone	1,369	799
Leon	1,565	914
Madison	622	363
Robertson	2,764	1,614
TOTAL	**60,518**	**35,341**

*The number of occupied households from 2010 census was obtained and divided by the county area (mi^2) to get #/mi^2. The county area in watershed was calculated and multiplied by the previous #/mi^2 to get the final household number in the table.

Grazing Livestock

Feces from grazing livestock can be a source of bacteria and nutrients in the watershed. Livestock with direct access to waterbodies directly deposit fecal matter in and near the water, which can strongly affect water quality. Health and quality of grazing areas also affects water quality. Proper grazing management is necessary for protecting water quality since overgrazed pastures yield increased runoff and pollutant loads.

Livestock populations in the watershed were quantified using 2012 National Agriculture Statistics Survey (USDA 2012) information for horses, goats, and sheep. Cattle numbers were estimated using stocking rates recommended by USDA NRCS personnel with stakeholder adjustments applied to the appropriate land cover types in the watershed (Table 4.5; Appendix D).

Table 4.5 Grazing livestock populations in the watershed (USDA 2012)

County	Livestock*			
	Cattle	**Horses**	**Goats**	**Sheep**
Brazos	18,501	1,978	1,314	590
Grimes	23,705	1,274	484	78
Leon	12,104	662	414	83
Limestone	7,723	442	248	75
Madison	5,528	51	149	52
Robertson	24,477	215	515	264
TOTAL	**92,038**	**4,622**	**3,122**	**1,141**

*The number of heads from 2012 census was obtained and divided by the county area (mi^2) to get #/mi^2. The county area in watershed was calculated and multiplied by the previous #/mi^2 to get the final livestock head in the table.

Commercial Poultry

According to TSSWCB, there were 57 poultry facilities in the watershed that house almost 9.9 million birds as of 2015 (Table 4.4). Poultry facilities are required to obtain a Water Quality Management Plan (WQMP) before operations begin. WQMPs prescribe proper handling and utilization of produced litter to ensure adequate water quality protection. On-farm, litter is stored in a litter barn or other impermeable layer for up to 30 days (TSSWCB 2010) before land application. Once land-applied or if not stored properly off-site, litter can become a potential bacterial and nutrient source if it is not handled correctly. TSSWCB estimates 65,282 tons of litter is produced annually. Of this, 5,858 tons is applied on-site and the remaining 58,782 tons is applied off-site. Industry professionals estimated that about 80% of the offsite litter is applied in the watershed (47,026 tons) and the remainder is exported out of the watershed.

Table 4.4 The maximum permitted poultry numbers from the WQMP data for the watershed (TSSWCB 2015)

Bird Type	Count
Pullet	95,600
Breeder	112,680
Broiler	9,660,584
Total	**9,868,864**

Wildlife and Feral Hogs

Wildlife is another *E. coli* and nutrient source in the watershed. Riparian areas provide the most suitable wildlife habitat in the watershed, leading most wildlife to spend the majority of their time in these areas. Fecal deposition is directly related to time spent in a given area, thus wildlife feces are considered a major source in the watershed. Wildlife population density estimates are limited to deer and feral hogs since information regarding other species is not available.

Deer populations were estimated using annual deer density estimates from Texas Parks and Wildlife Department (TPWD) surveys conducted in and near the watershed. Recent data (2014-2015) indicates the current density across the watershed is 32 acres per animal in appropriate land covers (hay pasture, herbaceous, shrub/scrub, cropland, forests). Using this density, a watershed deer population of 28,392 animals was derived. The feral hog population was estimated similarly. Stakeholder feedback indicated separate densities of feral hogs in wetland areas (8 ac/hog) and forests (13 ac/hog). Using these densities, a watershed wide estimate of 36,827 hogs was produced.

Illegal Dumping

Illegal dumping is a potential *E. coli* source in the watershed. Animal carcasses and trash can be direct sources of *E. coli* when discarded in or near waterbodies. Numerous deer, feral hog, and other carcasses have been observed under or adjacent to bridges, in the river, and scattered across the watershed.

Chapter 5 : Pollutant Source Assessment

Multiple approaches were used to assess watershed pollutant loadings to provide a more complete evaluation of potential pollution sources and their impacts on water quality. Each approach provides a piece of information needed to define and address specific pollutant sources. No method provides a perfect result or a definitive answer as each method analyzes data differently. Methods used included spatial water quality data analysis, load duration curves, spatial analysis of potential *E. coli* sources, and bacterial source tracking.

Water Quality Monitoring

Long-term water quality monitoring data collected indicate that two segments of the river (1209_03 and 1209_05) are currently impaired due to elevated *E. coli* concentrations. Supplemental monitoring was conducted twice a month from December 2014 to August 2016 and provided additional water quality and quantity data in these impaired segments. It should be noted that numerous high-flow and flood-flow events occurred during this monitoring period. Flow rates certainly influenced *E. coli* concentrations measured and demonstrate that nonpoint source pollution and/or instream resuspension of sediment are significant sources of *E. coli* in the river.

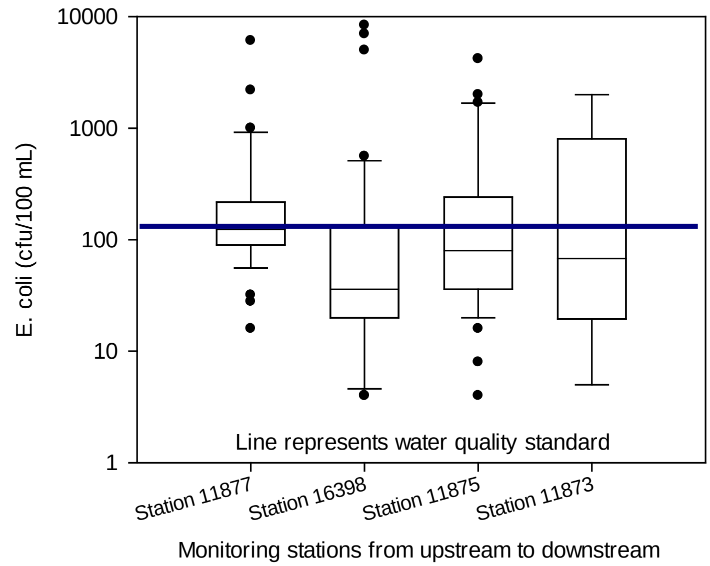


Figure 5.1 Boxplots for *E. coli* samples obtained during the two-year monitoring event on segment 1209

E. coli

Supplemental monitoring data for station 11877 continued to indicate that segment 1209_05 does not support its designated contact recreation use. The boxplot for station 11877 (Figure 5.1) demonstrates the distribution of E. coli concentrations measured. Almost half of the samples collected contained E. coli concentrations higher than those allowed by the water quality standard and the geometric mean of these samples is 162.3 cfu/100 mL. This is similar to the concentration reported in the *2014 Texas Integrated Report* (148.59) and further substantiates the impairment in this location.

Supplemental monitoring was also conducted in segment 1209_03 at station 16398. This portion of the river is listed as impaired for *E. coli,* even though its assessed geometric mean is 91.35 cfu/100 mL and therefore meets the applicable standard (Table 3.5). Only six samples were collected during the 2014 assessment period while 20 samples are needed for a proper assessment. As a result, its impaired listing was carried forward from the 2012 assessment (162 cfu/100 mL) which had adequate data. Data collected during the supplemental monitoring were generally within the water quality standard (Figure 5.1) compared to historic data. The geometric mean of these data was 73.93 cfu/100 mL and demonstrates compliance with the recreational standard (Table 5.1). When reassessed in 2017-2018, the data should yield removal of this portion of the river from the 303(d) List.

Station 11875 on segment 1209_02 was the other station included in the supplemental monitoring effort. Data indicate a slight increase in *E. coli* concentration compared to the *2014 Texas Integrated Report* (120.0 vs 78.2 cfu/100 mL), but continue to illustrate that this portion of the river meets its water quality standard.

No supplemental data collection was completed at station 11873 on segment 1209_01. Comparing existing data at this site to the upstream sites demonstrates little change in mean *E. coli* concentrations (Figure 5.1). This indicates that significant influxes of bacteria loading are likely not occurring in this lower portion of the waterbody.

Six Navasota River tributaries also have bacterial impairments (Table 3.5), but E. *coli* monitoring only occurs quarterly on Carters Creek and Gibbons Creek.

Dissolved Oxygen

During supplemental monitoring, dissolved oxygen levels in the river met the average standard of 5.0 mg/L and all samples were above the 3.0 mg/L minimum standard. However, long-term data used in biennial assessments reveal low DO concerns for segments 1209_01 (Station 11873) and 1209_02 (Station 11875). Average DO concentrations in these assessment units during the last statewide assessment period did not meet the water quality standard (5 mg/L). Supplemental monitoring conducted identified only three individual samples lower than the standard, indicating that low DO is not problematic in monitored areas. Segment 1209_01 was not included in this monitored area.

Recent quarterly monitoring on segment 1209_01 suggests that DO concentrations are improving. No individual values recorded since 2012 (10 samples) have been below 5 mg/L. Most of the values that did occur below allowable levels were collected during the 2011 drought and low flow summer conditions.

Duck Creek (1209H_01 and 1209H_02) remains impaired for low DO (Table 3.5); however, an aquatic life use assessment is currently underway that may result in a future water quality standards change. This assessment consists of intensive water quality monitoring and aquatic life community assessments that determine how well the creek is supporting aquatic life. Gibbons Creek (1209I_01) also has a concern for low DO (Table 3.4). Recent sampling indicates that DO concentrations are improving with only one sample collected since 2012 being lower than the average allowable level.

Nutrients

Nutrient concerns are not common in the watershed, but several do exist. Segment 1209_01 of the river has concerns for elevated nitrate and total phosphorus concentrations (Table 3.4). Segment 1209C (Carters Creek) has these same concerns plus an elevated Chlorophyll-a concern. No nutrient concerns exist in the watershed upstream of the Carters Creek – Navasota River confluence. Nutrient data collected upstream of the confluence during supplemental monitoring supports this finding (Table 5.1). These findings suggest that the primary source(s) of nutrient loading in the watershed are located in the Bryan/College Station area. Pollutants such as animal waste, fertilizer runoff, and wastewater effluent are the likely sources.

Load Duration Curve (LDC) Analysis

The relationship between flow and pollutant concentration in the watershed was established using LDCs. This approach allows existing pollutant loads to be calculated and compared to allowable loads and is the basis for estimating needed load reductions of a particular pollutant in order to achieve an established water quality goal. LDC also help determine whether point or nonpoint pollutant sources primarily cause stream impairments by identifying flow conditions when impairments occur. Although LDCs cannot identify specific pollutant sources (urban vs. agricultural, etc.), they can identify they likely pollutant type (point vs.

Table 5.1 Two-year water quality averages on the Navasota River

Station	# of WQ Samples	*E. coli* (cfu/100 mL)*	Dissolved Oxygen (mg/L)	Specific Conductance (µS/cm)	Turbidity (NTU)	# of Nutrient Samples	Ammonia Nitrogen (mg/L)	Nitrate Nitrite Nitrogen (mg/L)	Total Phosphorus (mg/L)
11877	37	162.34	8.03	311.83	51.21	22	0.13	0.46	0.04
16398	33	73.93	7.68	327.47	39.11	22	0.09	0.35	0.06
11875	35	120.00	7.78	342.35	55.45	22	0.10	0.36	0.05
11873	3	87.94	7.30	520.67					

*The geometric mean was used to calculate *E. coli* nonpoint). For example, if allowable load exceedances primarily occur during high flow or moist conditions, nonpoint source pollution is a contributor. If exceedances occur during low flow conditions, then point sources are the most likely source. Instream disturbances such as those caused by increased flow velocity (release from a dam) or physical agitation (animal walks in stream) are also known to cause *E. coli* increases under all flow conditions.

LDCs require at least 18 paired streamflow and pollutant data points for sufficient statistical confidence for interpretation. LDCs were completed for the supplemental monitoring sites on the Navasota River (stations 11877, 16398, 11875) using data collected from December 2014 to May 2016. Appendix F explains and interprets LDC development in detail.

For planning purposes, the LDC for station 11875 was chosen to establish needed loading reductions to meet water quality standards. This is the farthest site downstream with sufficient data to develop a LDC. The geometric mean of recent data from this site indicates that it is not impaired (Table 5.1), but LDC analysis indicates that load reductions are needed to meet allowable levels during wet conditions. *E. coli* loads and needed loading reductions across the watershed were similar; thus, station 11875 was deemed representative of the entire watershed. Further, the moist conditions flow category was selected by watershed stakeholders to establish needed loading reductions. High flow conditions are largely related to flooding which presents relatively unmanageable conditions. Thus, the moist condition scenario represents the first manageable grouping of pollutant loads (highlighted rows in Tables 5.2 - 5.4). Lastly, station 11875 is routinely monitored through the CRP program by the BRA and will be monitored into the future. This will provide a continued data record as a basis for future planning and management decisions. Flow measurements are not currently recorded at this station during routine CRP monitoring but will be needed to update LDCs in the future.

Station 11877

This site had the most paired *E. coli* and streamflow data points due to the presence of a USGS flow gauge. The majority of *E. coli* concentrations above the water quality standard occurred during high flow and moist conditions (Figure 5.2), indicating that elevated loads occur as a result of runoff. Nonpoint sources are washed into the stream during these events and increased flows also cause stream sediment resuspension that can release E. coli into the water column (Frey et al. 2015). Lake Limestone is about 17.8 miles upstream of this site and releases downstream can cause sediment resuspension and subsequent increases in E. coli concentrations. The annual load reduction needed to achieve the water quality standard during moist conditions is 1.70E+14 cfu/year at this station (Table 5.2).

Station 16398

The geometric mean of *E. coli* samples collected during supplemental monitoring demonstrates that this segment is meeting the water quality standard of 126 cfu/100 mL (Table 5.1). The LDC for this station shows that impairments do occur during moist and high flow conditions (Figure 5.3), however, they do not occur frequently enough to cause the geometric mean to exceed the water quality standard. LDC analysis determined that loading reduction is only needed during high flow conditions which are beyond feasible management (Table 5.3).

Station 11875

Similar to upstream sites, elevated *E. coli* concentrations occurred primarily during high flow and moist conditions (Figure 5.4) suggesting that nonpoint source pollution and resuspension of E. coli from stream sediments are responsible for elevated levels. Reductions are needed in high flow, moist conditions, and mid-range conditions; however, it is clear that one sample skewed the regression analysis in the mid-range condition category while the remaining points were within allowable levels. Using the moist conditions category as the basis for determining needed reductions, a decrease of 1.11E+15 cfu/year is needed to meet the water quality standard (Table 5.4). This level of reduction is inclusive of the reductions needed upstream to meet the water quality standard.

Table 5.2 ***E. coli*** **loads and reductions needed to meet the water quality goal at station 11877**

Flow Condition	% of Time Flow Exceeds	Daily Loading (cfu/day)	Annual Loading (cfu/year)	% Reduction Needed to Meet Goal	Needed Annual Load Reduction (cfu/year)
High Flows	0-10%	1.20E+14	4.39E+16	84%	2.75E+16
Moist Conditions	10-40%	3.02E+12	1.10E+15	35%	1.70E+14
Mid-range Conditions	40-60%	1.01E+11	3.67E+13	5%	2.32E+12
Dry Conditions	60-90%	9.41E+10	3.43E+13	*	*
Low Flows	90-100%	2.57E+10	9.40E+12	*	*

*Condition meets water quality goal and no reduction is needed

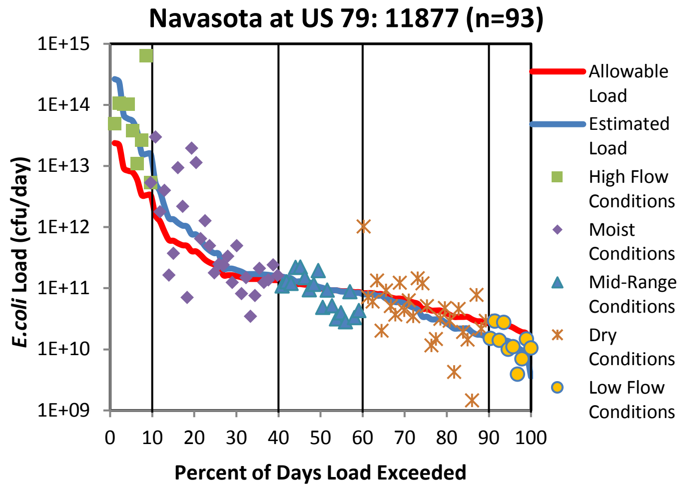


Figure 5.2 ***E. coli*** **LDC at station 11877 for monitored flow regimes**

Table 5.3 ***E. coli*** **loads and reductions needed to meet the water quality goal at station 16398**

Flow Condition	% of Time Flow Exceeds	Daily Loading (cfu/day)	Annual Loading (cfu/year)	% Reduction Needed to Meet Goal	Needed Annual Load Reduction (cfu/year)
High Flows	0-10%	6.54E+12	2.39E+15	49%	1.57E+15
Moist Conditions	10-40%	2.57E+13	9.39E+15	*	*
Mid-range Conditions	40-60%	6.37E+12	2.33E+15	*	*
Dry Conditions	60-90%	5.07E+10	1.85E+13	*	*
Low Flows	90-100%	1.51E+10	5.52E+12	*	*

*Condition meets water quality goal and no reduction is needed

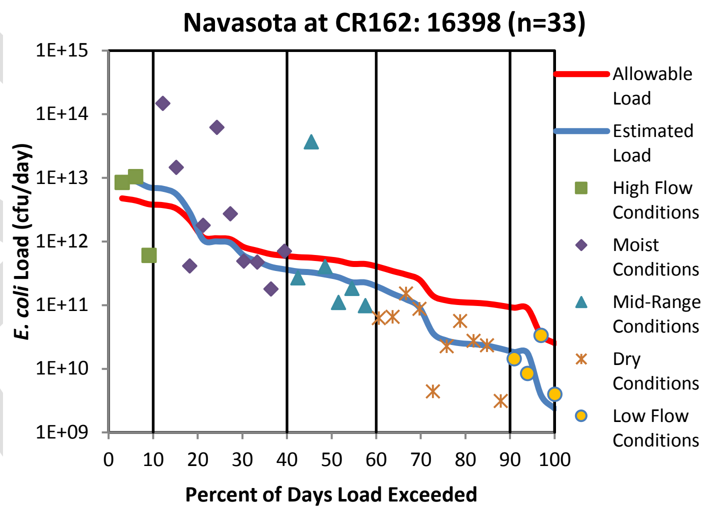


Figure 5.3 ***E. coli*** **LDC at station 16398 for monitored flow regimes**

Table 5.4 ***E. coli*** **loads and reductions needed to meet the water quality goal at station 11875**

Flow Condition	% of Time Flow Exceeds	Daily Loading (cfu/day)	Annual Loading (cfu/year)	% Reduction Needed to Meet Goal	Needed Annual Load Reduction (cfu/year)
High Flows	0-10%	1.09E+14	3.98E+16	70%	4.87E+15
Moist Conditions	10-40%	1.09E+13	3.99E+15	51%	1.11E+15
Mid-range Conditions	40-60%	5.62E+12	2.05E+15	25%	1.02E+14
Dry Conditions	60-90%	1.34E+11	4.89E+13	*	*
Low Flows	90-100%	5.01E+09	1.83E+12	*	*

*Condition meets water quality goal and no reduction is needed

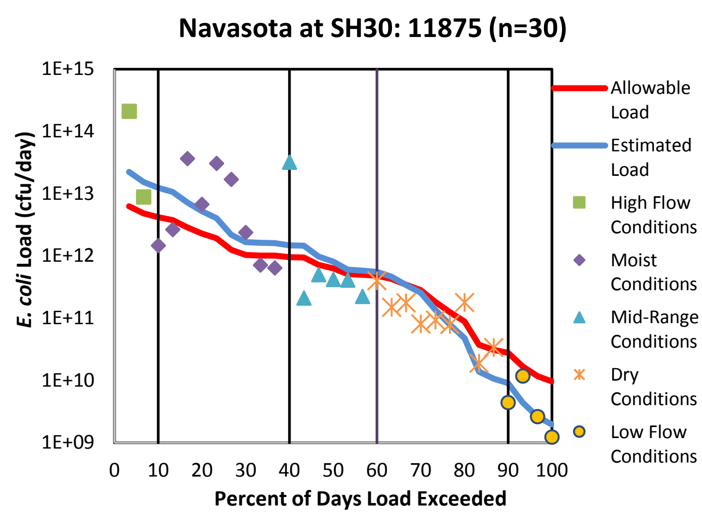


Figure 5.4 ***E. coli*** **LDC at station 11875 for monitored flow regimes**

Bacterial Source Tracking (BST)

BST is a process that matches the DNA of *E. coli* collected in water samples to the specific host it originated from and allows the source of the bacteria to be identified (Di Giovanni et al. 2013). Each *E. coli* source has a unique DNA fingerprint that can be compared to a reference library and be identified if the source has been identified before. Matches are categorized into source categories that represent the larger source groups in the watershed: 1) avian wildlife, 2) non-avian wildlife, 3) cattle, 4) pets, 5) other livestock, non-avian, 6) other livestock, avian, 7) human, and 8) unidentified.

