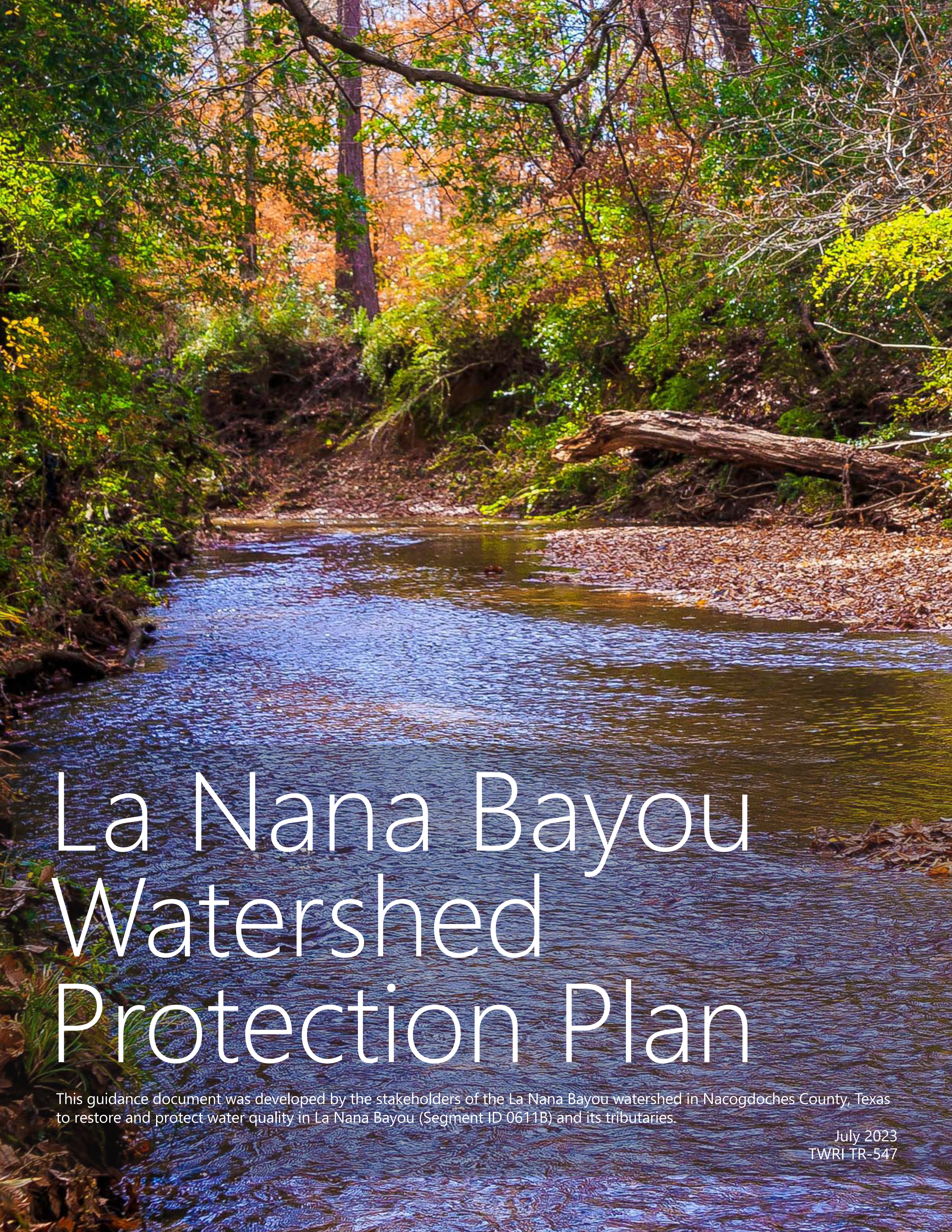


La Nana Bayou Watershed Protection Plan

This guidance document was developed by the stakeholders of the La Nana Bayou watershed in Nacogdoches County, Texas to restore and protect water quality in La Nana Bayou (Segment ID 0611B) and its tributaries.

July 2023
TWRI TR-547

La Nana Bayou Watershed Protection Plan

This guidance document was developed by the stakeholders of the La Nana Bayou watershed in Nacogdoches County, Texas to restore and protect water quality in La Nana Bayou (Segment ID 0611B) and its tributaries.

Authored and prepared by:

Emily Monroe[1], Lucas Gregory[1], Matthew McBroom[2], Jeremiah Poling[3], and Rene Barelas[3]

[1] Texas Water Resources Institute, [2] Stephen F. Austin State University, [3] Angelina & Neches River Authority

Texas Water Resources Institute Technical Report – 547

July 2023

College Station, Texas

Funding for the development of this watershed protection plan was provided in part through a federal Clean Water Act §319(h) grant provided by the United States Environmental Protection Agency and administered by the Texas Commission on Environmental Quality Nonpoint Source Program.

Cover photo: La Nana Bayou by Ed Rhodes, TWRI.

Texas Water Resources Institute make every drop count

Texas A&M AgriLife

EPA United States Environmental Protection Agency

Texas Commission on Environmental Quality

Acknowledgments

Liberty Hall along La Nana Bayou where most of the stakeholder meetings and educational programs took place. Photo by Emily Monroe, TWRI.

The development of this watershed protection plan would not have been possible without the contributions of the stakeholders that desire to protect and restore La Nana Bayou. Special appreciation is extended to the many residents that provided meaningful feedback to ensure this plan represents the realities of the watershed. Spending time and effort attending the many stakeholder meetings and reading through the drafts of this plan was vital to its successful completion and is greatly appreciated by the authors of this document.

Representatives from the following local and state agencies and organizations also provided key insights relevant to their specialties and specialized knowledge:

- Angelina & Neches River Authority
- City of Nacogdoches
- Nacogdoches County
- Nacogdoches County AgriLife Extension
- Nacogdoches County Soil and Water Conservation District
- Nacogdoches Independent School District
- Stephen F. Austin State University
- Texas A&M AgriLife Research and Extension Service
- Texas A&M Forest Service
- Texas Commission on Environmental Quality
- Texas State Soil and Water Conservation Board
- Texas Water Resources Institute
- United States Environmental Protection Agency
- United States Department of Agriculture – Natural Resources Conservation Service

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Acronym	Meaning
ACCESS	Active Community and Citizen Education for Science and Stewardship
AFOs	Animal feeding operations
AgriLife Extension	Texas A&M AgriLife Extension Service
AnU	Animal Unit
AU	Assessment Units
AVMA	American Veterinary Medical Association
BMP	Best Management Practice
CCT	Clean Coast Texas
cfu	Colony Forming Unit
cfs	Cubic Feet Per Second
CP	Conservation Plan
CRP	Clean Rivers Program
CSA	Critical Source Areas
CSP	Conservation Stewardship Program
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
DR	Designated representative
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
F	Fahrenheit
FDC	Flow duration curve
GIS	Geographic Information System
GBRA	Guadalupe-Blanco River Authority
HLHW	Healthy Lawns and Healthy Waters
ISD	Independent School District
L	Liter
LDC	Load Duration Curve
LIP	Landowner Incentive Program
LSHS	Lone Star Healthy Streams
mg	Milligram

Acronym	Meaning
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
mL	Milliliter
MM	Management Measure
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Database
NRCS	United States Department of Agriculture – Natural Resources Conservation Service
NWQI	National Water Quality Initiative
OSSF	On-site Sewage Facility
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCPP	Regional Conservation Partnership Program
RMU	Resource Management Units
SEP	Supplemental Environmental Projects
SFASU	Stephen F. Austin State University
SSO	Sanitary Sewer Overflow
SWCD	Soil and Water Conservation District
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TFS	Texas A&M Forest Service
Texas Integrated Report	*Texas Integrated Report of Surface Water Quality*
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
WPP	Watershed Protection Plan
WQMP	Water Quality Management Plan
WWTP	Wastewater Treatment Plant

Executive Summary

Sign at the beginning of the La Nana Creek Trail in Pecan Acres Park. Photo by Emily Monroe, TWRI.

A watershed is defined as the land area where all water that flows across or through it is channeled to the same point, such as a stream, river, lake, or the ocean. All lands are part of a watershed, from the smallest of backyards to the largest continent. The quality and quantity of water that flows into a water body impacts whether a habitat can support the chemical, physical, and biological communities within it. Watershed-based planning is a way to protect and restore water quality at local, manageable scales. The La Nana Bayou Watershed Protection Plan (WPP) is a comprehensive, stakeholder driven approach to improving the water quality in the La Nana Bayou watershed of Nacogdoches, Texas.

Problem Statement

The water quality of La Nana Bayou does not meet water quality standards for primary contact recreation according to the Texas Commission on Environmental Quality's Texas Water Quality Inventory and 303(d) List due to elevated bacteria. Additionally, the nitrate nitrogen and total phosphorus levels are of concern in the downstream portions.

Response

An initial assessment of the watershed was performed by TWRI, the Angelina & Neches River Authority (ANRA), and Stephen F. Austin State University (SFASU) in 2019. This report analyzed potential causes and sources of pollution through the collection of water quality data and watershed characteristics and provided a foundation for the planning process. The WPP was developed in accordance with the U.S. Environmental Protection Agency's nine key elements of effective watershed protection planning. The two-year process included stakeholders participating in planning meetings, coordinating and attending educational programs, and providing feedback on the issues impacting the local community.

Watershed Protection Plan Overview

The WPP development required coordination with various stakeholders over several years and focused on identifying potential sources of water pollution within the watershed, modeling pollutant loads and reductions needed in nonpoint sources of bacteria to achieve the relevant water quality standards determining which management measures can be implemented to reach desired goals. While no single pollutant source is the cause of bacteria issues in the watershed, potential pollutant sources include wildlife and invasive species, livestock, pets, stormwater runoff, illegal dumping, and failing wastewater treatment systems.

Pollutant Reductions

Using water quality data from the TCEQ Surface Water Quality Monitoring Information System, estimates for the relative bacteria load contributions and potential areas for reduction were identified using Load Duration Curves. This type of analysis can provide clues as to whether a bacteria issue is likely coming from a point source or nonpoint source of pollution. Bacteria levels were above the state's water quality standard for most of the year, during all flow levels, which indicates a compilation of several potential point and nonpoint sources are likely causing the issue.

Based on the available water quality data, the estimated *Escherichia coli (E. coli)* load reduction needed to meet the state's standard is 2.81×10^{14} cfu/year, an average load reduction of 80% across all three assessment units.

Recommended Actions

While the management measures identified in the plan are voluntary, they are strongly supported by and were developed in coordination with watershed stakeholders at local and state levels. Ultimately, nine management measures were decided upon and address a variety of potential sources. If these management measures are implemented, the estimated *E. coli* load reduction could be 1.57×10^{15} cfu/year.

Mitigate Urban Stormwater Runoff Issues

Stormwater runoff from rain events in urban areas, or in locations with large amounts of impervious surfaces, flows directly into water bodies, taking with it any pollutants that are on the surfaces like trash, oils, chemicals, and fecal matter. Whereas rain that falls on permeable surfaces, like grassy areas in parks, is mostly absorbed into the soil where pollutants can be naturally filtered out of the water. Installation of stormwater best management practices (BMPs) that reduce runoff or treat bacteria will result in direct reductions of bacteria loadings in the watershed.

Promote the Development of Water Quality Management Plans or Conservation Plans

Water quality management and conservation plans will be developed to address direct and indirect fecal deposition from cattle and other livestock. BMPs which reduce the time livestock spend in creeks or riparian corridors, improve grazing management, and decrease runoff will be recommended. Likely practices include prescribed grazing, cross-fencing, pasture planting, water wells, and watering facilities. Education programs will support and promote implementation adoption.

Obtain Technical Assistance for Urban Waterfowl Management

Overpopulation of waterfowl can exacerbate water quality issues and cause sanitation concerns in public use areas. Establishing a baseline for the type of waterfowl (domestic, invasive, resident, migratory, etc.) and population numbers will allow waterfowl experts to develop a plan that will foster a manageable population in the watershed, improve water quality, and improve bird population health. Education and outreach to residents and park visitors will address issues caused by feeding wild waterfowl, such as impacts to their health and water quality.

Promote Best Management Practices for Managing Feral Hog Populations

The overpopulation of wildlife species, both domestic and invasive, increases bacteria and nutrient loading across the watershed. Feral hogs and wild pigs, in addition to many types of wildlife, tend to live in riparian areas, preferring the dense habitat, food resources, and water availability along a water body to open areas. In addition to direct deposition of bacteria, wildlife use of riparian areas can also contribute to water quality issues via the degradation of ground cover and soil disturbances from activities like wallowing and rooting. Residents will have to voluntarily implement efforts to reduce feral hog populations throughout the watershed by reducing food supplies, becoming educated on how to remove hogs, and implementing the techniques learned.

Promote Proper Disposal of Pet Waste in Urban Areas

Due to the high concentration of bacteria in dog waste and the dependence on pet owners to manage pet waste, reducing bacteria loads from pets will rely on promoting the proper disposal of pet waste on homeowners' properties and in public areas. Making pet waste disposal extremely convenient through installation of pet waste stations in parks and along the La Nana Creek Trail system will assist pet owners in this task. Media campaigns that educate and encourage pet owners to pick up pet waste and properly dispose of it will be needed to increase adoption.

Identify, Inspect, and Remediate Failing On-site Sewage Facilities

On-site sewage facilities, otherwise known as septic systems, treat wastewater at the household level in areas that are not serviced by centralized wastewater treatment plants. A failing septic system, especially near a water body, can be a health hazard to the residents and the water body. Encountering human wastewater is the biggest potential risk to human health compared to bacteria from other sources, so education for homeowners on proper maintenance, and identifying and repairing failing septic systems in the watershed will mitigate untreated wastewater entering La Nana Bayou.

Reduce Illegal Dumping and Litter

Trash provides more surface area for bacteria to live and grow on, and animal carcasses dumped into a water body will decompose and add to water quality issues. While impacts to water quality are likely minimal from dumping alone, education and outreach can reduce the nuisance and associated bacteria loadings.

Work With Area Schools to Develop Water Quality and Conservation Programs for K-12 Students

Integrating watershed education into the schools is important to the La Nana Bayou WPP stakeholder group. This management measure is not expected to impact water quality directly like other BMPs but will instill the idea that watershed protection is everyone's responsibility. Integrating water quality and quantity lessons into schools starting at an early age will hopefully protect water resources in the future.

Continue and Expand Water Quality Monitoring Along La Nana Bayou and Banita Creek

The watershed stakeholders indicated a need to expand water quality data collection through additional bacteria sampling along La Nana Bayou. In addition, stakeholders would like to add at least one monitoring station on Banita Creek to capture water quality information before the creek enters La Nana Bayou. Monitoring bacteria in more locations along both water bodies is desired to create a higher spatial resolution of data, which will allow watershed stakeholders to better direct outreach resources to bacteria hotspots.

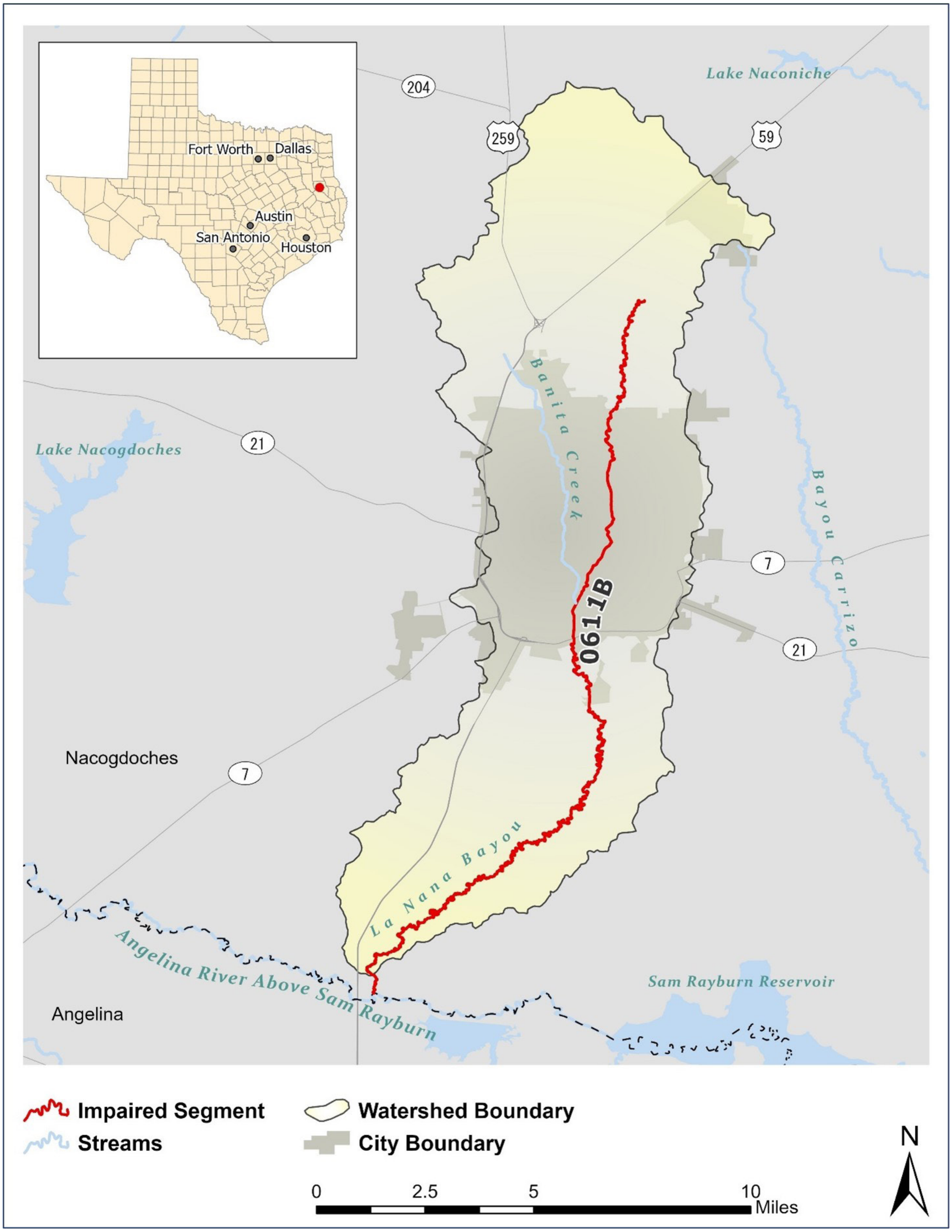
Tracking Implementation Goals

Implementing the WPP will require the allocation of financial resources, technical assistance, and education to achieve the desired water quality goals. To facilitate this process interim measurable milestones were established to evaluate the incremental progress of WPP implementation activities. These targets allow for implementation to occur over a ten-year period, which is important considering the potential time lag between implementation efforts and resulting water quality improvements. If satisfactory progress towards achieving milestones or water quality improvement is deemed impracticable due to funding constraints or other reasons, milestone tracking provides an opportunity to revisit and revise the implementation strategy. Stakeholders can then make efforts to increase BMP adoption and adjust strategies or focus areas as necessary.

A watershed coordinator position will be established that will be responsible for tracking implementation targets and water quality in the watershed. The evaluation of implementation progress and water quality will provide insights into the success of the WPP implementation. In cases where implementation targets or water quality improvements lag significantly, adaptive management efforts will be initiated to reassess the management recommendations and targets included in the WPP.

In conclusion, the La Nana Bayou Watershed Protection Plan provides a guide for stakeholders to improve water quality in the area and continue to enjoy La Nana Bayou.

Map of the La Nana Bayou Watershed



Chapter 1
The Watershed Approach

A tributary of La Nana Bayou in Pecan Acres park. Photo by Emily Monroe, TWRI.

A watershed is the area of land that water flows across or through as it makes its way to a specific point in a stream, river, lake, or even the ocean. That water can come from a variety of sources: rainfall, snow melt, springs, even your water hose. Every bit of land on our planet is part of a watershed. Watersheds can contain smaller subwatersheds, and can also be contained within larger watersheds, like the way a city can be within a county, and a county can be within a state. They can be as large as a continent, or as small as a backyard. A healthy watershed, according to the United States Environmental Protection Agency (EPA), is an area that supports dynamic environmental processes, habitats of sufficient size and connectivity to support native species, and meets the physical and chemical water quality standards needed to support biological communities (EPA 2023). The water that flows into a water body directly impacts the quality of that water body due to the natural processes and human activities that occur within a watershed.

Watershed-based planning is widely recognized by state, national, and international natural resource agencies as the preferred management method for protecting and restoring the quality of surface water and planning for its future use (EPA 2023). Since watersheds do not follow political boundaries such a county lines or city limits, key stakeholders must work together in unique ways to address water quality issues in their watershed. Key stakeholders include individuals, agencies, and organizations that live, work, or have some other relevant interest in the watershed. Involvement from these stakeholders ensures that only the most appropriate activities are selected and implemented for their watershed-based plan.

Watershed Protection Plan

A watershed protection plan (WPP) is a framework developed by stakeholders to address pollution problems through voluntary means. These problems can come from point source pollution, such as industrial discharges or wastewater treatment plants (WWTPs), or nonpoint source pollution, like surface water runoff that carries pollutant loads from urban and rural areas. Within the WPP framework, the technical and financial resources needed to address pollution issues can be better coordinated across stakeholder entities depending on local priorities and needs.

The La Nana Bayou WPP incorporates EPA's nine key elements of effective watershed protection planning, which include:

1. Identification of causes and sources of impairment
2. Expected load reductions from management strategies
3. Proposed management measures
4. Technical and financial assistance needed to implement management measures
5. Information, education, and public participation needed to support implementation
6. Schedule for implementing management measures
7. Milestones for progress of WPP implementation
8. Criteria for determining successes of WPP implementation
9. Water quality monitoring

Working Together and Partnerships

An excerpt from the La Nana Bayou Public Participation Plan

Stakeholders can participate in the development of the WPP through three main avenues: general participation, indirect participation (coordinating partners), and direct project participants.

General Participation: Public involvement is an important aspect of WPP development. General participation is open to any individuals interested in restoring and protecting their watershed. The process of general participation includes public involvement in various outreach events, providing feedback and comments on watershed issues, and provides the opportunity to become familiar with the watershed projects.

Indirect Participation: Stakeholder organizations may have overlapping goals or interests with individual stakeholders for developing a WPP. Those stakeholder organizations can participate by sharing resources, which increases efficiency and helps to achieve mutual targeted goals, and thus become coordinating partners in the WPP development process. Coordinating partners can be non-governmental organizations, local government, community groups, river authorities, local media outlets, etc. The main goal of establishing coordinating partnerships in the public participation plan is to include any potential watershed issues that direct project participants may have overlooked.

Coordinating partners can participate in WPP development in the following ways:

- Finding common goals and objectives and overlapping projects with the WPP.
- Identify emerging issues mutual to both the projects.
- Work and plan together with WPP stakeholders to solve the issues.
- Provide feedback and recommendations to WPP stakeholders for consideration.
- Participate in general meetings.
- Develop ideas and strategies to implement the plan.

Direct Project Participants: Direct project participants are the stakeholders that actively participate and provide input during the watershed planning and implementation process. These stakeholders work together to make recommendations on how the pollutant(s) of interest can most efficiently be reduced so that water quality standards are met.

Direct project participants of the La Nana Bayou WPP include but are not limited to:

- Texas Water Resources Institute (TWRI)
- Texas Commission on Environmental Quality (TCEQ)
- Residents of the watershed and surrounding area
- Texas A&M AgriLife Research and Extension Service
- Angelina & Neches River Authority (ANRA)
- Stephen F. Austin State University (SFASU)
- Texas A&M Forest Service (TFS)
- City of Nacogdoches
- Nacogdoches County
- Texas State Soil and Water Conservation Board (TSSWCB)
- Nacogdoches County Soil and Water Conservation District
- Resilient Nacogdoches
- State representatives' office
- Local business owners

Direct project participants can participate in WPP development in the following ways:

- Provide guidance on potential sources of bacteria and estimated pollutant loads.
- Guide identification of measures that could be implemented to address bacteria.
- Organize future meetings and discussion.
- Set goals and objectives.
- Identify level of implementation that is reasonable.
- Identify outreach and education that is needed.
- Foster implementation of the plan.

Five stakeholder meetings were held between August 2021 and August 2022, with an average attendance of 20 individuals. The stakeholder group represented at the first La Nana Bayou WPP planning meeting agreed to an informal stakeholder group structure where the full group met to work through the WPP rather than dividing based on interests, unless needed. This fluid stakeholder structure allowed the group to have additional meetings to discuss specific portions of the WPP. Decisions about what was or was not included in the WPP were determined by consensus. If consensus could not be reached, a simple majority vote by those present at the meeting determined the outcome.

Education and Outreach

Throughout the process of developing a WPP, stakeholders chose to participate in relevant education programs that helped inform them on activities and practices that are typically included in WPPs. Education is an integral part of the success of the development and the implementation of WPPs, and three programs were planned for the La Nana Bayou partnership:

1. August 23, 2022: Rainwater Simulator Demonstration and Stormwater Best Management Practices (BMPs). This program used a tabletop rainwater simulator to show the importance of maintaining healthy landscapes and pastures to prevent erosion from stormwater runoff.
2. September 7, 2022: Texas Watershed Stewards. This program educates participants on water quality, water laws and policies, agricultural and urban BMPs, basic hydrology, and general watershed management.
3. April 4, 2023: Lone Star Healthy Streams (LSHS). The objective of LSHS is the education of Texas farmers, ranchers, and landowners about proper grazing, feral hog management, and riparian area protection to reduce the levels of bacterial contamination in streams and rivers.

Taking Action

Part of the successful development and implementation of any plan — whether watershed-based or otherwise — is incorporating a systematic, iterative approach through adaptive management. The goals of the La Nana Bayou WPP can be reached by learning from favorable and unfavorable outcomes, adjusting inputs, and exploring alternative solutions based on information gathered throughout its implementation. Typically, WPPs are developed based on management measures and goals over a ten-year period; however, adaptive management allows for adjustments to be made as warranted based on feedback, needs, and new knowledge.

Chapter 2
Watershed Characterization

La Nana Bayou bridge crossing at Martinsville St. Photo by Emily Monroe, TWRI.

Watershed Description

La Nana Bayou is a 32-mile freshwater stream that extends from the confluence of the Angelina River south of the City of Nacogdoches in Nacogdoches County to the upstream perennial portion of the stream north of Nacogdoches at its confluence with Banita Creek (Figure 1). La Nana Bayou consists of a single segment, 0611B. Routine water quality monitoring began in 1996 and led to the inclusion of La Nana Bayou in the *2000 Texas Water Quality Inventory and 303(d)* List as being impaired for bacteria and not meeting its primary contact recreation standard. The segment also has concerns for elevated nitrate nitrogen and total phosphorous in its downstream reach.

TCEQ divided La Nana Bayou into three assessment units (AUs; 0611B_01, 0611B_02, 0611B_03) that TCEQ uses to incrementally evaluate water quality in the stream. Quarterly monitoring through the Clean Rivers Program (CRP) for field and conventional parameters, flow, and *Escherichia coli (E. coli)* at one monitoring station in each AU is performed by ANRA. This monitoring approach provides good spatial representation of data throughout La Nana Bayou; however, the quarterly monitoring regime limits understanding of temporal variability in flow and pollutant loading.

Physical Characteristics

Land Use and Land Cover

The La Nana Bayou watershed covers approximately 53,269 acres of deep East Texas that is a mixture of rural and urban land uses (Figure 2). According to the 2019 National Land Cover Database (NLCD), the dominant land covers in the watershed are forests, which cover almost 37%, and pastures, which cover slightly more than 28% of the watershed. Developed areas make up approximately 25%, with the City of Nacogdoches predominantly covering the middle portion of the watershed. Other land covers in decreasing order of land cover size include wetlands, open water, and barren land.

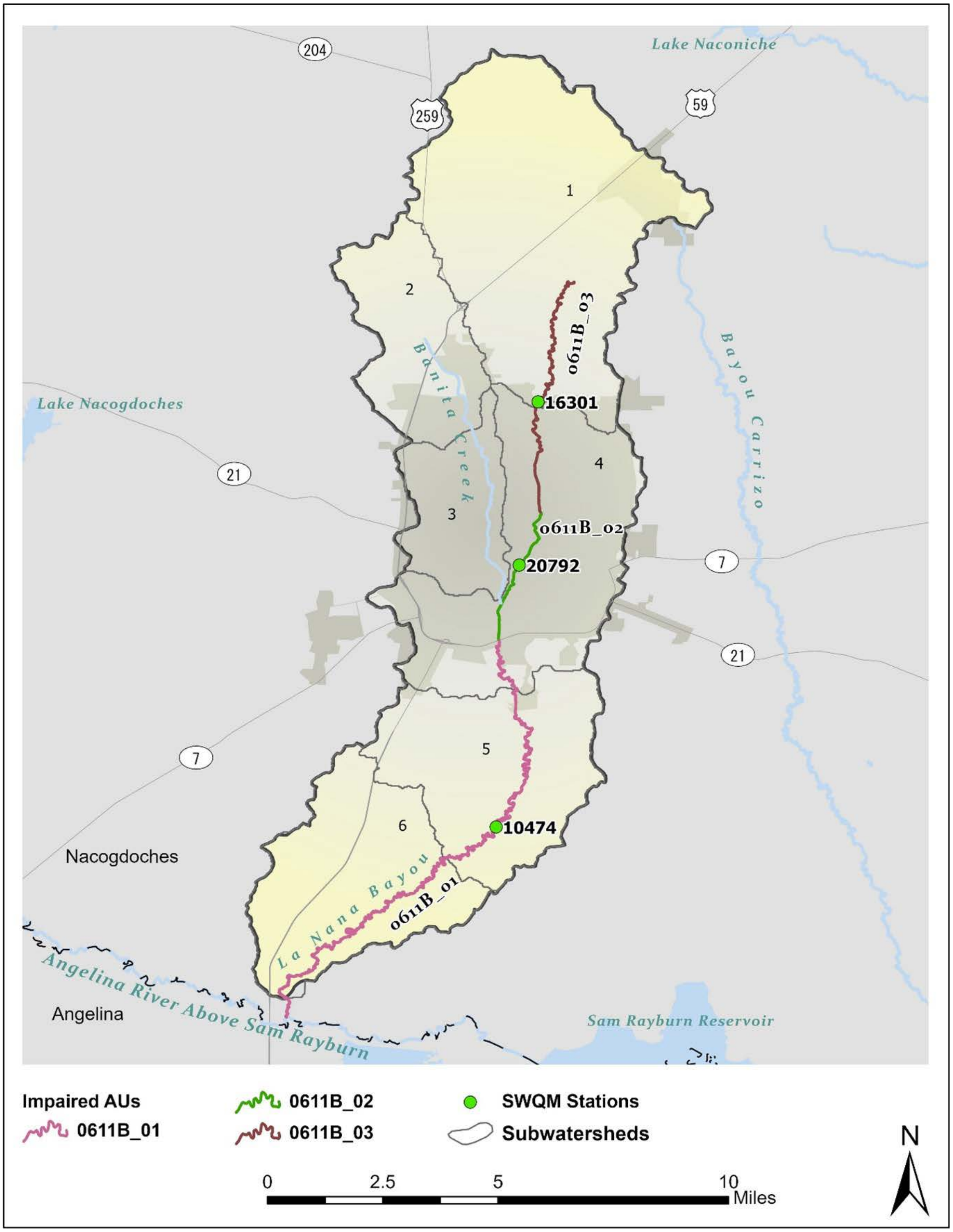


Figure 1. La Nana Bayou watershed boundaries, assessment units, and labeled subwatersheds.