The two most commonly used BST methods in Texas were utilized on Navasota River. The first is a paired approach that utilizes enterobacterial repetitive intergenic consensus sequence polymerase chain reaction (ERIC-PCR) and ribosomal deoxyribonucleic acid genetic fingerprinting (RiboPrinting). Combined, this is referred to as the ERIC-RP method. This approach compares *E. coli* DNA to a reference library to find genetic matches. *Bacteriodales* BST is the second method used. It tests for *Bacteroidales* DNA markers specific to humans, pigs (including feral hogs), and ruminants (including cattle, deer, llamas, and sheep) (Di Giovanni et al. 2011). Combined, these methods demonstrate the relative potential influence of differing sources of fecal contamination. All BST analysis represents the bacterial load in a very small volume of water (100 mL) at a specific point in time. Results only represent a snapshot of the watershed loading and should be considered as such.

Water samples collected at station 11875 (n=24) were analyzed using this paired BST approach. Wildlife contributions were the dominant *E. coli* source identified. This was expected due to the rural nature of the watershed and ample riparian habitat. This finding is similar to other rural watersheds in Texas (Di Giovanni et al. 2011).

ERIC-RP analysis demonstrated that sources in the terrestrial wildlife category were most common, followed by avian wildlife, cattle, other avian livestock, human, non-avian livestock, and pets (Figure 5.5). It should be noted that more than one quarter of samples were considered unidentified since their DNA fingerprints were less than

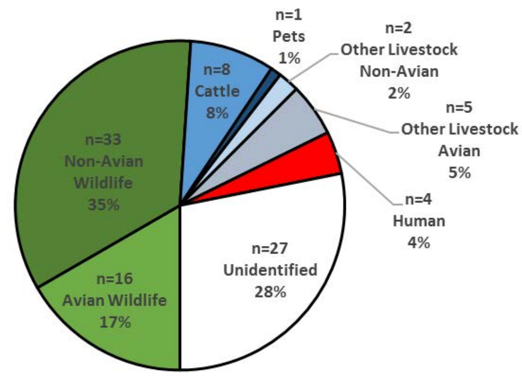


Figure 5.5 *E. coli* BST results for samples collected at station 11875 on state highway 30. Samples were collected from April 2015 to April 2016

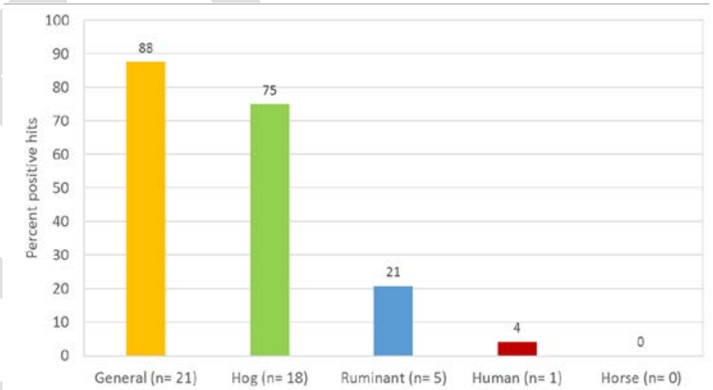


Figure 5.6 *Bacteriodales* BST results of samples collected at station 11875 from April 2015 to April 2016

80% similar to those contained in the *Texas* E. coli *BST Library.* Typically, locally collected known sources are integrated into the state-wide library during a project to minimize the number of unidentified samples. This was not carried out due to the proximity of previously collected *E. coli* source samples in and around the watershed.

Bacteriodales BST analysis found similar results (Figure 5.6). Wildlife also dominated with hogs (feral hogs) and ruminants (cattle, goats, sheep, and deer) DNA markers being identified in 75 and 21% of samples assessed respectively. Human influence was also noted; however, only one sample collected (4%) contained the human marker.

Collectively, these results indicate that a variety of *E. coli* sources are contributing to the overall load present in the Navasota River.

Spatial Analysis of Potential *E. coli* Loads

Spatial analysis of potential *E. coli* contributions aids in prioritizing subwatersheds for recommended management strategy implementation. This approach represents a worst-case *E. coli* load scenario by estimating the maximum *E. coli* load deposited in the watershed. This load could potentially runoff into nearby streams; however, significant die-off and entrainment into the soil occurs making the actual quantity of *E. coli* that enters a waterbody from these sources considerably less. Despite this detriment, this approach is useful for comparing potential loads across the watershed. Watershed loads can then be sorted by volume and prioritized for future management needs.

Potential *E. coli* loads were spatially distributed across the watershed based on subwatershed land use characteristics and animal estimates verified by stakeholders. *E. coli* loading rates were developed from published literature values regarding daily feces production and its *E. coli* content (Table 5.5). This allowed subwatershed-specific E. coli loads to be estimated for each source evaluated (Figures 5.7 and 5.8). These were then combined to produce an overall E. coli source load (Figure 5.8).

Potential *E. coli* loads calculated for each source varied among subwatersheds. Livestock and wildlife sources had higher potential loads in rural areas such as subwatersheds 13, 1, 2, 3, 5 and 6. Sources related more to urban areas were larger in subwatersheds that contain portions of Bryan and College Station (subwatersheds 10 and 12). Potential OSSF loadings were highest in Grimes County (subwatersheds 13 and 11) due to a higher estimated failure rate in those areas. Overall, subwatersheds 1 and 13 contribute the largest potential *E. coli* loads across the entire watershed while subwatersheds 2 and 3 closely follow with slightly lower contributions (Figures 5.7, 5.8; Table 5.6).

Comparing potential source loads directly, cattle represent the largest *E. coli* source in the watershed (Figure 5.9) followed by dogs and OSSFs. These sources have the highest potential load due largely to their numbers in the watershed; however, they do not necessarily constitute the largest amount of *E. c*oli to waterbodies in the watershed. Figure 5.9 provides a direct comparison of potential *E. coli* loads between evaluated sources.

Recreational Use Attainability Analysis

In 2010, the University of Houston at Clear Lake conducted recreational use attainability analyses (RUAAs) in the Navasota River watershed. Basic RUAAs were conducted on Country Club Branch, Cedar, Duck, Gibbons, Shepherd, Steele, and Wickson Creeks. This approach used stakeholder surveys, waterbody use information, stream surveys to document conditions, and public meetings. A comprehensive RUAA was conducted on the Navasota River and is more thorough. It incorporates two sampling trips to document waterbody use, characteristics and conditions. An extensive interview process is also included in comprehensive RUAAs.

During the Navasota River RUAA, swimming and wading was observed; however, fishing and hunting were more common. Potential sources of *E. coli* observed included illegal trash and animal carcass dumping, litter from fishing, animal evidence signs, and limited livestock access. Similar information was gleaned from basic RUAAs on the other evaluated waterbodies in the watershed.

Wildlife activity in and near the river bank is common and routinely observed at road crossings. Illegal dumping, especially animal carcass disposal, is quite problematic. An untold number of carcasses were observed during the RUAA process and water quality sampling, which does pose a contamination risk to the watershed.

Assessment Reconciliation

Results from the tools used to evaluate water quality and potential source contributions from across the watershed do not always agree. BST and spatial analysis of potential *E. coli* loadings are particularly at odds. However, each method evaluates a portion of the information available and provides unique insight into potential pollutant loading and watershed water quality.

BST, for example, is a direct test that identifies sources contributing to the overall pollutant loading at a specific point in time. Conversely, spatial analysis of potential *E. coli* loads presents a worst-case pollutant loading scenario that does not reflect the amount of actual *E. coli* entering the waterbody from evaluated sources. As a result, BST results and spatial analysis results should not be compared.

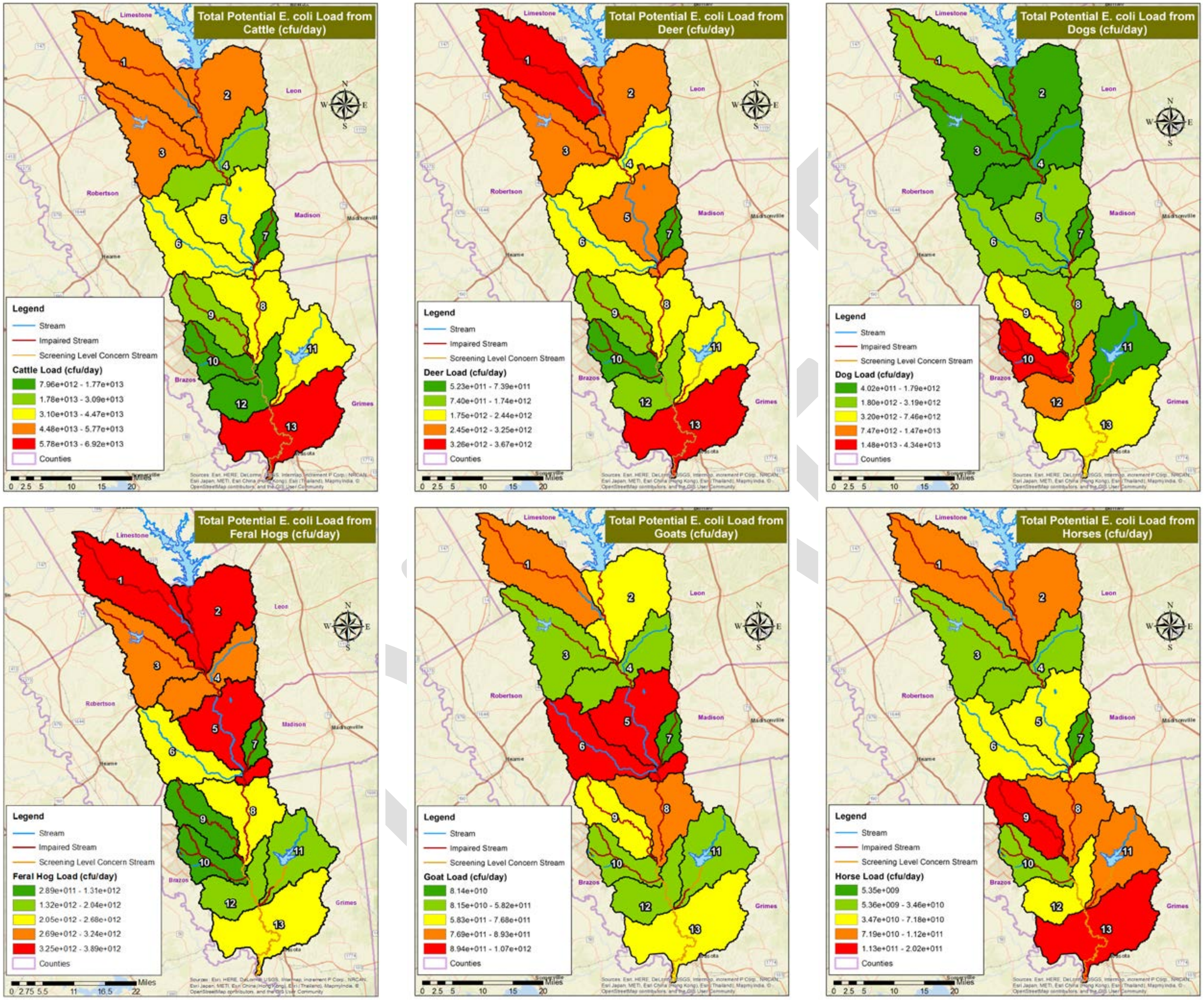


Figure 5.7 Spatial distribution of potential *E. coli* loads by subwatershed for cattle, deer, dogs, feral hogs, goats, and horses

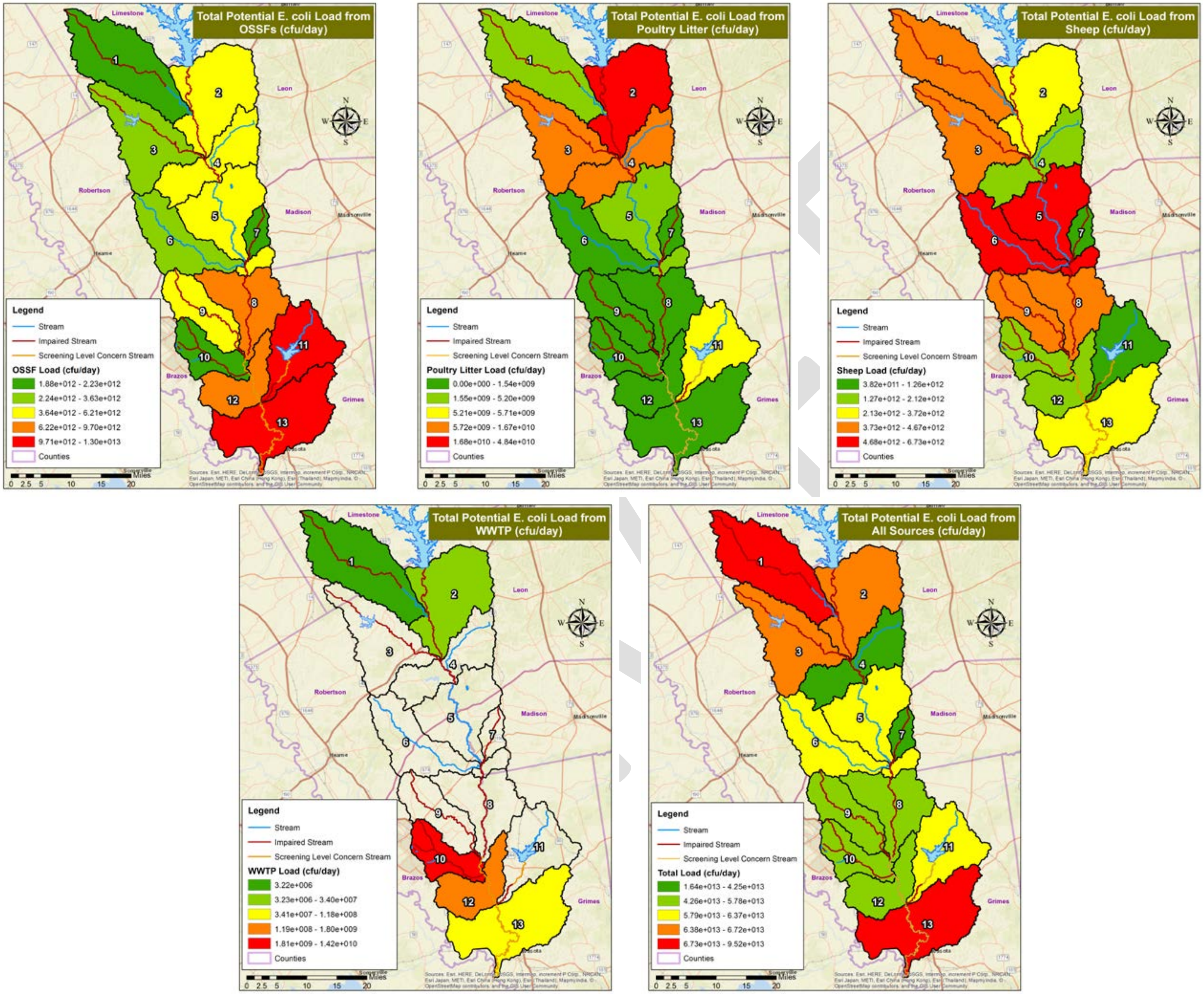


Figure 5.8 Spatial distribution of potential *E. coli* loads by subwatershed for OSSFs, poultry litter, sheep, WWTFs, and all potential sources combined

Figure 5.8 Spatial distribution of potential able 5.5 *E. coli* loading coefficients used to calculate potential subwatershed *E. coli* loads

Potential Pollutant Source		*E. coli* Loading Coefficient	Source
Cattle		5.39E+09 (cfu/AU/day)	Wagner & Moench 2009
Deer		9.45E+09 (cfu/AU/day)	
Horses		1.83E+08 (cfu/AU/day)	
Sheep		1.83E+11 (cfu/AU/day)	
Goats		1.60E+10 (cfu/AU/day)	
Feral Hogs		6.93E+09 (cfu/AU/day)	USEPA 2001
Dogs		2.50E+09 (cfu/dog/day)	Teague et al. 2009
Poultry Litter	IWC and/or Stacked	1.30E+01 (cfu/g/day)	Gentry and Coufal 2016 (Unpublished Data)
	No IWC and Not Stacked	1.92E+03 (cfu/g/day)	
OSSFs		4.42E+10 (cfu/OSSF/day)	Lowe et al. 2007; USEPA 2001; USEPA 2003; U.S. Census Bureau 2010
WWTFs		Varies: actual discharge monitoring data utilized	EPA ECHO Database