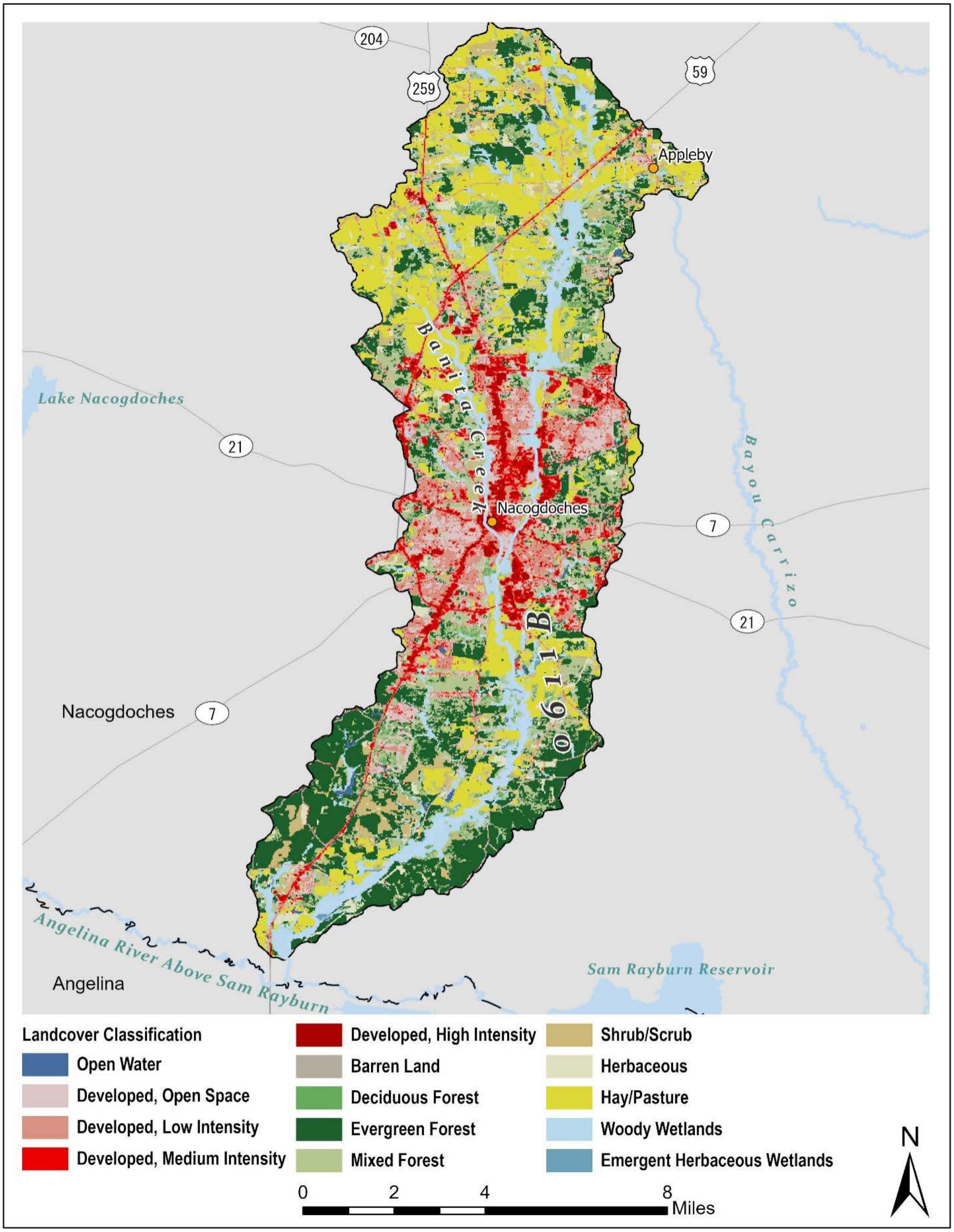


Figure 2. La Nana Bayou watershed land cover and land use.

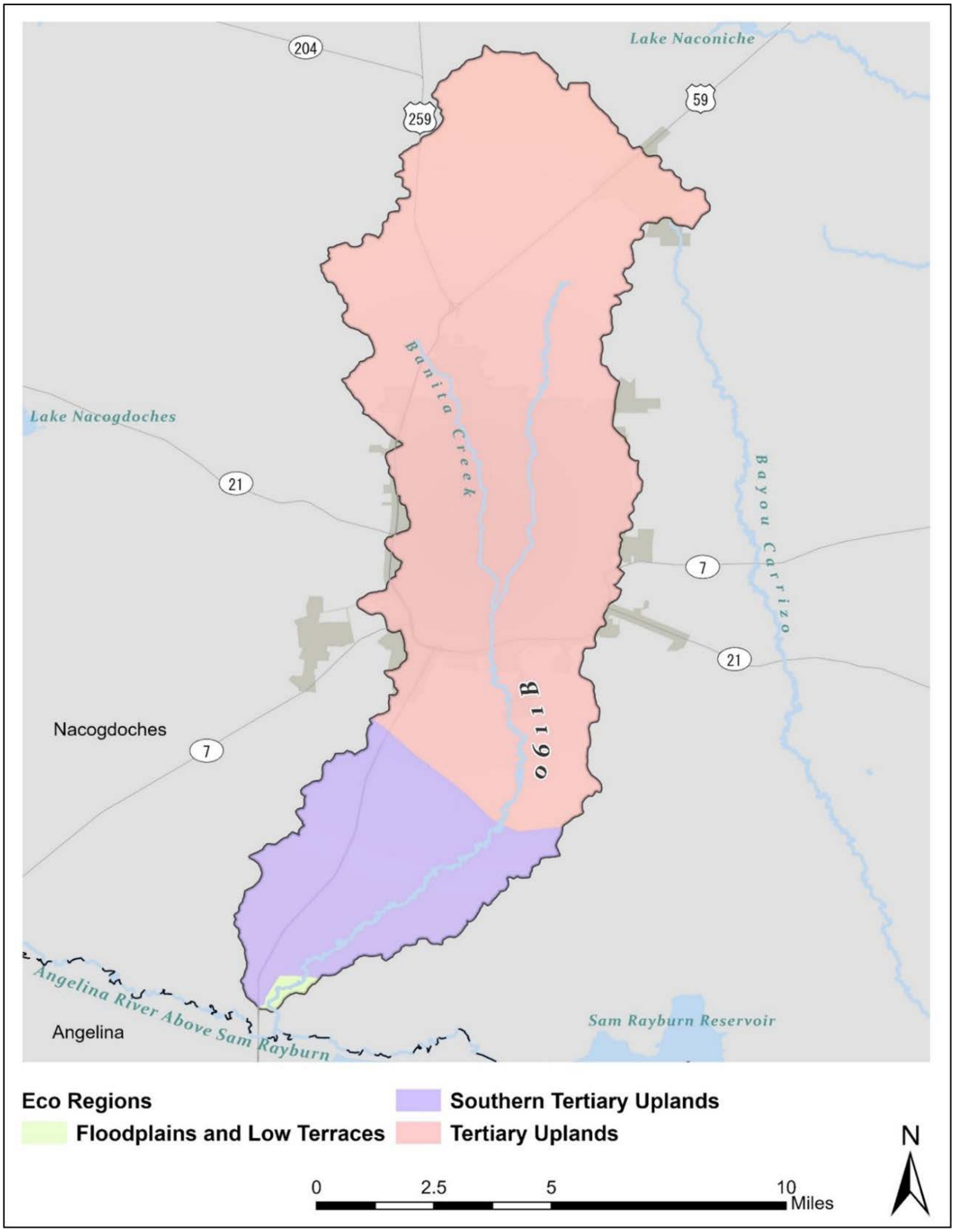


Figure 3. La Nana Bayou watershed Level IV ecoregions.

Table 1. Hydrologic soil groups, acres of coverage in La Nana Bayou watershed, and descriptions.

Hydrologic Soil Group	Acres	Description
Null	713	Not rated (not surveyed or water body)
A	6,544	Soils that have a high infiltration rate (low runoff potential) when thoroughly wet. These soils consist mainly of deep, well drained to excessively drained sands or gravelly sands and have a high rate of water transmission.
A/D	212	See below*
B	16,162	Soils that have a moderate infiltration rate when thoroughly wet. These consist mainly of soils having moderately deep or deep, moderately well drained or well drained soils with moderately fine texture to moderately coarse texture and have a moderate rate of water transmission.
B/D	320	See below*
C	24,698	Soils that have a slow infiltration rate when thoroughly wet. These consist mainly of soils having a layer that impedes the downward movement of water, or soils of moderately fine texture or fine texture and have a slow rate of wa-ter trans-mission.
C/D	1,873	See below*
D	2,747	Soils that have a very slow infiltration rate (high runoff potential) when thoroughly wet. They consist mainly of clays with a high shrink-swell potential, soils with a high water table, soils with a clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

*Certain wet soils are placed in Group D based solely on the presence of the water table within 24 inches of the surface, even though saturated hydraulic conductivity may be favorable for water transmission. If these soils can be adequately drained, they are assigned to dual hydrologic soil groups (A/D, B/D, and C/D) based on saturated hydraulic conductivity and water table depth when drained. The first letter applies to the drained condition and the second to the undrained condition. For purposes of hydrologic soil group, adequately drained means that seasonal high water tables are at least 24 inches below the surface in a soil where it would be higher in a natural state (USDA NRCS, 2018a).

Ecoregions

Ecoregions are land areas with ecosystems that contain similar quality and quantity of natural resources (Griffith et al. 2007). There are four separate delineated levels of ecoregions; with Level I being the most unrefined classification and Level IV being the most refined. The La Nana Bayou watershed area is within the Level III Ecoregion 35, known as the South Central Plains (Figure 3), and its location within Ecoregion 35 is subdivided into three Level IV Ecoregions 35a, 35b, and 35e, known as the Tertiary Uplands, the Floodplains and Low Terraces, and the Southern Tertiary Uplands, respectively. The landscape of Ecoregions 35a and 35e is mainly underlain by well-draining soils, sand, silt, and gravel. The main land cover is pine-hardwood deciduous forests, with scattered areas of pastures. A small southern portion of the watershed reaches into Ecoregion 35b, a flatter region prone to flooding, with poorly draining soils, and oak, maple, and pine forests.

Soils

The United States Department of Agriculture – Natural Resources Conservation Service (NRCS) provides information about soils collected by the National Cooperative Soil Survey, which are available through the Web Soil Survey (Soil Survey Staff 2022). This database describes soil components and properties and provides a hydrologic rating that groups soils by similar runoff properties. These ratings are useful for considering the potential for runoff from properties under consistent rainfall and cover conditions. Most soils in the watershed are classified as "Type B" and "Type C" soils (Table 1, Figure 4). "Type C" soils, which are indicative of slow infiltration and high runoff potential when wet, are the majority of soil types in the northern area of the watershed. "Type B" soils, which are indicative of moderate infiltration and moderate runoff potential when wet, are the majority of soil types in the central and southern areas of the watershed.

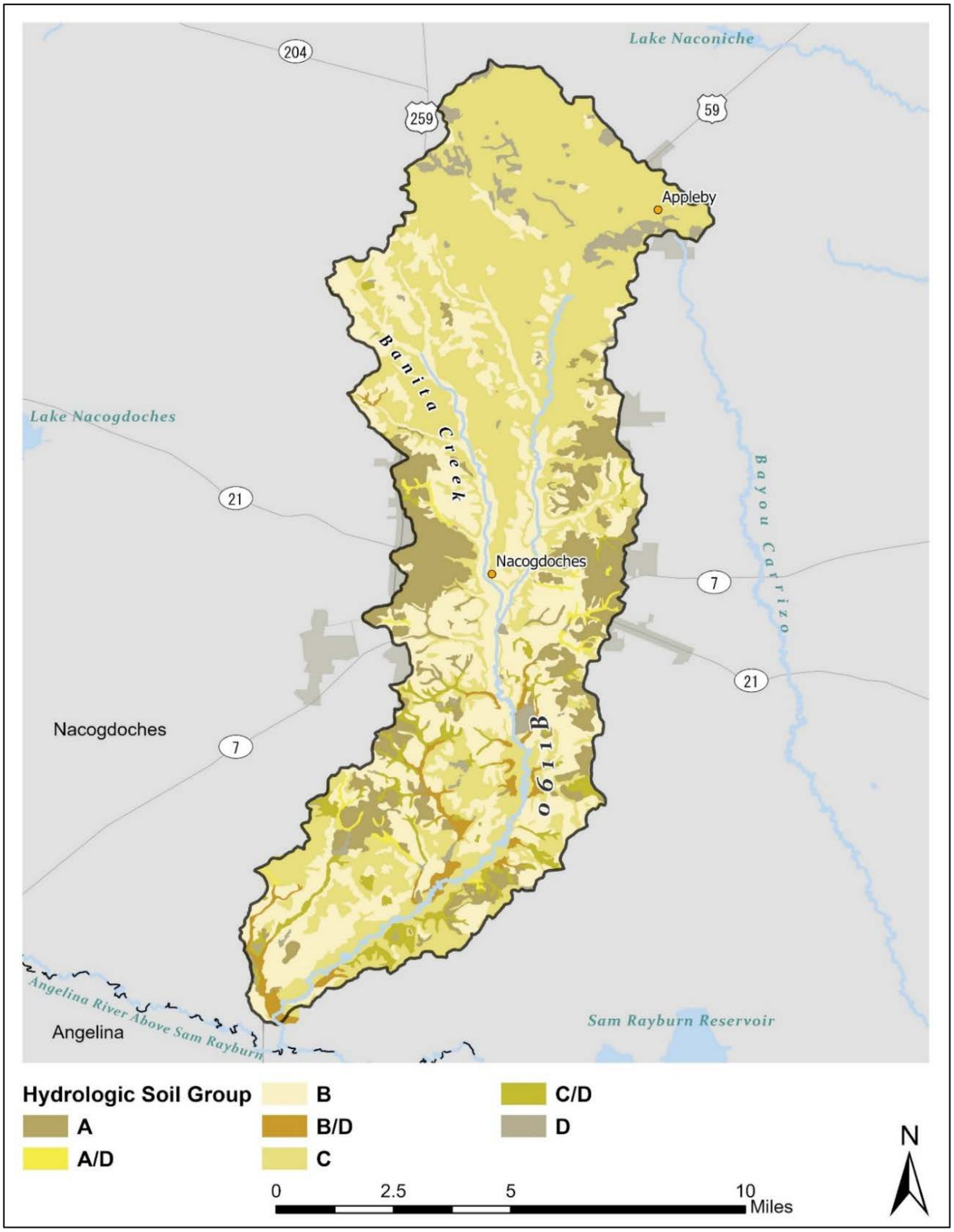


Figure 4. La Nana Bayou watershed hydrologic soil group classifications.

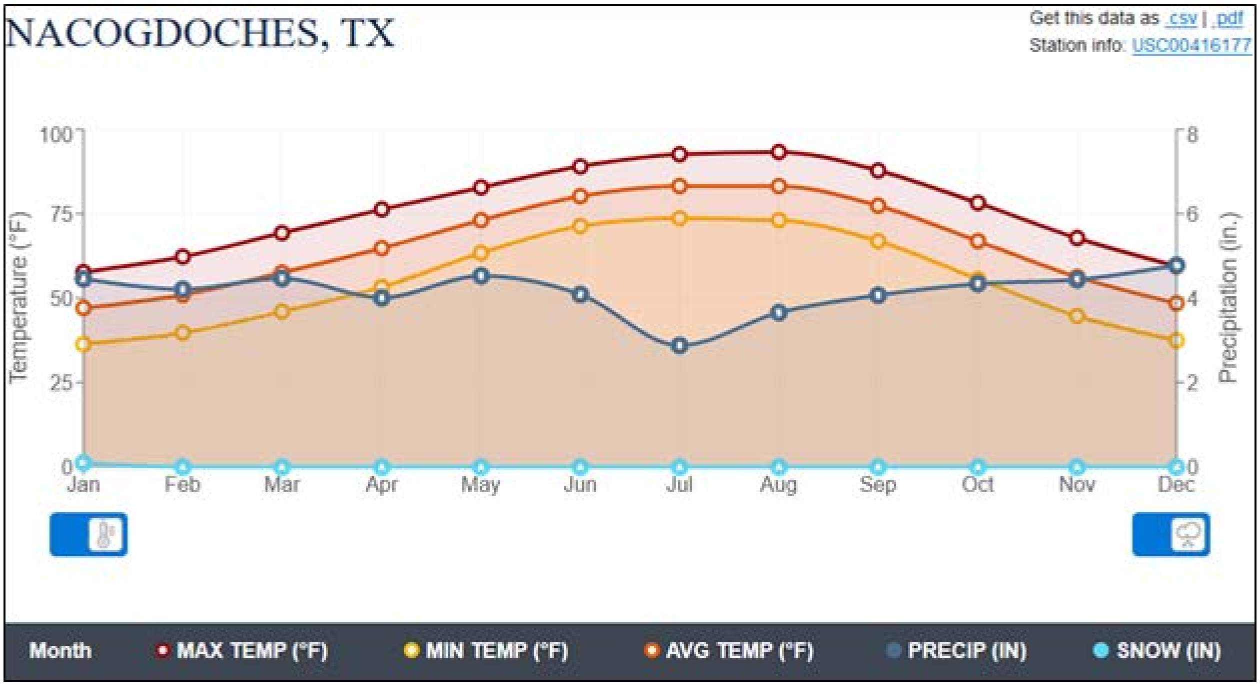


Figure 5. Nacogdoches, Texas, typical climate from 1991-2020.

Climate

The La Nana Bayou watershed is in the subtropical humid climate region (Larkin and Bomar 1983), which is characterized as a modified marine climate, including warm summers with occasional invasion of drier, cooler continental airflow offsetting the prevailing flow of tropical maritime air from the Gulf of Mexico. Average temperature generally peaks in August (93.3°F) and average low temperature generally occurs in January (36.4°F; Figure 5; National Oceanic and Atmospheric Administration 2021). Precipitation data from the Nacogdoches, Texas, weather station indicate that the watershed's mean annual rainfall from 1991–2020 was 49.94 inches. December is noted as the wettest month (4.78 inches), while July is typically the driest month (2.88 inches). Average annual precipitation values across the study area indicate that average annual rainfall ranges from 50 to 51 inches per year across the watershed (PRISM Climate Group 2012; Figure 6).

Topography

Watershed hydrology has many key components, including soil properties and topography. Slope and elevation determine the direction of water flow, while elevation and soil properties affect the quantity and speed with which water infiltrates into, flows over, or moves through the soil into a water body. Development and other activities may be limited by soil properties in certain areas. The elevation across the watershed ranges from a maximum of approximately 614 feet above mean sea level in the northwestern portion of the watershed to a minimum of about 175 feet above mean sea level where La Nana Bayou flows into the Angelina River (Figure 7).

Population

According to 2010 Census data, the population of La Nana Bayou watershed was estimated to be 36,710. The highest population densities and the bulk of population in the watershed are in the Nacogdoches city limits (Figure 8). The communities of Appleby and Redfield also have a higher concentration of homes and people compared to much of the watershed. Small clusters of homes exist throughout the watershed and normally occur along main roadways including highways 59 and 259, Farm-to-Market roads, and some county roads. Within Nacogdoches County, the average number of persons per household between 2015 and 2019 was estimated at 2.62 (U.S. Census Bureau 2021). Population in Nacogdoches County is expected to increase greatly over the next 50 years, with a 65% increase projected in the 2021 Regional Water Plan (Texas Water Development Board 2021).

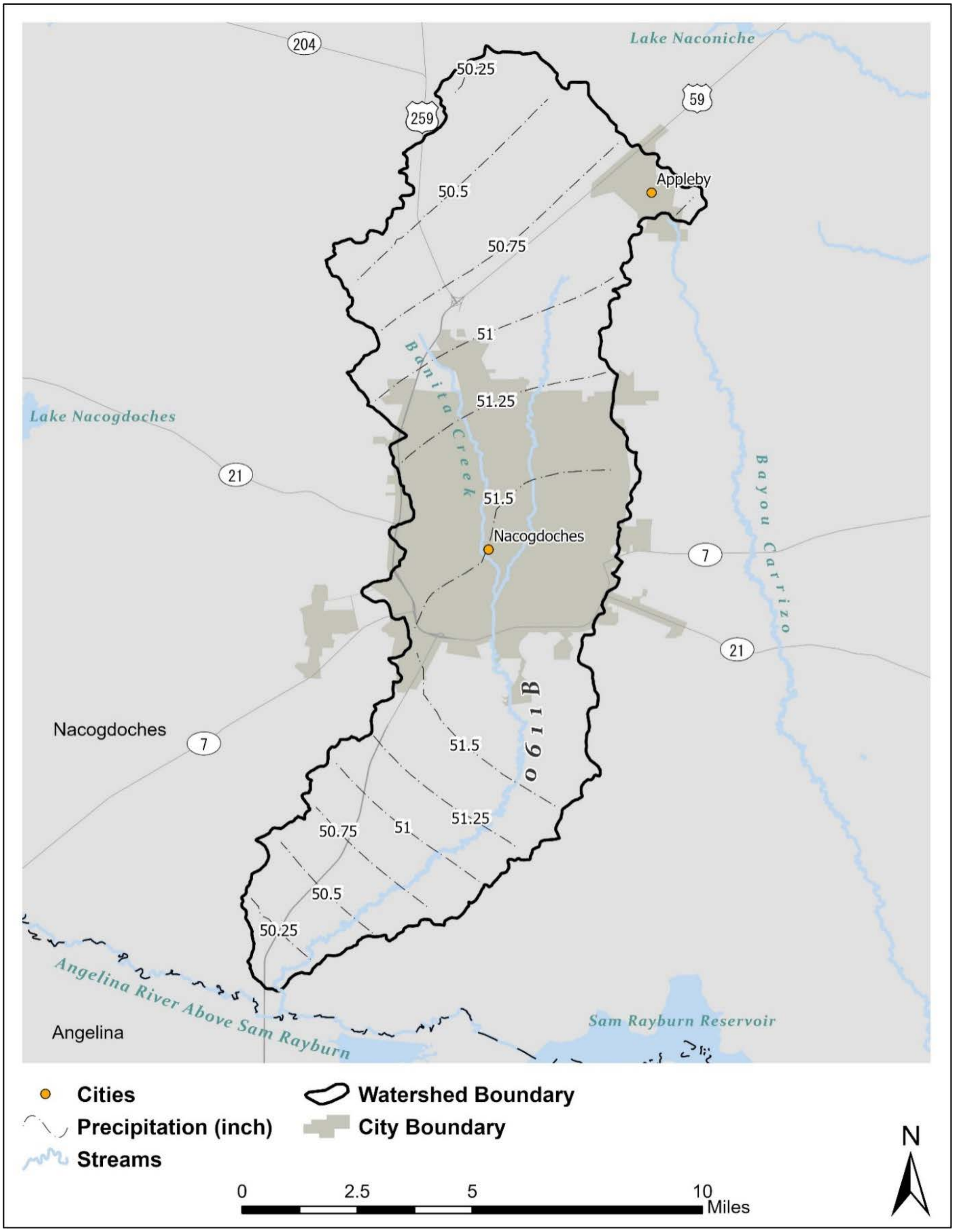


Figure 6. Normal average annual precipitation totals across the La Nana Bayou watershed.

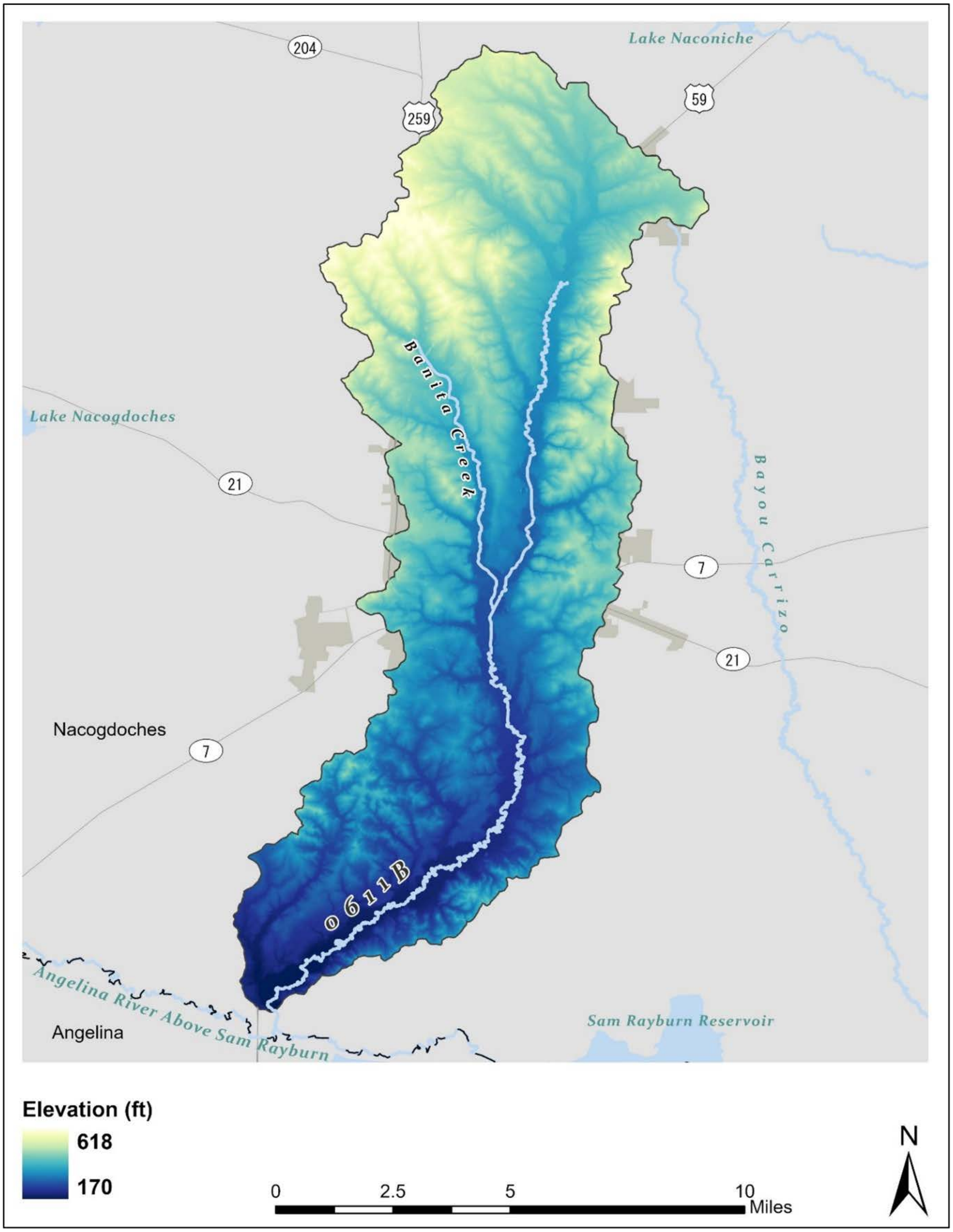


Figure 7. Topographical elevation of the La Nana Bayou watershed.

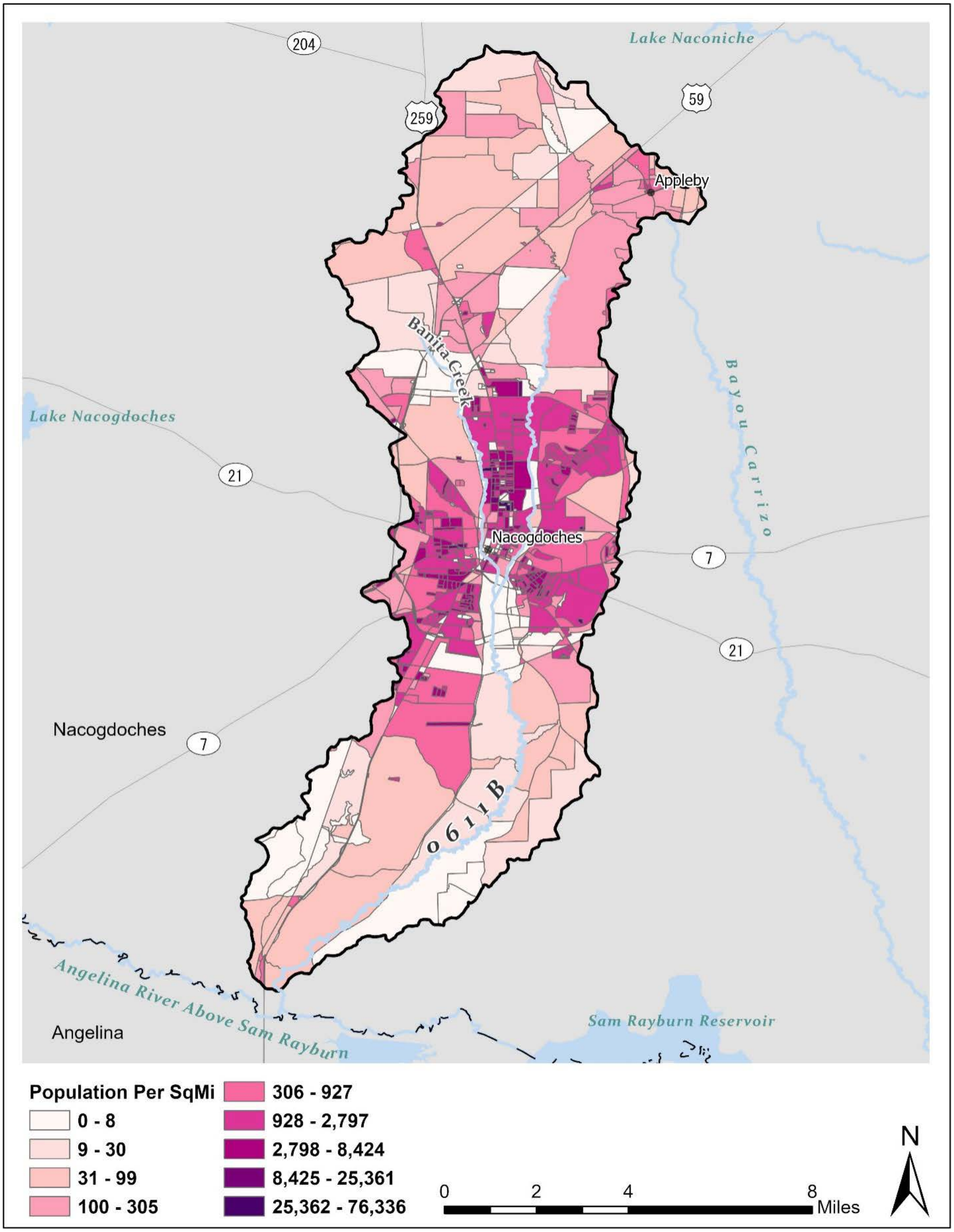


Figure 8. La Nana Bayou watershed population density by 2010 U.S. Census Blocks.