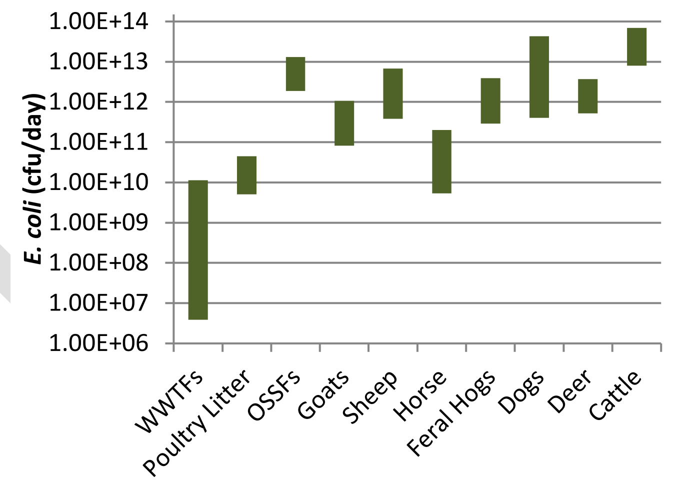


Figure 5.9 Differences in potential *E. coli* loadings by source as calculated in Appendix D

Table 5.6 Total calculated potential *E. coli* loads per subwatershed from each evaluated pollutant source

Subwatershed	Cattle	Feral Hogs	Deer	Horses	Goats	Sheep	Dogs	Failing OSSFs	WWTFs	Poultry Litter			Total *E. coli*
										On Site	Off Site	Total	
1	5.77E+13	3.74E+12	3.67E+12	1.02E+11	8.28E+11	3.88E+12	2.40E+12	2.23E+12	3.22E+06	6.96E+07	5.07E+09	5.14E+09	**7.12E+13**
2	5.12E+13	3.60E+12	3.25E+12	1.00E+11	7.59E+11	2.54E+12	1.48E+12	5.92E+12	3.40E+07	9.17E+09	3.92E+10	4.84E+10	**6.57E+13**
3	5.41E+13	3.24E+12	2.90E+12	2.61E+10	5.50E+11	3.72E+12	1.79E+12	3.48E+12	---	1.82E+09	1.49E+10	1.67E+10	**6.69E+13**
4	2.67E+13	3.01E+12	2.22E+12	3.46E+10	4.73E+11	1.81E+12	1.10E+12	4.85E+12	---	1.57E+09	1.18E+10	1.34E+10	**3.75E+13**
5	4.47E+13	3.89E+12	3.01E+12	6.80E+10	9.93E+11	5.20E+12	2.49E+12	5.82E+12	---	1.52E+09	3.68E+09	5.20E+09	**6.28E+13**
6	4.32E+13	2.55E+12	2.44E+12	7.18E+10	1.07E+12	6.73E+12	2.88E+12	3.63E+12	---	---	---	---	**6.03E+13**
7	1.31E+13	2.89E+11	5.23E+11	5.35E+09	8.14E+10	3.82E+11	4.02E+11	1.88E+12	---	---	---	---	**1.64E+13**
8	3.76E+13	2.68E+12	2.36E+12	1.12E+11	8.93E+11	4.41E+12	3.19E+12	8.40E+12	---	2.01E+08	1.34E+09	1.54E+09	**5.72E+13**
9	3.09E+13	1.31E+12	1.74E+12	1.51E+11	7.68E+11	4.64E+12	7.46E+12	6.21E+12	---	---	---	---	**5.20E+13**
10	7.92E+12	1.14E+12	7.39E+11	3.32E+10	3.47E+11	2.08E+12	4.34E+13	1.90E+12	1.42E+10	---	---	---	**5.65E+13**
11	4.20E+13	1.91E+12	2.23E+12	9.37E+10	5.82E+11	1.26E+12	1.78E+12	1.03E+13	---	---	5.71E+09	5.71E+09	**5.84E+13**
12	1.77E+13	2.04E+12	1.43E+12	5.76E+10	4.51E+11	2.12E+12	1.47E+13	9.69E+12	1.80E+09	---	---	---	**4.64E+13**
13	6.92E+13	2.50E+12	3.54E+12	2.02E+11	6.99E+11	3.01E+12	5.30E+12	1.30E+13	1.18E+08	---	---	---	**9.52E+13**
Total	**4.96E+14**	**3.19E+13**	**3.00E+13**	**1.06E+12**	**8.49E+12**	**4.18E+13**	**8.83E+13**	**7.73E+13**	**1.62E+10**	**1.43E+10**	**8.18E+10**	**9.61E+10**	**7.47E+14**

Instead, BST provides insight to the sources that are actually contributing to the waterbody and spatial analysis provides information regarding the distribution of those sources across the watershed.

Water quality data and subsequent analysis also provide useful information for reconciling information. Water quality measurements provide actual constituent concentrations under various flow regimes. Data assessment using tools like LDCs provides information regarding general pollutant source types contributing to the waterbody and illustrates when the it generally achieves standards relative to measured stream flow.

Local knowledge and observational data is perhaps most valuable. Information regarding sources, their distribution, and relative contributions to the overall pollutant load is critical for refining other assessments. Spatial assessments are particularly improved by stakeholder inputs. Isolated influences are also routinely identified by stakeholders. In the Navasota River watershed, specific problems with illegal dumping and failing OSSFs were identified through stakeholder feedback.

Considering this information collectively, management recommendations are tailored to address the sources of pollution most likely to cause water quality impairments in the watershed. No single source emerged as the primary contributor of *E. coli*; therefore, a diversified management approach is recommended to reduce loadings from manageable sources.

Assessment Conclusions

E. coli contributions to the watershed are diverse in their sources, distribution, and potential impacts on the waterbody. Of the sources identified as contributors, wildlife is the most common; however, it is the most difficult to manage. As a result, management will focus on a variety of manageable sources to achieve the 1.11E+15 cfu/year load reduction needed to meet the *E. coli* reduction goal at station 11875.

Chapter 6 : Management Strategies and Expected Loading Reductions

Recommended management strategies to achieve needed *E. coli* reductions in the Navasota River were developed based on stakeholder feedback, management recommendation effectiveness, and the understanding of current water quality stressors across the watershed. Analysis completed to identify major sources of *E. coli* in the watershed, their potential loading distribution, and actual *E. coli* loads provided necessary information to allow stakeholders to make informed decisions regarding needed management to improve water quality across the watershed.

Water Quality Goal

Establishing a clear water quality goal defines the target for future water quality and allows needed *E. coli* load reductions to be defined. Watershed stakeholders indicated that the applicable *E. coli* water quality standard is the most appropriate goal for the watershed. Thus, the primary contact recreation water quality standard for *E. coli* of 126 cfu/100 mL is the target value for all waterbodies in the watershed and was the basis for establishing needed *E. coli* load reductions.

The LDC approach was used to convert this water quality goal into a needed load reduction. Monitoring station 11875 (SH 30) was chosen as the index site to establish the needed reduction due to its proximity to the watershed outlet. It is the furthest monitoring station downstream where sufficient streamflow data existed to develop a reasonable LDC. Further, the moist conditions category was selected as the basis for identifying the needed amount of *E. coli* reduction. This scenario represents conditions where much of the measured excess loading occurs, but does not include extreme flow situations where management is not feasible. For moist conditions, the needed load reduction to meet the water quality standards and goal established by stakeholders is 1.11E+15 cfu/year.

Management Approach

No single source of *E. coli* in the watershed is the primary cause of current *E. coli* concentrations exceeding allowable levels. Instead, a variety of sources contribute *E. coli* to the river and its tributaries. Therefore, a diverse approach to management is recommended to address *E. coli* loading across the watershed. This approach focuses on contributing sources that are most feasibly managed and have the highest chance of producing instream *E. coli* reductions.

Sources that management recommendations address include feral hogs, humans, livestock, pets and stormwater. These sources do not represent all prospective *E. coli* contributions in the watershed, but are manageable with feasible strategies. Alternatively, wildlife sources were identified with BST results as the largest contributor of *E. coli* in the watershed. Generally, wildlife will receive little focus because managing their fecal deposition in the watershed is not practical and does not have a high likelihood of successfully reducing instream *E. coli* loads.

Priority implementation areas in the watershed were identified for each management recommendation using results from spatial analysis and stakeholder feedback. Priority locations were selected to maximize management effectiveness relative to instream water quality. As such, priority areas change shape and extent depending on the *E. coli* source addressed.

Stakeholder feedback was critical in selecting BMPs for inclusion as management recommendations. Stakeholders will implement these voluntary management strategies, thus their recommendation to include certain management measures implies a willingness to implement these recommendations. Only items suggested and agreed upon by watershed stakeholders are included.

Feral Hogs

Potential *E. coli* loading from feral hogs across the watershed represents a considerable potential influence on instream water quality. While other sources of *E. coli* are potentially larger in volume, feral hogs' preference for dense habitat, available food resources, and water enhance the potential affects that they have on instream water quality. Behaviors including rooting and wallowing further affect water quality by degrading ground cover, increasing soil/sediment disturbances, and decreasing bank stability. Each of these effects increases erosion and causes enhanced pollutant transport to waterbodies during runoff events. Wallowing in the edges of waterbodies also affects water quality between runoff events.

Physically removing hogs from the watershed is the best strategy for reducing their impact on water quality. A variety of methods exist to accomplish this goal, and other tactics can also improve the success of removal efforts. In the watershed, trapping animals is the most effective means for removing large number of hogs. With proper planning and diligence, trapping can successfully remove large numbers of hogs at once whereas shooting or catching with dogs typically results in fewer individuals being removed before they move to another part of the watershed. Shooting hogs is common across the watershed already, and should certainly continue. Aerial gunning is another effective option; however, watershed habitat and the human population distribution are not conducive for employing this tactic in the majority of the watershed.

Excluding feral hogs from supplemental feed is also an effective management tool. Feral hogs are opportunistic feeders and are commonly known to access supplemental feed stations such as wildlife feeders. Erecting exclusionary fences around deer feeders has been proven to reduce the ability of feral hogs to access these food sources (Rattan et al. 2010). Additionally, exclusion from easily accessible food sources can also enhance trapping success nearby.

Education resource delivery also improves feral hog removal effectiveness. The Texas A&M AgriLife Extension Service has developed a variety of educational resources that are available at: http://feralhogs.tamu.edu. They include information on feral hog biology, trapping techniques and types, wildlife feeder exclusion techniques, trap designs, research studies and more. Additionally, they deliver focused feral hog education programs that include hands-on trapping technology and technique demonstrations.

Trapping hogs may also provide a potential source of income, or at least a means to recuperate some costs associated with repairing feral hog damage and trapping efforts. The State of Texas allows live feral hogs to be transported to approved feral hog holding facilities where they can be sold to the holding facility. Purchase prices vary by facility and are market driven. Three holding facilities are currently located in the watershed and several others are nearby. An online mapping tool and listing of approved facilities is available at: http://www.tahc.state.tx.us/animal_health/feral_swine.html. Other informational resources such as regulations regarding feral hog movement and holding restrictions are also available at this website.

Each of these needs, priority management areas, and expected *E. coli* loading reductions are discussed further in Feral Hog Management Recommendation (page 28).

Feral hogs at a deer feeder

Pollutant Source: Feral Hogs

Problem: Direct and indirect fecal loading, riparian habitat destruction, forest and pasture damage from feral hogs

Objectives:

- Reduce fecal contaminant loading from feral hogs
- Reduce hog numbers
- Reduce food supply for feral hogs
- Provide education and outreach to stakeholders

Location: All subbasins

Critical Areas: Riparian areas and travel corridors from cover to feeding areas

Goal: To manage the feral hog population through available means in efforts to reduce the total number of hogs in the watershed by 15% (5,524 hogs) and maintain them at this level.

Description: Voluntarily implement efforts to reduce feral hog populations throughout the watershed by reducing food supplies, removing hogs, and educating landowners on hog removal techniques.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
Landowners, land managers, lessees	Voluntarily construct fencing around deer feeders to prevent feral hog utilization	2018–2028	$200 per feeder exclusion
	Voluntarily identify travel corridors and employ trapping and hunting in these areas to reduce hog numbers	2018–2028	N/A
	Voluntarily shoot all hogs on site; ensure that lessees shoot all hogs on site	2018–2028	N/A
Texas A&M AgriLife Extension Service	Deliver Feral Hog Education workshop	2018, 2021, 2025	$7,500 ea.

Estimated Load Reduction

Removing feral hogs will reduce bacteria loading in the watershed and direct deposition to waterbodies. This will primarily reduce direct deposition since they spend most of their time in riparian corridors. Feral hogs are estimated to contribute 3.19 E+13 cfu of *E. coli* to the watershed daily. Reducing the population by 15% yields a maximum annual load reduction of 3.49 E+15 cfu of *E. coli* when a reasonable attenuation factor that assumes 25% of the fecal bacteria deposited by feral hogs reaches the waterbody is used. See Appendix F for calculations.

Effectiveness:	Moderate: Reduction in feral hog population will result in a direct decrease in bacteria and nutrient loading to the streams; however, removing enough hogs to decrease their population is difficult.
Certainty:	Low: Feral hogs are transient and adapt to their environment. They move due to food availability, hunting, and trapping pressure. Removing 15% of the population each year will be difficult and is highly dependent upon the diligence of watershed landowners.
Commitment:	Moderate: Landowners are actively battling feral hog populations and will continue to do so as long as resources remain available. Hogs adversely affect their livelihood.
Needs:	Moderate: Funds are needed to provide education and outreach to further inform landowners about feral hog management options, adverse economic impacts of feral hogs, and what their options for dealing with feral hogs are. Additional tools to improve removal success are needed.

Livestock

Daily potential *E. coli* loading from livestock (cattle, goats, horses, and sheep) is larger than other sources in the watershed. Unlike some other sources, livestock waste is mostly deposited in upland areas away from waterbodies and is transported to downstream waters during runoff events. As a result, much of the *E. coli* in livestock waste dies before reaching a waterbody. However, livestock may access streams for water or cooling in some cases and can have a more direct impact on instream water quality.

Livestock resource utilization and fecal deposition are highly dependent upon availability and distribution of water, food, and shelter. This allows livestock to be managed easily compared to non-domesticated species. Improving the quality and distribution of forage and supplemental feed locations, expanding water availability, and establishing fences to better control their movement within a property can effectively reduce *E. coli* concentrations in runoff entering nearby waterways. Due to the size of the potential *E. coli* load to the watershed and the ability to modify animal behavior through management changes, addressing *E. coli* loading in the watershed from livestock is likely to have considerable impacts on instream water quality.

A variety of best management practices (BMPs) can achieve the goals of improving forage quality and distribution, diversifying water resource locations, and better distributing livestock across a property. NRCS and TSSWCB provide technical and financial assistance to producers to plan for and implement property specific BMPs. NRCS offers a variety of programs to develop and implement conservation plans (CPs) for entire operations or specific practices. TSSWCB, through local soil and water conservation districts (SWCDs), provides technical and financial assistance to develop and implement property specific water quality management plans (WQMPs) that ensure water quality improvements through planning, implementation, and maintenance of each practice. A variety of practices commonly implemented in the watershed through these programs (Table 6.1) have positive effects on forage health and utilization which improves water quality. Properly implemented and maintained fencing, prescribed grazing, and alternative water sources for livestock are documented to effectively reduce *E. coli* loading in runoff and instream water quality. As a result, these are the primary practices that are recommended for implementation in the watershed.

Table 6.1 Common BMPs implemented in the Navasota River watershed through NRCS and TSSWCB programs to improve forage and water quality

BMPs Implemented to Improve Forage Quality and Water Quality	
Fencing	Forage Planting
Herbaceous Weed Control	Brush Management
Livestock Pipeline	Nutrient Management
Prescribed Grazing	Heavy Use Area Protection
Livestock Water Well	Pest Management

These BMPs will improve water quality regardless of where they are implemented in the watershed, but their effectiveness is greater if they are in close proximity to a waterbody. Riparian areas are thus considered a priority; however, implementation on properties without riparian habitat is also strongly encouraged. Priority areas and expected *E. coli* load reductions from implementing these practices are described in the Livestock Management Recommendation on page 30.

Pollutant Source: Cattle and Other Livestock

Problem: Livestock derived fecal loading to waterbodies

Objectives:

- Work with landowners to develop property specific CPs and WQMPs to protect water quality
- Provide technical and financial assistance to producers
- Reduce fecal loading in riparian areas from livestock

Location: Priority subbasins identified below

Critical Areas: Properties with creek access and tributary access; especially those using them as water sources

Goal: To develop CPs and WQMPs focused on minimizing/planning the time spent by livestock in the riparian corridor and better utilizing available grazing resources across the property

Description: CPs and WQMPs will be developed to address direct and indirect fecal deposition from cattle and other livestock. BMPs to reduce time spent in the creek or riparian corridor, improve grazing distribution and grass quality, and decrease runoff will be recommended. Likely practices include prescribed grazing, cross-fencing, pasture planting, water wells, and watering facilities. Education program delivery will support and promote implementation adoption.

Implementation Strategies

Participation	Recommendations	Period	Capital Costs
Riparian Areas in all subbasins	Develop, implement, and provide financial assistance for livestock CPs* and WQMPs @ $15,000 per plan for 50 plans	2018–2028	$750,000
Upland Areas in subbasins 13, 1, 2, 3, 5, 6, 8, 11	Develop, implement, and provide financial assistance for livestock CPs* and WQMPs @ $15,000 per plan for 80 plans	2018–2028	$1,200,000
Texas A&M AgriLife Extension Service	Deliver *Lone Star Healthy Streams* programming to watershed landowners	2016, 2020, 2025	N/A

Estimated Load Reduction

Prescribed management will effectively reduce bacteria loads from the landscape and in some cases reduce direct fecal deposition to waterbodies. Prescribed grazing, cross fencing and watering facilities are estimated to produce annual load reductions from cattle alone at 1.83 E+15 cfu/year when implemented on the proposed number of properties. This assumes that each CP and WQMP will include prescribed grazing, cross-fencing and alternative watering facilities to collectively minimize the amount of time livestock spend in riparian areas. This estimate is further explained in Appendix F.

Effectiveness:	High: Decreasing the time that livestock spend in the riparian corridor and reducing surface runoff through effectively managing vegetative cover will significantly reduce NPS contributions of bacteria and other associated pollutants to the creek.
Certainty:	Moderate: Landowners acknowledge the importance of good land stewardship practices and management plan objectives; however, financial incentives are needed in many cases to increase CP and WQMP implementation.
Commitment:	Moderate: Landowners are largely willing to implement land stewardship practices that benefit the land and their operations; however, costs are often prohibitive and financial incentives are needed to increase implementation.
Needs:	High: Financial assistance is the primary need to promote implementation and will likely not occur without it; education and outreach are needed to illustrate animal production, economic and water quality benefits of plan development and implementation to producers.

*financial assistance available for CPs may be more than $15,000 per plan depending on the NRCS program the producer participates in

Wastewater

Human waste is another potentially significant source of *E. coli* loading in the watershed. Water is used to transport and treat our wastes through OSSFs and WWTFs, thus ensuring that these systems are properly functioning is important to protecting water quality and human health. Pathogens in human wastewater are likely more infectious to humans than pathogens from other species. As such, improving wastewater treatment efficacy in the watershed is very important.