Chapter 3
Water Quality

La Nana Bayou during a flash flood event along La Nana Creek Trail. Photo by Emily Monroe, TWRI.

Surface water quality throughout the state is monitored to ensure that the water body meets the criteria for its specific designated use as defined in the Texas Surface Water Quality Standards (TSWQS). These uses and their associated standards are implemented by TCEQ to ensure the state complies with requirements established under the federal Clean Water Act (CWA). Under the CWA (33 United States Code §1251.303), administered by EPA (40 Code of Federal Regulations §130.7), Texas is required 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.

Water Body Assessments

To satisfy commitments to the CWA, TCEQ conducts biennial water body assessments and publishes the Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d) (TCEQ 2020a), which describes all impaired water bodies not meeting their respective use standards. The most recent assessment, the *2020 Texas Integrated Report,* includes water quality assessment data collected from December 1, 2011 – November 30, 2018.

Water bodies are evaluated at the AU level, which is a subarea of a stream segment, defined as the smallest geographic area of use support reported in the assessment (TCEQ 2020a). Streams are divided into sections that share relatively homogeneous hydrological and chemical characteristics, allowing each AU to be monitored for any site-specific standards. Assessment Units are listed after the stream segment identification number to show which sub-area each represents. La Nana Bayou is stream segment 0611B, and its AUs are 0611B_01, 0611B_02, and 0611B_03 (Figure 9).

For AUs to be included in the Texas Integrated Report (and considered for WPP development), each corresponding station is required to have a minimum of 20 bacteria samples taken within seven years (TCEQ 2020b). In La Nana Bayou watershed, routine water quality data monitoring is performed by ANRA at three currently active stations, where they collect conventional, field, and bacteria parameters and flow measurements on a quarterly basis. La Nana Bayou is

Table 2. Watershed impairments listed in the *2020 Texas Integrated Report of Surface Water Quality*.

Parameter	Category	AU ID	Criteria
Bacteria	5b*	0611B_01	126 cfu/100 mL
		0611B_02	
		0611B_03	
Nitrate Nitrogen	CS	0611B_01	>20% exceedance (1.95 mg/L Screening Level)
Total Phosphorus	CS	0611B_01	>20% exceedance (0.69 mg/L Screening Level)

Colony forming units, cfu; concern for water quality based on screening levels, CS; liter, L; milliliter, mL; milligram, mg;
* Category 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 TSWQS.

Table 3. Water quality monitoring station summary from December 2011 – November 2018.

AU Description	AU ID	Station ID	# of samples	7-year *E. coli* geomean (cfu/100 mL)
From confluence of Angelina River, upstream to Loop 224	0611B_01	10474	26	279.46
Upstream from Loop 224 to FM 1878 in Nacogdoches	0611B_02	20792	35	576.58
Upstream side of FM 1878 to confluence with Banita Creek	0611B_03	16301	20	443.93

Colony forming units, cfu; *Escherichia coli, E. coli;*

listed in Category 5b of the *2020 Texas Integrated Report* for impairment due to excessive bacteria (TCEQ 2020s; Table 2). Concerns for elevated nitrate nitrogen and total phosphorus concentrations are also noted.

Texas Surface Water Quality Standards

Surface water quality standards in Texas are set to achieve specific goals for the state's many streams, rivers, lakes, and bays. These standards are set by TCEQ under the authority of the CWA (33 United States Code § 1251), are approved by EPA, and are implemented by TCEQ. These standards ensure surface water resources remain of high quality, are consistent with public health and enjoyment, propagation and protection of terrestrial and aquatic life, and continue to provide for the sustainable economic development of Texas. Designated uses for the state's surface water include supporting aquatic life, recreation, and public water supply sources. Water quality indicators for these uses include dissolved oxygen (DO; aquatic life use), *E. coli* (contact recreation), pH, temperature, total dissolved solids, sulfate, chloride (general uses), and a variety of toxins (aquatic life use, fish consumption and public water supply) (TCEQ, 2020b). La Nana Bayou is designated as a primary contact recreation use 1 water body and must support intermediate aquatic life use in AU_01 and 02, and a presumed high aquatic life use in AU_03.

Bacteria

To assess the potential risk of illness from contact recreation, concentrations of fecal indicator bacteria such as *E. coli* in water bodies are measured. The presence of these bacteria can indicate increased potential for related pathogens present in the intestinal tract of warm-blooded animals to also be in surface waters. Common sources of *E. coli* include wildlife, livestock, pets, failing on-site sewage facilities (OSSFs), urban/agricultural runoff, sewage overflow, and WWTPs. Currently TCEQ sets the water quality standard for primary contact recreation as a geometric mean of 126 cfu/100 mL of *E. coli* from at least 20 water samples collected within a seven-year period. All three La Nana Bayou AUs have *E. coli* concentrations above the acceptable primary contact recreation use 1 water quality standard (Table 3, Figure 10).

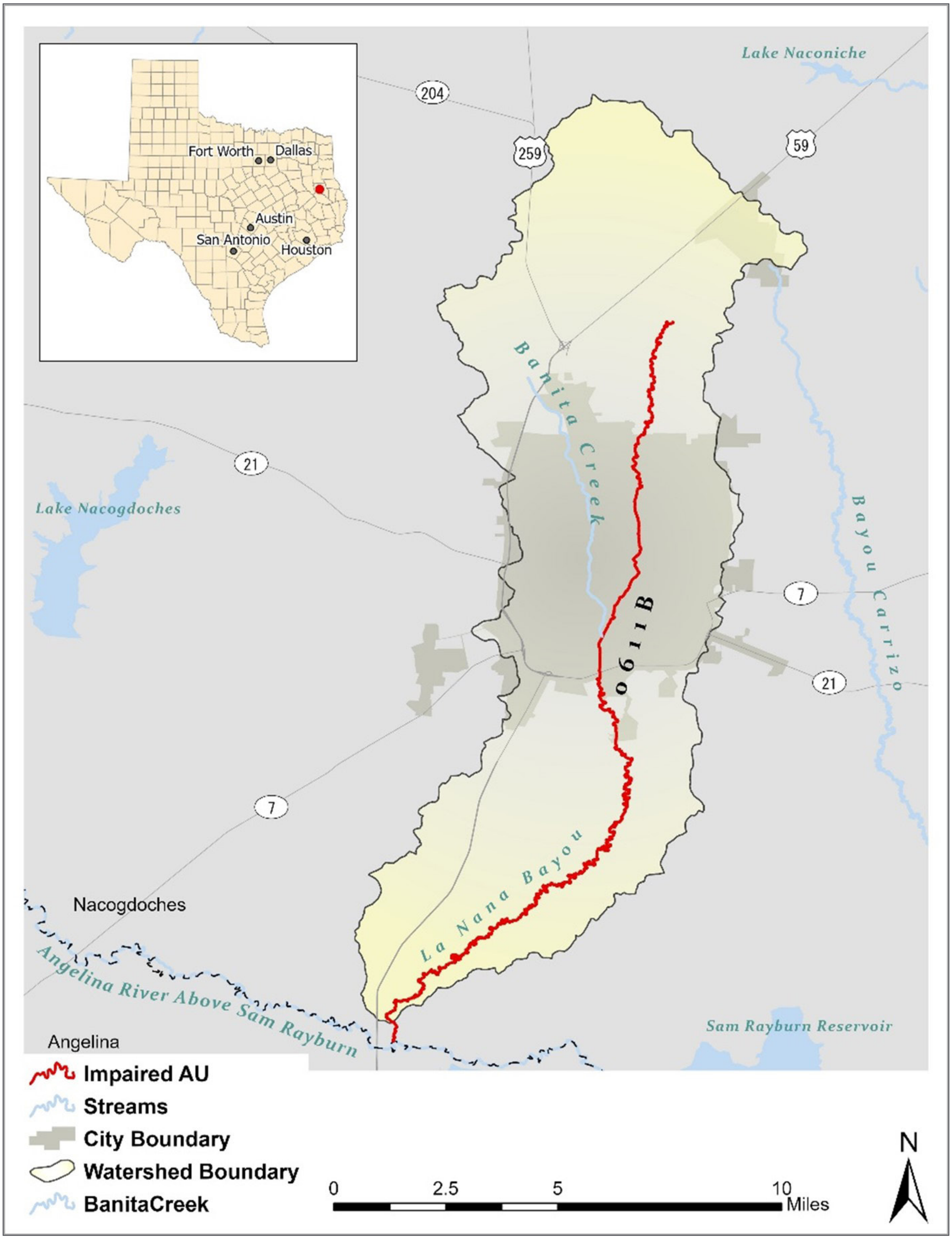


Figure 9. Boundaries of La Nana Bayou watershed.

Figure 10. Individual *E. coli* measurements and the seven-year rolling geometric mean since 2000..

Nutrients

Elevated nutrient concentrations, specifically nitrate nitrogen and total phosphorus, were found in AU 0611B_01 (Figure 11 and Figure 12). Both nitrogen and total phosphorus are used by aquatic plants and algae to grow, and excessive concentrations can lead to algae blooms which will reduce DO instream and can affect fish respiration. The main nutrient sources in watersheds are typically WWTP effluent and fertilizer application in urban yards or agricultural fields that are then introduced into the surface water as runoff. Runoff can also carry newly eroded sediment particles that have nutrients bound to them, further increasing the nutrient concentrations in streams.

Although Texas does not currently have numeric nutrient criteria set for surface water, screening concentrations have been developed to evaluate nutrient loading. Screening concentrations for nutrient parameters are based on the 85th percentile values of a similar water body type. A concern for water quality is identified if the screening level is exceeded more than 20% of the time. The screening concentration for nitrate nitrogen is 1.95 mg/L and total phosphorus is 0.69 mg/L. Only the downstream station, 10474, consistently exceeded the TCEQ screening level for nitrate nitrogen and total phosphorus (Table 4).

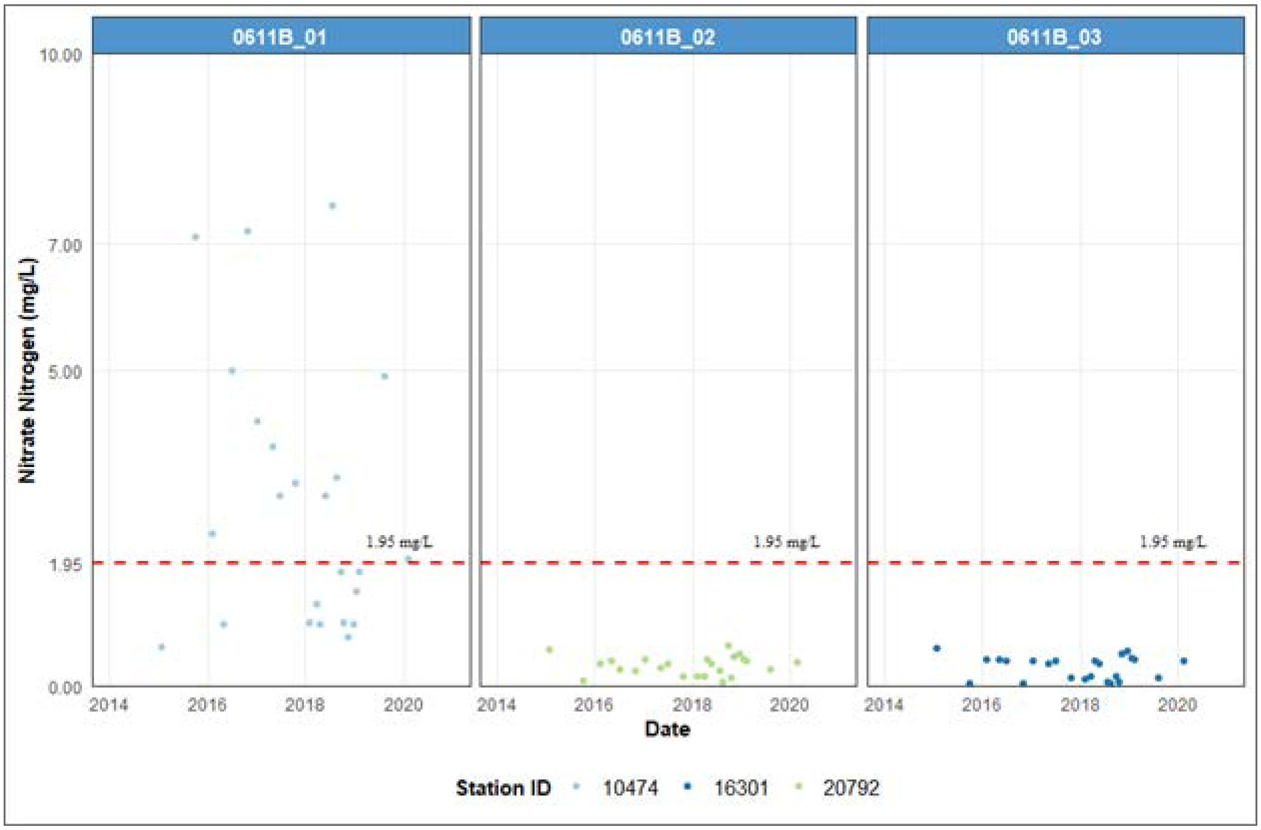


Figure 11. Nitrate Nitrogen measurements since 2014.

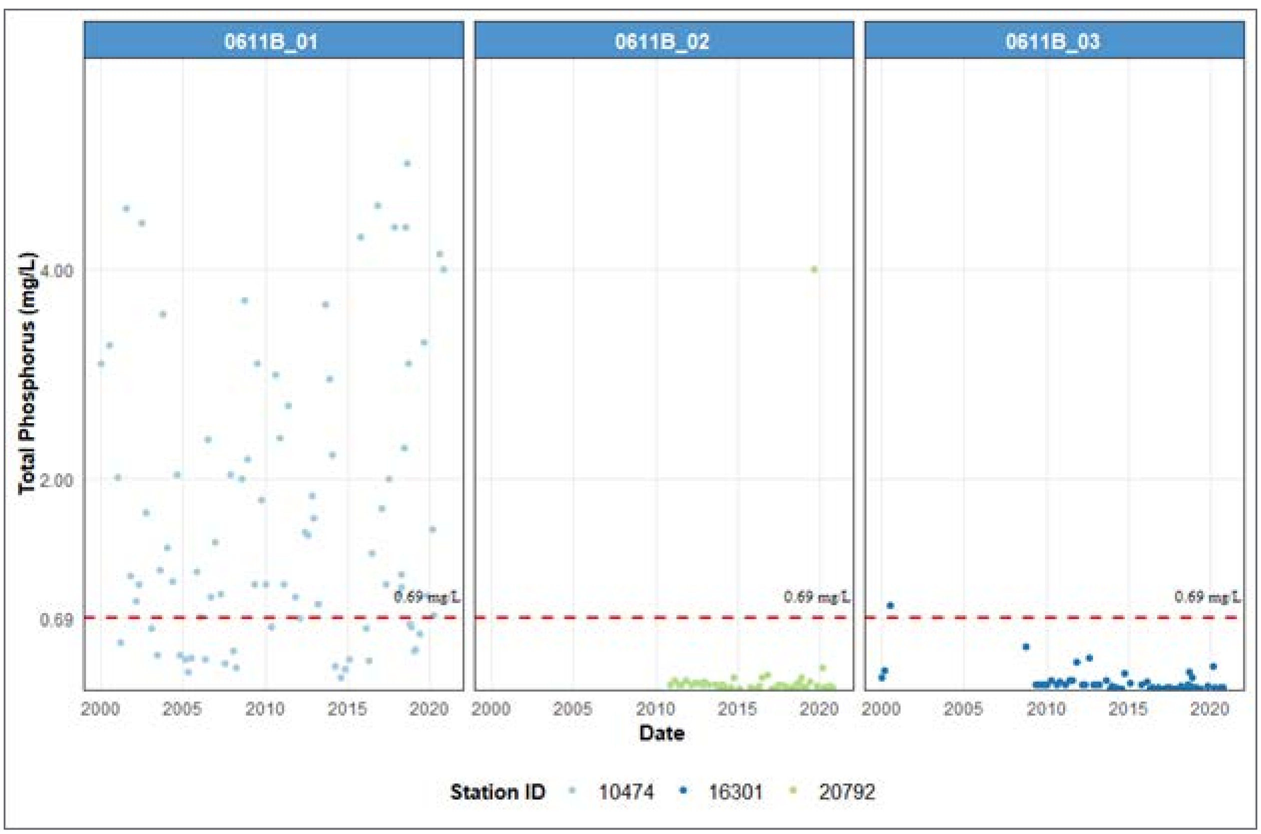


Figure 12. Total Phosphorus measurements since 2000.

Table 4. TCEQ screening levels for Nitrate Nitrogen and Total Phosphorus in a freshwater stream.

Parameter	Screening Level	Threshold	Assessment Results from the 2020 TIR
Nitrate Nitrogen	1.95 mg/L	> 20% exceedance	4.71 mg/L
Total Phosphorus	0.69 mg/L		2.36 mg/L

milligram, mg; liter, L; 2020 *Texas Integrated Report, 2020 TIR;*

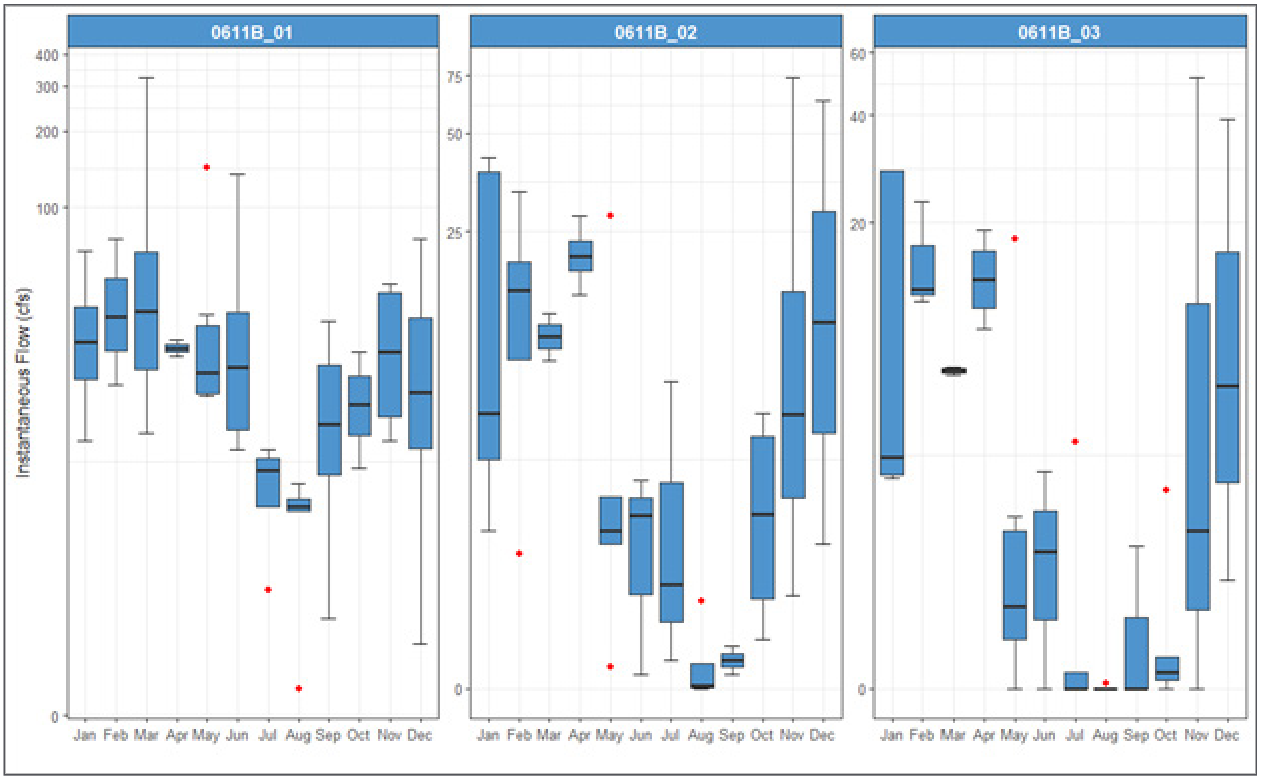


Figure 13. Monthly average instantaneous flow measurements (cfs) by station.

Flow

Streamflow is the main driver behind assimilating and diluting pollutants and is critical to the health of the stream as streamflow fluxes in response to precipitation and anthropogenic changes. Streamflow in La Nana Bayou is consistent as the region experiences above average precipitation for Texas, except for the upstream AU, 0611B_03, which exhibits some intermittent flow patterns as measured at station 16301. Downstream at station 10474, the median value for low-flow periods was 9.3 cubic feet per second (cfs), while the median high-flow value was 134 cfs (Figure 13).

Dissolved Oxygen

Dissolved oxygen is the primary measurement used to determine a water body's ability to support and maintain aquatic life and related activities. If DO levels in a water body drop too low (or are "depressed"), fish and other aquatic species will not survive due to low oxygen availability. None of the AUs in La Nana Bayou were listed as impaired for depressed DO in the *2020 Texas Integrated Report,* though levels continue to be monitored. The grab sample DO concentrations are typically above the screening levels in all three AUs (Figure 14).

Dissolved oxygen concentrations fluctuate throughout the day depending on environmental factors. The lowest levels of DO occur just before dawn as both plants and animals in the water consume oxygen through respiration, while the highest levels of DO occur in mid to late afternoon, due to increased photosynthesis. Seasonal fluctuations in DO are common due to decreased oxygen solubility in water as temperature increases and it is common to see lower DO levels during the summer.

While DO does fluctuate naturally, human activities can impact levels as well. Excess fertilizers and manure in the water can lower DO as aquatic plants and algae grow in response to the increased nutrient levels, which increases respiration and consumption of DO. In addition, decaying organic matter from plant die-off can also reduce DO concentrations as bacteria break down the materials and subsequently consume oxygen.

Figure 14. Dissolved oxygen concentrations for La Nana Bayou since 2000.

Chapter 4
Potential Pollution Sources

La Nana Bayou near Main St. with high water level during a flash flood event. Photo by Emily Monroe, TWRI.

The previous chapter discussed what impairments and concerns exist within La Nana Bayou: excessive bacteria *(E. coli)* and elevated nutrient concentrations (nitrogen and total phosphorus). The sources of these pollutants are categorized as either a "point source" or "nonpoint source." Point sources enter receiving waters at identifiable locations, while nonpoint sources typically enter the water body via runoff. Potential pollution sources in the watershed were identified through stakeholder input, project partners, and watershed monitoring (Table 5).

Point Source Pollution

Point sources of pollution are discernible outlets such as pipes, ditches, containers, or other vessel discharging pollutants (CWA §502) and they are regulated by the National Pollutant Discharge Elimination System and the Texas Pollutant Discharge Elimination System (TPDES). These can include municipal and industrial WWTP permits, general wastewater permits, and general stormwater permits. Other examples of point source pollution include confined animal feeding operations, concrete production, wastewater evaporation ponds, pesticide general permits, and Multi-Sector General Permits.

Wastewater Treatment Plants

In the La Nana Bayou watershed, only two WWTPs have TPDES discharge permits (Figure 15). The municipal WWTP (TPDES permit #WQ0010342004) is operated by the City of Nacogdoches and is permitted to discharge 12.88 million gallons per day (MGD) of treated effluent into La Nana Bayou with a maximum *E. coli* concentration of 126 cfu/100 mL (Table 6). The other facility permitted to discharge wastewater to La Nana Bayou is the Cal-Tex Lumber Company (TPDES permit #WQ0004198000). Their permit allows for the discharge of industrial cooling, storm, and wash water from their milling facility. No permit limits exist for flow rate or *E. coli* concentrations for Cal-Tex Lumber because it is not a municipal WWTP.

Table 5. Summary of pollutant impacts and causes by source.

Pollutant source	Pollutant impacts	Potential causes
Wastewater Treatment Plants and Sanitary Sewer Overflows	Bacteria and nutrients from un-treated wastewater may enter water bodies	• Overflow during large storm events • Systemic failures due to age, lack of routine maintenance, etc.
Wildlife and Livestock	Direct and indirect transfer of bacteria from waste; erosion of soil from riparian degradation	• Animals directly depositing feces into water body or in riparian area • Wallowing and rooting in riparian areas cause erosion and soil issues
Pets	Direct and indirect transfer of bacteria from waste	• Pet owners not properly disposing of waste in public areas and at home • Lack of education regarding impacts from improper pet waste management
Urban Stormwater Runoff	Water may quickly enter water body and carry bacteria, litter, oils, and nutrients with it, especially during flood conditions	• Impervious surfaces (e.g., parking lots, roadways) • Dumping chemicals in storm drains • Excessive application of fertilizers and pesticides
Illegal Dumping	Direct and indirect contamination of water body from trash and decaying carcasses	• Litter and animal carcasses dumped near water bodies • Trashed areas tend to stay trashed
On-site Sewage Facilities (Septic Systems)	Improper treatment or disposal of waste may cause wastewater with harmful bacteria to surface and enter water bodies through runoff, especially from households close to rivers and creeks	• Poor functionality due to site design, age, lack of maintenance (e.g., routine pumping) • Incorrect treatment of waste (e.g., not chlorinating system properly, pouring household chemicals down drain)

Table 6. Reported data from the WWTP in La Nana Bayou (April 2017 – April 2022).

Facility Name (TPDES Permit No.)	Flow (MGD)		*E. coli* (cfu/100 mL)		Exceedance Violations
	Permitted	Average	Permitted	Average	
City of Nacogdoches (#WQ0010342004)	12.88	6.33	126	2	None

Colony forming units, cfu; milliliter, mL; *Escherichia coli, E. coli;*

Table 7. SSO events in Nacogdoches County between January 2016 and April 2021 (Stormwater permit violation information is provided by TCEQ regional offices upon request).

Facility	Date	Gallons	Cause
Pilgrim's Pride @ 928 Martin Luther King Jr. Blvd.	1/12/2016	6700	Pump failure causing overflow into parking lot
Pilgrim's Pride @ 2842 FM 1275	10/18/2017	200	Alarm and retaining curb failure caused discharge into drainage ditch

Sanitary Sewer Overflows

Sanitary sewers are systems that collect and transport wastewater to appropriate treatment facilities. The release of raw sewage from these lines, also known as a sanitary sewer overflow (SSO) event, happens when sewer lines fail due to age, lack of maintenance, or are overloaded during rain events. In Nacogdoches, two SSO events were reported between 2016 and mid-2021 (Table 7).

Nonpoint Source Pollution

Nonpoint source pollution occurs when rainfall causes runoff of pollutants into drainage ditches, lakes, rivers, or other water bodies (CWA §319(h)). Nonpoint source pollution can include bacteria from livestock or pet waste, wildlife waste, urban and agriculture runoff, failing OSSFs, and other sources.

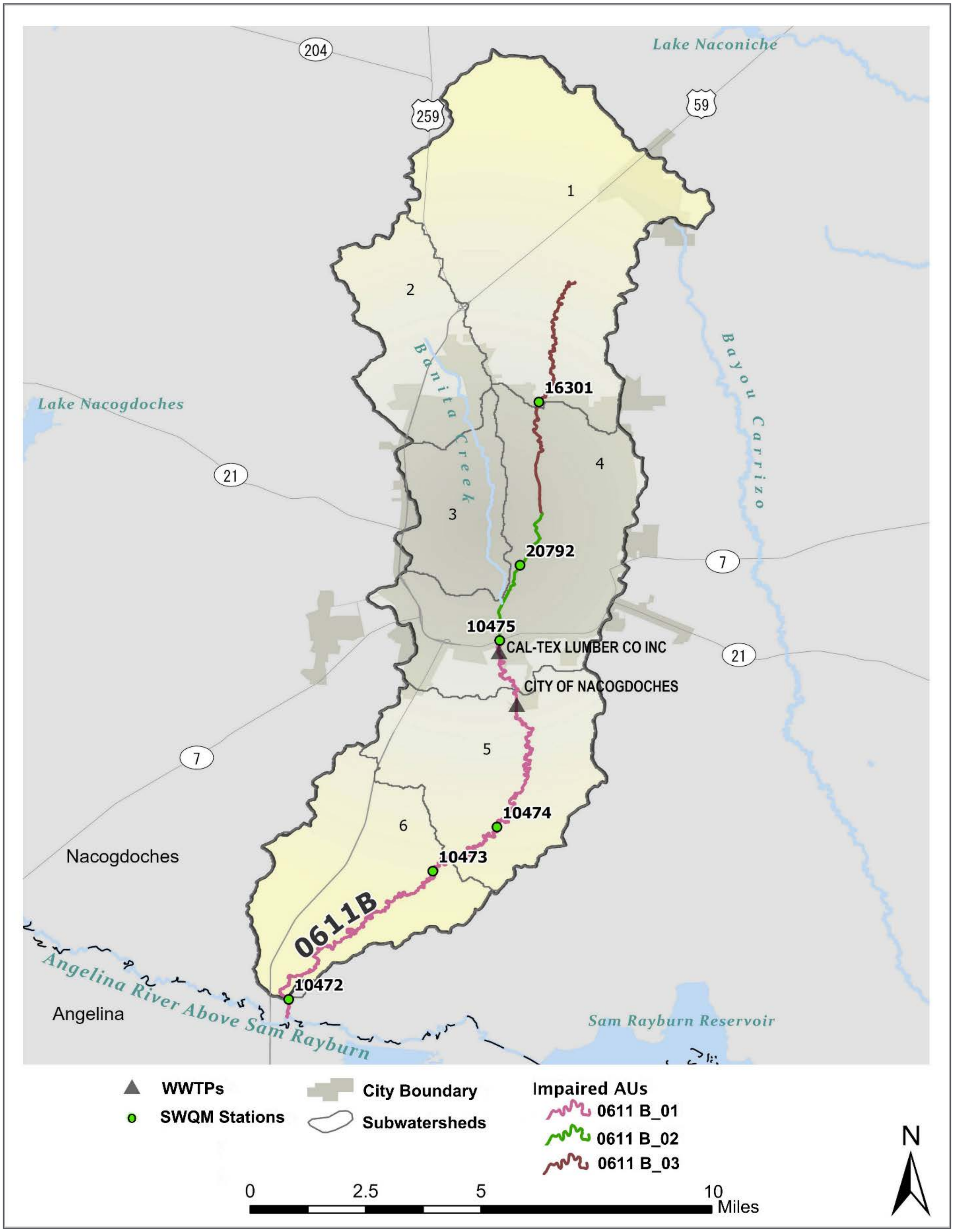


Figure 15. La Nana Bayou subwatersheds, water quality monitoring stations, and permitted wastewater outfalls.