When working as designed, these systems do an excellent job of effectively treating wastewater and minimizing pathogen transmission to the environment. However, system failures of multiple types can cause improperly treated or even raw waste to enter soil and water.

On-Site Sewage Facilities

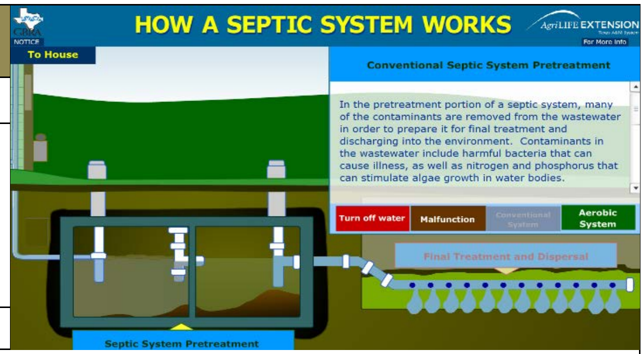
OSSFs are used to treat wastewater in rural areas of the watershed. Conventional systems use a septic tank and gravity fed drain field that separates solids from wastewater prior to distribution of the water into soil where actual treatment takes place. Soil is the most critical component of these systems and it must be able to readily accept wastewater, yet provide a sufficient level of treatment capacity to effectively retain pathogens. Within the watershed, the majority of soils are not suitable for this type of OSSF. According to NRCS soil suitability ratings and soils maps, roughly 60% of the soils in the watershed are considered somewhat or severely limited for OSSF drain field purposes. In these soils, advanced treatment systems must be used to effectively treat wastewater.

Aerobic treatment units are the most common advanced treatment system used in the watershed. They utilize aerobic digestion to decompose many materials in wastewater and reduce the nutrient and bacteria content of the treated wastewater. Paired with disinfection processes, these systems produce highly treated wastewater that is safe for surface application as irrigation water. Operation and maintenance requirements for these systems are more rigorous than for conventional systems. Lack of proper maintenance is common and readily leads to system failures.

Failing OSSFs are noted as a widespread concern across the watershed by numerous stakeholders. The actual number of failing systems is unknown; however, it is estimated that as many as 1,700 systems may be malfunctioning. A number of factors including improper design, system selection, insufficient maintenance, and lack of education regarding OSSFs are all cited by OSSF professionals and stakeholders as primary reasons for these failures. Further, lack of knowledge regarding OSSFs and limited financial resources are also cited as reasons that system failures are not being addressed. To address these needs, focused education efforts for OSSF owners, maintenance providers, installers, and inspectors are needed. Additionally, resources to assist limited resource owners with identifying OSSF problems, performing repairs, or even replacing these systems are needed.

Each of these needs, priority management areas, and expected *E. coli* loading reductions from addressing OSSF failures are discussed further in the OSSF Management Measures (pages 32 and 33).

Pollutant Source: Failing OSSFs



Problem: Pollutant loading from failing or nonexistent OSSFs

Objectives:

- Identify and inspect failing OSSFs in the watershed
- Secure funding to promote OSSF repairs/replacements in low income areas
- Repair or replace OSSFs as funding allows

Location: All subbasins

Critical Areas: Entire watershed, but specifically OSSFs situated on soils that are not suitable for OSSF drain fields and within 150 yds of a perennial waterway. Primarily subbasins 12, 11, 13, 10, 7, 1, 9, 8, and 6.

Goal: To identify, inspect and repair or replace (as appropriate) 100 failing OSSFs in the watershed that are located within 'very limited soils' and 50 failing OSSFs located within somewhat limited soils.

Description: OSSF failures will be addressed by working to identify and inspect failing OSSFs within critical areas. Failing systems will be repaired or replaced as appropriate to bring them into compliance with local requirements.

Implementation Strategies

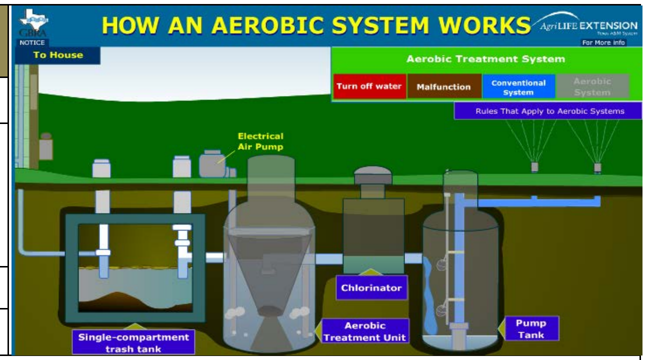
Participation	Recommended Strategies	Period	Capital Costs
Counties or TWRI	Administer OSSF repair/replacement program to address deficient systems identified during inspections	2018 – 2028	$10,000/yr
County DR or Contractor	Identify and inspect failing OSSFs within priority areas; system proximity to waterbody increases priority	2018 – 2028	$750/inspection
Contractor	Repair/replace OSSFs as funding allows	2018 – 2028	$7,500 per system (est.)

Estimated Load Reduction

As planned, a total of 150 OSSFs will be repaired or replaced throughout the watershed. For those systems that are addressed within very limited soils, an annual *E. coli* loading reduction of 8.07 E+12 is expected to be realized instream per system. Systems addressed within somewhat limited soils are expected to yield an annual *E. coli* loading reduction instream of 4.84 E+12 each. Combined, the 150 planned OSSF repairs or replacements will produce an expected annual loading reduction from their continued proper functioning of 1.05 E+15. See Appendix F for loading reduction calculations.

Effectiveness:	High: Replacement or repair of failing OSSFs will yield direct *E. coli* reductions to the waterways and near waterway areas of the watershed.
Certainty:	Low: Funding available to identify, inspect and repair or replace OSSFs is limited; thus, the actual level of implementation attainable is uncertain.
Commitment:	Moderate: Watershed stakeholders identified OSSFs as a considerable source of *E. coli* in the Navasota River. Addressing this source will have the greatest effect on protecting human health and is a top priority.
Needs:	High: Funding to identify, inspect and repair/replace OSSFs is limited. Costs to administer a program, identify, inspect, and repair or replace OSSFs are considerable. Many homeowners with failing OSSFs may not realize that their OSSF is failing, so delivering educational resources to them is critical. Some homeowners may know they need a new OSSF, but may not have funds available to acquire one.

Pollutant Source: Lack of OSSF Maintenance



Problem: Pollutant loading from failing or nonexistent OSSFs

Objectives:

- Provide education and outreach to OSSF owners, installers and maintenance providers on the proper selection, design, installation, operation and maintenance of OSSFs

Location: All subbasins

Critical Areas: Entire watershed

Goal: To provide needed education and outreach to watershed landowners who own and operate OSSFs, pumping services and maintenance providers enabling them to better manage, repair or replace OSSFs as needed.

Description: Education and outreach delivery to OSSF owners, installers, and maintenance providers in the watershed will be provided. Information regarding proper OSSF design, installation, operation, inspection, maintenance, and repair procedures will be delivered. Information will be provided to interested parties outlining available resources to assist them with OSSF repair or replacements.

Implementation Strategies

Participation	Recommended Strategies	Period	Capital Costs
Texas A&M AgriLife Extension Service	Deliver homeowner and landowner education and outreach events	2019, 2023, 2027	$3,500 ea.
	Deliver designers, installers, maintenance providers, sludge haulers education and outreach events	2018, 2022, 2026	$3,500 ea.

Estimated Load Reduction

It is difficult to determine expected load reductions based on education and outreach program delivery due to uncertainty in the number of program participants and the amount of practice implementation attributable to program discussions. Therefore, a total expected loading reduction has not been established for this practice; however, each OSSF repair or replacement in the watershed is estimated to produce a minimum annual *E. coli* load reduction 2.56 E+12 cfu. See Appendix F for loading reduction calculations.

Effectiveness:	Moderate: Education is critical for ensuring that OSSFs in the watershed are functioning properly. County DRs cite OSSF education as a major need across the watershed.
Certainty:	Low: It is not known how many OSSF owners, pumping services or maintenance providers will attend trainings and how many attendees will apply information learned in the events. Education requirements for installers, service providers and some homeowners are met through these programs, so they should be well attended.
Commitment:	Moderate: The Texas A&M AgriLife Extension Service currently operates an OSSF education, outreach and training program. With funding provided, their programs can be delivered in the Navasota River watershed. The Brazos County Health Department has also offered to aid instructors by providing perspectives on OSSFs rules and regulations in education events across the watershed.
Needs:	Low: Funding to deliver the educational programming in the watershed is needed, but is not substantial.

Centralized Wastewater Treatment Systems

Centralized wastewater treatment systems provide wastewater treatment for incorporated areas of the watershed that are densely populated. Rather than treating wastewater at its origin, centralized systems transfer untreated wastewater to a treatment facility through a sanitary sewer system. These systems use intricate networks of underground pipes, pumps and manholes to transfer wastewater from houses and businesses to the treatment facility. As designed, sanitary sewers are sized to carry sewage from its origin to the treatment facility.

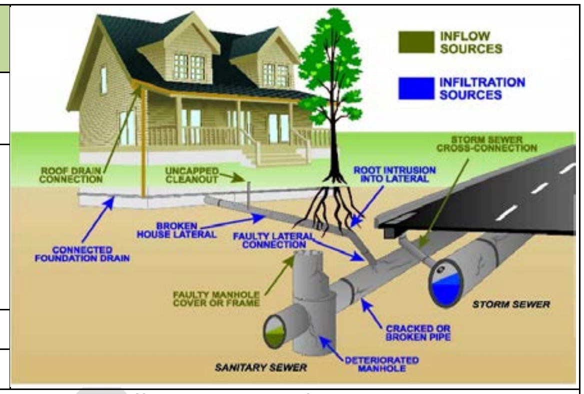
Inflow and infiltration are issues common to all sanitary sewer systems that can overload the system and cause backups into homes and streets. Inflow occurs primarily during large runoff events and can occur through uncapped cleanouts and gutter connections to the sewer system or through cross connections with storm sewers and faulty manhole covers. Infiltration occurs slowly as it generally occurs through cracks and breaks in lateral lines on private property or sewer mains, bad connections between laterals and sewer mains, and in deteriorated manholes. Tree roots can also grow into these cracks and breaks causing further damage and system blockages.

Within the watershed, inflow and infiltration were identified as the largest issue that centralized systems must deal with regardless of system size. During localized flooding, some homeowners open sewer cleanout to drain their property. If enough instances of this occur, a significant source of inflows can occur and contribute to sanitary sewer overloading. Infrastructure cracks and breaks also occur due to system age and changing soil moisture conditions which ultimately allow water to enter and leave the system.

Currently, efforts are underway within all centralized systems to identify and address these issues. System inspections and subsequent repairs are used to address many inflow and infiltration issues, but this approach is both time consuming and expensive. Additional resources are needed to expand efforts to identify problem areas and make needed repairs to prevent future inflow and infiltration issues. Education and outreach are needed to reduce excessive inflows from opened cleanouts.

These needs are further discussed and outlined in the Centralized Wastewater Management Measure (page 35).

Pollutant Source: Centralized Wastewater



Problem: Wastewater conveyance system failures cause inflow and infiltration issues that may result in system overloads

Objectives:

- Work with WWTFs in watershed to continue and expand system inspections to identify problem areas
- Work with WWTFs to increase rate of WWTF conveyance system repairs

Location: WWTF service areas

Critical Areas: All WWTFs

Goal: Work with entities operating WWTFs to continue and expand inspection efforts and identify problematic areas within their WWTFs. Once identified, work to repair or replace problematic infrastructure to reduce inflow and infiltration issues and minimize WWTF overload occurrences.

Description: Identify potential locations within wastewater conveyance systems where inflow and infiltration occur using available strategies (e.g. smoke tests, camera inspections, etc.). Prioritize system repairs or replacements based on system impacts (largest impact areas addressed first). Complete repairs or replacements to reduce future inflow and infiltration issues and WWTF overloading.

Implementation Strategies

Participation	Recommendations	Period	Capital Costs
WWTF Operating Entities	Perform WWTF conveyance system testing to ID inflow and infiltration problem areas; prioritize problem areas for repair/replacement	2018-2028	~$2,000 for equipment; consumable cost varies by amount of testing
WWTF Operating Entities	As funds allow, repair or replace WWTF conveyance infrastructure	2018-2028	$100 - $150/ft Total cost TBD
WWTF Operating Entities	Provide educational resources regarding inflow and infiltration (uncapped cleanouts; faulty sewer lines) and effect of malfunctions with utility bill inserts	2018-2028	N/A

Estimated Load Reduction

Load reductions from inspections and subsequent repairs or replacements of wastewater conveyance infrastructure and education delivery cannot be accurately estimated. Not all inflow and infiltration to WWTF conveyance systems results in WWTF overloading. Instead, the number of inflow and infiltration locations repaired and the reduced number of WWTF overloads will signify progress made in reducing pollutant loading to the Navasota River.

Effectiveness:	High: Reducing the number and volume of inflow and infiltration issues will directly reduce *E. coli* loading to receiving waters. Moderate: Education deliver via utility bill inserts will reach some folks, but not all. The number of people changing their behavior cannot be quantified.
Certainty:	Moderate: Each entity operating a WWTF in the watershed already performs inflow and infiltration inspections and makes repairs as needed and as funding allows. High: Utility bill inserts are common and information on inflow and infiltration can easily be included.
Commitment:	Moderate: Each entity operating a WWTF indicated that they will continue to perform inspections and repairs within their respective collection systems and acknowledged the need for increased education and outreach.
Needs:	High: Financial assistance needs are great. Operating budgets for entities are small and already strained, making financial assistance to inspect and repair conveyance systems a must. Low: Utility bill inserts are a low cost delivery mechanism that is already included in most budgets.

Urban Stormwater

Stormwater generated in urban areas is a potentially large source of *E. coli* entering waterbodies despite the rural nature of the watershed. The cities of Bryan and College Station and surrounding areas in Brazos County have and continue to see tremendous growth. With this growth, concentration of potential *E. coli* sources and generation of excessive stormwater due to impervious surfaces occurs. Stormwater management is common in the area and five entities currently hold municipal separate storm sewer system (MS4) permits. These permits require development of stormwater management plans that include at least six control measures regarding public education and outreach, public involvement/participation, detection and elimination of illicit discharges, controls for construction site stormwater, post-construction stormwater management, and pollution prevention measures for municipal operations. Additionally, a TMDL and TMDL Implementation Plan was developed for Carters and Burton Creek in Brazos County and approved in August 2012. These documents outline actions that each MS4 entity will take to mitigate and reduce detrimental effects of stormwater on instream water quality.

Additional action that can be taken to reduce the potential *E. coli* load from stormwater is to improve management of dog waste. Potential *E. coli* loading from dog waste was identified as the second largest potential source in the watershed. Since dogs are associated with humans, managing their waste is relatively easy compared to other potential sources in the watershed. If not managed properly, dog waste and the *E. coli* it contains are readily transported to local waterways during irrigation and rainfall events that produce runoff. Cleaning up dog waste and disposing of waste in the trash can is a very simple, yet effective way to reduce *E. coli* loading in the watershed.

Adoption of this practice is not widespread and will require additional efforts to encourage wider implementation. Many public areas such as city parks and dog parks are equipped with dog waste stations; however, their use can be increased. In some cases, dog owners are simply not concerned or do not realize the importance of properly disposing of their dog's waste while in other cases, waste collection bags may not be available. Even in locations where waste collection is required by law, improper disposal of waste has been observed. At home, dog owners can simply 'recycle' plastic shopping bags to collect dog waste and dispose of it in their dumpster. Increased education and outreach is needed to raise awareness regarding the water quality impacts of improper waste disposal.

Pollutant Source: Urban Stormwater: Dog Waste

Problem: Improperly disposed dog waste is left on the surface and washes into streams during rainfall or irrigation runoff

Objectives:

- Expand education and outreach messaging regarding the need to properly dispose of dog fecal matter
- Properly stock and maintain pet waste stations

Location: Entire watershed

Critical Areas: High dog concentration areas: Subwatersheds 10, 12

Goal: To reduce the amount of dog waste in the watershed that may wash into waterbodies during rainfall and irrigation runoff by providing educational and physical resources to increase stakeholder awareness of the water quality and potential health issues caused by excessive dog waste. Effectively manage *E. coli* loading from 20% of the estimated dog population, or 7,068 dogs.

Description: Expand distribution of educational messaging regarding the need to properly dispose of pet waste in the watershed. Specifically target homeowners and the general public. Stock and maintain existing dog waste stations in parks and other public areas to facilitate increased collection and proper disposal of dog waste.

Implementation Strategies

Participation	Recommendations	Period	Capital Costs
Cities, counties, HOAs	Provide needed maintenance supplies for pet waste stations: est. 100 stations	2018-2028	$85 annual/station: $85,000 total
Cities, HOAs	Provide educational resources to residents through existing avenues: e.g.: newsletters, websites, etc.	2018-2028	N/A

Estimated Load Reduction

Effectively managing dog waste will reduce bacteria loads from the landscape and prevent it from entering waterbodies during rainfall or irrigation induced runoff; however, it will not prevent all *E. coli* from entering the waterbody. Collecting and disposing of waste along with solid wastes will contain *E. coli* present in the waste to a landfill where it will not affect water quality. Collecting and disposing of waste will result in 6.84 E+11 cfu/day of *E. coli* being removed per dog managed when using a conservative estimate that only 75% of the *E. coli* deposited are actually removed. At this rate, managing waste from 7,068 dogs will reduce the overall watershed loading by 4.84 E+15 cfu/year. This estimate is further explained in Appendix F.

Effectiveness:	High: Collecting and properly disposing of dog waste is a sure way to prevent *E. coli* it contains from entering local waterways. This will directly reduce the quantity of *E. coli* in the watershed.
Certainty:	Moderate: A large number of dog owners already collect and properly dispose of dog waste. Those who don't may be a difficult audience to reach or convince that dog waste should be collected and discarded properly despite their respective reasons for not doing so.
Commitment:	Moderate: Most parks currently have pet waste stations installed; however, maintenance is sometimes less frequent than it needs to be. Signage is up in many locations stating that dog owners are required to pick up after their pet; however, little to no enforcement occurs.
Needs:	Low: Increasing maintenance on existing pet waste stations is something that could easily occur. Landscapers can easily add this to their list of items when mowing parks if resources are provided.

Expected Loading Reductions

Reducing *E. coli* loads across the watershed and the amount of *E. coli* in the river is the goal of this WPP. Management measures included in this plan will directly reduce *E. coli* loads once implemented. Management measures described in Ch. 6 will provide the bulk of expected loading reduction when the WPP is fully implemented (Table 6.2). Other actions planned such as general education and outreach programs, will also provide reductions that are not easily quantified. Management measures recommended for dogs, feral hogs, livestock, and OSSFs will provide the bulk of measureable reductions. Improvements within centralized wastewater collection systems and urban stormwater management will also improve water quality. The current volume of these contributions and their influence on instream water quality are not known and precludes the ability to estimate an accurate loading reduction. Education programs will also result in water quality improvements when participants modify their practices based on information gained. These reductions can be quantified after implementation programs through surveys, but cannot be accurately predicted.

Table 6.2 Estimated *E. coli* loading reductions expected from full WPP implementation

Management Measure	Expected *E. coli* Load Reduction
Agricultural Management Measures	
Water Quality Management Plans (TSSWCB/Local SWCDs)	1.83×10^{15} cfu/year
Conservation Plans (NRCS)	
Livestock Management Education and Outreach	
Feral Hog Management	
Feral Hog Removal	3.49×10^{15} cfu/year
Supplemental Feeding Exclosures	
Feral Hog Education and Outreach Programming	
OSSF Management	
OSSF Repair and Replacement	1.05×10^{15} cfu/year
OSSF Owner Education and Outreach	
OSSF Installer and Service Provider Education and Outreach	
Urban Stormwater Management	
Dog Waste Management and Disposal	4.84×10^{15} cfu/year
Dog Waste Management Education and Outreach	
General Stormwater Management Education and Outreach	

Chapter 7 : Plan Implementation

Implementing the WPP is a complex operation that will require active participation by many parties for a 10-year implementation period. Implementation will focus on addressing readily manageable sources of *E. coli* in the watershed to achieve water quality targets. This effort will require significant financial commitments, technical assistance, continued water quality education and outreach, and a strong desire to improve and protect local land and water resources to meet the reasonable implementation schedule, targets, and costs (Table 7.1).

Management recommendations in the WPP are voluntary, but are supported at prescribed levels by watershed stakeholders. The exceptions to this are control actions described in the *Implementation Plan for Three TMDLs in the Carters Creek Watershed* (TCEQ, 2012). Control actions included in this document are compulsory and include: 1) implementing entity-specific municipal separate storm sewer system (MS4) phase II stormwater management programs throughout the watershed, and 2) monitoring WWTF effluent *E. coli* concentrations according to individual permit requirements. These actions are only required within the confines of the Carters Creek watershed and are already requirements of individual permits held by the permitted entity.

Schedule, Milestones, and Estimated Costs

Implementing the Navasota River WPP will occur over a 10-year period; however, additional management and time may be needed as identified through adaptive management. The schedule, milestones, and estimated costs associated with planned implementation were discussed and developed in coordination with watershed stakeholders during the WPP development process. Management measures were selected based on their ability to address *E. coli* loading in the watershed and effectively manage the target source at a reasonable cost.

A complete list of management activities and goals, responsible parties, estimated costs are included in Table 7.1. Implementation goals are included incrementally to reflect anticipated implementation timeframes. In specific cases, funding acquisition, personnel hiring, or program initiation may delay the start of implementation. This approach provides incremental implementation targets that can be used as a gauge to measure implementation progress. If sufficient progress is not made, adjustments will ensue to increase implementation and meet established goals. Adaptive management may also be utilized to adjust the planned approach if the original strategy is no longer feasible or effective.

Table 7.1 Management recommendations, responsible party, implementation goals, and estimated costs

Management Measure	***Responsible Party***	***Unit Cost***	***Number Implemented Time Frame (year)***			***Total Cost***
			1-3	***4-6***	***7-10***	
Feral Hog Management						
Feeder Exclusion	Landowner/ Lessees	~$200/ feeder	As many as possible			N/A
Voluntary Hog Re-moval	Landowner/ Lessees	N/A	5,524 hogs/year			N/A
Feral Hog Extension Associate	AgriLife Extension	$75,000/ yr[1,2]	1			$750,000
Livestock Management						
Water Quality Management Plans	TSSWCB/ SWCDs	$15,000/ WQMP	20	40	70	$1,950,000
WQMP Technician	TSSWCB/ SWCDs	$75,000/ yr[1]	1			$750,000
OSSF Management						
Repair or Replace Failing OSSFs; Decommission fail-ing OSSF	Homeowner	$7,500/ OSSF	20	50	80	$1,125,000
OSSF Inspections for Repairs/Replace	Counties/ Contractors	$750/ OSSF	20	50	80	$112,500
Administer OSSF Re-pair/Replace Pro-gram	County/TWRI/ Other	$10,000/ yr	1			$100,000
Homeowner OSSF Education Event	AgriLife Extension	$3,500	1	1	1	$10,500
Installer & Service Provider Education Events	AgriLife Extension	$3,500	1	1	1	$10,500
Centralized Wastewater Collection System Management						
Conveyance System Inspections	Wastewater Utilities	~$2,000 equipment cost	Annual inspections as funding al-lows			$2,000 plus con-sumables (TBD)
Conveyance System Repairs	Wastewater Utilities	$100 - $150/ft.	As needed and as funding allows			TBD*
Urban Stormwater Management						
Pet Waste Station Maintenance	Cities, HOAs, Counties	$85/yr/ sta-tion	100 stations annually			$85,000[+]
Pet Waste Education Materials	Cities, HOAs, Utilities	N/A	Annually, addition to current in-formational flyers			N/A*
Implement MS4 Per-mits	MS4 Permittees	N/A	Continuously			N/A*

- * costs are included in current operating budgets or capital improvement plans in most cases
- [+] some costs are included in current operating budgets for cities; not all stations are covered

Chapter 8 : Assistance Needs

Implementing this WPP combines a series of complex tasks to achieve the common goal of improving water quality in the Navasota River. Many technical and financial resources will be needed to successfully implement this plan. Resource needs vary by task and are described below.

Technical Assistance

Designing, planning, and implementing some management recommendations in this plan will require technical expertise. In these instances, appropriate support will be sought to provide needed technical guidance. Funds required to secure needed expertise will be included in requests for specific projects and will come from a variety of resources.

Feral Hog Management

Assistance for feral hog control activities is needed to provide information to watershed stakeholders regarding feral hog control approaches, options, and best practices. The Texas A&M AgriLife Extension Service and TPWD provide educational resources through local programs and other public events. Delivery of these events in the watershed will continue and be directed to address landowner needs. Information regarding most aspects of feral hog control is available at: http://feralhogs.tamu.edu/

Livestock Management

Documented efforts to improve livestock management across the watershed will require significant technical assistance from the TSSWCB, local SWCDs and local NRCS personnel. Producers requesting planning assistance in the watershed will work with these entities to define management goals and objectives and develop a management plan that prescribes effective practices that will achieve stated goals and improve water quality.

The level of planning required to meet the plan's implementation goals is significant and will require considerable personnel time. A technician position will be required to develop WQMPs and encourage producer participation in available programs. This position will work with existing resource management personnel such as local Texas A&M AgriLife Extension Service agents, NRCS personnel and others to identify and engage potential participants.

OSSF Management

Effectively reducing the pollutant load from OSSFs will require technical assistance in multiple forms. Continued County DR support and involvement is critical to effectively manage OSSFs throughout the watershed. This will include assisting in funding acquisition, identifying prospective program participants, publicizing repair and replacement funding availability, assisting homeowners in applying for funding support, and collaborating with inspectors, designers, and installers.

Technical assistance for education and outreach delivery regarding OSSF design, function, operation and maintenance is needed in the watershed. The Texas A&M AgriLife Extension Service will provide the bulk of this information and County DRs will support efforts by identifying specific needs, helping to plan program delivery, and providing content regarding local rules and regulations.

Centralized Wastewater

Technical assistance needs for addressing inflow and infiltration issues within wastewater collection systems will vary depending on capacity to perform needed tasks within each entity. Collection system inspections using smoke testing or autonomous video technology and making needed repairs may require contractors to conduct or consulting engineers to design these projects.

Urban Stormwater

Limited technical assistance for urban stormwater management is needed. Entities in the watershed under MS4 permits have staff that largely fill these needs. For structural projects, engineering design may be needed and will be integrated into the cost of the project.

Education and Outreach

Continued delivery of education and outreach resources to watershed stakeholders is critical for successful implementation of the WPP. The education program will address relevant topical areas and will require cooperation, coordination, and participation by multiple entities. Topical experts, local entity staff, and others as appropriate will be relied upon to deliver necessary content to targeted audiences. Existing resources will be utilized where possible and local efforts to provide these resources to broad-based and targeted audiences will be continued. Should additional funding needs arise for content development or delivery, supplemental funds from external sources will be sought.

Education delivery will focus on primary sources of *E. coli* and other pollutants identified throughout the watershed. Landscape and water resource management, OSSF operation and maintenance, OSSF design and installation, stormwater management, feral hog biology and management, livestock management, and nutrient management programming will all be delivered in the watershed in multiple locations as demand warrants (Table 8.1).

Training for city and county staff is also necessary for effectively reducing pollutant loading in the watershed. Many staff are required to obtain continuing education credits on an incremental basis in their respective areas of expertise. This education will further protect and improve local water resources by ensuring that appropriate personnel are informed of new techniques, requirements, and resources.

Financial Assistance Sources

Successful WPP implementation will require significant financial resources (Tables 7.1 and 8.1). Diverse funding sources will be sought to meet fiscal requirements. Resources will be leveraged where possible to extend the impacts of acquired and contributed implementation funds.

Grant funds will be relied upon to initiate implementation efforts. They will supplement existing funding resources such as city and county program funds. Existing state and federal programs will also be expanded or leveraged with acquired funding to further implementation impacts. Grant funds are not a sustainable source of financial assistance, but are necessary to assist in WPP implementation. Other sources of funding will be utilized and creative funding approaches will be sought where appropriate. Sources of funding that are applicable to this WPP and will be sought as appropriate are described in this chapter.

Federal Funding Sources

Conservation Stewardship Program (CSP)

CSP is a voluntary conservation program administered by the USDA-NRCS that encourages producers to address resource concerns in a comprehensive manner. This includes adding, maintaining, improving and managing conservation activities. The program is available for private agricultural lands including cropland, grassland, prairie land, improved pasture and rangeland. CSP encourages landowners and stewards to improve conservation activities on their land by installing and adopting additional conservation practices. Practices may include, but are not limited to prescribed grazing, nutrient management planning, precision nutrient application, manure application and integrated pest management. Program information can be found at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/

Conservation Reserve Program (CRP)

CRP is a voluntary program for agricultural landowners administered by the USDA Farm Service Agency (FSA). Individuals may receive annual rental payments to establish long term, resource conserving covers on environmentally sensitive land. The goal of the program is to reduce runoff and sedimentation to protect and improve lakes, rivers, ponds, and streams. Financial assistance covering up to 50 percent of the cost to establish approved conservation practices, enrollment payments, and performance payments are available through the program. Information on the program is available at: http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

Contact your local FSA office for more information on this and other programs or to enroll:

Brazos and Grimes Counties:	(979) 846-4814
Leon and Madison Counties:	(936) 544-3857
Limestone County:	(254) 729-2310
Robertson County:	(979) 828-3338

Table 8.1 Education and outreach implementation schedule, responsible party, and estimated costs

Education & Outreach Activity	*Responsible Party*	*Number Implemented Time Frame (year)*			*Cost*
		1-3	*4-6*	*7-10*	
General Resource Management Programming and Resources					
Texas Watershed Steward Trainings	Extension	---	1	1	N/A*
Texas Well Owner Network Training	Extension	1	1	---	N/A*
Texas Riparian Ecosystem Training	Extension	1	1	---	N/A*
Watershed Newsletter	WS Coordinator	3	3	4	$5,000
Agriculture Programming					
Lone Star Healthy Streams Training	Extension	1	1	1	N/A*
Forage Management Seminars (Nutrients, Pesticide, Water Quality)	Extension	3	3	4	N/A⁺
Management Practice Field Days	Extension/ WS Coordinator/ NRCS	2	2	3	N/A⁺
Feral Hog and Wildlife Management Programming					
Feral Hog Management Workshops	Extension/ TPWD	3	3	4	$30,000
Wildlife Management Workshops	Extension/ TPWD	1	1	1	$9,000
OSSF Management Programming					
OSSF Owner O&M Training	Extension/ Counties	3	3	4	$30,000
OSSF Installer & Maintenance Provider Training	Extension/ Counties	2	2	2	$18,000
Urban Programming					
Stormwater E&O Events and Information	MS4 Entities	Per Respective Stormwater Management Program			N/A*

*additional funding not required; currently funded through existing resources

⁺additional funding not required; local programs, participants cover program costs

Environmental Quality Incentives Program (EQIP)

EQIP is a voluntary conservation program operated by the USDA-NRCS that assists farmers and ranchers to address natural resource concerns by implementing activities to improve soil, water, plant, animal, air and other resources associated with agricultural land. An EQIP contract can extend up to 10 years and provides financial and technical assistance for planning and implementing prescribed conservation practices. Individuals engaged in livestock or agricultural production on eligible land are permitted to participate in EQIP. Practices selected address natural resource concerns and are subject to the NRCS technical standards adapted for local conditions. They also must be approved by the local SWCD. Local Work Groups are formed to provide recommendations to the USDA-NRCS that advise the agency on allocations of EQIP county base funds and identify local resource concerns. Watershed stakeholders are strongly encouraged to participate in their local Work Group to promote the objectives of this WPP with the resource concerns and conservation priorities of EQIP. Information regarding EQIP can be found at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

Contact local NRCS Service Centers for further CSP and EQIP program information or other available programs:

Brazos and Grimes Counties:	(979) 846-4814
Leon County:	(903) 536-2940
Limestone County:	(254) 729-2310
Madison County:	(936) 348-2173
Robertson County:	(979) 828-3626

Rural Development Water & Environmental Programs

USDA Rural Development provides grants and low interest loans to rural communities for potable water and wastewater system construction, repair, or rehabilitation. Funding options include:

- Rural Repair and Rehabilitation Loans and Grants: provides assistance to make repairs to low income homeowners' housing to improve or remove health and safety hazards.
- Technical Assistance and Training Grants for Rural Waste Systems: provides grants to non-profit organizations that offer technical assistance and training for water delivery and waste disposal.
- Water and Waste Disposal Direct Loans and Grants: assists in developing water and waste disposal systems in rural communities with populations less than 10,000 individuals.

More Information about the Rural Development Program can be found at: http://www.rd.usda.gov/programs-services/all-programs/water-environmental-programs

Clean Water Act §319(h) Nonpoint Source Grant Program

USEPA provides grant funding to the state of Texas to implement NPS pollution reduction projects through the Clean Water Act §319(h) Nonpoint Source Grant Program. TCEQ and TSSWCB administer these grants; TSSWCB administers funds for agricultural and silvicultural NPS pollution while TCEQ administers funds that address urban and other areas of NPS pollution. WPPs that satisfy the nine key elements of successful watershed based plans (Appendix A) are eligible for funding through this program. To be eligible for funding, implementation measures must be included in the accepted WPP and meet other program rules. Some commonly funded items include:

- Development and delivery of educational programs
- Water quality monitoring
- OSSF repairs and replacements, land BMPs, waterbody clean-up events and others

Further information can be found at: https://www.tceq.texas.gov/waterquality/nonpoint-source/grants/grant-pgm.html and http://www.tsswcb.texas.gov/managementprogram

State Sources

Clean Rivers Program (CRP)

The TCEQ administers the Texas CRP, a state fee-funded program that provides surface water quality monitoring, assessment, and public outreach. Allocations are made to 15 partner agencies (primarily river authorities) throughout the state to assist in routine monitoring efforts, special studies, and outreach efforts. The Brazos River Authority (BRA) is the CRP partner for the Navasota River watershed. The program supports water quality monitoring, annual water quality assessments, and engages stakeholders in addressing water quality concerns in the Brazos River basin. In FY2017, BRA has allocated approximately $71,500 in program funding for monitoring in the Navasota River watershed. Further program information can be found at: http://www.brazos.org/About-Us/Water-Quality/Clean-Rivers-Program

Clean Water State Revolving Fund

The TWDB provides low cost financing for a variety of wastewater, stormwater, reuse, and other pollution control projects. Political subdivisions and private entities are eligible to apply for loans at lower than market rates to plan, design, acquire, or construct projects. Loans can have flexible terms and principal forgiveness for qualifying parties. Further information is available at: http://www.twdb.texas.gov/financial/programs/CWSRF/

Economically Distressed Area Program

The TWDB administers the Economically Distressed Area Program to provide grants and loans for water and wastewater projects where current service is unavailable or inadequate to meet state standards. Political subdivisions and non-profit water supply corporations can apply for funding to plan, design, acquire, or construct new water or wastewater systems. Renovation of existing systems is also permissible. Specific eligibility requirements and other program information is available at: https://www.twdb.texas.gov/financial/programs/EDAP/

Texas Capital Fund

The Texas Capital Fund Infrastructure Development program is available to eligible units of local government (cities and counties) in rural areas to construct new or replace old public infrastructure. Grants range from $100,000 to $1.5 million. Program information is available at: https://texasagriculture.gov/GrantsServices/RuralEconomicDevelopment/TexasCapitalFund.aspx

Supplemental Environmental Projects (SEP)

The TCEQ administers the SEP program which is responsible for directing fines, fees and penalties for environmental violations to reduce environmental pollution. Entities undergoing an enforcement can choose to invest penalty dollars to improve the environment instead of paying into the Texas General Revenue Fund. Program dollars can be directed to improvement activities including OSSF repair, wildlife habitat restoration, and clean-ups. Pre-approved SEP projects eligible in the watershed include cleanup of unauthorized dumpsites, household hazardous waste collection, wastewater treatment assistance (repair or replace failing OSSFs). Further information about SEPs and how to apply can be found at: https://www.tceq.texas.gov/legal/sep

Water Quality Management Plan Program (WQMP)

WQMPs are property-specific management plans developed and implemented to improve land and water quality. Technical assistance to develop plans that meet producer and state goals is provided by the TSSWCB and local SWCDs. Once the plan is developed, the TSSWCB may financially assist implementing a portion of prescribed BMPs. As of 2015, TSSWCB has developed and certified 59 WQMPs in the watershed that are focused primarily on poultry production operations. Through these plans, 15,215 acres are enrolled and include practices such as conservation cover (1,411 ac), forage harvest management (2,342 ac), prescribed grazing (4,701 ac), heavy use area protection (1,494 ac), nutrient management (3,757 ac), and critical area plantings (363 ac.). Financial assistance provided through the program to counties in the watershed totaled $26,310 in 2015 and $44,670 in 2016.