Table 8. Deer and feral hog estimates for the La Nana Bayou watershed.

Animal	Applicable Land Use / Land Cover Classes	Acres in Watershed	Density (acre/ animal)	Estimated Population in Watershed
Feral Hog*	Forest, Pastures, Shrub/ Scrub, Wetlands	39,574	33.33	1,187
Deer†		39,574	56.49	700

* Feral hogs were estimated based upon a density of 33.3 acres per hog (Wagner and Moench 2009).
† Deer populations are estimated based upon Texas Parks and Wildlife Department (TPWD) estimates of 56.49 acres per deer (Alan Cain, personal communication, Jan 25, 2021).

Table 9. NASS survey livestock estimates for the La Nana Bayou watershed.

Nacogdoches County NASS Numbers Scaled to Watershed	Livestock				
	Cattle	Hog	Horse	Goat	Sheep
	2,900	4	98	40	17

Wildlife and Invasive Species

The difference in the designation between "wildlife" and "invasive species" is that wildlife is considered native to the US, like white-tailed deer, and invasive species are nonnative animals like wild pigs (also referred to as feral hogs). Non-domesticated animals tend to live within the same type of habitat or land use: riparian corridors that are not barren or developed. Bacteria from wild animals enters the water body through direct deposition when wading and through runoff during a storm event. Feral hogs tend to be particularly destructive to riparian vegetation which also reduces the riparian area's capacity to filter bacteria from other sources. Estimates of most wildlife including raccoons, opossums, and birds are difficult to ascertain; therefore, management measures commonly focus on two species with practical management options: white-tailed deer and feral hogs (Table 8).

Both species prefer similar land cover classes: forest, pasture, shrub, and wetlands. While they mostly travel through riparian corridors, they can also be found in the pastures, croplands, and rangelands, especially at night. Feral hogs are significant contributors of fecal bacteria to water bodies as they spend much of their time wallowing in and around the water. These non-native, invasive hogs also cause erosion and soil loss issues due to their rooting and wallowing habits.

Livestock

Domestic livestock and/or the use of their manure as fertilizer can introduce *E. coli* into water bodies. La Nana Bayou watershed livestock populations were estimated using the National Agricultural Statistics Service (NASS) survey data. Since NASS data are county-based, populations for cattle, horses, hogs, sheep, and goats were estimated based upon the percentage of rural area within the watershed (Table 9).

La Nana Bayou watershed contains five animal feeding operations (AFOs), which are required to obtain Water Quality Management Plans (WQMPs) from TSSWCB before operations can begin. These WQMPs are reviewed and agreed to by local soil and water conservation districts (SWCDs) and NRCS, and they do not allow discharge of animal waste. The AFOs in the watershed include poultry and dairy operations that are planned to house 709,100 broilers and 190 dairy cows, respectfully. WQMPs developed for these operations describe management practices required for each operation and include nutrient management, prescribed grazing, waste management, and watering facilities. Management varies by plan and is designed to fit the specific operation and property (TSSWCB 2017).

Pets

Cats and dogs can be a major contributor to *E. coli* in a watershed if pet waste is not properly discarded. Domestic pets are associated with human populations, thus most cats and dogs in the La Nana Bayou watershed are expected to be in and near the City of Nacogdoches. In rural areas, dogs tend to roam so proper waste disposal may not be practical. In urban areas, pet owners' behavior must be influenced through education and conveniently placed waste bins, especially since those areas are more densely populated.

Nationwide survey data from the American Veterinary Medical Association (AMVA) suggests that there are 0.457 cats and 0.614 dogs per household in the U.S. (AVMA, 2019), which equates to approximately 8,247 cats and 11,079 dogs in the La Nana Bayou watershed. Additionally, public survey research conducted in the Eastern U.S. indicates that waste from roughly 40% of dogs is not properly disposed of (Center for Watershed Protection 2021). Similarly, 30% of all cats are estimated to be outdoor cats whose waste is not properly discarded (American Pet Products Association 2014). While these numbers are not from the watershed, they provide some insight regarding potential pet waste influences on water quality and are assumed applicable for watershed pollutant loading assessments.

Stormwater Runoff

Rainfall generated stormwater is a vehicle for almost all pollutant types that impact surface water bodies. Debris, dissolved pollutants, fecal matter, nutrients (nitrogen, phosphorus, etc.), sediment, and more are transported overland and into water bodies when sufficient rainfall occurs to create runoff. This is a natural and important process, but excess quantities of any of these constituents can be detrimental to instream water quality. Runoff occurs from all land cover and soil types when rainfall rates exceed the soil's infiltration capacity. Impervious surfaces including buildings, parking lots, and roadways are common in developed land uses and all increase runoff generation to a volume above what would occur naturally. In developed areas, the timing when water arrives in the stream is also altered and generally leads to increased peak flows which lead to higher flooding potential. Combined, these factors can all have adverse effects on instream water quality.

Illegal Dumping

Improper waste disposal is an issue across the La Nana Bayou watershed and the surrounding area. Although most trash items dumped are not necessarily major sources of bacteria and nutrient pollution, areas that are littered tend to become dumping areas for others as well, which can cause blockages and flooding or more surface area for bacteria to grow on. Other commonly dumped items, like animal carcasses and household chemical containers, can contribute additional bacteria and nutrients to the watershed.

On-site Sewage Facilities

As much of the La Nana Bayou watershed is rural, most residents outside of Nacogdoches rely on OSSFs to treat domestic wastewater. OSSFs are an acceptable wastewater treatment alternative for households that are unable to connect to municipal sewer systems. If OSSFs are properly designed, installed, routinely inspected, and properly managed, they can provide an adequate level of waste treatment and disinfection. However, failing OSSFs can lead to nonpoint bacterial and nutrient contamination within a watershed.

Improper site design, age, and lack of maintenance like regular pumping and proper chlorination can cause OSSFs to fail to treat waste before it enters the environment. The ability of the soil to absorb wastewater affects the ability of a conventional OSSF to function as well. Soil suitability rankings for OSSF design were developed by NRCS based on topography, saturated hydraulic conductivity, depth to the water table, ponding, flooding, etc. (NRCS, 2020), and soils were divided into three categories: not limited, somewhat limited, and limited. If an OSSF is not properly designed, systems in a somewhat limited or very limited soil type have increased risk of failure. The soils in the La Nana Bayou watershed are considered somewhat limited or very limited (Figure 16).

Based upon 911 address points occurring outside of municipal service regions as reported by Nacogdoches County (2018) and reviewed by the City of Nacogdoches and ANRA to verify areas connected to centralized sewer service, a total of 2,838 OSSFs was estimated for La Nana Bayou watershed (Figure 17). The Nacogdoches County Environmental Services Department Designated Representative (DR) estimates that about 30% of OSSFs in the county are failing (personal communication, November 2021), which means that roughly 851 OSSFs are expected to be failing within the watershed. The estimate for failing OSSFs could also include households that do not have any OSSF on their property, so wastewater is entering the watershed untreated.

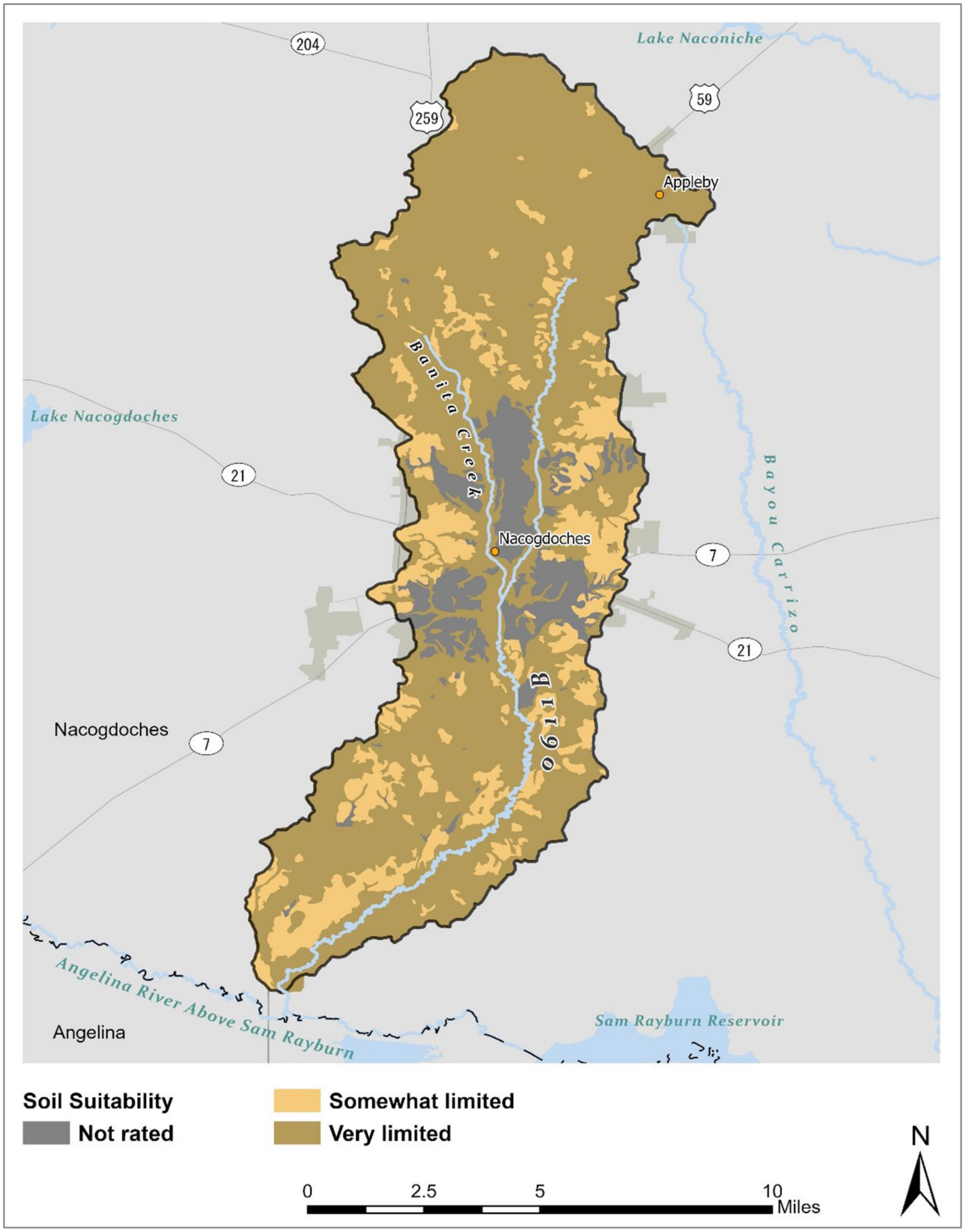


Figure 16. NRCS Soil Suitability ratings for the La Nana Bayou watershed.

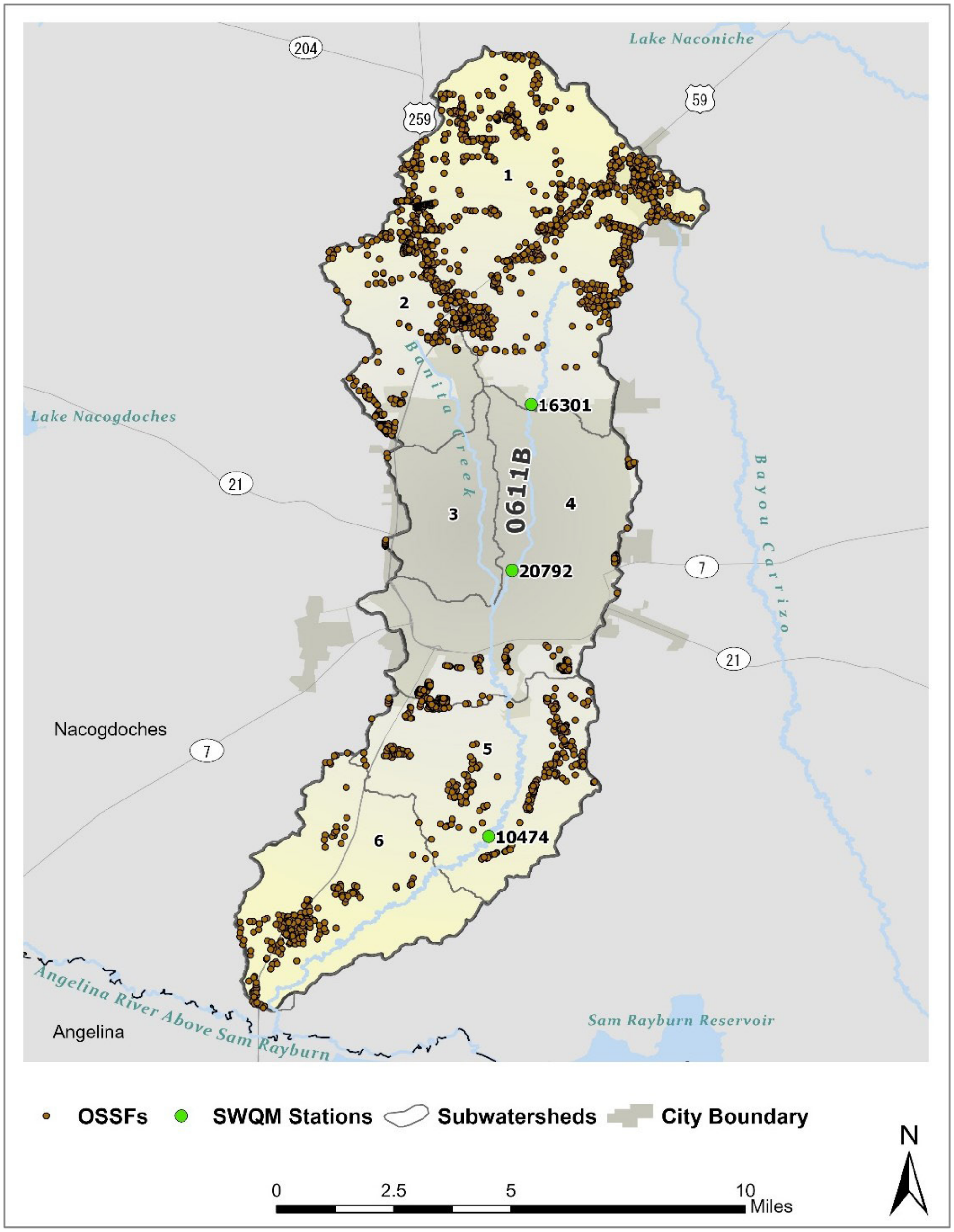
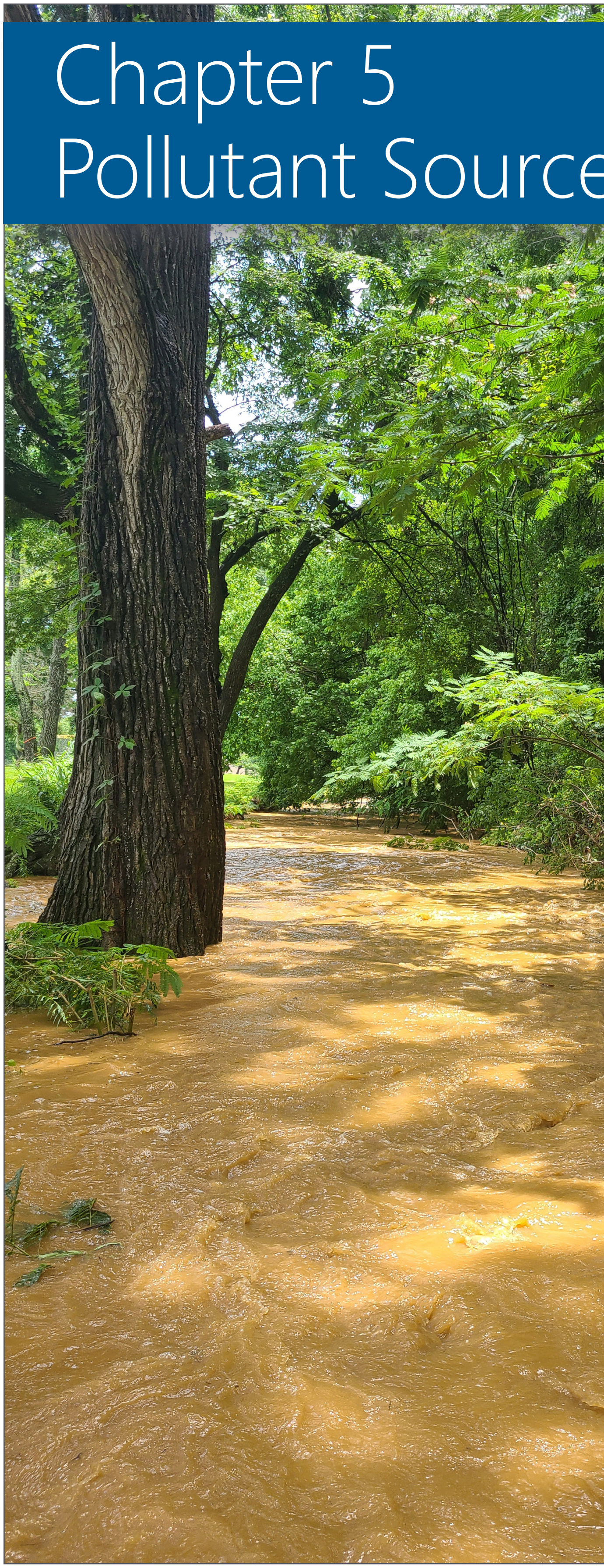


Figure 17. Estimated OSSF locations in the La Nana Bayou watershed.

Chapter 5
Pollutant Source Assessment



La Nana Bayou near Main St. with high water levels during a flash flood event. Photo by Emily Monroe, TWRI.

Once potential pollution sources for a watershed are determined, water sampling can assist stakeholders with determining the needed reduction in pollutant load from each source to achieve primary contact water quality standards. The pollutant load is the concentration of bacteria or nutrients that flows through a specific part of a water body (like a monitoring site) at a specific point in time. A water body's capacity for assimilating pollutants without being considered impaired depends on its hydrological characteristics.

Bacteria load capacities for La Nana Bayou were calculated using the load duration curve (LDC) method with data from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database (TCEQ SWQMIS 2021). This chapter covers estimates of the relative bacteria load contributions and potential areas for reductions from the various pollution sources identified in Chapter 4. Load reductions for nutrients were not developed because there are no nutrient standards for freshwater streams in Texas. However, nutrient management is still an important consideration, and practices implemented to reduce bacteria issues in the watershed typically also mitigate nutrient concerns.

Load Duration Curve Analysis

Load Duration Curves categorize water quality information during various flow conditions. First, a flow duration curve (FDC) is constructed using streamflow measurements that summarizes how often a given flow is exceeded, ranked highest to lowest. The FDC is then multiplied by the allowable pollutant concentration (126 cfu/100 mL for *E. coli)* minus a margin of safety of 10% to determine the maximum acceptable pollutant load across all flow conditions. Measurements above the FDC line exceed the water quality standard for that parameter while measurements below the line do not. A percent reduction can be calculated based on the difference between the current measured load and the allowable load. For more information, EPA has extensive guidance on the development and application of FDCs and LDCs for water quality analysis (EPA 2016).

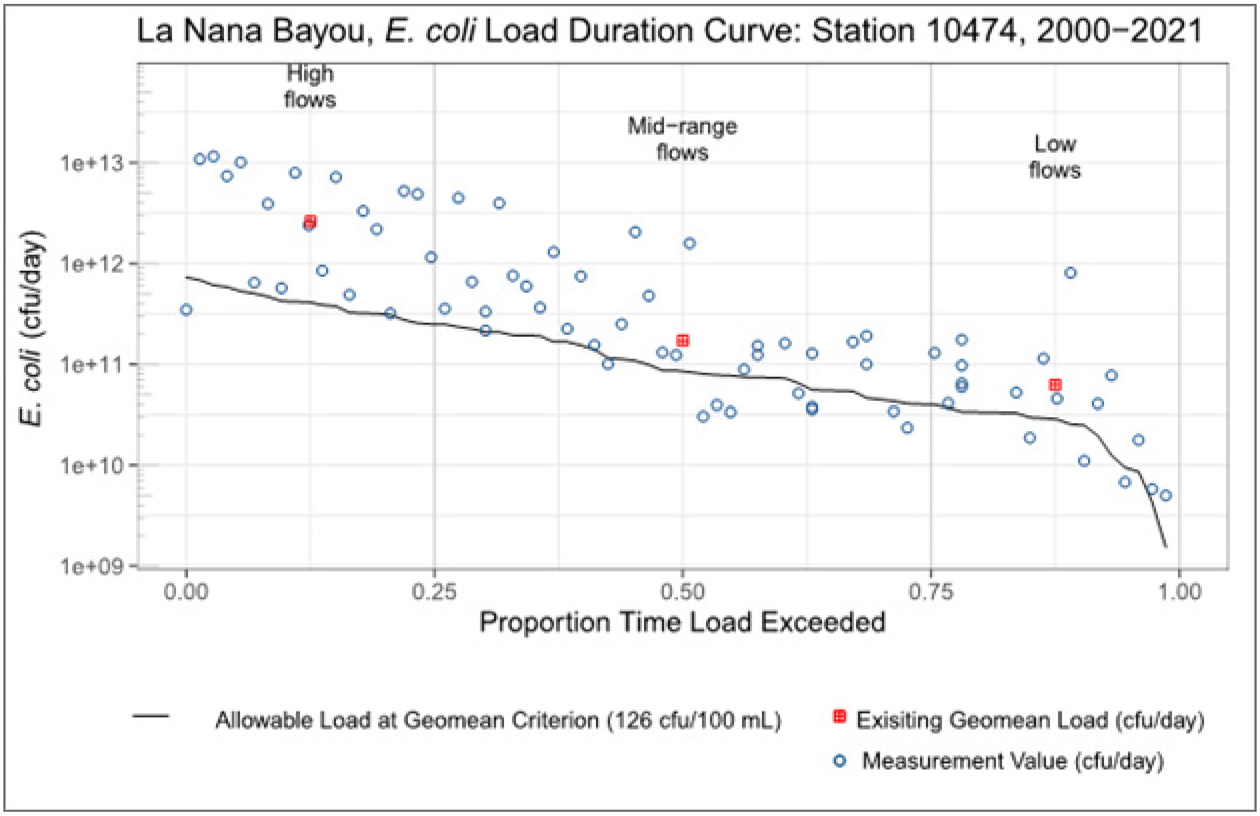


Figure 18. LDC for *E. coli* at Station 10474.

While LDCs cannot identify a specific pollutant source, they can give clues for the most likely category of pollution the source falls under depending on when the exceedance occurs: high loads during a period of low flow can indicate the issue is a point source pollution problem — like discharge from a pipe — while higher loads during high flow likely indicate nonpoint source pollution from runoff. In La Nana Bayou, the bacteria geomeans for all AUs were above the water quality standard for most of the year, which indicates a diverse set of sources contributing to bacteria loads, requiring a diverse set of management recommendations.

Bacteria LDCs

Load Duration Curves for bacteria were developed from the first available data collected at each station through 2021. Quarterly water quality grab sample data and instantaneous flow measurements were downloaded from the TCEQ SWQMIS. Results of the LDC calculations show that all three AUs of La Nana Bayou exceed the primary contact recreation water quality standard for bacteria during all flow conditions (Figure 18, Figure 19, and Figure 20).

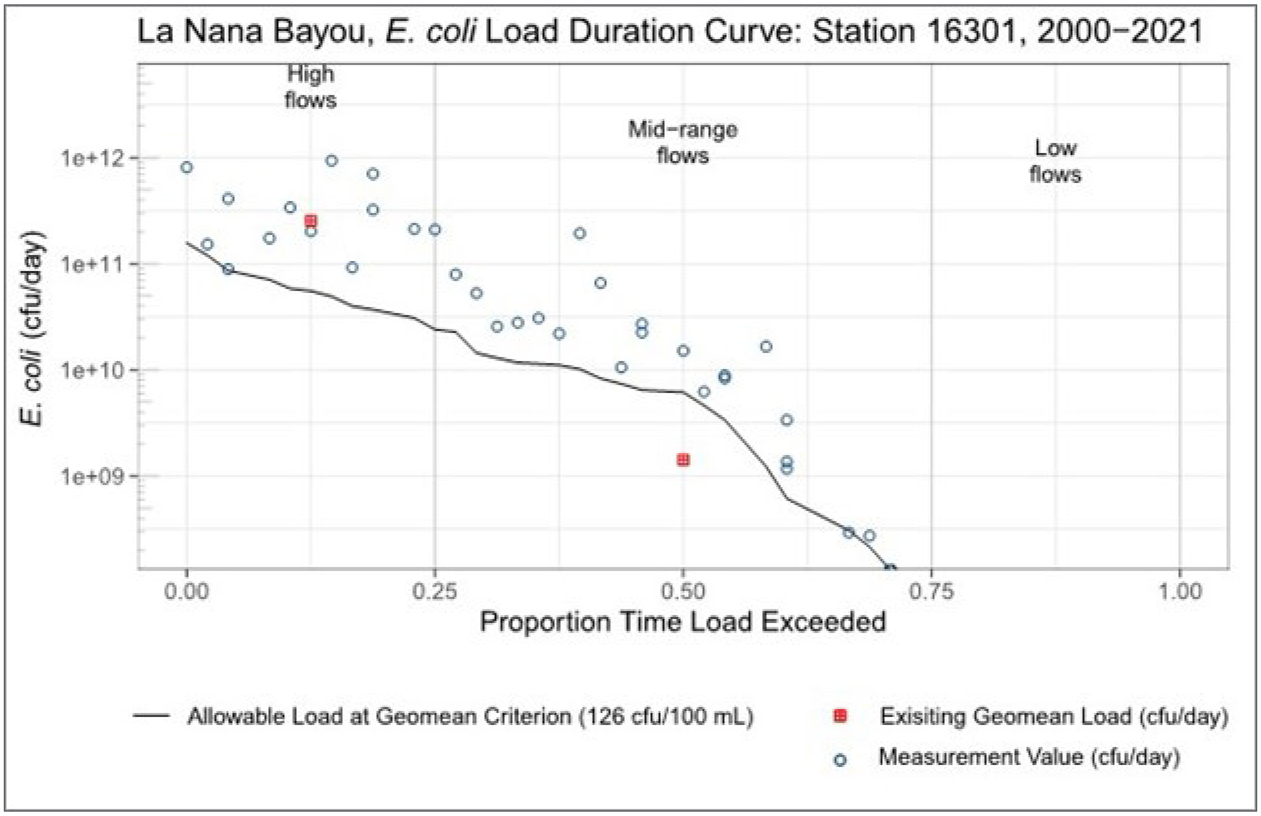


Figure 19. LDC for *E. coli* at Station 16301.

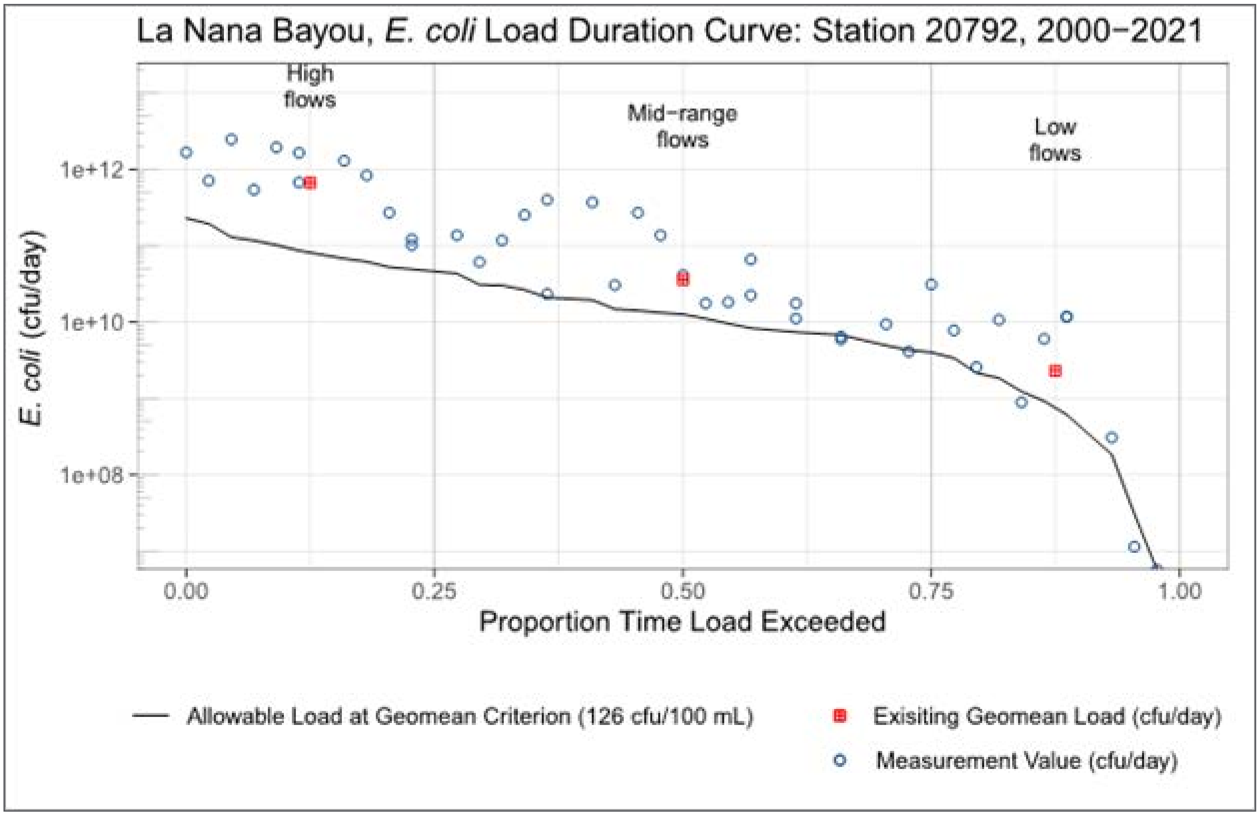


Figure 20. LDC for *E. coli* at Station 20792.

Table 10. Estimated *E. coli* load reductions needed to meet primary contact water quality standards in AU 0611B_01.

La Nana Bayou Station: 10474	Flow Condition		
	Lowest Flows	Mid-Range Flows	Highest Flows
Days per year	91.25	182.5	91.25
Median Flow (cfs)	9.3	27	134
Existing Geomean Concentration (cfu/100 mL)	275	259	742
Allowable Daily Load (Billion cfu)	28.67	83.23	413.08
Allowable Annual Load (Billion cfu)	2,616.06	15,190.01	37,693.74
Existing Daily Load (Billion cfu)	62.57	171.09	2,432.59
Existing Annual Load (Billion cfu)	5,709.65	31,223.92	221,974.23
Annual Load Reduction Needed (Billion cfu)	3,093.59	16,033.90	184,280.49
Percent Reduction Needed	54.18%	51.35%	83.02%
Total Annual Load (Billion cfu)	258,907.80		
Total Annual Load Reduction (Billion cfu)	**203,407.99**		
Total Percent Reduction	**78.56%**		

Colony forming units, cfu; milliliter, mL;

Table 11. Estimated *E. coli* load reductions needed to meet primary contact water quality standards in AU 0611B_02.

La Nana Bayou Station: 16301	Flow Condition		
	Lowest Flows	Mid-Range Flows	Highest Flows
Days per year	40.15	127.75	91.25
Median Flow (cfs)	0.001	2.4	18
Existing Geomean Concentration (cfu/100 mL)	193	451	577
Allowable Daily Load (Billion cfu)	0.0031	7.40	55.49
Allowable Annual Load (Billion cfu)	0.12	945.16	5,063.34
Existing Daily Load (Billion cfu)	0.0047	26.48	254.10
Existing Annual Load (Billion cfu)	0.19	3,383.06	23,186.87
Annual Load Reduction Needed (Billion cfu)	0.07	2,437.90	18,123.53
Percent Reduction Needed	34.72%	72.06%	78.16%
Total Annual Load (Billion cfu)	26,570.12		
Total Annual Load Reduction (Billion cfu)	**20,561.50**		
Total Percent Reduction	**77.39%**		

Colony forming units, cfu; milliliter, mL;

Annual Load Reduction Needed for Bacteria

The LDC results also indicate the level of daily bacteria load La Nana Bayou can have without becoming impaired. Therefore, using the current daily load, the *E. coli* reduction needed to meet water quality standards was determined for each AU (Table 10, Table 11, and Table 12). These *E. coli* load reductions served as the basis to determine the goals for recommended management measures.

Nutrient Loads

As previously discussed, Texas does not currently have nutrient standards for water quality but has set screening levels. The screening level for nitrate nitrogen is 1.95 mg/L and the screening level for total phosphorus is 0.69 mg/L. Only AU 0611B_01 (Station ID 10474) is listed in the *2020 Texas Integrated Report* section Water Bodies with Concerns for Use Attainment and Screening Levels for nutrient concerns in La Nana Bayou. The measured concentrations of each

Table 12. Estimated *E. coli* load reductions needed to meet primary contact water quality standards in AU 0611B_03.

La Nana Bayou Station: 20792	Flow Condition		
	Lowest Flows	Mid-Range Flows	Highest Flows
Days per year	91.25	182.5	91.25
Median Flow (cfs)	0.3	3.6	28
Existing Geomean Concentration (cfu/100 mL)	315	405	972
Allowable Daily Load (Billion cfu)	0.92	11.10	86.32
Allowable Annual Load (Billion cfu)	84.39	2,025.34	7,876.30
Existing Daily Load (Billion cfu)	2.31	35.67	665.86
Existing Annual Load (Billion cfu)	210.97	6,510.01	60,760.05
Annual Load Reduction Needed (Billion cfu)	126.58	4,484.67	52,883.75
Percent Reduction Needed	60.00%	68.89%	87.04%
Total Annual Load (Billion cfu)	67,481.03		
Total Annual Load Reduction (Billion cfu)	**57,495.01**		
Total Percent Reduction	**85.20%**		

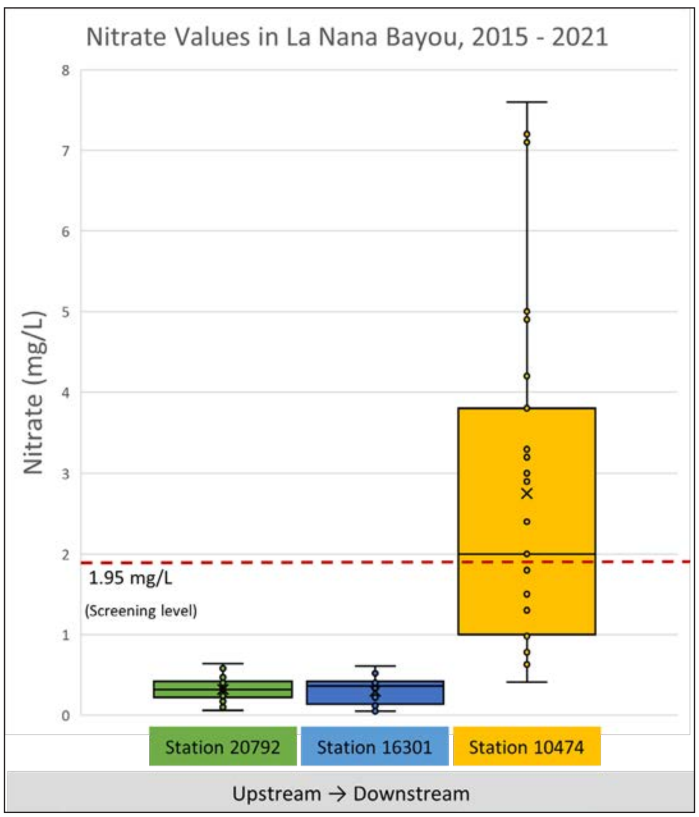


Figure 21. The range of nitrate nitrogen concentrations by station.

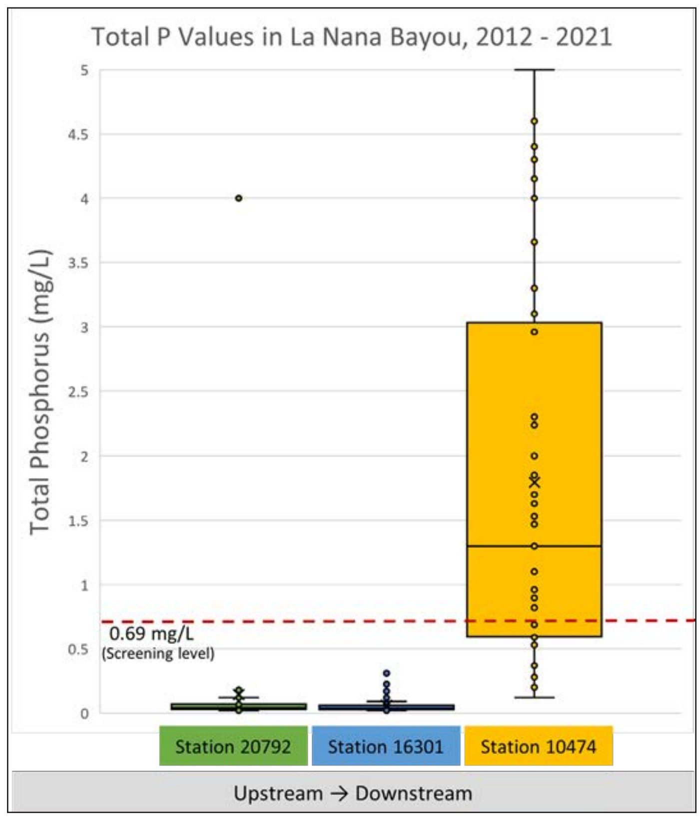


Figure 22. The range of Total Phosphorus (P) concentrations by station.

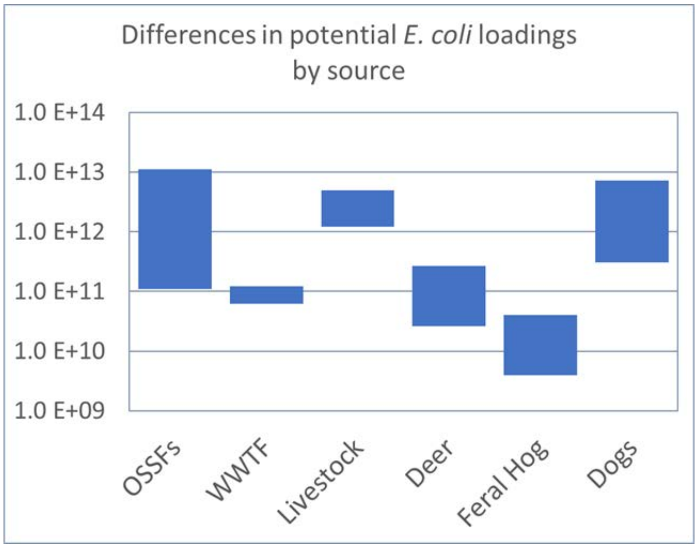


Figure 23. The ranges for potential bacteria loading by source for La Nana Bayou.

nutrient by station show that the downstream segment, represented by Station 10474, has the highest nitrate nitrogen and total phosphorus concentrations (Figure 21 and Figure 22) within La Nana Bayou.

GIS Analysis

Using stakeholder input and the best available data, a geographic information systems (GIS) analysis was performed to determine the relative potential load contribution from each subwatershed. Spatial analyses assist with prioritizing when and where management measures should be implemented for the greatest need and highest potential impact. The following estimates show only the potential for bacteria to enter La Nana Bayou in each subwatershed relative to the others based on the characteristics from Chapter 2 (slope, soil, land cover, and land use), not the actual amounts expected to enter the creek.

Estimates for animal populations are based on the number of animals each land type can support per acre. Livestock numbers were obtained from the NASS at the county level, deer population estimate came from the Resource Management Unit (RMU) density survey, and feral hog estimates are from Texas A&M Natural Resources Institute's feral hog calculation method. Sources that are not necessarily tied to land use (WWTPs, OSSFs, and pet waste) were estimated based on the physical location of WWTPs and 911 addresses from the Texas Natural Resources Information System.

Loadings by source indicate that failing OSSFs have the highest potential impact, followed by waste from dogs, livestock, then other wildlife (Figure 23). With only two wastewater permits in the watershed and only one treatment plant, the estimated loading from WWTP is relatively small compared to that from other sources.

Wastewater Treatment

OSSFs

The areas with the highest potential load are mainly outside of the urbanized area of the City of Nacogdoches in Subwatersheds 1, 2, 5, and 6, with the highest concentration of OSSFs being in Subwatershed 1 (Figure 24).

Permitted Wastewater Treatment

There are only two facilities in the watershed with permits to release wastewater into La Nana Bayou, Cal-Tex Lumber and the City of Nacogdoches WWTP. Cal-Tex Lumber only discharges industrial cooling, storm, and wash water from their milling facility so their potential bacteria load is assumed to be very minimal. The City of Nacogdoches WWTP discharges into Subwatershed 5 (Figure 25) but has had no exceedance violations for bacteria within the last five years of the development of this WPP.

Livestock

FThere are approximately 2,900 cattle in the watershed, and a relatively low number of other livestock types (See Chapter 4, Table 5). Subwatersheds 1 and 2 have the most hay/pasture, herbaceous, and shrub land use types, so the potential for bacteria from livestock is highest in the northern portion of the La Nana Bayou watershed (Figure 26).

Wildlife and Invasive Species

While we often have different goals for managing wild animals due to their value to the hunting community or their tendency for property destruction, their impact on water quality is similar. Subwatersheds 1, 5, and 6 are at the highest risk for bacteria loading from wildlife and invasive species (Figure 27 and Figure 28).

Domestic Pets

Pets can contribute bacteria to the watershed when their waste is not disposed of properly and it washes into nearby water bodies during storm events, especially in urbanized areas where pets are more concentrated. Management efforts should be focused in Subwatershed 4, where the most pet owners are located, as well as several popular dog parks and walking trails along the creek (Figure 29).

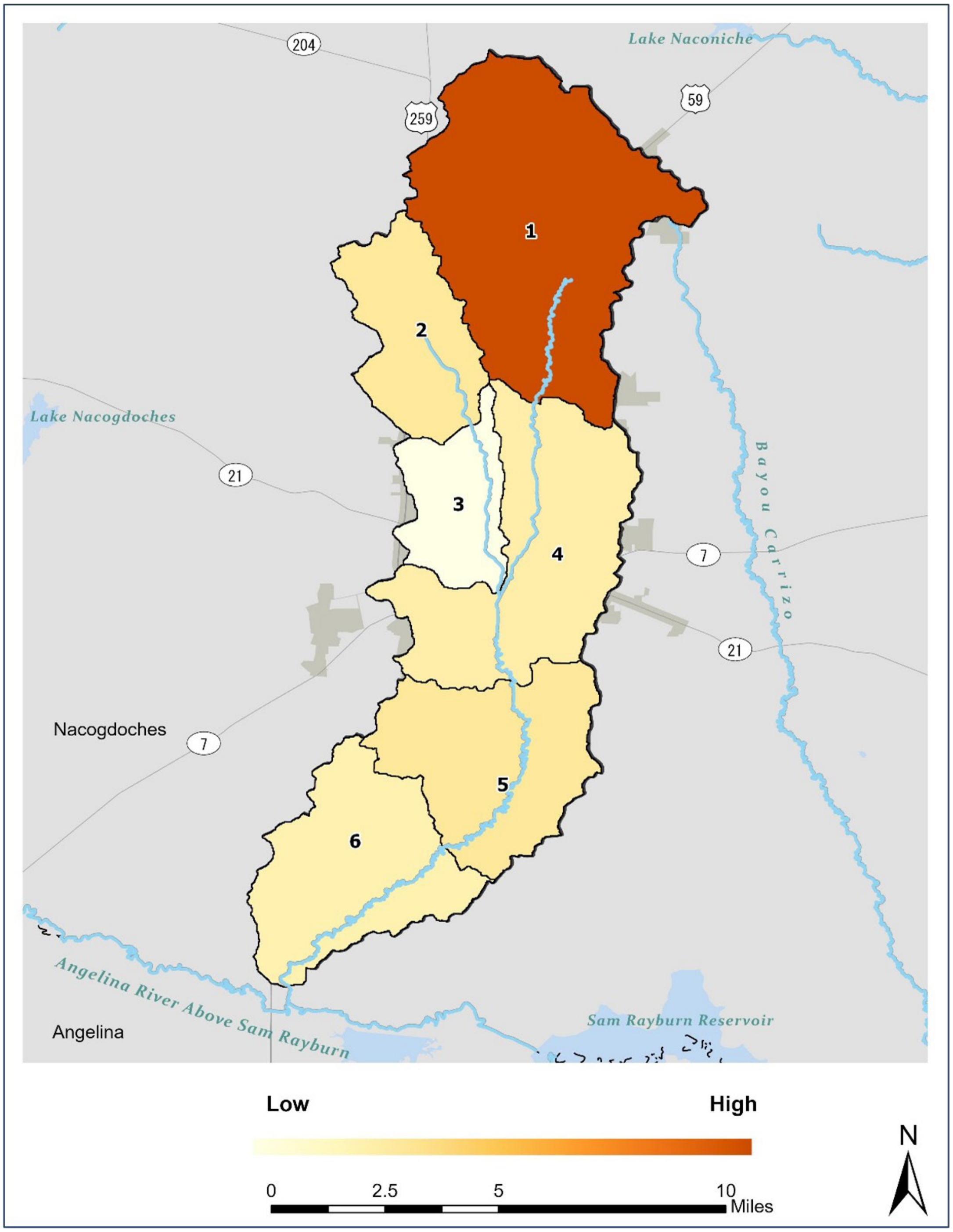


Figure 24. Estimated bacteria load contributions from failing OSSFs.

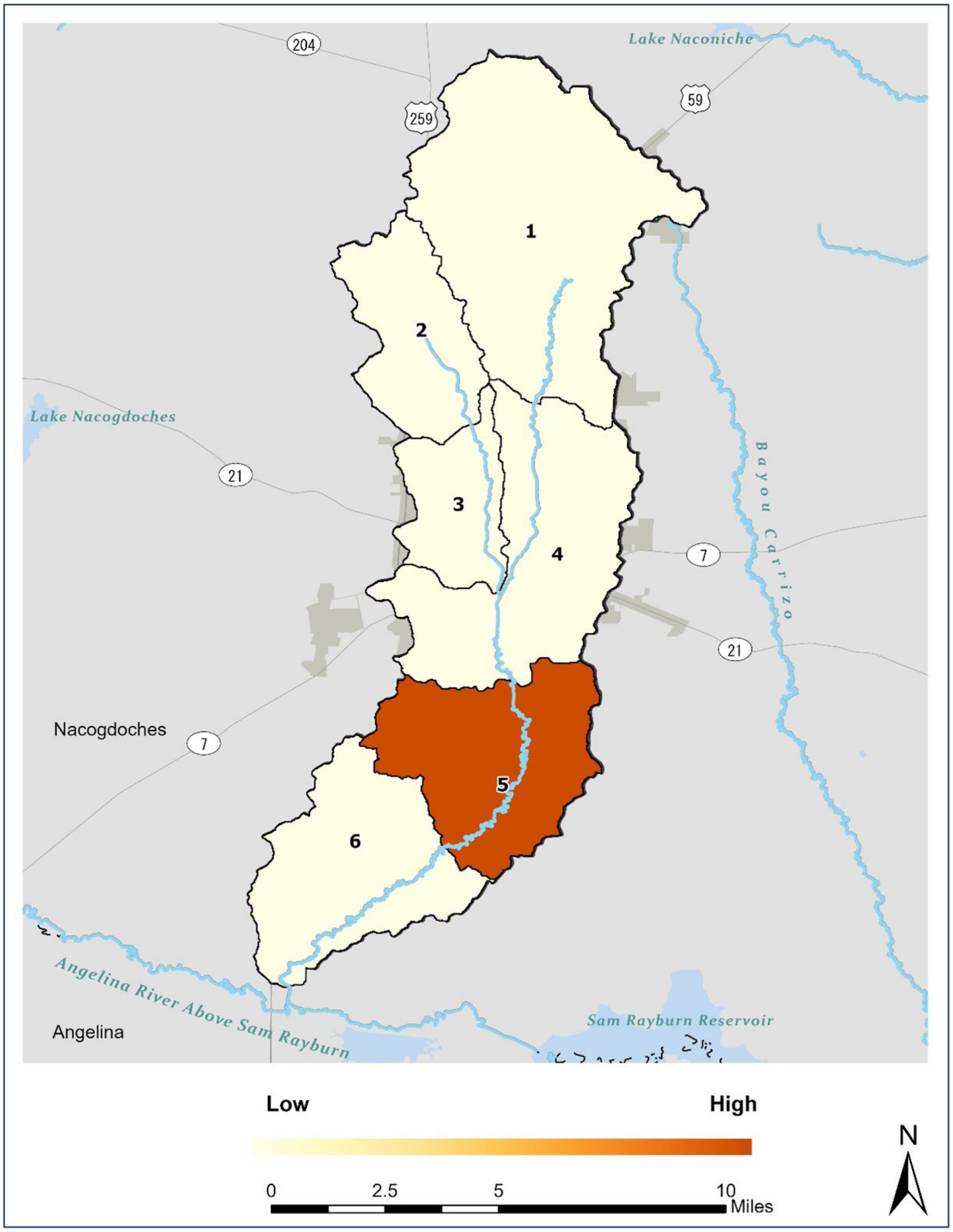


Figure 25. Estimated bacteria load contributions from WWTPs.

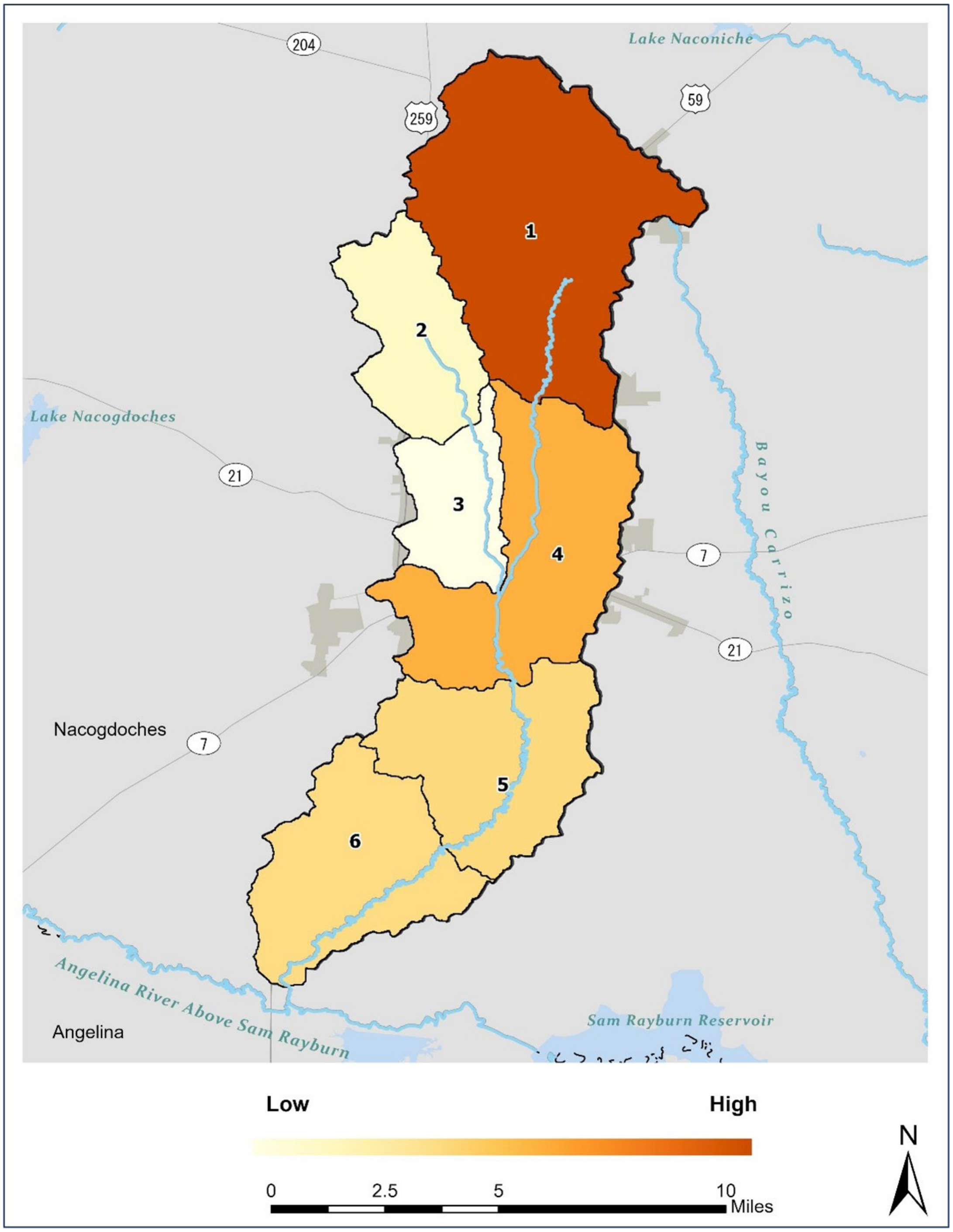


Figure 26. Estimated bacteria load contribution from livestock.

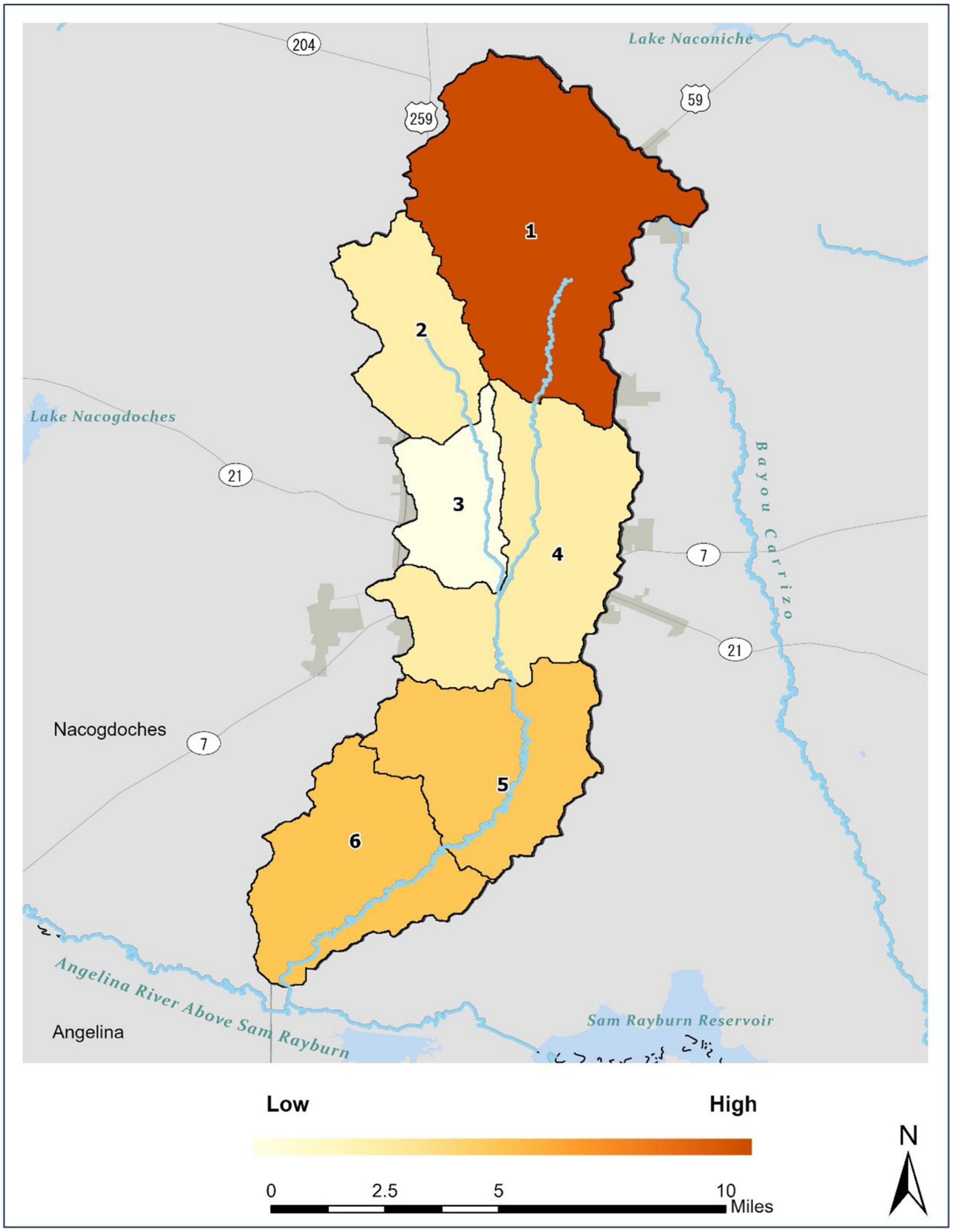


Figure 27. Estimated bacteria load contribution from wildlife.

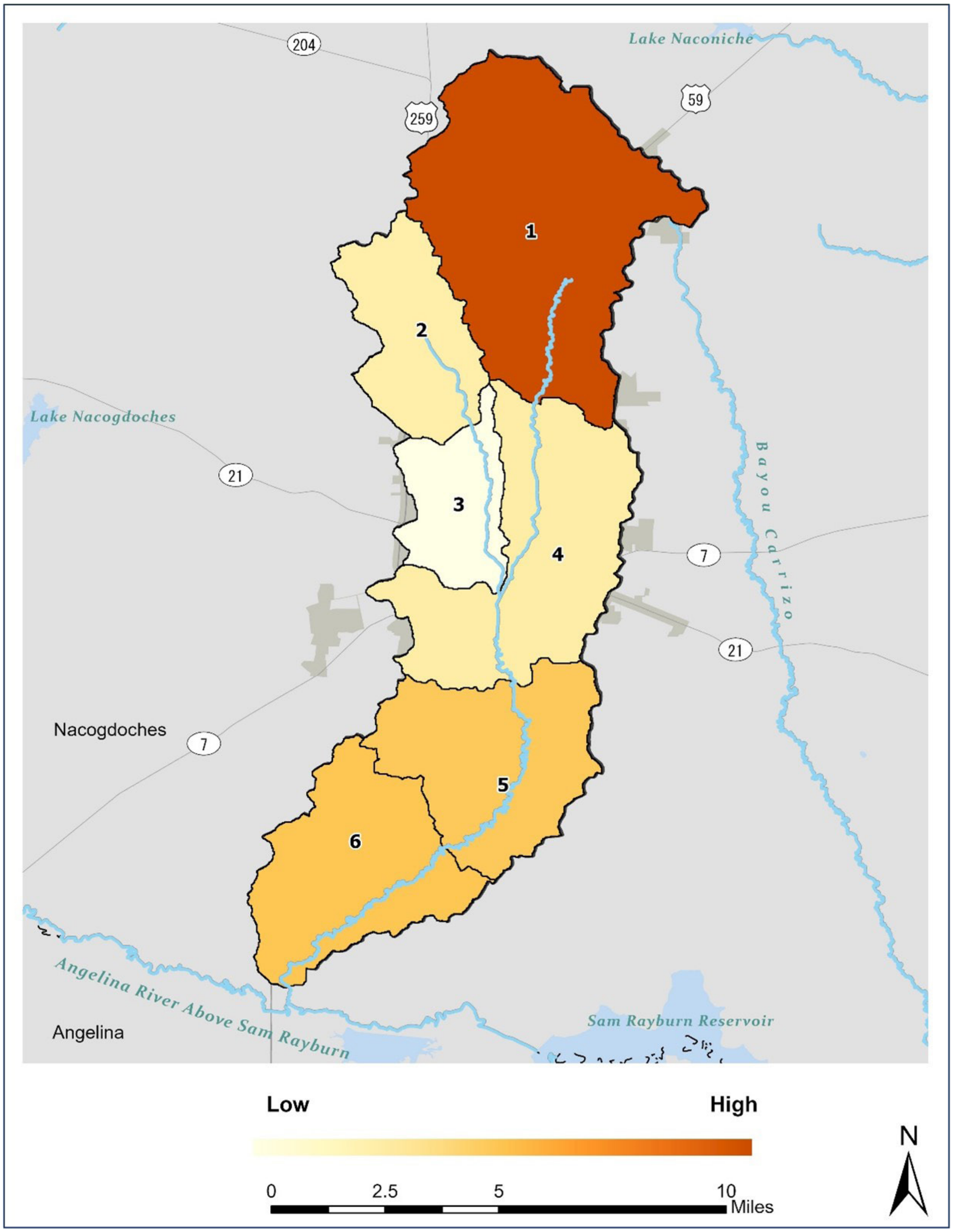


Figure 28. Estimated bacteria load contribution from feral hogs.