Feral Hog Abatement Grant Program

TDA provides grant funding to governmental agencies (counties, cities, etc.) and Texas higher education institutions for practical and effective projects to develop and implement long-term feral hog abatement strategies. Texas A&M AgriLife Extension Service and the Texas Parks and

Wildlife Department (TPWD) currently receive funding through this program. In the past, individual and groups of counties have applied to receive funds for programs to control feral hogs including providing community traps or bounty payments. More information is available at: https://www.texasagriculture.gov/GrantsServices/Trade-andBusinessDevelopment/FeralHogGrantProgram

Texas Farm and Ranch Lands Conservation Program

The Texas Farm and Ranch Lands Conservation Program was established and is administered by TPWD to conserve high value working lands to protect water, fish, wildlife, and agricultural production that are at risk of future development. The program's goal is to educate citizens on land resource stewardship and establish conservation easements to reduce land fragmentation and loss of agricultural production. Program information is available from TPWD at: http://tpwd.texas.gov/landwater/land/private/farm-and-ranch/

Landowner Incentive Program

TPWD administers the Landowner Incentive Program to work with private landowners to implement conservation practices that benefit healthy aquatic and terrestrial ecosystems and create, restore, protect, or enhance habitat for rare or at-risk species. The program provides financial assistance but does require the landowner to contribute through labor, materials, or other means. Further information about this program is available at: http://tpwd.texas.gov/landwater/land/private/lip/

Other Sources

Private foundations, non-profit organizations, land trusts and individuals can potentially assist with implementation funding some aspects of the WPP. Funding eligibility requirements for each program should be reviewed before applying to ensure applicability. Some groups that may be able to provide funding include but are not limited to:

- **Cynthia and George Mitchell Foundation**: Provides grants for water and land conservation programs to support sustainable protection and conservation of Texas' land and water resources
- **Dixon Water Foundation**: Provides grants to non-profit organizations to assist in improving/maintaining watershed health through sustainable land management
- **Meadows Foundation**: Provides grants to non-profit organizations, agencies, and universities engaged in protecting water quality and promoting land conservation practices to maintain water quality and water availability on private lands
- **Texas Agricultural Land Trust**: Funding provided by the trust assists in establishing conservation easements for enrolled lands

Chapter 9 : Implementation Support and Success

Effectively implementing this WPP will take concerted efforts by many dedicated stakeholders; however, they will need additional support in many cases. Coordinating actual implementation efforts, working to secure funding, tracking implementation progress, and monitoring to demonstrate implementation success are all activities that are beyond the responsibility of a single stakeholder. Additional implementation support needs are described below.

Coordinating Implementation

Implementing the WPP will require significant time and effort. A full-time position is recommended to support plan implementation. This position will be responsible for working with stakeholders to identify funding opportunities, develop and file funding applications, administer projects, keep stakeholders engaged, coordinate and organize educational programming, track implementation progress, and document incremental improvements in watershed condition. Funding needs for this position are estimated at $95,000 annually and include salary, benefits, travel, and needed supplies to perform necessary tasks.

Water Quality Monitoring

Since the goal of the WPP is to improve and restore water quality in the Navasota River watershed, continued monitoring is necessary. Monitoring data are also necessary to track changes in water quality that result from WPP implementation. However, water quality is affected by many factors in a watershed and any changes that occur from WPP implementation may be difficult to identify in the river. A focused monitoring approach that utilizes several types of monitoring is recommended to provide needed data to gauge implementation success.

Routine Water Quality Monitoring

Quarterly water quality monitoring conducted in the watershed by BRA through the CRP program has and will continue to be the standard for assessing instream water quality. BRA currently monitors 13 stations in the Navasota River watershed and plans to continue monitoring at this level for the foreseeable future. Of these, five stations are in the watershed below Lake Limestone and are monitored on a quarterly basis. Stations monitored include 11877 (US 79), 11875 (SH 30), and 11873 (SH 6) on the Navasota River, station 11785 on Carters Creek, and station 18800 on Gibbons Creek. Data collected at these sites includes *E. coli,* temperature, pH, DO, conductivity, nitrate, ammonia, total phosphorus, chlorophyll-a and other observational data. Flow rate is only recorded at station 11877. Data collected at these sites will be useful for tracking long-term WPP implementation effects and will provide the benchmark for water quality improvements in the watershed as reported in biennial water quality assessments conducted by TCEQ (the *Texas Integrated Report*). This data will provide needed water quality trend information and demonstrate the cumulative effects on instream water quality.

Targeted Water Quality Monitoring

To assess the effects of specific implementation efforts on water quality, targeted sampling efforts will be completed in association with specific implementation projects. Monitoring can include a variety of approaches but will be selected based on the most appropriate monitoring type for the specific implementation effort. Examples of targeted monitoring that can be utilized to document implementation effects on downstream water quality include multiple subwatershed, paired watershed, and multiple watershed monitoring. Using near-continuous automated sampling on tributaries of the Navasota River will allow annual loadings to be calculated and compared before and after implementation. Intensive grab sampling can also be utilized if automated sampling is not appropriate. In all cases, it is imperative that ample pre-implementation monitoring be conducted to detect changes in water quality.

The most appropriate approach will be selected in association with planned implementation efforts. Specific sampling approaches, duration, frequency, and objectives will be determined at that time. Regardless of sampling specifics, *E. coli* and flow measurements will be the primary objectives of any monitoring effort. Field parameters, nutrients, and sediment may also be recorded if deemed necessary during monitoring planning activities.

Implementation Success

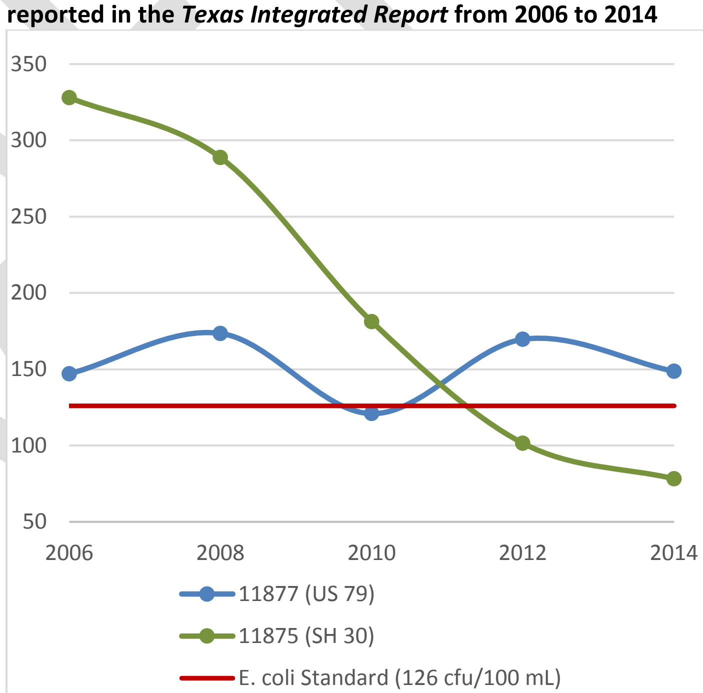
WPP implementation success will be measured by progress made in achieving numerical implementation targets. Each management recommendation includes implementation targets for the 10-year implementation period (Ch. 6; Table 7.1, Table 8.1) which is presumed to begin in 2018. Incremental targets are also provided as benchmarks for implementation success. Water quality changes will be monitored in association with implementation success to further quantify WPP success. The watershed coordinator will track implementation across the watershed and report findings to stakeholders at least annually.

In some cases, implementation targets may not be met at the pace outlined in the WPP (Table 7.1, Table 8.1). This may occur due to lack of funds, stakeholder will, or other unforeseen circumstances. Should this occur, adaptive management will be utilized to adjust the WPP implementation strategy as appropriate. Adaptive management is the act of changing strategies as information is gained.

Progress toward achieving the established water quality target of 126 cfu/100 mL will also be used to evaluate the need for adaptive management. It is understood that changes in water quality are influenced by many factors and that implementation efforts may take considerable time to appear in water quality data. Because of this, sufficient time will be allowed for implementation to occur before adaptive management will be triggered by water quality measures. Progress toward meeting the water quality target will be gauged with geometric mean assessments of the most recent three years of available data within TCEQ's surface water quality monitoring information system (SWQMIS).

The *Texas Integrated Report* will also be used to gauge implementation effectiveness. This document uses a seven-year moving assessment time frame that is delayed by two years. The 2026 *Texas Integrated Report* will be the first assessment to use data collected exclusively within the WPP implementation period. Water quality improvements may be harder to identify using this longer data window, thus these biennial assessments will not be the primary measure of implementation success. However, the *Texas Integrated Report* is the water quality benchmark for Texas and will be used to gauge long-term implementation success. Changes in *E. coli* concentrations are obvious, but not consistent in past *Texas Integrated Reports*. Downstream, water quality has markedly improved (station 11875) in the last 10 years while upstream, water quality has remained relatively consistent (Figure 9.1). This figure will be updated in the future to provide an extended look at water quality changes over time.

Figure 9.1 *E. coli* concentrations at key monitoring stations reported in the *Texas Integrated Report* from 2006 to 2014



References

AVMA. 2012. U.S Pet Ownership Calculator. [Internet]. American Veterinary Medical Association.; [2015 Oct 20]. Available from: https://www.avma.org/KB/Resources/Statistics/Pages/US-pet-ownership-calculator.aspx

Brenner, F.J., Mondok, J.J., McDonald, Jr., R.J. 1996. "Watershed Restoration through Changing Agricultural Practices." Proceedings of the AWRA Annual Symposium Watershed Restoration Management: Physical, Chemical and Biological Considerations. Herndon, VA: American Water Resources Association, TPS-96-1, pp. 397-404.

Byers, H.L., Cabrera, M.L., Matthews, M.K., Franklin, D.H., Andrae, J.G., Radcliffe, D.E., McCann, M.A., Kuykendall, H.A., Hoveland, C.S., Calvert II, V.H. 2005. "Phosphorus, sediment, and *Escherichia coli* loads in unfenced streams of the Georgia Piedmont, USA." *Journal of Environmental Quality*. 34:2293-2300.

Cook, M.N. 1998. "Impact of Animal Waste Best BMPs on the Bacteriological Quality of Surface Water." master's thesis. Virginia Polytechnic Institute and State University.

Di Giovanni G, Casarez E, Gentry E, Martin E, Gregory L, Wagner K. 2013. Support analytical infrastructure and further development of a statewide bacterial source tracking library. [Internet]. College Station: Texas Water Resources Institute; TR-448. [cited 2016 Aug 3]. Available from: http://twri.tamu.edu/reports/2013/tr448.pdf

Frey SK, Gottschall N, Wilkes G, Gregoire DS, Topp E, Pintar DM, Sunohara M, Marti R, Lapen DR. 2015. Rainfall-induced runoff from exposed streambed sediments: An important source of water pollution. Journal of Environmental Quality 44: 236-247

Gregory LF, Blumenthal B, Wagner KL, Borel KE, Karthikeyan R. 2013. Estimating on-site sewage facility density and distribution using geo-spatial analyses. Journal of Natural and Environmental Science 4(1): 14-21

Griffith GE, Bryce SA, Omernik JM, Comstock JA, Rogers AC, Harrison B, Hatch SL, Bezanson D. 2004. Ecoregions of Texas (color poster with map, descriptive text, and photographs) (map scale 1:2,500,000). Reston: U.S. Geological Survey.

Hagedorn, C., Robinson, S.L., Filtz, J.R., Grubbs, S.M., Angier, T.A., Reneau Jr., R.B. 1999. "Determining sources of fecal pollution in a rural Virginia watershed with antibiotic resistance patterns in fecal streptococci." *Applied and Environmental Microbiology*. 65:5522-5531.

LCRA. Coordinated Monitoring Schedule for FY 2016. [Internet]. 2015. Lower Colorado River Authority; [2015 Sept 10]. Available from: https://cms.lcra.org/default.aspx

Line, D. E. 2002. "Changes in land use/management and water quality in the Long Creek watershed." *Journal of the American Society of Agronomy*. 38:1691-1701.

Line, D. E. 2003. "Changes in a stream's physical and biological conditions following livestock exclusion." *Transactions of the ASAE*. 46:287-293.

Lombardo, L.A., Grabow. G.L., Spooner, J., Line, D. E., Osmond, D.L., Jennings, G.D. 2000. Section 319 Nonpoint Source National Monitoring Program: Successes and Recommendations. NCSU Water Quality Group, Biological and Agricultural Engineering Department, NC State University, Raleigh, North Carolina.

Lowe KS, Rothe NK, Tomaras JMB, DeJong K, Tucholke MB, Drewes J, McCray JE, Munakata-Marr J. 2007. Influent constituent characteristics of the modern waste stream from single sources: Literature review. Water Environment Research Foundation and IWA Publishing; [2016 July 26]. Available from: http://www.ndwrcdp.org/documents/04-DEC-1a/04DEC1P1.pdf

Meals, D.W. 2001. "Water quality response to riparian restoration in an agricultural watershed in Vermont, USA." *Water Science and Technology*. 43:175-182.

Meals, D.W. 2004. “Water quality improvements following riparian restoration in two Vermont agricultural watersheds” in Manley, T.O., Manley, P.L., Mihuc, T.B. editors. *Lake Champlain: Partnerships and Research in the New Millennium*. New York: Kluwer Academic/Plenum Publishers.

NLCD. 2011. Multi-resolution land characteristics consortium: national land cover database 2011. [Internet]. USGS; [cited 2014 Nov 17]. Available from: http://www.mrlc.gov/nlcd2011.php

NRCS. Web Soil Survey: Soil Data Explorer: Suitabilities and Limitations for Use. [Internet]. 2015. USDA; [2015 Sept 9]. Available at: http://websoilsurvey.sc.egov.usda.gov/

Omernik JM. 1995. Ecoregions: A spatial framework for environmental management. In: W.S., T.P. Simon, editors. Biological Assessment and Criteria: tools for water resource planning and decision making. Boca Raton (FL): Davis Lewis Publishers; p 49-62

Omernik JM. 2004. Perspectives on the nature and definition of ecological regions. Environmental Management. 34(Supplement 1):S27-S38.

Peterson, J.L., Redmon, L.A., McFarland, M.L. 2011. *Reducing Bacteria with Best BMPs for Livestock: Heavy Use Area Protection.”* Texas A&M AgriLife Extension Service. ESP-406.

Rattan, JM, Higginbotham, BJ, Long, DB, Campbell, TA. 2010. Exclusion fencing for feral hogs at White-tailed deer feeders. *Texas Journal of Agriculture and Natural Resource.* 23: 83-89.

Sheffield, R.E., Mostaghimi, S., Vaughan, D. H., Collins Jr., E.R., Allen, V.G. 1997. “Off-Stream Water Sources for Grazing Cattle as a Stream Bank Stabilization and Water Quality BMP.” *Transactions of the ASAE*. 40:595-604.

TCEQ. 2012a. Three Total Maximum Daily Loads for Indicator Bacteria in the Carters Creek Watershed. Available at: https://www.tceq.texas.gov/assets/public/waterquality/tmdl/85carters/85-CartersCreekTMDL-Adopted.pdf

TCEQ. 2012b. Implementation Plan for Three Total Maximum Daily Loads for Indicator Bacteria in the Carters Creek Watershed. Available at: https://www.tceq.texas.gov/assets/public/waterquality/tmdl/85carters/85A-CartersCreekIPlan-Approved.pdf

TCEQ. 2014. SWQMIS. [Internet]. Texas Commission on Environmental Quality; [2014 Sept 12]. Available from: http://www80.tceq.texas.gov/SwqmisPublic/public/default.htm.

TCEQ. 2015a. Municipal & industrial wastewater outfalls. [GIS layer]. Texas Commission on Environmental Quality; [2015 Oct 21]. Available from: https://www.tceq.texas.gov/gis/download-tceq-gis-data

TCEQ. 2015b. 2014 Guidance for assessing and reporting surface water quality in Texas. [Internet]. Texas Commission on Environmental Quality; [cited 2015 June 17]. Retrieved from: https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/14txir/2014_guidance.pdf

TCEQ. 2015c. 2014 Texas Integrated Report: Assessment results for Basin 12 – Brazos River. [Internet]. Texas Commission on Environmental Quality; [cited 2016 July 28]. Available from: https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/14txir/2014_basin12.pdf

TCEQ. 2015d. 2014 Texas Integrated Report – Texas 303(d) List (Category 5). [Internet]. Texas Commission on Environmental Quality; [cited 2016 July 28]. Available from: https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/14txir/2014_303d.pdf.

TCEQ 2015e. 2014 Texas Integrated Report index of water quality impairments. [Internet]. Texas Commission on Environmental Quality; [cited 2016 July 28]. Available from: https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/14txir/2014_imp_index.pdf

Teague A, Karthikeyan R, Babbar-Sebens M, Srinivasan R, Persyn RA. 2009. Spatially explicit load enrichment calculation tool to identify potential *E. coli* sources in watersheds. Transactions of the ASABE 52(4): 1109-1120

TSSWCB. 2015a. Water quality management plan data. [2015 Apr 4]. Obtained from TSSWCB.

TSSWCB. Water Quality Management Plan Program. [Internet]. 2015b. Texas State Soil and Water Conservation Board; [2015 Oct 27]. Available from: https://www.tsswcb.texas.gov/en/wqmp

TWDB. 2014. 2016 Regional water plan: population & water demand projections. [Internet]. Texas Water Database; [2014 Nov 19]. Available from: http://www.twdb.state.tx.us/waterplanning/data/projections/2017/popproj.asp

TWDB. 2016a. Lake Limestone (Brazos River Basin). [Internet]. Texas Water Development Board; [2016 June 15]. Available from: http://www.twdb.texas.gov/surfacewater/rivers/reservoirs/limestone/index.asp

TWDB. 2016b. Gibbons Creek Reservoir (Brazos River Basin). [Internet]. Texas Water Development Board; [2016 June 15]. Available from: http://www.twdb.texas.gov/surfacewater/rivers/reservoirs/gibbons_creek/index.asp

TWDB. 2016c. Twin Oaks Gibbons Creek Reservoir (Brazos River Basin). [Internet]. Texas Water Development Board; [2016 June 15]. Available from: http://www.twdb.texas.gov/surfacewater/rivers/reservoirs/twin_oaks/index.asp

TWDB. 2016d. Carrizo-Wilcox Aquifer. [Internet]. Texas Water Development Board; [2016 June 16]. Available from: http://www.twdb.texas.gov/groundwater/aquifer/majors/carrizo-wilcox.asp

TWDB. 2016e. Gulf Coast Aquifer. [Internet]. Texas Water Development Board; [2016 June 16]. Available from: http://www.twdb.texas.gov/groundwater/aquifer/majors/gulf-coast.asp

U.S. Census Bureau. 2010. Data generated by Katelyn Lazar; using American FactFinder. [Internet]. U.S. Department of Commerce; [2015 Oct 20]. Available from: http://factfinder2.census.gov

USDA. 2012. 2012 Census Volume 1, Chapter 2: County Level Data. [Internet]. United States Department of Agriculture; [cited 2015 Oct 21]. Available from: http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/

USEPA. 1991. Guidance for water quality based decisions: The TMDL process. Washington, D.C.: U.S. Environmental Protection Agency: Office of Water; EPA 440/4-91-001

USEPA. 2001. Protocol for developing pathogen TMDLs. [Internet]. 1st ed. Washington, D.C.: U.S. Environmental Protection Agency: Office of Water; EPA 841-R-00-002

USEPA. 2003. Onsite Wastewater Treatment Systems Manual. Washington, D.C.: U.S. Environmental Protection Agency: Office of Water; EPA 625/R-00/008

USEPA. 2012. Recreational Water Quality Criteria. Washington, D.C.: U.S. Environmental Protection Agency: Office of Water; EPA 820-F-12-058

USEPA. 2015. Enforcement and Compliance History Online. [Internet]. United States Environmental Protection Agency; [2015 Oct 20]. Available from: http://echo.epa.gov

Wagner KL. 2011. Evaluation of methods to assess and reduce bacterial contamination of surface water from grazing lands. Doctoral dissertation: Texas A&M University; [cited 2015 Oct 27]. Available from: http://oaktrust.library.tamu.edu/handle/1969.1/ETD-TAMU-2011-08-9914

Wagner K, Moench E. 2009. Education program for improved water quality in Copano Bay: task two report. [Internet]. College Station: Texas Water Resources Institute [cited 2016 Feb 23]. Available from: http://twri.tamu.edu/reports/2009/tr347.pdf

30 TAC § 307.7. 2014. Texas Administrative Code on environmental quality of Texas surface water quality standards: site-specific uses and criteria. [Internet]. Texas State Legislature; [cited 2015 Jun 22]. Available from:

http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&ti=30&ch=307&rl=7

30 TAC § 307.9. 2014. Texas Administrative Code on environmental quality of Texas surface water quality standards: determination of standards attainment. [Internet] Texas State Legislature; [cited 2015 Jun 22]. Available from: http://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=T&app=9&p_dir=N&p_rloc=166382&p_tloc=&p_ploc=1&pg=4&p_tac=&ti=30&pt=1&ch=307&rl=7

33 USC § 1251 et seq. 2002. Clean Water Act of 1972. [Internet]. United States Senate; [cited 2015 Jan 22]. Retrieved from: http://www.epw.senate.gov/water.pdf

40 CFR § 130.7. 2013. Code of Federal Regulations. [Internet]. United States Congress; [cited 2015 Jan 22]. Retrieved from: http://www.gpo.gov/fdsys/pkg/CFR-2013-title40-vol23/pdf/CFR-2013-title40-vol23-sec130-7.pdf

Appendix A: Elements of Successful Watershed Protection Plan

The Clean Water Act section 319(h) grant funding program requires WPP development to follow the 'Elements of Successful Watershed Plans' in USEPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (2008) and contain sufficient information on these elements in order to be eligible for implementation funding.