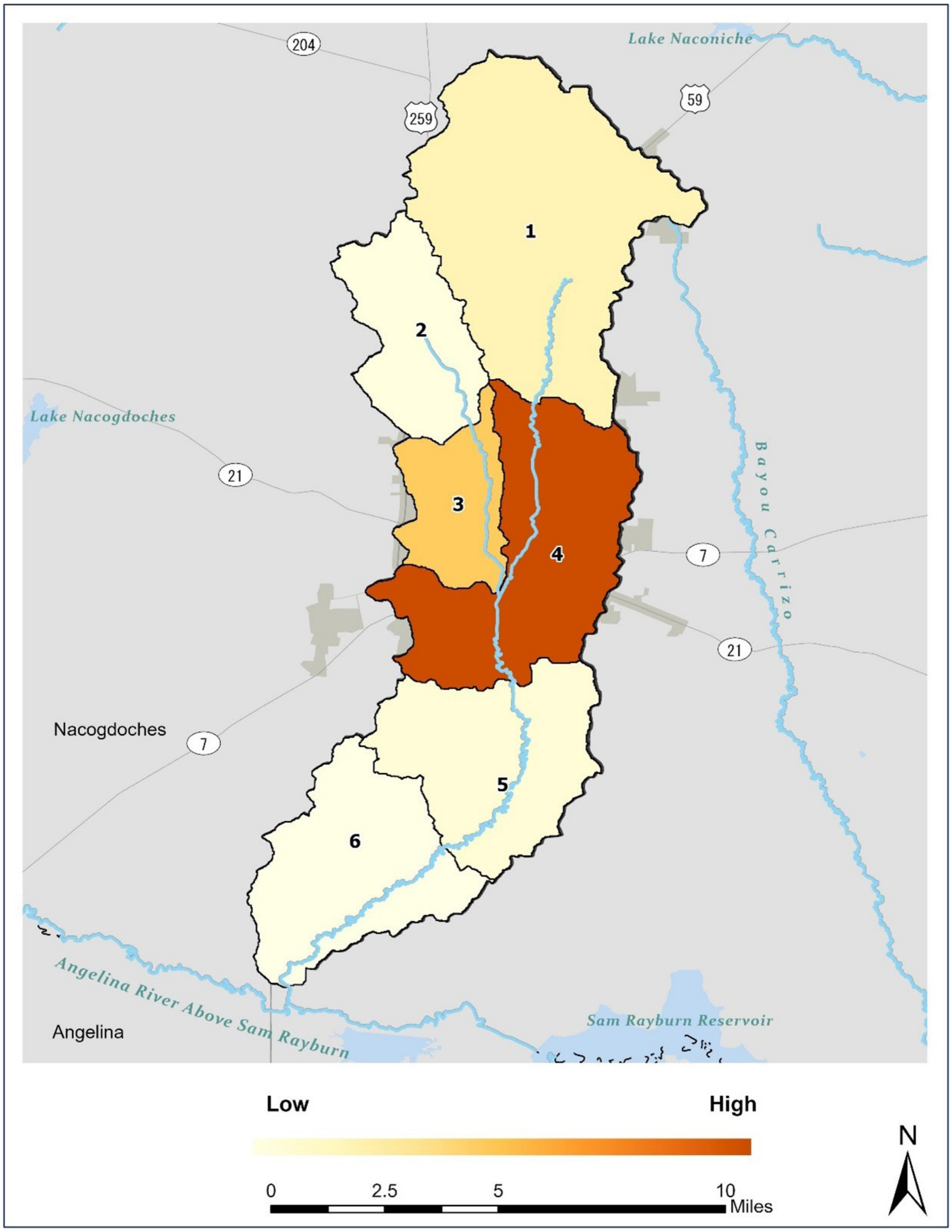


Figure 29. Estimated bacteria load contribution from pets (dogs).

Chapter 6
Management Measures

La Nana Bayou. Photo by Lucas Gregory, TWRI.

Since no single source of *E. coli* was found to be the primary cause of water quality issues in La Nana Bayou, multiple strategies should be used to address pollution concerns. A diverse range of management measures was selected by stakeholders to focus resources on the stakeholder's highest priorities in the watershed. Input from watershed residents was crucial throughout the decision-making process for these suggested management strategies. Management measures suggested in this chapter are voluntary and will rely on stakeholder adoption for successful implementation; therefore, receiving stakeholder input on willingness to adopt these practices was paramount. All management measures were discussed with and approved by the stakeholders to ensure community support and successful implementation.

Estimated potential load reductions for management measures are presented with each recommended action discussed in this chapter. The loading estimates presented are based on the predicted worst-case scenario loadings that were discussed in Chapter 4. As a result, these estimates do not predict real loadings that are occurring or expected load reductions that may be realized instream. Actual reductions are dependent on several factors that may trigger the need for adaptive implementation strategies. Potential annual load reductions from suggested management measures indicate that it is possible to reduce bacteria loads entering the water bodies in the La Nana Bayou watershed to levels that will support primary contact recreation use.

Priority implementation areas for recommended management strategies were identified based on spatial analysis and stakeholder feedback. While management measures can be implemented throughout the watershed, priority locations were selected based on where management strategies could be most effective in removing or reducing potential loadings. The strategies outlined in this chapter are:

1. Mitigate urban stormwater runoff issues
2. Promote the development of WQMPs or conservation plans
3. Obtain technical assistance for urban waterfowl management
4. Promote BMPs for managing feral hog populations
5. Promote proper disposal of pet waste in urban areas
6. Identify, inspect, and remediate failing OSSFs

Table 13. Management Measure 1: Mitigate Urban Stormwater Runoff Issues.

<table>
<tr><th colspan="4">Pollutant Source: Urban Stormwater Management</th></tr>
<tr><td colspan="4">Problem: Fecal bacteria, nutrient loading, and erosion from stormwater runoff in developed and urbanized areas</td></tr>
<tr><td colspan="4">Objectives:
• Organize general stormwater management education and outreach programs.
• Educate residents about stormwater BMPs.
• Work with city government and local institutions to identify and implement BMPs and low impact development techniques.
• Monitor the effectiveness of BMPs and suggest new techniques to manage stormwater.</td></tr>
<tr><td colspan="4">Critical Areas: Urban areas of the watershed, with priority in subwatersheds 3 and 4</td></tr>
<tr><td colspan="4">Goal: Reduce E. coli loading associated with urban stormwater runoff through implementation of stormwater BMPs as appropriate and to increase awareness of stormwater pollution and management.</td></tr>
<tr><td colspan="4">Description: Potential locations and types of stormwater runoff management BMP demonstration projects will be identified in coordination with the city of Nacogdoches, Nacogdoches County, public works, and property owners.</td></tr>
<tr><th colspan="4">Implementation Strategy</th></tr>
<tr><th>Participants</th><th>Recommendations</th><th>Period</th><th>Capital Costs</th></tr>
<tr><td>City of Nacogdoches, Nacogdoches County</td><td>Identify and install stormwater BMPs as funding becomes available</td><td>2022-2031</td><td>$4,000-$45,000/acre (estimate)</td></tr>
<tr><td>City of Nacogdoches, AgriLife Extension</td><td>Deliver education and outreach to landowners</td><td>2022-2031</td><td>N/A</td></tr>
<tr><th colspan="4">Estimated Load Reduction</th></tr>
<tr><td colspan="4">Installation of stormwater BMPs that reduce runoff or treat bacteria will result in direct reductions in bacteria loadings in the watershed. Potential load reductions were not calculated because the location, type, and size of projects installed will dictate the potential load reductions; however, they have not been identified yet.</td></tr>
<tr><td>Effectiveness</td><td colspan="3">Moderate to High: The effectiveness of BMPs at reducing bacteria and nutrient loadings is dependent on the design, site selection and maintenance of the BMP.</td></tr>
<tr><td>Certainty</td><td colspan="3">Moderate: Installation of BMPs requires sustained commitment from city officials or property owners.</td></tr>
<tr><td>Commitment</td><td colspan="3">Moderate to High: Urban stormwater management is a priority for the city.</td></tr>
<tr><td>Needs</td><td colspan="3">Moderate: Support in the form of financial and technical assistance is needed to identify the best application of and promote the adoption of stormwater management policies.</td></tr>
</table>

Best management practices, BMPs; *Escherichia coli, E. coli;* Texas A&M AgriLife Extension Services, AgriLife Extension;

7. Reduce illegal dumping and litter
8. Work with area schools to develop water quality and conservation programs for K-12 students
9. Continue and expand water quality monitoring along La Nana Bayou and Banita Creek

Management Measure 1 – Mitigate Urban Stormwater Runoff Issues

Stormwater runoff from rain events in urban areas, or in locations with large amounts of impervious surfaces, flows directly into water bodies, taking with it any pollutants that are on the surface like trash, oils, chemicals, and fecal matter. Whereas rain that falls on permeable surfaces like grassy areas in parks, is mostly absorbed into the soil. Therefore, increasing the amount of pervious surface in urban areas can reduce the stormwater runoff, which leads to less nonpoint source pollution entering surface waters.

The main objective of Management Measure 1 is to organize general stormwater management education and outreach programs to increase residents' awareness of stormwater BMPs. The entities involved will be AgriLife Extension, cities, property owners, and contractors. The second objective is to work with local municipalities to identify and install demonstration BMPs that manage stormwater runoff as appropriate and as funding permits. Commonly used BMPs for stormwater management are rain gardens, rain barrels/cisterns, green roofs, permeable pavements, bio retention, swales, and detention ponds. These BMPs can be adopted based on the precipitation amount, pattern, and local preferences. The third objective is to monitor the effectiveness of BMPs and suggest new techniques to manage stormwater. Therefore, multiple processes can be introduced to identify the most effective one.

Table 14. Management Measure 2: Promote the Development of Water Quality Management Plans or Conservation Plans.

<table>
<tr><th colspan="4">Pollutant Source: Cattle and Other Livestock</th></tr>
<tr><td colspan="4">Problem: Livestock-derived fecal loading into water bodies.</td></tr>
<tr><td colspan="4">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 from livestock in riparian areas</td></tr>
<tr><td colspan="4">Location: Subwatersheds 1 and 2, with priority given to properties near water bodies</td></tr>
<tr><td colspan="4">Critical Areas: Properties with creek and tributary access, especially those being used as livestock watering sources</td></tr>
<tr><td colspan="4">Goal: Develop up to 25 CPs and/or WQMPs focused on minimizing the time spent by livestock in the riparian corridor and better use of available grazing resources across the property.</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><th colspan="4">Implementation Strategy</th></tr>
<tr><th>Participants</th><th>Recommendations</th><th>Period</th><th>Capital costs</th></tr>
<tr><td>Producers, NRCS, TSSWCB, SWCDs</td><td>Develop, implement, and provide financial assistance for up to 25 livestock CPs and WQMPs @ $15,000 per plan</td><td>2022–2031</td><td>$375,000</td></tr>
<tr><td>AgriLife Extension, SWCD, City of Nacogdoches</td><td>Deliver education and outreach programs and workshops to landowners</td><td>2022–2031</td><td>N/A</td></tr>
<tr><th colspan="4">Estimated Load Reduction</th></tr>
<tr><td colspan="4">Prescribed management will reduce loadings associated with livestock by reducing runoff from pastures and rangeland as well as reducing direct deposition by livestock. Implementation of 25 WQMPs and CPs is estimated to reduce annual loads from livestock by 3.77 $x10^{14}$ cfu of E. coli per year in the watershed (Appendix B).</td></tr>
<tr><td>Effectiveness</td><td colspan="3">High: Decreasing the time that livestock spend in riparian areas and reducing runoff through effectively managing vegetative cover will directly reduce nonpoint source contributions of bacteria and other pollutants to creeks.</td></tr>
<tr><td>Certainty</td><td colspan="3">Moderate: Landowners acknowledge the importance of good land stewardship practices and management plan objectives; however, financial incentives are often needed to promote WQMP and CP implementation.</td></tr>
<tr><td>Commitment</td><td colspan="3">Moderate: Landowners are willing to implement stewardship practices shown to improve productivity; however, costs are often prohibitive and financial incentives are needed to increase implementation rates.</td></tr>
<tr><td>Needs</td><td colspan="3">High: Financial costs are a major barrier to promote implementation. Education and outreach are needed to demonstrate benefits of plan development and implementation to producers.</td></tr>
</table>

Best management practice, BMPs; Conservation Plans, CPs; *Escherichia coli, E. coli;* Water Quality Management Plans, WQMPs; Soil and Water Conservation Districts, SWCDs; Stephen F. Austin State University, SFASU; Texas A&M AgriLife Extension Service, AgriLife Extension; Texas Parks and Wildlife Department, TPWD;

Management Measure 2 – Promote the Development of Water Quality Management Plans or Conservation Plans

Bacteria from livestock waste is usually transported from deposition in upland areas to water bodies via runoff during rain events, and the longer transport time causes much of the *E. coli* to die off before it reaches the water. However, livestock will spend time around and wading in water if they have access to it, which allows for direct deposition of fecal matter into the water body and a direct impact on water quality. Livestock activities are influenced by the availability of drinking water, feed, and shade structures, so they can be managed by providing alternative sources of water and shade away from riparian areas. These measures can effectively reduce potential bacteria loading from runoff and direct deposition.

The most appropriate management practices for a property will vary depending on a variety of factors but WQMPs and conservation plans (CPs) can be developed with technical assistance from NRCS, TSSWCB, and local SWCDs. Common practices include brush management, fencing, filter

Table 15. Management Measure 3: Obtain Technical Assistance for Urban Waterfowl Management.

Pollutant Source: Urban Waterfowl			
Problem: An overpopulation of waterfowl contributes bacteria to water bodies due to direct fecal deposition.			
Objectives: • Conduct a study to identify the types and numbers of waterfowl in perceived problem areas • Work with bird experts to develop and implement best course of action to address potential population issue • Educate public on issues related to feeding wild waterfowl populations			
Location: Subwatersheds 3 and 4			
Critical Areas: Public parks, SFASU Campus Detention Pond (Ag Pond)			
Goal: To reduce waterfowl populations to improve water quality and sanitary conditions around public use areas			
Description: Overpopulation of waterfowl can exacerbate water quality issues and cause sanitation concerns in public use areas. Establishing a baseline for the type of waterfowl (domestic, invasive, resident, migratory, etc.) and population numbers will allow waterfowl experts to develop a plan that will foster a manageable population in the watershed, improve water quality, and improve bird population health. Education and outreach to residents and park visitors will address issues caused by feeding wild waterfowl, such as impacts to their health and water quality.			
Implementation Strategy			
Participants	**Recommendations**	**Period**	**Capital costs**
Residents, AgriLife Extension, TPWD, Environmental Engineers	Conduct a waterfowl census survey; work with experts to manage population; educate public on egg health.	2022–2031	$5,000 – $30,000 depending on extent of management efforts
Estimated Load Reduction			
Reductions will be dependent on the plans developed by technical experts that are adopted by the city, SFASU, and other landowners that have bird populations on their property.			
Effectiveness	High: Decreasing the number of waterfowl living around riparian areas and ponds in the watershed will result in an immediate improvement of water quality and sanitation issues.		
Certainty	Moderate: Manageable waterfowl populations is a priority to many groups across the area for both the health of the animals and the watershed.		
Commitment	Moderate: Stakeholders are actively seeking ways to achieve manageable waterfowl populations at SFASU and in some public areas.		
Needs	Moderate: Technical assistance and some financial support is needed to support planning, implementation, and education and outreach efforts.		

Stephen F. Austin State University, SFASU; Texas A&M AgriLife Extension Service, AgriLife Extension; Texas Parks and Wildlife Department, TPWD;

strips, grade stabilization, stream crossings, heavy use area protection, and watering facilities. Some CP programs also include financial assistance for the landowner. The La Nana Bayou watershed stakeholder group has a goal of supporting the development of an additional 25 WQMPs, or similar CPs, in the watershed.

Management Measure 3 – Obtain Technical Assistance for Urban Waterfowl Management

Stakeholders requested assistance in addressing waterfowl living near detention ponds and riparian areas along La Nana Bayou, as their fecal deposition directly into and near the water bodies could be contributing to the bacteria issues. The Upper Cibolo Creek WPP included a thorough investigation into the types of waterfowl living along the creek and expert-recommended management strategies that could foster a manageable waterfowl population. This included short-term strategies such as capture and relocation, and long-term strategies like egg oiling (for invasive species only) to reduce the number of eggs that hatch and educating the public about the consequences of feeding birds. Using the Upper Cibolo Creek WPP as a guide for La Nana Bayou, management measures will include conducting a population survey of waterfowl in areas with a perceived population issue and working with technical experts to reduce the population if needed (Bass et al. 2013).

Table 16. Management Measure 4: Promote BMPs for Managing Feral Hog Populations.

<table>
<tr><th colspan="4">Pollutant Source: Feral Hogs</th></tr>
<tr><td colspan="4">Problem: Direct and indirect fecal loading, riparian habitat destruction, soil damage, and erosion from rooting.</td></tr>
<tr><td colspan="4">Objectives:
• Reduce fecal contaminant loading from feral hogs through population reduction
• Reduce easily accessible food supplies for feral hogs
• Provide education and outreach to stakeholders on BMPs to deter the presence of feral hogs on their property</td></tr>
<tr><td colspan="4">Location: Entire watershed, with highest priority in subwatersheds 1, 5, and 6</td></tr>
<tr><td colspan="4">Critical Areas: Riparian areas and travel corridors from cover to feeding areas</td></tr>
<tr><td colspan="4">Goal: Manage the feral hog population through available means to reduce the total number of current hogs in the watershed by 10% and maintain them at this level over 10 years of implementation.</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><th colspan="4">Implementation Strategy</th></tr>
<tr><th>Participants</th><th>Recommendations</th><th>Period</th><th>Capital costs</th></tr>
<tr><td>Landowners, land managers, and lessees</td><td>Voluntary construction of fencing around deer feeders to prevent feral hog use, voluntary identification of travel corridors and employment of trapping and hunting in these areas to reduce hog numbers, and voluntary hunting of hogs</td><td>2022–2031</td><td>$200/feeder</td></tr>
<tr><td>AgriLife Extension, counties</td><td>Provide support for a feral hog extension associate to trap and hunt feral hogs in the watershed as well as provide educational resources to stakeholders</td><td>2022–2031</td><td>$75,000/year</td></tr>
<tr><th colspan="4">Estimated Load Reduction</th></tr>
<tr><td colspan="4">Removing and maintaining feral hog populations directly reduces fecal loading potential to water bodies in the watershed. Reducing the total feral hog population by 10% of the current population in the watershed is estimated to reduce potential annual loads by 1.03 x 10^{12} cfu of E. coli per year (Appendix B).</td></tr>
<tr><td>Effectiveness</td><td colspan="3">Moderate: Reduction in feral hog population will result in a direct decrease in bacterial and nutrient loading to the streams; however, removing enough hogs to decrease their overall population will be difficult.</td></tr>
<tr><td>Certainty</td><td colspan="3">Low: Feral hogs are transient and adapt well to their environment. They move freely due to food and habitat availability, and hunting/trapping pressure. Removing 10% of the population each year will be difficult and is highly dependent upon the diligence of watershed landowners.</td></tr>
<tr><td>Commitment</td><td colspan="3">Moderate: Landowners are actively battling feral hog populations and will continue to do so if resources remain available.</td></tr>
<tr><td>Needs</td><td colspan="3">Moderate: Funds are needed to provide education and outreach to further inform landowners about feral hog management options and the destructive impact when hogs are not managed.</td></tr>
</table>

Escherichia coli, E. coli; Texas A&M AgriLife Extension Service, AgriLife Extension;

Management Measure 4 – Promote BMPs for Managing Feral Hog Populations

The overpopulation of wildlife species, both domestic and invasive, increases *E. coli* and nutrient loading across the watershed. Like other types of wildlife, feral hogs and wild pigs primarily live in riparian areas, preferring the dense habitat, food resources, and water availability along a water body to open areas. In addition to direct deposition of bacteria, wildlife use of riparian areas can also contribute to water quality issues via the degradation of ground cover and soil disturbances from activities like wallowing and rooting.

The most immediate impact to water quality is the physical removal of feral hog populations through hunting and trapping. Trapping can successfully remove large numbers of hogs with proper planning and consistency. Because feral hogs have a high growth rate of an average 21% per year (Timmons et al. 2012), which causes large populations, shooting individual pigs and using dogs during hunting is less effective than trapping, but is still a helpful strategy to implement to manage populations.

Education and outreach can help landowners learn about the BMPs they can implement themselves to keep feral

Table 17. Management Measure 5: Promote Proper Disposal of Pet Waste in Urban Areas.

Pollutant Source: Pet Waste (Dogs)			
Problem: Improperly disposed dog waste is left on surface areas and washes into streams via rainfall or irrigation runoff.			
Objectives: • Educate residents on disposal of pet waste • Install and maintain pet waste stations in public areas			
Location: Entire watershed, highest priority in subwatersheds 3 and 4			
Critical Areas: Urban areas, homes with dogs near waterways			
Goal: Reduce the amount of dog waste in the watershed that may wash into water bodies during runoff events by providing educational and physical resources to increase stakeholder awareness of the water quality and potential health issues caused by excessive dog waste			
Description: Expand distribution of educational messaging regarding the need to properly dispose of pet waste in the watershed. Specifically target homeowners and the 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 Strategy			
Participants	**Recommendations**	**Period**	**Capital costs**
Nacogdoches County	Install at least 10 pet waste stations in area parks and other potentially high dog concentration areas @ $500/station	2022-2031	$5,000
Nacogdoches County	Develop and provide educational resources to residents	2022-2031	N/A
Estimated Load Reduction			
Load reductions resulting from this management measure are reliant on changes in people's behavior. Assuming 12% of targeted individuals respond by properly disposing of pet waste, the annual load reduction would be approximately 1.15 x10^{15} cfu of *E. coli* per year (Appendix B).			
Effectiveness	High: Collecting and properly disposing of dog waste is known to prevent *E. coli* and nutrients from entering local waterways and will directly reduce the quantity of *E. coli* in the watershed.		
Certainty	Low: Some dog owners already collect and properly dispose of dog waste. Those who do not 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: There are trails along La Nana Bayou and many public parks in the area and installing pet waste stations is a low-cost, high-impact management measure.		
Needs	Low to Moderate: Pet waste stations are relatively inexpensive, and the additional work required to maintain stations should be minimal.		

Escherichia coli, E. coli;

hog populations low. Promoting resources like AgriLife Extension's Wild Pig website can teach landowners about practices like exclusionary fencing to block feral hogs from having access to deer feeders, trapping techniques and designs, and pig biology. Public participation in these BMPs is crucial to the success of reducing water quality issues caused by feral hogs. For more information, visit https://wildpigs.nri.tamu.edu/.

Management Measure 5 – Promote Proper Disposal of Pet Waste in Urban Areas

Due to the high concentration of *E. coli* in dog waste and the dependence on pet owners to manage pet waste, reducing bacteria loads from pets will rely on promoting the proper disposal of pet waste on homeowners' properties and in public areas. Making pet waste disposal extremely convenient through installation of pet waste station in parks and along the La Nana Creek Trail system will assist pet owners in this task. Media campaigns that educate and encourage pet owners to pick up pet waste and properly dispose of it will be needed to increase adoption. Convenient, well-managed pet waste stations are low-cost solutions that can have a positive impact on water quality and sanitation issues in public areas.

Table 18. Management Measure 6: Identify, Inspect, and Remediate Failing On-Site Sewage Facilities.

<table>
<tr><th colspan="4">Pollutant Source: OSSFs</th></tr>
<tr><td colspan="4">Problem: Bacteria loading from failing or nonexistent OSSFs.</td></tr>
<tr><td colspan="4">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
• Provide education and outreach to homeowners</td></tr>
<tr><td colspan="4">Location: Subwatersheds 1, 2, 5, and 6, with priority to households close to perennial water bodies.</td></tr>
<tr><td colspan="4">Critical Areas: OSSFs situated on soils that are not suitable for septic drain fields and/or are within 500 yards of Banita Creek and La Nana Bayou.</td></tr>
<tr><td colspan="4">Goal: Because failing septic systems pose a higher human health risk than some of the other potential pollutant sources, stakeholders expressed a desire to identify, inspect, and repair or replace (as appropriate) at least 30 of the potentially 851 failing OSSFs in the watershed.</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><th colspan="4">Implementation Strategy</th></tr>
<tr><th>Participants</th><th>Recommendations</th><th>Period</th><th>Capital costs</th></tr>
<tr><td>Nacogdoches County</td><td>Administer OSSF repair/replacement program to address deficient systems identified during inspections</td><td>2022–2031</td><td>$10,000/year</td></tr>
<tr><td>Nacogdoches County</td><td>Identify and inspect failing OSSFs within priority areas; increased priority for OSSFs near water body</td><td>2022–2031</td><td>$750/inspection</td></tr>
<tr><td>AgriLife Extension, Nacogdoches County</td><td>Deliver education and outreach programs and workshops to homeowners</td><td>2022–2031</td><td>N/A</td></tr>
<tr><td>Homeowners</td><td>Repair/replace OSSFs as funding allows</td><td>2022–2031</td><td>~$7,500+ each</td></tr>
<tr><th colspan="4">Estimated Load Reduction</th></tr>
<tr><td colspan="4">At a minimum, the repair or replacement of 30 failing OSSFs in the watershed would result in a potential load reduction of 4.52 x 10^{13} cfu of E. coli per year (See Appendix B).</td></tr>
<tr><td>Effectiveness</td><td colspan="3">High: Replacement or repair of failing OSSFs will yield direct E. coli reductions to the waterways.</td></tr>
<tr><td>Certainty</td><td colspan="3">Low: Funding available to identify, inspect, and repair or replace OSSFs is limited; thus, the actual level of implementation attainable is uncertain.</td></tr>
<tr><td>Commitment</td><td colspan="3">Moderate: Depending on funding sources available and stakeholder buy-in on allowing outside assistance, this is a strategy that could potentially have the greatest effect on human health and should be a top priority.</td></tr>
<tr><td>Needs</td><td colspan="3">High: Costs to administer a program, identify, inspect, and repair/replace OSSFs are considerable. Many homeowners with failing OSSFs may not realize it, so delivering them educational resources on proper septic system maintenance is critical. Other homeowners may know that they need a new OSSF but may not have funds available to acquire one.</td></tr>
</table>

Escherichia coli, E. coli; Texas A&M AgriLife Extension Service, AgriLife Extension; on-site sewage facilities, OSSFs;

Table 19. Management measure 7: Reduce Illegal Dumping and Litter.

Pollutant source: Litter and pollution from illegal dumping
Problem: Illegal dumping of trash and animal carcasses in and along waterways
Objectives: • Promote and expand education and outreach efforts in the watershed • Install and maintain trash receptacles in public areas and along water bodies • Support cleanups and other efforts to reduce illegal dumping
Critical Areas: Entire watershed with focus on bridge crossings and public access areas
Goal: Increase awareness of proper disposal techniques and reduce illicit dumping of waste and animal carcasses in water bodies throughout the watershed.
Description: Education and outreach materials will be developed and delivered to residents throughout the watershed on the proper disposal of carcasses and waste materials. Also, working with responsible parties will lessen the impact of illicit dumping and improper animal carcass disposal.
Implementation strategy

Participants	**Recommendations**	**Period**	**Capital costs**
AgriLife Extension, Nacogdoches County, City of Nacogdoches	Develop and deliver educational and outreach materials to residents	2022-2031	N/A
Nacogdoches County, City of Nacogdoches	Install and maintain trash receptacles and promptly remove dumped trash and carcasses from common dumping areas	2022-2031	$500 – $1,000 per receptacle
Nacogdoches County Residents	Support efforts to reduce illegal dumping, initiate clean-up days, and promote protecting the waterways and public spaces	2022-2031	N/A

Estimated load reduction	
Load reductions are likely minimal from this management measure and were not quantified.	
Effectiveness	Low: Preventing illicit dumping, especially animal carcasses, is likely to reduce bacteria loads by some amount, although this loading is likely limited to areas with public access.
Certainty	Moderate: Anticipating changes in resident behavior due to education and outreach is difficult at best. Reaching residents that illegally dump is likely difficult.
Commitment	Moderate: Many stakeholders indicate illicit dumping occurs; however, enforcement is difficult in rural areas. The issue is not a high priority and commitment of limited resources will likely remain low.
Needs	Moderate: Some financial resources will be required to develop educational materials. Information could be incorporated into ongoing watershed-related educational and outreach efforts.

Texas A&M AgriLife Extension Service, AgriLife Extension;

Management Measure 6 – Identify, Inspect, and Remediate Failing On-Site Sewage Facilities

On-site sewage facilities, otherwise known as septic systems, treat wastewater at the household level in areas that are not serviced by centralized WWTPs. A failing septic system, especially near a water body, can be a health hazard to the residents and the water body. Encountering human wastewater is the biggest potential risk to human health compared to bacteria from other sources, so education for homeowners on proper maintenance, and identifying and repairing failing septic systems in the watershed will mitigate untreated wastewater entering La Nana Bayou.

Management Measure 7 – Reduce Illegal Dumping and Litter

Stakeholders have expressed concern about the presence of litter and animal carcasses in the watershed. Trash provides more surface area for bacteria to live and grow on, and animal carcasses dumped into a water body will decompose and add to water quality issues. While impacts to water quality are likely minimal from dumping alone, education and outreach can reduce the nuisance and associated bacteria loadings.

Table 20. Management Measure 8: Work with Area Schools to Develop Water Quality and Conservation Programs for K-12 Students.