A. Identification of Causes and Sources of Impairment

Identifying the causes and sources that need to be controlled to achieve load reductions estimated in the WPP. Sources that need to be controlled should be identified at the significant subcategory level with estimates of the extent to which they are present in the watershed.

See Chapters 4 & 5

B. Expected Load Reductions

An estimate of the load reduction expected for the management measures proposed as part of the WPP.

See Chapter 6; Appendix F

C. Proposed Management Measures

Description of management measures to be implemented to achieve the estimated load reductions and identification of the areas where measures are needed to implement the plan. A critical area should be determined for each combination of source and BMP.

See Chapters 6 & 7

D. Technical and Financial Assistance Needs

Estimate of the technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan. Authorities include the specific state or local legislation which allows, prohibits, or requires an activity.

See Chapter 8

E. Information, Education, and Public Participation Component

Information/education component to enhance public understanding and encourage early and continued participation in selecting, designing, and implementing the appropriate NPS management measures.

See Chapter 8

F. Schedule

Schedule for implementing the NPS management measures in the WPP that is reasonably expeditious.

See Chapters 7 & 8.

G. Milestones

Description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented.

See Chapters 7 & 8

H. Load Reduction Evaluation Criteria

Criteria to determine if loading reductions are being achieved over time and progress is being made towards attaining water quality standards and, if not, criteria for determining whether the WPP needs to be revised.

See Chapter 9

I. Monitoring Component

A monitoring component to evaluate the implementation effectiveness over time. The monitoring component should include required project-specific needs, the evaluation criteria, and local monitoring efforts.

See Chapter 9

Appendix B: Land Use/Land Cover Definitions and Methods

Watershed LULC information was obtained from the 2011 National Land Cover Database (NLCD). ArcGIS 10.3 software by Environmental Systems Research Institute (ESRI) was used to process the data and quantify LULC categories within defined subwatersheds (Table 2.3). Category definitions are:

- **Developed** – Land use category that includes areas of high, medium, and low development and developed open space. Development includes areas where people live or work in high numbers, areas with a mixture of vegetation and constructed materials. Open space includes areas where vegetation cover is dominant with some development, such as golf courses, parks, and large homes. Impervious surfaces account for 50-100% for development areas and less than 20% for open space. For this combined category, development is present and impervious surfaces are between 0-100%.

- **Barren Land** – Bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material compose the barren land classification. Generally, vegetation accounts for less than 15% of total cover.

- **Cultivated Crops** – Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.

- **Forest** –Areas dominated by trees generally taller than 5 meters, and greater than 20% of total vegetation cover. Species include deciduous, evergreen, and those that do not fall into either category.

- **Wetlands** – Includes wetlands and emergent herbaceous wetland. The vegetation in wetlands consists of forests, shrublands, and/or perennial herbaceous vegetation, accounting for 25-100% of cover. Emergent herbaceous wetlands consist of 75-100% of perennial herbaceous vegetation and the soil or substrate is covered or periodically saturated with water.

- **Hay/Pasture** – Areas that include a variety of grasses, legumes, or grass-legume mixtures plant for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

- **Herbaceous** – Areas that are dominated by grammanoid (grasses) or herbaceous vegetation with the areas consisting of 80% total vegetation. The areas may be utilized for grazing, but not for intensive BMPs.

- **Open Water** – All areas of open water, generally with less than 25% cover of vegetation or soil.

- **Shrub/Scrub** – Areas that are dominated by woody plants or shrubs which are less than 5 meters tall and a canopy typically greater than 20% of total vegetation.

Appendix C: On-Site Sewage Facility Estimation and Analysis

Map Development

An estimate of the locations and numbers of OSSFs in the watershed were determined using available information since watershed wide information on exact OSSF locations does not exist. A combination of 911 address point data, aerial imagery, 2010 Census Block data, and city limit boundaries was used to approximate OSSF locations as described in Gregory et al. 2013. Points within city limits where WWTFs service is provided were removed. Satellite imagery was used to validate that 911 addresses were houses and not electrical boxes or barns. Lastly, the number of remaining points was compared to the number of housing units reported in the watershed 2010 census block data (U.S. Census Bureau 2010). ESRI ArcGIS 10.3 was used to create this layer and appropriate maps.

Estimates of OSSFs placement in relation to soil suitability for septic drain fields was also assessed. A septic drain field soil suitability map developed by NRCS (2015) was integrated into the GIS and allowed the number of OSSFs within the three defined soil suitability categories: very limited, somewhat limited, not limited. OSSF density was also evaluated using ArcGIS by defining the density within one-mile radius (Figure 4.2).

Failing OSSFs Calculation

OSSF failure rates were developed by county based on feedback received from county designated representatives and watershed stakeholders. Local knowledge regarding system age, improper design for the soils, general lack of proper maintenance, and direct observations informed the development of failure rates (Table C.).

Most subwatersheds lie within multiple counties with different failure rates. A weighted average failure rate was calculated for each subwatershed to reflect this distribution using ArcGIS. The portion of the subwatershed within each county was determined and multiplied by the appropriate failure rate (Tables C.1 and C.2; equation below). Using this information, an estimate of the number of failing OSSFs was calculated for each subwatershed (Appendix D, Table D.6).

Table C.1 OSSF failure rates by county

County	OSSF Failure Rate
Brazos	0.05
Grimes	0.2
Leon	0.1
Limestone	0.1
Madison	0.1
Robertson	0.1

Table C.2 Percent of each subwatershed in the counties and the calculated weighted OSSF failure rate

Sub-watershed	Total Acres	Brazos		Grimes		Leon		Limestone		Madison		Robertson		OSSF Failure Rate*
		Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	
1	118,722							87,314	0.735			31,407	0.265	0.100
2	108,342					89,404	0.825					18,938	0.175	0.100
3	96,276							8,919	0.093			87,357	0.907	0.100
4	73,405					41,387	0.564					32,017	0.436	0.100
5	97,538	22,150	0.227	250	0.003	26,304	0.270			27,291	0.280	21,543	0.221	0.089
6	77,150	34,046	0.441									43,104	0.559	0.078
7	16,710									16,709	1.000			0.100
8	74,893	35,856	0.479	38,098	0.509					939	0.013			0.127
9	56,402	56,401	1.000											0.050
10	43,577	42,808	0.982	769	0.018									0.053
11	75,764			75,763	1.000									0.200
12	52,260	34,478	0.660	17,781	0.340									0.101
13	115,297	41,042	0.356	74,254	0.644									0.147

$$* \, Weighted\ OSSF\ Failure\ Rate = (\%\ in\ Brazos\ Cnty * 0.05) + (\%\ in\ Grimes\ Cnty * 0.2) + (\%\ in\ Leon\ Cnty * 0.1) + (\%\ in\ Limestone\ Cnty * 0.1) + (\%\ in\ Madison\ Cnty * 0.1) + (\%\ in\ Roberton\ Cnty * 0.1)$$

Appendix D: Spatial Analysis of *E. coli* Loading Development and Calculations

To improve knowledge regarding the distribution of potential *E. coli* loads and inform management decisions, worst case scenario *E. coli* contributions were mapped across the watershed. Information regarding the number and distribution of evaluated species and published *E. coli* and fecal production rates were combined to estimate daily *E. coli* loading in the watershed.

Animal Estimates

The number of animals within the watershed was estimated based on best available information. Published data (USDA NASS 2012 Census of Agriculture) or known animal densities (TPWD estimates for deer; literature values for feral hogs) were used as starting points to establish populations when available. Recommended livestock stocking rates were also used to back-calculate appropriate populations. In these cases, animal species were assigned to appropriate LULC classes (Table D.1) at the recommended density to estimate the population.

Table D.1 Assigned LULC classes for animals in the watershed

Animal	LULC Applied
Cattle	Improved Pasture: Hay/Pasture
	Unimproved Pasture: Shrub/Scrub; Herbaceous
Deer	Shrub/Scrub; Herbaceous; Forest; Hay/Pasture; Cultivated Crops; Wetlands
Feral Hogs	Forest; Wetlands; Shrub/Scrub
Horses	Hay/Pasture
Goats	Shrub/Scrub; Herbaceous
Sheep	Shrub/Scrub; Herbaceous
Dogs	*Associated with housing units

*not a LULC designation

Recommended county stocking rates were provided by NRCS and adjusted based on local stakeholder feedback. Stakeholders agreed that feral hogs and deer densities were the same throughout the watershed, while cattle stocking rates differed by county (Table D.2) Stakeholder feedback was used to establish a combined feral hog stocking rate of 8 acres/hog in wetlands LULC and 13 acres/hog in forest and shrub/scrub LULC. The 32 acres/deer stocking rate reported by TPWD for deer was applied to all assigned LULC classes shown in Table D.1. Population estimates for horses, sheep, and goats were not modified from values reported in the USDA NASS 2012 Census of Agriculture. These numbers were scaled down from county estimates to reflect only the portion of the county in the watershed (Table D.8). The dog population was estimated based on dog ownership statistics by household (AVMA 2015) and the number of housing units estimated in the watershed (US Census Bureau, 2010) as described in chapter 4.

Table D.2 Stocking rates for each county in the watershed

County	Cattle	
	Improved (acres/AU)	Unimproved (acres/AU)
Brazos	6	12
Grimes	5	16
Leon	5	16
Limestone	5	12
Madison	5	16
Robertson	4	8

Once stakeholders provided input and agreed that animal density estimates were appropriate, county populations were estimated. The appropriate animal density for the LULC acreage in portion of each county within the watershed was applied to generate these estimates (Table D.7).

Map Development

Subwatershed Animal Estimates

County scale animal estimates are not appropriate when developing management recommendations based on hydrology. Instead, these estimates were converted to the subwatershed scale by determining the total area of each county within each subwatershed and then separating it by LULC classes. The stocking rate (or animal density) approach previously described was then applied to appropriate acres to establish subwatershed population estimates (Table D.8).

Animal estimates were then converted to animal units (AU) to allow comparisons between species. One AU is 1,000 lbs of animal weight and is commonly used to quantify the grazing impact of livestock and similar animals. Dogs were not converted to AUs as the conversion factor does not apply to this animal. Animal unit conversion factors (Table D.3) were multiplied by subwatershed animal estimates to calculate subwatershed AUs (Table D.8).

Table D.3 AU conversion factors (Wagner and Moench 2009)

Animal	AU Conversion Factor
Cattle	1.000
Horse	1.250
Goat	0.170
Sheep	0.200
Feral Hog	0.125
Deer	0.112

Animal E. coli Load Calculations and Maps

Average daily *E. coli* production differs by species due to many factors. Wagner and Moench (2009) completed an extensive literature review and documented the range of fecal coliform production per AU for a variety of species. These numbers were converted to *E. coli* using a 0.63 conversion factor created by dividing the *E. coli* water quality standard (126 cfu/100 mL) by the old fecal coliform water quality standard (200 cfu/100 mL). This yielded estimated daily *E.coli* production rates per AU (Table D.4). Dog *E. coli* production was identified from published literature values (Teague et al. 2009) and feral hog numbers were adapted from USEPA 2001. These rates were multiplied by the number of AUs in each subwatershed to calculate the maximum potential *E. coli* load for each evaluated animal species within each subwatershed (Table 5.6). Loading estimates were mapped by subwatershed and grouped using five color-coded categories (Figures 5.7 and 5.8).

Table D.4 Daily *E. coli* production by species

Animal	*E.coli* Production per Day (cfu/AU/day)
Cattle	5.39e+09
Horses	1.83e+08
Goats	1.60e+10
Sheep	1.83e+11
Deer	9.45e+09
Feral Hogs	6.93E+09
Dogs	2.50e+09*

*cfu/dog/day

Poultry Litter E. coli Load Calculation and Map

Poultry litter from broiler operations in the watershed represents another potential *E. coli* source; however, its application is not consistent in space or time within the watershed. WQMP data from TSSWCB provided relatively accurate information regarding annual litter production and its planned use on and off-farm by subwatershed. Industry representatives provided the following information regarding the fate of litter produced in the watershed:

- 15% of litter planned for on-farm use is stored prior to land application
- 85% of litter planned for on-farm use is taken from the house and directly land applied
- 40% of litter planned for off-farm use is stored prior to land application
- 60% of litter planned for off-farm use is taken from the house and directly land applied
- 40% of all litter produced is in-house windrow composted
- 60% of all litter produced is not in-house windrow composted
- 80% of litter planned for off-site use remains in the watershed; 20% is exported

E. coli content in poultry litter varies based on management (able 5.5; Coufal and Gentry, 2016), thus this information was important for selecting the appropriate *E. coli* concentration to use for developing a loading estimate. *E. coli* content was applied to the appropriate percentage of litter in each treatment category (Table D.5) using the equations below. E. coli loading estimates (Table 5.6) were mapped by subwatershed after converting annual loads to daily loads and grouped using five color-coded categories (Figures 5.8). Subwatersheds with no color did not contain large poultry operations.

Table D.5 Percentage of on-site and off-site litter within each treatment category

	On Site Litter		Off Site Litter	
	Field: 85%	**Stacked: 15%**	**Field: 60%**	**Stacked: 40%**
IWC: 40%	0.34	0.06	0.24	0.16
No IWC: 60%	0.51	0.09	0.36	0.24

$$\boldsymbol{E. coli\ from\ On\ Site\ Litter} = \left(Onsite\ litter\ in\ subwatershed\ (g) * 0.51 * 1920\frac{cfu}{g}\right) + \left(Onsite\ litter\ in\ subwatershed\ (g) * 0.49 * 13\frac{cfu}{g}\right)$$

$$\boldsymbol{E. coli\ from\ Off\ Site\ Litter} = (\ 0.80 * \left(\left(\ Offsite\ litter\ in\ subwatershed\ (g) * 0.36 * 1920\frac{cfu}{g}\right) + \left(\ Offsite\ litter\ in\ subwatershed\ (g) * 0.64 * 13\frac{cfu}{g}\right)\right)$$

OSSF E. coli Load Calculation and Map

The number of failing OSSFs in each subwatershed was calculated by multiplying the subwatershed failure rate (Table C.2) by the corresponding number of OSSFs. This number (Table D.6) was used to calculate the potential *E. coli* load from OSSFs using the quantity of *E. coli* expected in effluent from a failing OSSF as calculated in the equations below. Subwatershed OSSF loads (Table 5.6) were mapped to demonstrate potential influences in the watershed (Figure 5.8).

$$\boldsymbol{OSSF\ E. coli\ Load} = \#\ of\ OSSFs * \frac{10^6 cfu}{100mL} * 0.63 * \frac{70\ gallons}{person} * \frac{3785.41\ mL}{1\ gallon} * \frac{2.65\ people}{household} = 4.42x10^{10} cfu/OSSF$$

Where:

- 10^6 cfu/100 mL = fecal coliform concentration in OSSF effluent (Lowe et al. 2007)
- 0.63 = fecal coliform to *E. coli* conversion factor (*E. coli* standard/fecal coliform standard)
- 70 = gallons of effluent produce per person per day (USEPA 2003)
- 3785.41 = mL per gallon
- 2.65 = average number of people per household in the watershed (US Census Bureau, 2010)

Table D.6. Failing OSSFs by subwatershed

Subwatershed	OSSF Failure Rate	# of OSSFs	# of Failing OSSFs
1	0.100	505	50
2	0.100	1340	134
3	0.100	788	79
4	0.100	1097	110
5	0.089	1480	132
6	0.078	1054	82
7	0.100	425	42
8	0.127	1497	190
9	0.050	2811	141
10	0.053	818	43
11	0.200	1161	232
12	0.101	2169	219
13	0.147	2004	294
Total		17,149	1,748

WWTF E. coli Load Calculation and Map

Measured flow rates and *E. coli* concentrations (Table 4.2) reported to EPA were used to calculate an estimated *E. coli* load from WWTFs in the watershed. To calculate the load, flow rate was converted from million gallons per day to mL and multiplied by the reported *E. coli* concentrations as shown in the equation below. Individual WWTF loads were summed by subwatershed for mapping purposes (Figure 5.8). Subwatersheds with no WWTF were not color-coded.

$$\boldsymbol{WWTP\ E. coli\ Load} = reported\ flow\ (MGD) * 3.785412x10^9 \left(\frac{mL}{million\ gallons}\right) * \mathrm{E. coli}\ concentration\ \left(\frac{cfu}{100\ mL}\right)$$

Total Potential *E. coli* Loadings

Potential *E. coli* loads calculated for each evaluated source were summed within each subwatershed to create a total potential loading estimate (Table 5.6). The total loading estimate map illustrates the cumulative potential loads across the watershed (Figure 5.8) and is useful for demonstrating potential water quality stresses spatially.