<table>
<tr><th colspan="5">Youth Watershed Protection Education</th></tr>
<tr><td colspan="5">Objectives:
• Develop and expand education and outreach efforts for K-12 students in the area
• Provide technical assistance and training to teachers on watershed education</td></tr>
<tr><td colspan="5">Critical Areas: Entire watershed, at schools</td></tr>
<tr><td colspan="5">Goal: Increase awareness of watershed protection topics among K-12 students</td></tr>
<tr><td colspan="5">Description: Work with Nacogdoches ISD educators to determine what kind of programming already exists in their schools and what would be helpful. Develop or integrate existing educational materials for schools. Provide “train the trainer” opportunities for teachers to learn the materials and how to administer them effectively.</td></tr>
<tr><th colspan="5">Implementation strategy</th></tr>
<tr><th colspan="2">Participants</th><th>Recommendations</th><th>Period</th><th>Capital costs</th></tr>
<tr><td colspan="2">AgriLife Extension, Watershed Coordinator, Nacogdoches ISD</td><td>Develop and deliver education and outreach materials to teachers and students. Train teachers on watershed protection planning.</td><td>2022–2031</td><td>~$5,000 - $10,000 to get started with development</td></tr>
<tr><th colspan="5">Estimated load reduction</th></tr>
<tr><td colspan="5">Load reductions are likely minimal from this management measure and were not quantified.</td></tr>
<tr><td>Effectiveness</td><td colspan="4">Low to Moderate: While there may not be a direct correlation to water quality improvement, education and outreach is an effective tool to create awareness.</td></tr>
<tr><td>Certainty</td><td colspan="4">Moderate: Predicting behavior change is difficult but can be tracked through surveys, tests, and other evaluation methods.</td></tr>
<tr><td>Commitment</td><td colspan="4">Moderate to High: There is a lot of interest in the watershed in working with youth to develop environmental conservation programming.</td></tr>
<tr><td>Needs</td><td colspan="4">Moderate: Some financial and technical resources will be required to develop educational materials and coordinate training.</td></tr>
</table>

Independent school district, ISD; Texas A&M AgriLife Extension Service, AgriLife Extension;

Management Measure 8 – Work with Area Schools to Develop Water Quality and Conservation Programs for K-12 Students

The stakeholder group that developed this WPP has several members that are part of the local Independent School District (ISD), including teachers, parents of young children, and school board members. Integrating watershed education into the schools is important to the group. This management measure is not expected to impact water quality immediately but will instill the idea that watershed protection is everyone’s responsibility. Integrating water quality and quantity lessons into schools starting at an early age will hopefully protect water resources in the future and develop future watershed coordinators.

Table 21. Management Measure 9: Continue and Expand Water Quality Monitoring along La Nana Bayou and Banita Creek.

Continue and Expand Water Quality Monitoring			
Objectives: • Continue monitoring water quality in La Nana Bayou • Add more sampling events to the current quarterly regimen to increase temporal data • Add a monitoring station on Banita Creek • Increase number of sampling sites along both water bodies to collect more bacteria data			
Critical Areas: Along La Nana Bayou and Banita Creek			
Goal: Increase spatial and temporal resolution of data and better direct technical and financial resources			
Implementation strategy			
Participants	**Recommendations**	**Period**	**Capital costs**
ANRA, SFASU	Identify best monitoring site along La Nana Bayou and Banita Creek to collect more data	2022–2031	N/A
Estimated load reduction			
Load reductions are likely minimal from this management measure and were not quantified.			
Effectiveness	Moderate: This management measure will not directly impact water quality.		
Certainty	Moderate: Stakeholders are very interested in collecting additional data.		
Commitment	High: Water quality monitoring is already ongoing, and ANRA and SFASU are ready to increase their presence along the water bodies to add additional monitoring events.		
Needs	Moderate to High: Financial assistance is needed for personnel, equipment, and lab costs.		

Angelina and Neches River Authority, ANRA; Stephen F. Austin State University, SFASU;

Management Measure 9 – Continue and Expand Water Quality Monitoring along La Nana Bayou and Banita Creek

The watershed stakeholders indicated a need to expand water quality data collection through additional bacteria sampling along La Nana Bayou. In addition, stakeholders would like to add at least one monitoring station on Banita Creek to capture water quality information before it enters La Nana Bayou. Monitoring solely bacteria in more locations along both water bodies is also desired to create a higher spatial resolution of data. This will allow watershed stakeholders to better direct outreach resources to bacteria hotspots.

Table 22. Management measure summary.

Management Measure	Participants	Estimated Unit Cost	Implementation Goals (years after implementation begins)						Estimated total cost
			0-1	2-3	4-5	6-7	8-9	10	
1. Urban Stormwater Management									
Identify and install stormwater BMPs as funding becomes available	City of Nacogdoches, Nacogdoches County, property owners, environmental engineers, contractors	$4,000 – $45,000 per acre treated	As many as possible						N/A
Deliver education and outreach to landowners	City of Nacogdoches, AgriLife Extension, Watershed Coordinator	N/A	As often as possible						N/A
2. Develop WQMPs and CPs									
Provide financial and technical assistance for CPs and WQMPs	Producers, NRCS, TSSWCB, SWCDs	$15,000 per plan	2	3	5	5	5	5	$375,000
Education events and outreach	AgriLife Extension, SWCDs, NRCS, City of Nacogdoches, Watershed Coordinator	N/A	Approximately once every 3 years						N/A
3. Urban Waterfowl Management									
Conduct a waterfowl census survey; work with experts to manage population; educate public on egg health	Residents, AgriLife Extension, TPWD, environmental engineers, Watershed Coordinator	$5,000 – $30,000	At least one census, at least one management plan including outreach and education efforts						$5,000 to $30,000, depending on scope
4. Feral Hog Management									
Feral hog removal workshop	AgriLife Extension, Watershed Coordinator	$7,500 each	3						$22,500
Provide resources to support a county feral hog trapper	AgriLife Extension, Nacogdoches County	~$75,000 per year	1						~$750,000*
Install feral hog enclosures	Landowners	$200 per feeder	As many as possible						Varies
Feral hog removal	Landowners	Varies	10% reduction						Varies
Bounty program	AgriLife Extension, Nacogdoches County, landowners	Varies	As many as possible						Varies
5. Proper Pet Waste Disposal									
Install and maintain 10 pet waste stations	City of Nacogdoches	$500 per station	2	2	2	2	2		$5,000
Develop and deliver educational and outreach materials	City of Nacogdoches, Nacogdoches County	N/A	As many as possible						N/A

Management Measure	Participants	Estimated Unit Cost	Implementation Goals (years after implementation begins)						Estimated total cost
			0-1	2-3	4-5	6-7	8-9	10	
6. OSSF Remediation and Education									
Develop OSSF remediation outreach materials	Nacogdoches County, ANRA, Watershed Coordinator	N/A	1						N/A
Repair or replace at least 85 failing OSSFs	Homeowner, county designated representative, contractor	$7,500 per system	5	10	10	20	20	20	$637,500
Deliver education and outreach programs and workshops to homeowners	AgriLife Extension, county designated representative, Watershed Coordinator	N/A	3						N/A
7. Reduce Illegal Dumping and Litter									
Develop education and outreach materials	Nacogdoches County, City of Nacogdoches, ANRA, Watershed Coordinator	N/A	Develop and deliver annually						TBD
Install and maintain trash receptacles in public areas and along water bodies	Nacogdoches County, City of Nacogdoches, Watershed Coordinator	$500 – $1,000 per receptacle	1		1		1		~$3,000 +
Host clean-up days; promote protecting the waterways and public spaces	Nacogdoches County, City of Nacogdoches, ANRA, residents, Watershed Coordinator	N/A	1		1		1		N/A
8. Water Quality Education for Students									
Develop and deliver education and outreach materials to K-12 students and teachers	AgriLife Extension, Watershed Coordinator, Nacogdoches ISD	$10,000	1						$10,000
9. Reduce Illegal Dumping and Litter									
Identify sites along La Nana Bayou and Banita Creek to monitor	ANRA, SFASU, Watershed Coordinator	N/A	Once at beginning of project						N/A
Water quality monitoring at La Nana Bayou and Banita Creek	ANRA, SFASU, Watershed Coordinator	$2,500 per year per site	5 – 25 sites per month per year						~$12,000 – $60,000 per year
General Watershed Management									
Provide resources in support of a watershed coordinator	TCEQ, TSSWCB, Nacogdoches County, City of Nacogdoches, ANRA, SFASU	~75,000 per year	1						~750,000*
Semi-annual meetings	Watershed Coordinator	$300 per meeting	Semi-annually						$6,000

Angelina & Neches River Authority, ANRA; Best management practices, BMPs; conservation plans, CPs; Independent School District, ISD; Natural Resources Conservation Service, NRCS; on-site sewage facility, OSSF; Stephen F. Austin State University, SFASU; soil and water conservation districts, SWCDs; Texas A&M AgriLife Extension Service, AgriLife Extension; Texas Parks and Wildlife Department, TPWD; Texas State Soil and Water Conservation Board, TSSWCB; wastewater treatment facility, WWTF; water quality management plan, WQMP;

*Includes salary and fringe over 10 years

Table 23. Estimated *E. coli* load reductions for management measures that can be quantified.

Management Measure	Summarized *E. coli* Load Reduction
Agricultural management measures	3.77×10^{15} cfu/year
Feral hog population management	1.03×10^{12} cfu/year
OSSF remediation	4.52×10^{13} cfu/year
Pet waste management	1.15×10^{15} cfu/year
Total reduction	**1.57×10^{15} cfu/year**
Total reduction needed (from Ch. 5)	*2.81×10^{14} cfu/year*

colony forming units, cfu;

Expected Load Reduction Summary

Implementation of the management measures in the WPP will reduce *E. coli* loads across the watershed. Many of the management measures will provide direct *E. coli* load reductions. Other management measures, such as education and outreach programs, will result in reductions through behavior change but are not easily quantified.

The largest expected load reductions will result from the management measures recommended for livestock, pet waste, OSSFs, and feral hogs (Table 23). While their contributions are smaller, improvements in urban stormwater management, urban waterfowl management, and reduction in illegal dumping are expected to add to the total load reduction.

Chapter 7 Education and Outreach Plan

La Nana Bayou with high water levels during a flash flood event. Photo by Emily Monroe, TWRI.

Education Programs

Effective education and outreach are foundational to all successful WPP implementation efforts. Long-term commitments from residents will be necessary for achieving improvements in the watershed. The education and outreach component of implementation will focus on keeping the public, landowners, and agency personnel informed of project activities, providing information about appropriate management practices, and assisting in identifying and forming partnerships to lead the effort.

Watershed Coordinator

Leading the implementation of the WPP will require a watershed coordinator. This position will either be a new employee in one of the many stakeholder groups involved in the development and will solely focus on WPP implementation, like the Plum Creek Watershed Partnership has done, or will be a voluntary position carried out by a current stakeholder who is already working in the watershed in a similar capacity.

A successful watershed coordinator will primarily focus on establishing relationships and maintaining stakeholder support during the life of the WPP. This will allow them to secure funding for implementing the management measures, track implementation success, and adapt the plan as needed. During the development of this WPP, TWRI, ANRA, and SFASU shared this role, but a dedicated watershed coordinator is recommended to ensure the plan is supported in the future.

Future Stakeholder Engagement

To sustain engagement, the stakeholder group will coordinate the transition from WPP development to implementation by continuing to host educational programs and public meetings after submitting the WPP for review, updating the website, participating in local events to promote WPP awareness, and applying for implementation funding. News articles, newsletters, and the project website will be primary tools used to communicate with watershed stakeholders on a regular basis and will be developed to update readers periodically on implementation progress, provide information on new implementation opportunities, inform them on available technical or financial assistance, and other items of interest related to the WPP effort.

Education Programs

Hosting a variety of workshops in the watershed will be an important part of successful WPP implementation. Multiple programs geared toward providing information on various sources of potential pollutants and feasible management strategies have been and will continue to be hosted in the watershed. As implementation and data collection continues, the adaptive management process will be used to select the most appropriate educational workshops to meet the needs of the stakeholders.

Youth Education

The La Nana Bayou watershed stakeholders have a high interest in developing and implementing watershed education programs for primary and secondary schools. There are already several state-wide and ISD-specific watershed education programs available in Texas, so the stakeholder group will work with local school administrators to identify the needs of the teachers and students, research existing programs, and develop programs or materials to fill gaps. Existing resources that could serve as a model for developing programs in Nacogdoches include Austin's watershed education programming, the Guadalupe-Blanco River Authority's (GBRA) classroom tools, and TWRI's Texas Active Community and Citizen Education for Science and Stewardship (ACCESS) program.

The City of Austin's Watershed Education School Outreach programs has activities, videos, and more organized by grade level that can be found online at: www.austintexas.gov/department/watershed-youth-education. In the Guadalupe River Basin, GBRA staff will visit classes to teach lessons covering watershed protection topics like conservation, quality, and general water resources. They also allow educators to rent activity trunks for free that include supplies and instructions for lessons covering water properties, water cycle, and a variety of conservation topics. TWRI, along with Texas A&M Engineering Experiment Station and TSSWCB, have developed the ACCESS program that connects teachers and students to water education resources available in the state. This program includes workshops that educate teachers on citizen science opportunities and how to use GIS in the classroom, and provides toolkits, project materials, and access to online water education resources. Information about this program is available at: https://access.twri.tamu.edu.

Lone Star Healthy Streams Workshop

The LSHS program is geared towards expanding stakeholders' knowledge on how beef cattle producers can improve grazing lands to reduce nonpoint source pollution. This statewide program promotes the adoption of BMPs that have been proven to effectively reduce bacterial contamination of streams. In addition, LSHS provides educational support for developing CPs by illustrating the benefits of many practices available for inclusion in a CP to program participants.

OSSF Operation and Maintenance Workshop

Training on OSSF rules, regulations, operation, and maintenance will be delivered in the watershed. This training will be delivered by AgriLife Extension and consists of education and outreach practices to promote the proper management of existing OSSFs and to garner support for efforts to further identify and address failing OSSFs through inspections and remedial actions. Homeowners also have the option to use a free online training module developed by GBRA in cooperation with AgriLife Extension that provides an overview of septic systems, how they operate, and what maintenance is required to sustain proper functionality and extend system life. This module is available at: https://www.gbra.org/presentations/septic/index.html. Additionally, AgriLife also provides a more in depth online coursefor homeowners regarding proper operation, maintenance, and monitoring service of aerobic treatment systems at: https://ossf.tamu.edu/event/homeowner-maintenance-of-atu-online/.

Healthy Lawns and Healthy Waters

Healthy Lawns and Healthy Waters (HLHW) is an educational training program that aims to improve and protect surface water quality by enhancing Texas residents' awareness and knowledge of BMPs for residential landscapes. Funding for HLHW is provided in part through CWA 319(h) grants from EPA that are administered through TCEQ. This program is designed to train homeowners and landowners to design and install residential rainwater capture devices and educate them about the importance of soil testing and how to determine nutrient application rates. The goal of this program is to train Texans regarding reduced runoff, water quality, and BMPs for protecting their home landscape, watershed, and surface waters. More information can be found at the HLHW webpage: https://hlhw.tamu.edu/.

Texas Well Owners Network

Private water wells are a source of water for many Texas residents. The Texas Well Owners Network program provides needed education and outreach that focuses on private drinking water wells and the impacts on human health and the environment that can be mitigated by using proper management practices. Through this program well screenings are conducted and well owners are provided with useful information to assist them in better managing their water supplies. More information on this program can be found at the Texas Well Owners Network website: https://twon.tamu.edu/.

Riparian and Stream Ecosystem Education Program

Healthy watersheds and good water quality go hand in hand with properly managed riparian and stream ecosystems. Delivery of the Riparian and Stream Ecosystem Education Program will increase stakeholder awareness, understanding, and knowledge about the nature and function of riparian zones. Additionally, the program will educate stakeholders on the benefits of riparian zones and the BMPs that can be implemented to protect them while minimizing nonpoint source pollution. Through this program, riparian landowners will be introduced to local technical and financial resources to improve management and promote healthy watersheds and riparian areas on their land.

Feral Hog Management Workshop

AgriLife Extension personnel deliver periodic workshops focusing on feral hog management. This workshop will educate landowners on the negative impacts of feral hogs, effective control methods, and resources to help them control this invasive species.

Land Management and Wildlife Management Workshops

Wildlife has numerous significant impacts on the La Nana Bayou watershed and as a result, periodic wildlife management workshops are warranted to provide information on strategies and resources that are available to landowners and others interested in protecting wildlife habitat. The watershed coordinator will work with AgriLife Extension wildlife specialists and TPWD as appropriate to plan and secure funding to deliver workshops in and near the watershed.

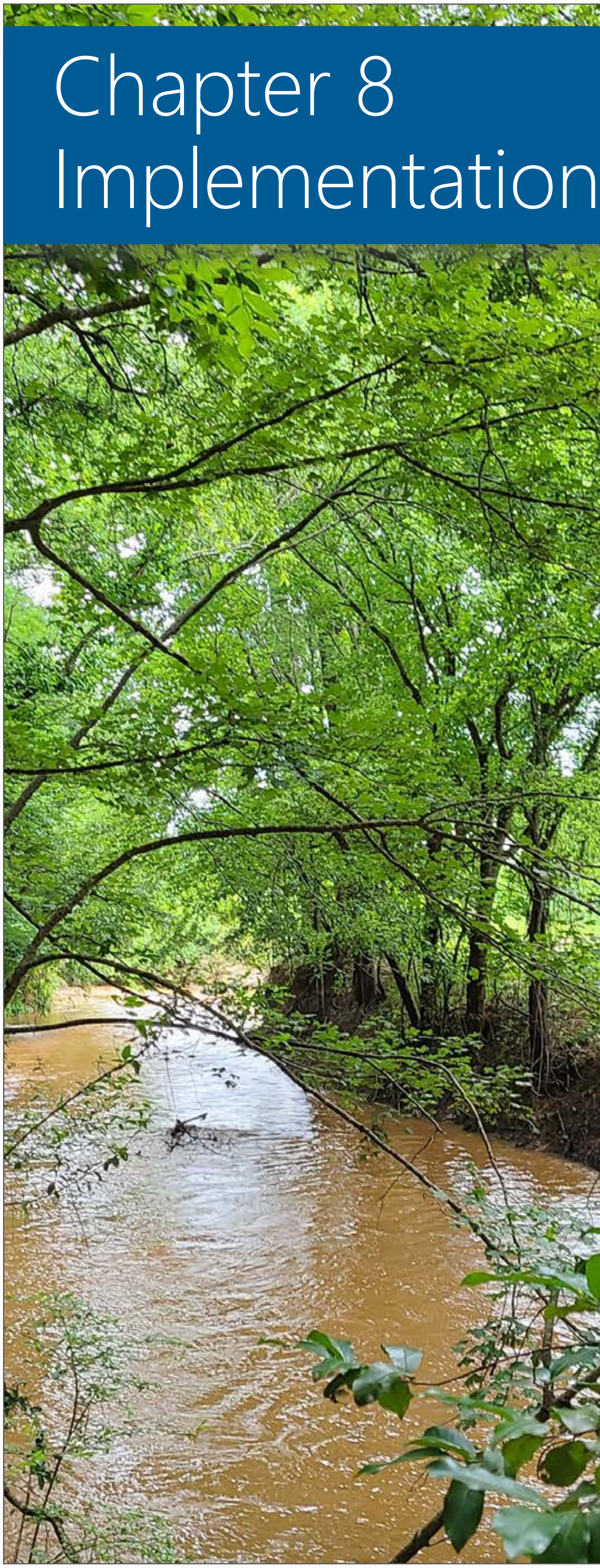
Public Meetings

Public meetings will provide a platform for the watershed coordinator and project personnel to provide WPP updates and planning information such as implementation progress, near-term implementation goals and projects, information on how to sign-up or participate in active implementation programs, contact information for specific implementation programs, and other information as appropriate. These meetings will also keep stakeholders engaged by providing a platform for feedback and discussing adaptive management as necessary to keep the WPP relevant to watershed and water quality needs. This will be accomplished by reviewing water quality data, implementation goals, and milestones during at least one public meeting annually and actively discussing how watershed needs can be better served. Feedback will be incorporated into WPP addendums as appropriate. It is anticipated that public meetings will be held on an annual basis, and any additional meetings will be scheduled based on need.

Newsletters and News Releases

Annual watershed newsletters will be developed and sent directly to actively engaged stakeholders and will be published on the watershed website between project meetings. News releases will also be developed and distributed as needed through the mass media outlets in the area and will be used to highlight significant events and accomplishments related to WPP implementation and to continue to raise public awareness and support for watershed protection. Newsletters and media releases will also be used to advertise public meetings and inform stakeholders of implementation programs, eligibility requirements, when and where to sign up, and what the specific programs will entail.

Chapter 8
Implementation Resources



La Nana Bayou from the La Nana Creek Trail. Photo by Emily Monroe, TWRI.

This chapter identifies potential technical and financial assistance sources available to implement management measures in the La Nana Bayou watershed. Grant funding will be a substantial source of implementation funding given the type and variety of needs identified. Funding support for a local watershed coordinator to guide WPP implementation and facilitate long-term success of the plan is also critical and will be sought through grant opportunities.

Technical Assistance

Designing, planning, and implementing the many management recommendations in the WPP will require technical expertise. In these cases, appropriate technical support will be sought. Funding required to secure needed expertise will be included as appropriate in requests for specific projects. Potential technical assistance sources for each management measure are listed below (Table 24).

OSSF Remediation

Identifying failing OSSFs requires trained personnel and available time. County DRs or septic service providers can provide expertise and help identify systems in need of repairs or replacement. Technical support is also needed to help secure funding for large-scale programs to repair or replace failing OSSFs. Education and outreach content for OSSF owners is also technical in nature and requires trained personnel. Texas A&M AgriLife Extension Service personnel can provide these educational resources.

Stormwater Runoff

Urban stormwater infrastructure and stormwater management efforts can benefit from technical assistance provided through education programs, BMP demonstrations, and public or privately funded projects. Practice demonstrations provide physical teaching tools and allow decision makers to see how BMPs look and function. This is especially useful for encouraging green stormwater infrastructure in areas where traditional practices are common. AgriLife Extension, ANRA, and Texas A&M Forest Service (TFS) will coordinate with city and county officials to develop and implement demonstration sites and full-scale projects as needed. Technical assistance with education and outreach programming is available through AgriLife Extension and TFS. Structural

Table 24. Summary of potential sources of technical assistance.

Management Measure (MM)	Technical Assistance
MM1: Mitigate Urban Stormwater Runoff Issues	City, AgriLife Extension, TFS
MM2: Promote the Development of Water Quality Management Plans or Conservation Plans	SWCD, NRCS, County, AgriLife Extension
MM3: Technical Assistance for Urban Waterfowl Management	City, County, TPWD and other state agencies, wildlife protection groups
MM4: Promote BMPs for Managing Feral Hog Populations	County, AgriLife Extension, ANRA, TPWD
MM5: Promote Proper Disposal of Pet Waste in Urban Areas	City, County, ANRA, AgriLife Extension
MM6: Identify, Inspect, and Remediate Failing On-Site Sewage Facilities	County, designated representatives, AgriLife Extension
MM7: Reduce Illegal Dumping and Litter	City, County, ANRA
MM8: Work with Area Schools to Develop Water Quality and Conservation Programs for K-12 Stu-dents	Nacogdoches ISD, Texas Education Agency, ANRA, SFASU, other Texas educational institutions, TWRI
MM9: Continue and Expand Water Quality Monitor-ing Along La Nana Bayou and Banita Creek	ANRA, SFASU

Angelina & Neches River Authority, ANRA; Best management practices, BMPs; conservation plans, CPs; Independent School District, ISD; management measure, MM; Natural Resources Conservation Service, NRCS; on-site sewage facility, OSSF; Stephen F. Austin State University, SFASU; soil and water conservation districts, SWCDs; Texas A&M AgriLife Extension Service, AgriLife Extension; Texas Parks and Wildlife Department, TPWD; Texas State Soil and Water Conservation Board, TSSWCB; Texas Water Resources Institute, TWRI; wastewater treatment facility, WWTF; water quality management plan, WQMP;

projects may need engineering designs that should be integrated into the costs of the projects.

Wildlife and Invasive Species

Watershed stakeholders can benefit from technical assistance regarding white-tailed deer and feral hog control approaches, options, best practices, and regulations. AgriLife Extension and TPWD can provide educational resources through local programs and public events. Online resources regarding feral hog trap and transport regulations, trap construction and design, and trapping techniques are also available at AgriLife Extension's "Coping with Feral Hogs" webpage: https://feralhogs.tamu.edu/.

Livestock Management

Technical assistance to develop and implement practices to improve livestock management is available from TSSWCB, SWCD, AgriLife Extension, and county agencies. Interested producers must request planning assistance and these agencies will work with each producer to define operation-specific management goals and objectives and develop a management plan that prescribes effective practices that will achieve stated goals while also improving water quality.

Pet Waste

Limited technical assistance is available to directly address pet waste. City public works departments, homeowner associations, and other entities as appropriate will be relied upon to identify viable sites for additional pet waste stations. These entities may also be able to provide operation and maintenance of current and future pet waste collection sites. Educational materials can be provided to cities and counties through AgriLife Extension and ANRA.

Reduce Illicit Dumping

Efforts to reduce illicit dumping will focus on education and outreach in conjunction with hazardous waste collection events throughout the watershed. AgriLife Extension and ANRA will provide technical assistance with education and outreach efforts. County law enforcement and TPWD game wardens are the primary source for enforcement and monitoring activities associated with illicit dumping. The cities and counties, in concert with ANRA, will continue efforts to secure funding support for cleanups and trash collection locations.

Technical Resources Overview

Texas A&M AgriLife Extension

AgriLife Extension is a statewide outreach and education agency with offices in every county of the state. AgriLife Extension provides a network of professional educators, volunteers, and local county extension agents. AgriLife Extension will be consulted to develop and deliver education programs, workshops, and materials as needed.

County or City Designated Representatives

New OSFFs construction or replacement of OSSFs in Nacogdoches County requires a permit on file with local authorized agents. Permits must be applied for through a TCEQ-licensed professional installer. The county or city's DR is responsible for approving or denying permits. Site evaluations must be done by a TCEQ-licensed Site Evaluator, licensed maintenance provider, or licensed professional installer.

Natural Resources Conservation Service

The NRCS provides conservation planning and technical assistance to private landowners who have voluntarily worked with NRCS personnel to prevent erosion, improve water quality, and promote sustainable agriculture. Assistance is available to help landowners maintain and improve private lands, implement improved land management technologies, protect water quality and quantity, improve wildlife and fish habitat, and enhance recreational opportunities. There are local NRCS service centers in Nacogdoches and Lufkin.

Angelina & Neches River Authority

Valuable assistance is provided by ANRA in all or parts of the 17 counties located in the Angelina and Neches River Basins in east Texas. The river authority also provides routine water quality monitoring data to the state's database, administers water quality related environmental programs, permit compliance monitoring, an industrial pretreatment program, and provides WWTP operation expertise. ANRA will be a primary source of water quality data and environmental technical assistance across the watershed.

Soil and Water Conservation Boards

A SWCD, like a county or school district, is a subdivision of the state government, and are administered by a board of five directors who are elected by their fellow landowners. There are 216 individual SWCDs organized in Texas. It is through this conservation partnership that local SWCDs can furnish technical assistance to farmers and ranchers for the preparation of a complete soil and water CP to meet each land unit's specific capabilities and needs. The local SWCD is the Nacogdoches SWCD at 1122 N University Drive., Ste B.

Texas Commission on Environmental Quality

A variety of programming and personnel resources that can provide technical support for WPP implementation is offered by TCEQ. The TCEQ Sanitary Sewer Overflow Initiative is a voluntary program for permitted WWTPs and municipalities. Through the initiative, an SSO Plan is developed outlining the causes of SSOs, mitigative and corrective actions, and a timeline for implementation. Assistance for SSO planning and participation in the SSO Initiative is available through the TCEQ Regional Office (Region 10, Beaumont) and the TCEQ Small Business and Environmental Assistance Division.

Regional offices of TCEQ also provide resources and expertise for environmental monitoring activities, investigating compliance at permitted facilities and responding to complaints, developing enforcement actions for violations, and performing environmental education and technical assistance for communities as needed. Regional offices also respond to environmental emergencies (disasters, spills, etc.) and evaluate public exposure to hazardous materials.

Texas Parks and Wildlife Department

The TPWD's Private Land Services is a program to provide landowners with practical information on ways to manage wildlife resources that are consistent with other land use goals, to ensure plant and animal diversity, to provide aesthetic and economic benefits, and to conserve soil, water, and related natural resources. The agency offers assistance in developing property-specific wildlife habitat management plans and can aid in tracking the expected water quality improvements. Additionally, TPWD offers a habitat management workshop through their regional biologists. To participate, landowners may request assistance by contacting the TPWD district serving their county.

Texas State Soil and Water Conservation Board

The operation of local SWCDs is supported by TSSWCB. In addition, TSSWCB leads the WQMP Program by providing technical assistance for developing management and CPs at no charge to agricultural producers. Visits with the local SWCD offices are the first step for operators to begin the plan development process.

Financial Resources

Successful WPP implementation will require substantial financial resources. Diverse funding sources will be sought to meet these needs. 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. 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 that are applicable to this WPP will be sought as appropriate and are described in this section.

Federal Sources

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

Grant funding is provided to the State of Texas by EPA for implementation of projects that reduce nonpoint source pollution through the CWA §319(h) Nonpoint Source Grant Program. These grants are administered by TCEQ and TSSWCB. Implementation measures included in WPPs that satisfy EPA's nine key elements of successful watershed-based plans and meet other program rules are eligible for funding though the 319(h) grant program. Some commonly funded items include, but are not limited to:

- Development and delivery of education programs
- Water quality monitoring
- OSSF repairs and replacements
- BMP installation and demonstrations
- Water body cleanup events

Further information can be found on the TCEQ Nonpoint Source Grant Program: https://www.tceq.texas.gov/water-quality/nonpoint-source/grants/grant-pgm.html and the TSSWCB Nonpoint Source Management Program: https://www.tsswcb.texas.gov/programs/texas-nonpoint-source-management-program webpages.

Conservation Stewardship Program

The Conservation Stewardship Program (CSP) is a voluntary conservation program administered by the NRCS that encourages producers to address resource concerns in a comprehensive manner by undertaking additional conservation activities and improving, maintaining, and managing existing conservation activities. The program is available for private agricultural lands including cropland, grassland, prairie land, improved pasture, and rangeland. Landowners and stewards are encouraged to improve conservation activities on their land by installing and adopting additional conservation practices including, but not limited to, prescribed grazing, nutrient management planning, precision nutrient application, manure application, and integrated pest management. Program information can be found on the CSP webpage at: https://www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program.

Conservation Reserve Program

The Conservation Reserve Program is a voluntary program for agricultural landowners administered by the Farm Service Agency. Individuals may receive annual rental payments to establish long-term, resource conserving practices 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% of the costs to establish approved conservation practices, enrollment payments, and performance payments are available through the program. Information on the program is available online at: https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index.

Environmental Quality Incentives Program

The NRCS operates the Environmental Quality Incentives Program (EQIP), which is a voluntary program that provides financial and technical assistance to agricultural producers through contracts up to a maximum term of 10 years. These contracts provide financial assistance to help plan and implement conservation practices that address natural resource concerns and provide opportunities to improve soil, water, plant, animal, air, and related resources on agricultural land and non-industrial private forestland. Individuals engaged in livestock or agricultural production on eligible land are also permitted to participate in EQIP. Practices selected must address natural resource concerns, are subject to the NRCS technical standards adapted for local conditions and must be approved by the local SWCD. Local work groups are formed to provide recommendations to the NRCS that advise the agency on allocations of EQIP county-based 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: https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives.