Animal Estimates by County and Subwatershed

Table D.7 Estimated animal numbers in the watershed by county

County	Cattle			Feral Hogs	Deer	Horses	Goats	Sheep	Dogs
	Improved Pasture	Unimproved Pasture	Total						
Brazos	14,898	3,610	18,508	10,103	7,154	1,978	1,314	590	29,559
Grimes	22,255	1,454	23,709	5,680	5,889	1,274	484	78	2,092
Leon	9,695	2,409	12,104	6,295	4,422	662	414	83	799
Limestone	5,724	1,999	7,723	3,517	2,813	442	248	75	914
Madison	5,164	345	5,509	1,386	1,340	51	149	52	363
Robertson	19,539	4,945	24,484	9,847	6,771	215	515	264	1,614

Table D.8 Estimated animal numbers and animal units by subwatershed. The AU numbers and dog estimates were used to calculate the potential *E.coli* loads

Subwatershed	Cattle						Feral Hogs		Deer		Horses		Goats		Sheep		Dogs
	Improved Pasture		Unimproved Pasture		Total												
		AU		AU		AU		AU		AU		AU		AU		AU	
1	8,149	8,149	2,556	2,556	10,705	10,705	4,315	539	3,463	388	444	555	975	166	106	21	958
2	7,714	7,714	1,788	1,788	9,501	9,501	4,152	519	3,071	344	438	548	656	112	69	14	592
3	8,107	8,107	1,927	1,927	10,034	10,034	3,736	467	2,741	307	114	143	635	108	102	20	715
4	3,764	3,764	1,189	1,189	4,953	4,953	3,475	434	2,099	235	151	189	427	73	50	10	438
5	6,885	6,885	1,416	1,416	8,301	8,301	4,489	561	2,846	319	297	372	692	118	142	28	997
6	6,097	6,097	1,910	1,910	8,007	8,007	2,944	368	2,303	258	314	392	651	111	184	37	1,153
7	2,369	2,369	69	69	2,438	2,438	333	42	495	55	23	29	73	12	10	2	161
8	6,044	6,044	925	925	6,969	6,969	3,098	387	2,233	250	491	614	640	109	120	24	1,276
9	4,956	4,956	776	776	5,731	5,731	1,513	189	1,642	184	658	822	282	48	127	25	2,983
10	1,119	1,119	351	351	1,477	1,477	1,315	164	698	78	145	182	132	22	57	11	17,343
11	7,152	7,152	643	643	7,795	7,795	2,209	276	2,106	236	409	512	925	157	34	7	711
12	2,822	2,822	470	470	3,292	3,292	2,358	295	1,348	151	252	315	357	61	58	12	5,890
13	12,099	12,099	735	735	12,835	12,835	2,890	361	3,345	375	885	1,106	639	109	82	16	2,120

Appendix E: Load Duration Curve Development

Load duration curves (LDCs) are tools that help identify pollutant source types in a watershed. LDCs combine measured *E. coli* concentrations and flow volumes to calculate an *E. coli* load for that given flow condition. A regression line plotted through available data is compared to the allowable load for the waterbody (water quality standard combined with flow rate) to demonstrate when *E. coli* loads are higher than they should be in relation to streamflow. If exceedances generally occur under low flow conditions, direct deposition or point sources of pollution are the likely culprit. Exceedances generally occurring under higher flow conditions typically represent nonpoint source pollution. At least 18 paired *E. coli* samples and flow measurements must be available to develop a LDC.

Flow Duration Curve (FDC)

The first step of LDC development involves creating a FDC. Recorded flow data for a particular monitoring location is sorted into a descending order and ranked from highest to lowest. The frequency of a particular flow in the stream (percent of days flow is met or exceeded) is determined for each flow measurement ((individual flow rank/total # of ranks)*100). The FDC is created by graphing the flow volume versus frequency (Figure E.1).

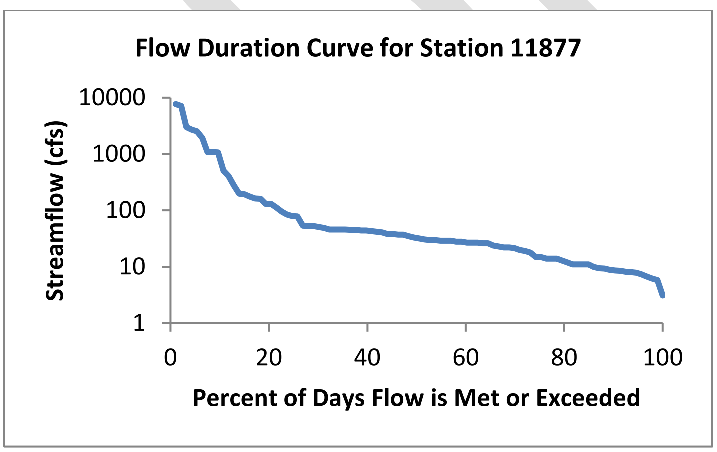


Figure E.1 Example of a FDC

Load Duration Curve (LDC)

Watershed stakeholders selected the current water quality standard of 126 cfu/100 mL of *E. coli* as the water quality goal to attain through implementation of the WPP. This standard is converted to a maximum allowable *E. coli* load for each flow condition. The maximum allowable load is then graphed along with the FDC to establish the water quality goal (red line, Figure E.). Monitored *E. coli* loads are then overlain on the graph. Samples above the red line indicate that the actual load exceeded the long-term water quality standard at that point in time.

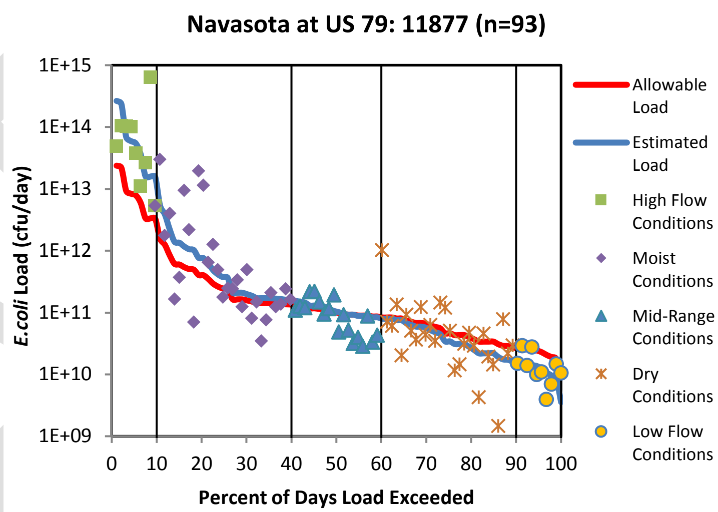


Figure E.2 An example of a developed LDC of the watershed

Regression analysis is then completed using a USGS program called Load Estimator (LOADEST). The estimated load (blue line) is the "line of best fit" through the individual monitoring samples. In cases where the blue line is above the red line, the *E. coli* load in the in the waterbody is generally higher than the allowable levels. When the blue line is at or below the red line, the *E. coli* load present is within allowable levels and the waterbody is supporting its water quality standard at that point. The difference between estimated and allowable loads is calculated and represents the loading reduction needed to achieve the water quality goal for the waterbody.

Appendix F: Load Reduction Calculations

Expected *E. coli* load reductions from recommended BMPs included in the WPP are based on best available information regarding practice effectiveness reported in literature, the anticipated number of treatments to be implemented, and the presumed *E. coli* loading from the managed species. Median practice efficiency values were used in loading reduction calculations developed to reflect expected per unit loading reductions. This approach allows quick assessment of expected loading reductions at various levels of implementation.

Feral Hogs

Loading reductions for feral hogs are simple. Removing the hog removes the *E. coli* load completely. The feral hog population in the watershed is estimated to be 36,827 animals as determined by watershed stakeholders. This estimate is based on the assumption that feral hogs primarily inhabit wetland and forested areas at a presumed density of 8 ac/hog and 13 ac/hog respectively. Stakeholders acknowledge that they use almost the entire watershed, but that their primary habitat is in these more secluded areas.

The estimated loading reduction expected from feral hog management was calculated by combining the daily fecal loading rate per hog, estimated number of hogs removed, and number of days annually that the practice will be implemented. Feral hogs also have an affinity for dense riparian cover, thus a 25% riparian stream impact factor is also incorporated. The goal established is to remove 15% of the total feral hog population annually. By removing the hogs from the watershed completely, the potential *E. coli* load from feral hogs is assumed to decrease by 15% as well.

Daily Feral Hogs Load Reduction Expected

$$= \#\, feral\ hogs\ removed * 1.1E + 10\frac{cfu}{day} * 0.63 * Proximity\ Factor * 365\frac{days}{year}$$

In this equation inputs are as follows:

- 1.1 E+10 = the fecal coliform production in cfu/day per feral hog (USEPA 2001)
- 0.63 = fecal coliform to *E. coli* conversion factor
- Proximity Factor = a percentage based impact factor that accounts for an assumed stream impact factor to be applied based on feral hog affinity for riparian habitats = 25%

Feral Hog Removal Load Reduction Estimate:

<u>*Annual Load Reduction*</u>

$$= 5{,}524\ hogs\ removed * 1.1E + 10\frac{cfu}{day} * 0.63 * 0.25\ Proximity\ Factor * 365\frac{days}{year}$$

Total Annual Feral Hog Removal Load Reduction = 3.49E+15 cfu

Livestock

Estimating *E. coli* loading reductions from livestock involves multiple management recommendations and a variety of animal species. However, cattle are by far the dominant livestock animal present in the watershed and make up approximately 93% of the total livestock population. Therefore, cattle were presumed to be the species managed through livestock focused management. Using county level data, average farm/ranch size is estimated at 280 acres each. Using this information, livestock population data, and the area of the watershed suitable for livestock grazing, approximately 51 AUs are estimated to be housed on each farm/ranch. For evaluation purposes, it is presumed that each WQMP developed will cover 280 acres, which houses 51 AUs. In reality, each WQMP will vary in size and AU numbers.

Efficiency values for applicable BMPs are used to estimate the amount of *E. coli* reduction expected by implementing the practice. Reported literature values were aggregated and median values were identified and utilized in this assessment (Table F.1).

Table F.1 Livestock BMP bacteria removal efficiencies

Management Practice	*E. coli* Removal Efficiency		
	Low	High	Median
Fencing[1]	37%	46%	42%
Prescribed Grazing[2]	66%	72%	69%
Watering Facility[3]	85%	85%	85%

[1] Brenner 1996, Cook 1998, Hagedorn et al. 1999, Line 2002, Line 2003, Lombardo et al. 2000, Meals 2001, Meals 2004, Peterson 2011
[2] Tate et al. 2004, USEPA 2010
[3] Byers et al. 2005, Hagedorn et al. 1999, Sheffield et al. 1997

A generic equation consisting of the number of animal units, average daily cattle *E. coli* production, and the selected BMPs' median effectiveness value (Table F.1) was used to calculate potential load reductions for each of the three BMPs most likely to be implemented through WQMPs. This generic equation allows for a post implementation assessment to be easily performed after WQMPs have been developed, the practices implemented are known, and number of AUs planned are known.

Daily Potential Load Reduction Expected from Cattle

$$= \#\ of\ WQMPs * \#\ of \frac{cattle}{WQMP} * 5.39E+9 \frac{cfu}{day} * BMP\ Effectiveness\ Rate * Proximity\ Factor$$

In this equation, inputs are as follows:

- WQMPs are water quality management plans and are a planning mechanism that incorporates management measures such as prescribed grazing and alternative water sources to address water quality issues.
- 5.39 E+9 = the presumed *E. coli* production in cfu/day per cattle AU
- BMP Effectiveness rate = median of BMP efficiencies as illustrated in Table F.1.
- Proximity Factor = a percentage-based impact factor that accounts for an assumed stream impact factor to be applied based on the location of the BMP (riparian areas = 25% and upland areas = 5%)

Specific load reduction estimates will depend on the number of participating ranchers, specific practices implemented, property location, and the number of cattle managed by a specific BMP. Properties with riparian access are the primary implementation focus regardless of subwatershed. Upland areas in sub-watersheds 13, 1, 2, 3, 5, 6, 8, and 11 will also receive WQMP implementation focus. Combined, it is recommended that 130 WQMPs be developed watershed-wide with 50 being focused near riparian areas and 80 in upland areas. It is assumed that each WQMP will include prescribed grazing and fencing. Watering facilities are only presumed for riparian access pastures.

Annual load reduction calculations also assume a number of days per year that the practice will be used by the management target. These are assumed to be:

<u>Prescribed Grazing:</u>

Riparian Pastures:	73 days per year
Upland Pastures:	292 days per year

<u>Watering Facility:</u>

Riparian Pastures only:	73 days per year

<u>Cross Fencing:</u>

Riparian Pastures:	73 days per year
Upland Pastures:	292 days per year

Prescribed Grazing Load Reduction Estimate:

<u>Annual Riparian Property Grazing Load Reduction</u>

$$= \left(50\ WQMPs * 51 \frac{cattle}{WQMP} * 5.39E+9 \frac{cfu}{day} * .69\ BMP\ Effectiveness\ Rate * 0.25\ Proximity\ Factor * 73 \frac{days}{year}\right) + \left(50\ WQMPs * 51 \frac{cattle}{WQMP} * 5.39E+9 \frac{cfu}{day} * .69\ BMP\ Effectiveness\ Rate * 0.05\ Proximity\ Factor * 292 \frac{days}{year}\right)$$

<u>Annual Riparian Pasture Prescribed Grazing Load Reduction = 3.12E+14 cfu</u>

<u>Annual Upland Property Grazing Load Reduction</u>

$$= 80\ WQMPs * 51 \frac{cattle}{WQMP} * 5.39E+9 \frac{cfu}{day} * .69\ BMP\ Effectiveness\ Rate * 0.05\ Proximity\ Factor * 365 \frac{days}{year}$$

Annual Riparian Pasture Prescribed Grazing Load Reduction = 2.77E+14 cfu

Total Prescribed Grazing (Riparian + Upland) Load Reduction= 5.88E+14 cfu

Total Prescribed Grazing (Riparian + Upland) Load Reduction= 5.88E+14 cfu

Watering Facility Load Reduction Estimate:

Annual Watering Facility Load Reduction

$$= 50\ WQMPs * 51\frac{cattle}{WQMP} * 5.39E+9\frac{cfu}{day} * .85\ BMP\ Effectiveness\ Rate * 0.25\ Proximity\ Factor * 73\frac{days}{year}$$

Annual Watering Facility Load Reduction = 2.13E+14 cfu

Cross Fencing Load Reduction Estimate:

Annual Riparian Property Cross Fencing Load Reduction

$$= \left(50\ WQMPs * 51\frac{cattle}{WQMP} * 5.39E+9\frac{cfu}{day} * .42\ BMP\ Effectiveness\ Rate * 0.25\ Proximity\ Factor * 73\frac{days}{year}\right) + \left(50\ WQMPs * 51\frac{cattle}{WQMP} * 5.39E+9\frac{cfu}{day} * .42\ BMP\ Effectiveness\ Rate * 0.05\ Proximity\ Factor * 292\frac{days}{year}\right)$$

Annual Riparian Area Cross Fencing Load Reduction = 1.90E+14 cfu

Annual Upland Area Cross Fencing Load Reduction

$$= 80\ WQMPs * 51\frac{cattle}{WQMP} * 5.39E+9\frac{cfu}{day} * .42\ BMP\ Effectiveness\ Rate * 0.05\ Proximity\ Factor * 365\frac{days}{year}$$

Annual Riparian Area Cross Fencing Load Reduction = 8.43E+14 cfu

Annual Cross Fencing (Riparian + Upland) Load Reduction= 1.03E+15 cfu

Estimated loading reductions for each practice described above were summed to estimate the total *E. coli* load expected from implementing 130 WQMPs over the 10-year implementation period.

Total WQMP Loading Reduction Estimate: 1.83E+15

OSSFs

OSSFs are common in the Navasota River watershed and 17,149 are estimated to be in use. Presumed failure rates range from 5 to 20% depending on county. System age, lack of maintenance, and soil suitability are the primary factors leading to failures. This information yields an estimate of 1,747 failing OSSFs across the watershed. To estimate expected loading reductions, the influence of a failing OSSF was evaluated based on the suitability of soils for receiving effluent. NRCS defines soil suitability for OSSF drain fields as not limited, somewhat limited, and very limited. These ratings relate to the ability of the soil to absorb effluent which is based on soil texture, infiltration capacity, slope, and other factors. A reasonable goal of replacing 150 failing OSSFs was established in the WPP.

Daily Potential Load Reduction Expected from OSSF Repair or Replacement

$$= \#\ of\ OSSFs\ addressed * 1.00E+7\frac{cfu}{100mL} * 0.63 * 70\frac{\frac{gallons}{person}}{day} * 3785.2\frac{mL}{gallon} * 2.65\frac{persons}{household} * Soil\ Suitability\ Factor$$

Assumptions:

- $1.00E+7\frac{cfu}{100mL}$ = fecal coliform concentration in OSSF effluent (Horsley and Witten 1996)
- 0.63 = fecal coliform to *E. coli* conversion factor

- $3785.2 \frac{mL}{gallon}$ = number of milliliters in a gallon
- 70 gallons per person per day effluent production (Horsley and Witten 1996)
- 2.65 persons per household average in watershed (US Census Bureau, 2010)
- Soil Suitability Factor = a percentage based impact factor that accounts for an assumed stream impact factor applied based on soil type (very limited soils = 50%; somewhat limited soils = 30%; not limited = 10%)

OSSF Load Reduction Estimate:

Annual Very Limited Soils Load Reduction

$$= 100\ OSSFs\ addressed * 1.00E+7 \frac{cfu}{100mL} * 0.63 * 70 \frac{\frac{gallons}{person}}{day} * 3785.2 \frac{mL}{gallon} * 2.62 \frac{persons}{household} * 365 \frac{days\ used}{year} * 0.5$$

Annual Very Limited Soils OSSF Load Reduction = 8.07E+14 cfu

Annual Somewhat Limited Soils Load Reduction

$$= 50\ OSSFs\ addressed * 1.00E+7 \frac{cfu}{100mL} * 0.63 * 70 \frac{\frac{gallons}{person}}{day} * 3785.2 \frac{mL}{gallon} * 2.65 \frac{persons}{household} * 365 \frac{days\ used}{year} * 0.3$$

Annual Somewhat Limited Soil OSSF Load Reduction = 2.42 E+14 cfu

Combined, replacement of these 150 OSSFs across the watershed is expected to significantly reduce *E. coli* loading.

Total OSSF Loading Reduction Estimate: 1.05E+15

Dogs

E. coli loading from dogs is based on the assumption that not all dog waste is currently disposed of properly. The watershed is estimated to contain 35,341 dogs and improved management is recommended for 20% of this total. Collecting and disposing of their waste in the trash will remove the majority of *E. coli* present in fecal matter from the watershed and prevent it from washing into area streams during runoff events. It is assumed that 75% of the waste can be removed by collection and proper disposal.

Daily Potential Load Reduction Expected from Dog Waste Management

$$= \#\ of\ dogs\ managed * 2.5E+09 \frac{cfu}{\frac{dog}{day}} * 0.75\ Effectiveness\ Factor * days/year$$

Assumptions:

- $2.5E+9 \frac{cfu}{dog/day}$ = daily dog *E. coli* production (Teague et al. 2009)
- 365 = days per year
- 0.75 = presumed practice efficiency

Annual Dog Management Load Reduction

$$= 7{,}068\ dogs\ managed * 2.5E+09 \frac{cfu}{\frac{dog}{day}} * 0.75\ Effectiveness\ Factor * 365 \frac{days}{year}$$

Annual Dog Management Load Reduction = 4.84 E+15 cfu