National Water Quality Initiative

The National Water Quality Initiative (NWQI) is administered by NRCS, and is a partnership between NRCS, state water quality agencies, and EPA to identify and address priority impaired water bodies through voluntary conservation. Conservation systems include practices to promote soil health and reduce erosion and nutrient runoff. Further information is available online at: https://www.nrcs.usda.gov/programs-initiatives/national-water-quality-initiative.

Regional Conservation Partnership Program

The Regional Conservation Partnership Program (RCPP) is a comprehensive, flexible program that uses partnerships to stretch and multiply conservation investments to reach conservation goals on a regional or watershed scale. Through the RCPP and NRCS, state, local, and regional partners coordinate resources to help producers install and maintain conservation activities in selected project areas. Partners leverage RCPP funding in project areas and report on the benefits achieved. Information regarding RCPP can be found on the

RCPP webpage at: https://www.nrcs.usda.gov/programs-initiatives/rcpp-regional-conservation-partnership-program.

Rural Development: Water and Environmental Programs

The Rural Development Program 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: provide 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: assist non-profit organizations that offer technical assistance and training for water delivery and waste disposal.
- Water and Waste Disposal Direct Loans and Grants: assist 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: https://www.rd.usda.gov/programs-services/water-environmental-programs.

Urban Water Small Grants Program

The objective of the Urban Waters Small Grants Program, administered by EPA, is to fund projects that will foster a comprehensive understanding of local urban water issues, identify and address these issues at the local level, and educate and empower the community. In particular, the Urban Waters Small Grants Program seeks to help restore and protect urban water quality and revitalize adjacent neighborhoods by engaging communities in activities that increase their connection to, understanding of, and stewardship of local urban waterways. More information about the Urban Waters Small Grants Program can be found online at: https://www.epa.gov/urbanwaterspartners/urban-waters-small-grants-old.

State Sources

Clean Rivers Program

The Texas CRP is a state fee-funded program administered by TCEQ 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 partner for the La Nana Bayou watershed is ANRA. The program supports water quality monitoring, annual water quality assessments, and engages stakeholders in addressing water quality concerns in the La Nana Bayou watershed. More information about the ANRA CRP is available at: https://www.anra.org/conservation-recreation/water-quality-activities/clean-rivers-program/.

Clean Water State Revolving Fund

The Clean Water State Revolving Fund (CWSRF), authorized through the CWA and administered by the Texas Water Development Board (TWDB), provides low-interest loans to local governments and service providers for infrastructure projects that include stormwater BMPs, WWTPs, and collection systems. The loans can spread project costs over a repayment period of up to 20 years. Repayments are cycled back into the fund and used to pay for additional projects. Through 2020, the program has committed approximately $10 billion for projects across Texas. More information on CWSRF is available on the TWDB CWSRF webpage: http://www.twdb.texas.gov/financial/programs/CWSRF/.

Landowner Incentive Program

The Landowner Incentive Program (LIP), administered by TPWD, assists 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 on the TPWD LIP webpage: https://tpwd.texas.gov/landwater/land/private/lip/.

Supplemental Environmental Projects

The Supplemental Environmental Projects (SEP) program, administered by TCEQ, directs fines, fees, and penalties for environmental violations toward environmentally beneficial uses. Through this program, a respondent in an enforcement matter can choose to invest penalty dollars to improve the environment, rather than paying into the Texas General Revenue Fund. Program dollars may be directed to OSSF repair, trash clean up, and wildlife habitat restoration or improvement, among other things. Program dollars may be directed to entities for single, one-time projects that require special approval from TCEQ or directed entities (such as Resource Conservation and Development Councils) with pre-approved "umbrella" projects. Further information about SEP is available on the TCEQ SEP webpage: https://www.tceq.texas.gov/compliance/enforcement/sep/sep-main.

Texas Farm and Ranch Lands Conservation Program

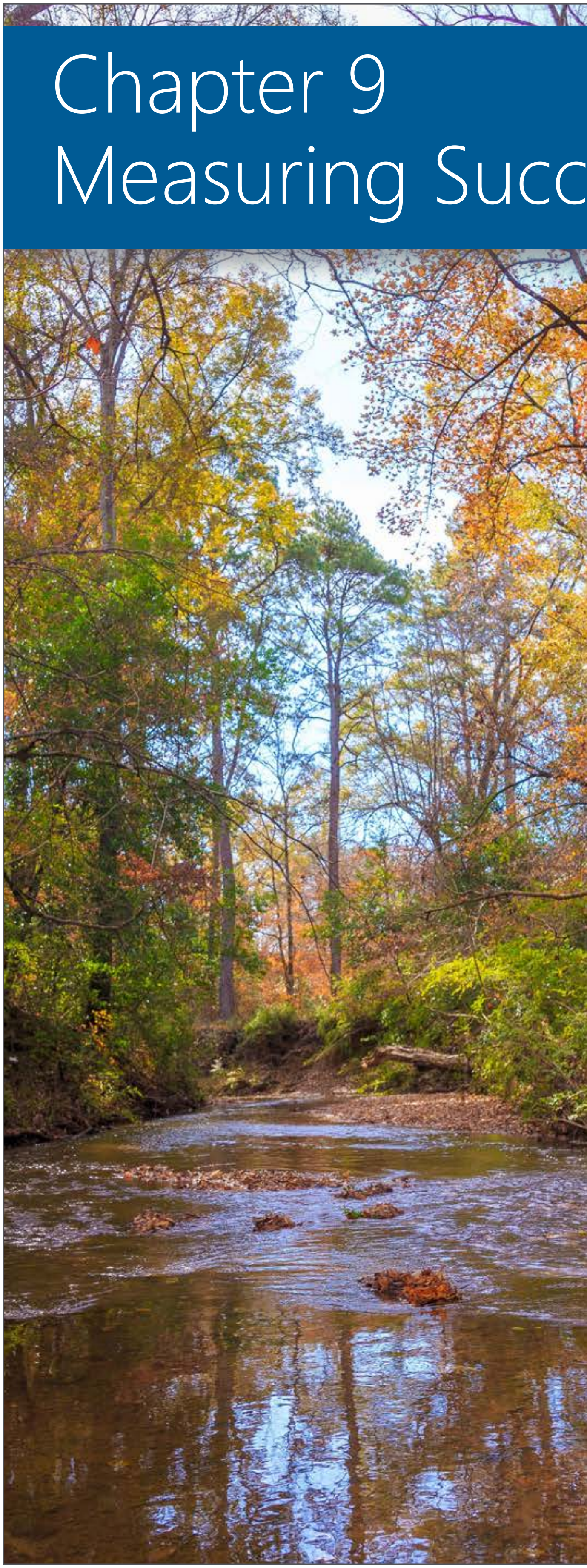
The Texas Farm and Ranch Lands Conservation Program was established and is administered by TPWD to conserve high value working lands to protect water, fish, wildlife, and agricultural production that are at risk of future development. The program's goal is to educate citizens on land resource stewardship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

Additional Sources

Private foundations, non-profit organizations, land trusts, and individuals can potentially assist with implementing 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.
- Partnerships with local industry in the watershed could also provide in-kind donations or additional funding for implementation projects.
- Texas Agricultural Land Trust: funding provided by the trust assists in establishing conservation easements for enrolled lands.

Chapter 9
Measuring Success



La Nana Bayou. Photo by Ed Rhodes, TWRI.

Implementing this WPP requires coordination with many stakeholders over the next 10 years. Implementation will focus on addressing readily manageable bacteria sources in the watershed to achieve water quality targets. This plan identified substantial financial resources, technical assistance, and education required to achieve these targets. Management measures identified in this WPP are voluntary but supported at the recommended levels by watershed stakeholders.

Measuring WPP implementation impacts on water quality is a critical process. Planned water quality monitoring at critical locations will provide data needed to document progress toward water quality goals. While improvements in water quality are the preferred measure of success, documenting implementation accomplishments can also be used. Combining water quality data and implementation accomplishments helps facilitate adaptive management by illustrating which recommended measures are working and which measures need modification.

Water Quality Targets

An established water quality goal defines the target for future water quality and allows the needed bacteria load reductions to be defined. The stakeholder selected water quality goal in La Nana Bayou is the existing primary contact recreation water quality standard for *E. coli* of 126 cfu/100 mL (Table 25). If there are revisions or adoption of new water quality standards (such as nutrients), these targets may be revised or amended as appropriate.

Additional Data Collection Needs

Continued water quality monitoring in La Nana Bayou is necessary to track changes resulting from WPP implementation. Currently, ANRA conducts quarterly water quality monitoring at three monitoring stations in the watershed, which is used in the state water quality assessment, is critical for future evaluations, and should be continued. Additionally, stations 10474, 20792, and 13096 were used in LDC analysis to determine needed load reductions to meet the water quality targets listed above. Continued data collection over time is imperative for changes in bacteria loading to be evaluated.

Table 25. Water quality targets for impaired water bodies in the La Nana Bayou watershed.

Station	Segment	Current Concentration*	5 Years After Implementation*	10 Years After Implementation*
10474	0611B_01	279.46	76.73	≤126
20792	0611B_02	576.58	225.29	≤126
16301	0611B_03	443.93	158.97	≤126

*Geometric mean in units of cfu of *E. coli* per 100 mL of water

The current monitoring site distribution and data collection frequency across the watersheds limit potential to observe subtle changes in water quality that result from WPP implementation. Defining localized water quality changes from specific implementation activities will require focused water quality monitoring efforts. These can only be planned once specific WPP implementation activities and locations are known and will require funding support. Targeted water quality monitoring could include paired watershed studies, multiple watershed studies, or edge of field runoff analysis where different land use or management measures have been implemented. Data derived from this monitoring could demonstrate the applicability of different BMPs within the watershed. Targeted monitoring may also include more intensive sampling in other stream segments to identify potential pollutant sources.

Through the adaptive management process and WPP updates, future water quality monitoring needs will be evaluated and adjusted as necessary. This could include adding new sites to address new concerns or areas of interest in the watershed, and the data collected at new sites will be included in the quality assurance project plans developed with future monitoring efforts. Stakeholders are interested in collecting data along Banita Creek, another water body in the watershed that is not currently monitored, as well as collecting more data along La Nana Bayou.

Data Review

Watershed stakeholders are responsible for evaluating WPP implementation impacts on instream water quality. Stakeholders will use TCEQ's statewide biennial water quality assessment approach, which uses a moving seven-year geometric mean of bacteria data collected through the state's CRP as a primary means of gauging implementation success. This assessment is published in the Texas Integrated Report and is available on the TCEQ Integrated Report webpage: https://www.tceq.texas.gov/waterquality/assessment/305_303.html. It is noted that a two-year lag occurs between data reporting and assessment results in the Texas Integrated Report, therefore the 2026 or 2028 Texas Integrated Report will likely be the first to include water quality data collected after WPP implementation begins.

Identifying water quality improvements from WPP implementation is challenging if relying only on the seven-year-data window used for the Texas Integrated Report. Another method to evaluate water quality improvements is using the geometric mean of the most recent three years of water quality data identified within TCEQ's SWQMIS. To support data assessment as needed, trend analysis and other appropriate statistical analyses will be used. Regardless of method used, water quality changes resulting from WPP implementation will be difficult to determine and may be overshadowed by activity in the watershed that negatively influences water quality. As such, data review will not be relied on exclusively to evaluate WPP effectiveness. Data will be summarized and reported to watershed stakeholders at least annually through stakeholder meetings and ANRA's annual CRP meeting.

The watershed coordinator will be responsible for tracking implementation targets and water quality in the watershed. Implementation progress and water quality will be evaluated to describe the success of WPP implementation to that point. Should implementation targets or water quality improvements lag significantly, adaptive management efforts will be initiated to reevaluate management recommendations and targets included in the WPP.

Interim Measurable Milestones

WPP implementation will occur over a 10-year timeframe. Milestones can be useful in evaluating incremental implementation progress of management measures described in the WPP. Milestones outline a clear process for progression throughout implementation. Interim measurable milestones for management measures and education and outreach are addressed in Chapter 6. In some cases, funding acquisition, personnel hiring, or program initiation may delay the start of some items. This approach provides incremental targets to measure progress throughout WPP implementation. Adaptive management may be used where necessary to reorganize or prioritize varying implementation aspects to achieve overarching water quality goals.

Adaptive Management

Watersheds are dynamic by nature with countless variables governing landscape processes; therefore, uncertainty is expected and the WPP was developed with this in mind. As WPP implementation progresses, it is necessary to track water quality over time and make needed adjustments to the implementation strategy. Including an adaptive management approach in the WPP provides flexibility that enables such adjustments.

Adaptive management is the ongoing process of accumulating knowledge regarding impairment causes and water quality response as implementation efforts progress and adjusting management efforts as needed. As implementation activities are instituted, water quality is tracked to assess impacts. This information can be used to guide adjustments to future implementation activities. This ongoing, cyclical implementation and evaluation process can focus project efforts and optimize its impacts. Watersheds where impairments are dominated by nonpoint source pollutants are good candidates for adaptive management. Progress toward achieving established water quality targets will also be used to evaluate the need for adaptive management. An annual implementation progress and water quality trends review will be presented to stakeholders during meetings.

Due to numerous factors that can influence water quality and the time lag that often appears between implementation efforts and resulting water quality improvements, sufficient time should be allowed for implementation to occur before triggering adaptive management. In addition to water quality targets, if satisfactory progress toward achieving milestones is determined to be infeasible due to funding, implementation scope, or other reasons that would prevent implementation, adaptive management provides an opportunity to revisit and revise the implementation strategy. If stakeholders determine inadequate progress toward water quality improvement or milestones is being made, efforts will be made to increase BMP adoption and adjust strategies or focus areas as appropriate.

References

American Pet Products Association. 2014. American Pet Products Association National Pet Owners Survey. Accessed November 16, 2021. https://www.americanpetproducts.org/pubs_survey.asp.

American Veterinary Medical Association 2019. American Veterinary Medical Association U.S. Pet Ownership Statistics. Accessed September 29, 2021. https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics.

Bass, R., Burger, D., Vargas, M., Dean, K., Dulay, M., Bilbe, L., and Talley, A. 2013. Upper Cibolo Creek Watershed Protection Plan. https://www.ci.boerne.tx.us/DocumentCenter/View/3690/Upper-Cibolo-Creek-Watershed-Protection-Plan-PDF.

Browner, C. 1996. Watershed Approach Framework, United States Environmental Protection Agency.

(EPA). https://www.epa.gov/sites/default/files/2015-06/documents/watershed-approach-framework.pdf.

Center for Watershed Protection 2021. Center for Watershed Protection: Pollution Prevention Fact Sheet: Animal Waste Collection. Accessed November 16, 2021. https://www.stormwatercenter.net/Pollution_Prevention_Factsheets/AnimalWasteCollection.htm.

Clean Water Act (CWA). 33 U.S.C. §1251 et seq. (1972). https://www.govinfo.gov/content/pkg/USCODE-2018-title33/pdf/USCODE-2018-title33-chap26.pdf.

Farm Service Agency. 2023. Conservation Reserve Program. https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index.

GBRA. How a Septic System Works. https://www.gbra.org/presentations/septic/index.html.

Griffith, G., Bryce, S., Omernik, J., & Rogers, A. 2007. Ecoregions of Texas. Texas Commission on Environmental Quality.

Larkin, T.J. and Bomar, G.W. 1983. Climatic Atlas of Texas: Texas Water Development Board Limited Publication 192. http://www.twdb.state.tx.us/publications/reports/limited_printing/doc/LP192.pdf.

Nacogdoches County. 2018. Address Points Shapefile, December 26, 2019. Accessed October 1, 2021. http://co.nacogdoches.tx.us/maps/public_geodata_downloads/.

National Oceanic and Atmospheric Administration. 2021. U.S. Climate Normals 1991-2020. https://www.ncei.noaa.gov/access/us-climate-normals/#dataset=normals-monthly&timeframe=30&location=TX&station=USC00416177.

NRCS. Conservation Stewardship Program. https://www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program.

NRCS. Environmental Quality Incentives Program. https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives.

NRCS. National Water Quality Initiative. https://www.nrcs.usda.gov/programs-initiatives/national-water-quality-initiative.

NRCS. Regional Conservation Partnership Program. https://www.nrcs.usda.gov/programs-initiatives/rcpp-regional-conservation-partnership-program.

On-Site Sewage Facilities (OSSF). 2021. Homeowner Maintenance of ATU-ONLINE. https://ossf.tamu.edu/event/homeowner-maintenance-of-atu-online/.

PRISM Climate Group, Oregon State University. 2012. 30-Year Normals. 30-Year Normal Precipitation Spatial Data. http://www.prism.oregonstate.edu/normals/.

Rural Development. Water & Environmental Programs. https://www.rd.usda.gov/programs-services/water-environmental-programs.

Soil Survey Staff, NRCS. 2022. Web Soil Survey. Available online. Accessed March 3, 2022. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

TCEQ. 2020a. 2020 Texas Integrated Report - Texas 303(d) List (Category 5). https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/20txir/2020_303d.pdf.

TCEQ. 2020b. 2020 Guidance for Assessing and Reporting Surface Water Quality in Texas. https://wayback.archive-it.org/414/20200910072311/https:/www.tceq.texas.gov/assets/public/waterquality/swqm/assess/20txir/2020_guidance.pdf.

TCEQ. 2022. Supplemental Environmental Projects (SEPs). https://www.tceq.texas.gov/compliance/enforcement/sep/sep-main.

TCEQ. 2023. Nonpoint Source Grant Program. https://www.tceq.texas.gov/waterquality/nonpoint-source/grants/grant-pgm.html.

TCEQ SWQMIS. 2021. Surface Water Quality Web Reporting Tool. https://www80.tceq.texas.gov/SwqmisPublic/index.htm.

TCEQ. Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d). https://www.tceq.texas.gov/waterquality/assessment/305_303.html.

Texas Parks and Wildlife. Landowner Incentive Program. https://tpwd.texas.gov/landwater/land/private/lip/.

Texas Parks and Wildlife. Texas Farm and Ranch Lands Conservation Program. https://tpwd.texas.gov/landwater/land/private/farm-and-ranch/.

Texas Water Development Board. 2021. Regional Water Plan County Population Projections. https://www3.twdb.texas.gov/apps/reports/Projections/2022%20Reports/pop_county.

Texas Water Development Board. Clean Water State Revolving Fund (CWSRF) Loan Program. http://www.twdb.texas.gov/financial/programs/CWSRF/.

Timmons, J. B., Higginbotham, B., Lopez, R., Cathey, J. C., Mellish, J., Griffin, J., Sumrall, A., Skow, K. 2012. Feral hog population growth, density and harvest in Texas. Texas A&M AgriLife Extension Service. Report. https://agrilifetoday.tamu.edu/wp-content/uploads/2019/10/sp-472.pdf.

TSSWCB. 2017. Water Quality Management Plans for Poultry Operations. https://tsswcb.texas.gov/sites/default/files/2022-03/poultry-wqmp-information-august-2017.pdf.

TSSWCB. Texas Nonpoint Source Management Program. https://www.tsswcb.texas.gov/programs/texas-nonpoint-source-management-program.

United States Environmental Protection Agency (EPA). 2016. Monitoring and Evaluating Nonpoint Source Watershed Projects. Approaches to Load Estimation. https://www.epa.gov/sites/default/files/2016-06/documents/nps_monitoring_guide_may_2016-combined_plain.pdf.

United States Environmental Protection Agency (EPA). 2022. Urban Waters Small Grants – OLD. https://www.epa.gov/urbanwaterspartners/urban-waters-small-grants-old.

United States Environmental Protection Agency (EPA). 2023. Healthy Watersheds Protection Basic Information and Answers to Frequent Questions. www.epa.gov/hwp/basic-information-and-answers-frequent-questions.

U.S. Census Bureau. 2021. American Community Survey. https://www.census.gov/quickfacts/fact/table/nacogdochescountytexas,US/PST045219.

Wagner, K. L. and Moench, E. 2009. Education Program for Improved Water Quality in Copano Bay. Task Two Report. College Station, TX: Texas Water Resources Institute. TR-347. https://oaktrust.library.tamu.edu/handle/1969.1/93181.

Appendix A: GIS Analysis and Potential Load Calculations

A GIS analysis was used to estimate potential bacteria loads in the watershed and subwatersheds. This approach estimates potential loads by subwatershed and allows stakeholders to consider results for prioritizing management implementation. This geospatial approach provides an easy method to understand relative contributions and spatial distribution across the watershed without relying on data-intense (and expensive) modeling techniques. The analysis distributes inputs across the watershed based on land use and land cover attributes using GIS. The bacteria loadings are calculated from published bacteria production data and are then spatially distributed across the watershed based on appropriate land cover.

Agriculture Bacteria Loading Estimates

The first step to calculate potential bacteria loads from cattle was to develop cattle population estimates across the watershed, for which stakeholder input was critical. Because watershed-level livestock numbers are not available, livestock populations were estimated using the NASS 2017 census counts. The population estimate value was multiplied by the ratio of nonurban land in the watershed to nonurban land in the entire county. Finally, to standardize stocking rates based on relative livestock grazing patterns compared to one 1,000-pound mature cow, the estimated numbers of animals in the watershed were converted to animal units (AnU). This conversion was used to yield the total number of AnU for livestock and wildlife (see below). The assumptions used in this method are documented in Wagner and Moench (2009) and Borel et al. (2015; Table 26).

Table 26. Bacteria loading assumptions for livestock.

Assumptions			
	Estimated Number of Animals in watershed	**AnU Conversion**	**Fecal coliform production rate**
Cattle	2,899	1	8.55×10^{9} cfu/AnU-day†
Goats	40	0.17	2.54×10^{10} cfu/AnU-day†
Sheep	17	0.2	2.90×10^{11} cfu/AnU-day†
Horses	98	1.25	2.91×10^{8} cfu/AnU-day†
Fecal coliform to *E. coli* conversion rate		0.63 *E. coli* per cfu fecal coliform	

Animal units of cattle, AnU; colony forming units, cfu; *Escherichia coli, E. coli;*
† Wagner and Moench 2009

Using cattle population estimates, the potential annual load across the watershed and for individual subwatersheds was calculated as:

$$PAL_{cattle} = AnU \times FC_{cattle} \times Conversion \times 365 \frac{days}{year}$$

Where:

PAL_{cattle} = Potential annual *E. coli* loading attributed to cattle

AnU = Animal Units of cattle

FC_{cattle} = Fecal coliform rate of cattle

$Conversion$ = Estimated fecal coliform to *E. coli* conversion rate

The estimated potential annual loading across all subbasins due to cattle is: 5.7×10^{15} cfu *E. coli*/year.

Using population estimates of other livestock in the watershed, the annual load from goats, sheep, and horses were individually calculated as:

$$PAL_{livestock} = AnU \times FC_{livestock} \times \ Conversion \times 365 \frac{days}{year}$$

Where:

$PAL_{Livestock}$ = Potential annual *E. coli* loading

AnU = Animal Units conversion

$FC_{Livestock}$ = Fecal coliform rate

Conversion = Estimated fecal coliform to *E. coli* conversion rate

The estimated potential annual loading across all subwatersheds due to all other livestock is 2.75×10^{14} cfu *E. coli*/year.

Collectively, we estimated the total potential loading across the watershed from all livestock as 5.97×10^{15} cfu *E. coli*/year.

Dog Bacteria Loading Estimates

The dog population in the watershed was estimated using AVMA statistics for average number of dogs per household and an estimate of number of households derived from Census block data (AVMA 2019).

Table 27. Bacteria loading assumptions for dogs.

Assumptions	
Average dogs per home	0.614
Number of homes	18,045
Estimated number of dogs	11,080
Fecal coliform production rate for dogs*	5.0×10^9 cfu/animal-day
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform

Colony forming units, cfu; *Escherichia coli, E. coli;*
* EPA 2001

Using the assumptions listed in Table 17, the potential annual bacteria load from dogs is estimated as:

$$PAL_d = N_d \times FC_d \times \ Conversion \times 365 \frac{days}{year}$$

Where:

PAL_d = Potential annual *E. coli* loading attributed to dogs

N_d = Number of dogs

FC_d = Fecal coliform loading rate of dogs

Conversion = Estimated fecal coliform to *E. coli* conversion rate

The estimated potential annual loading across all subbasins due to dogs is 1.27×10^{16} cfu *E. coli*/year. A 12% annual load reduction would remove 1.53×10^{15} cfu *E. coli*/year from the water body.

OSSF Bacteria Loading Estimates

Using the OSSF estimates, potential *E. coli* loading across the watershed and for individual subwatersheds was estimated. Methods to estimate OSSF locations and numbers are described in Chapter 4 of this WPP.

Table 28. Bacteria loading assumptions for OSSFs.

Assumptions	
Estimated Number of OSSFs in watershed	2,835
Estimated failure rate	30%*
Average number of people per household	2.49[1]
Assumed sewage production rate	70 gallons per person per day[2]
Fecal coliform concentration in sewage	1.0×10^6 cfu/100 mL[3]
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform

Colony forming units, cfu; *Escherichia coli, E. coli;* milliliter, mL;
* Assumption from personal communication with Nacogdoches County DR, November 2021.
[1] US Census Bureau 2010
[2] Borel et al. 2015
[3] EPA 2001

Using the assumptions listed in Table 28, the potential annual bacteria load from OSSFs is estimated as:

$$PAL_{ossf} = N_{ossf} \times N_{hh} \times \ Production \ \times Failure\ Rate \ \times FC_s \times Conversion \times 3{,}578.2 \ \frac{mL}{gallon} \times 365 \frac{days}{year}$$

Where:

PAL_{ossf} = Potential annual *E. coli* loading attributed to OSSFs

N_{ossf} = Number of OSSFs

N_{hh} = Average number of people per household

Production = Assumed sewage discharge rate

Fail Rate = Assumed site specific failure rate

FC_s = Fecal coliform concentration in sewage

Conversion = Estimated fecal coliform to *E. coli* conversion rate

Therefore, the potential annual loading attributed to OSSFs from the estimated 30% failure rate is 1.02×10^{13} cfu *E. coli*/year.

Feral Hog and Wildlife Bacteria Loading Estimates

Feral hog populations were estimated based on an assumed population density of 33.3 acres/hog, this number was chosen based on stakeholder input, and 39,574 acres of available habitat identified in the NLCD. Potential bacteria loadings from feral hogs were estimated using GIS analysis and the assumptions in Table 29.

Table 29. Bacteria loading assumptions for feral hogs.

Assumptions	
Number of feral hogs in the watershed	1,188
Animal Unit conversion factor for feral hogs	0.125*
Fecal coliform production rate for feral hogs	1.21×10^9 cfu fecal coliform per animal*
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform

Colony forming units, cfu; *Escherichia coli, E. coli;*
* Wagner and Moench 2009

The potential annual bacteria load from feral hogs is estimated as:

$$PAL_{fh} = N_{fh} \times AnUC \times FC_{fh} \times Conversion \times 365 \frac{days}{year}$$

Where:

PAL_{fh} = Potential annual *E. coli* loading attributed to feral hogs

N_{fh}= Number of feral hogs

$AnUC$ = Animal Unit Conversion

FC_{fh} = Fecal coliform loading rate of feral hogs

Conversion = Conversion fecal coliform to *E. coli* conversion rate

Therefore, the estimated potential annual loading attributed to feral hogs is: 4.13×10^{13} cfu *E. coli*/year.

White-tailed deer estimates for the watershed are not available, therefore estimates from the TPWD RMU 14 and 15 were used. The average estimated deer density for RMU 14 and 15 from 2005 through 2019 is 56.49 acres per deer. Applying this density to pasture, cultivated crops, rangeland, and forest resulted in an estimated 701 deer in the watershed. Potential bacterial loadings were estimated using a GIS analysis and the assumptions in Table 30.

Table 30. Bacteria loading assumptions for white-tailed deer.

Assumptions	
Number of white-tailed deer in the watershed	701
Animal Unit conversion factor for white-tailed deer	0.112*
Fecal coliform production rate for white-tailed deer	1.5×10^{10} cfu fecal coliform per animal*
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform

Colony forming units, cfu; *Escherichia coli, E. coli;*
* Wagner and Moench 2009

The potential annual bacterial load from white-tailed deer is estimated as:

$$PAL_{wtd} = N_{wtd} \times AnUC \times FC_{wtd} \times Conversion \times 365 \frac{days}{year}$$

Where:

PAL_{wtd} = Potential annual *E. coli* loading due to white-tailed deer

N_{wtd} = Number of white-tailed deer

$AnUC$ = Animal Unit Conversion

FC_{wtd} = Fecal coliform loading rate of white-tailed deer

Conversion = Estimated fecal coliform to *E. coli* conversion rate

Therefore, the estimated potential annual loading attributed to white-tailed deer is 2.71×10^{14} cfu *E. coli*/year

WWTP Bacterial loading Estimates

Potential loadings from WWTPs were calculated as maximum permitted discharges of the City of Nacogdoches' WWTP multiplied by the maximum permitted *E. coli* concentration. The other permitted discharger, Cal-Tex Lumber, is not included because it only discharges cooling, storm, and wash water from their milling facility.

Table 31. Bacteria loading assumptions for City of Nacogdoches WWTP.

Assumptions	
Maximum permitted daily discharge	12.88 MGD
Permitted *E. coli* concentration of effluent	1.26 cfu *E. coli* per 1 mL

Colony forming units, cfu; *Escherichia coli, E. coli;*

Using the assumptions listed in Table 31, the potential annual bacterial load from WWTPs is estimated as:

$$PAL_{wwtf} = Discharge \times Concentration_{max} \times 3{,}785.2\ \frac{mL}{gallon} \times 365\,\frac{days}{year}$$

Where:

PAL_{wwtf} = Potential annual *E. coli* loading attributed to WWTPs

Discharge = Maximum permitted daily discharge from each WWTP

$Conversion_{effluent}$ = Permitted *E. coli* concentration of effluent

Therefore, the estimated potential annual loading attributed to WWTPs is 2.24×10^{13} cfu *E. coli*/year.

Appendix A. References

AVMA (American Veterinary Medical Association). 2018. 2017–2018 U.S. Pet Ownership & Demographics Sourcebook. Schaumberg, IL: American Veterinary Medical Association. https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics.

Borel, K., Karthikeyan, R., Berthold, A. T., Wagner, K. 2015. Estimating *E. coli* and Enterococcus loads in a coastal Texas watershed. Texas Water Journal. 6 (1): 33-44. https://doi.org/10.21423/twj.v6i1.7008.

U.S. Environmental Protection Agency. 2001. Protocol for Developing Pathogen TMDLs: Source Assessment. 1st Edition. Washington, DC: U.S. Environmental Protection Agency. EPA 841-R-00-002. https://nepis.epa.gov/Exe/ZyPURL.Cgi?Dockey=20004QSZ.txt.

USCB (U.S. Census Bureau). 2021. County Quick Facts from the American Community Survey. https://www.census.gov/quickfacts/fact/table/US/PST045221.

United States Department of Agriculture National Agricultural Statistics. 2017. Census of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Texas/.

U.S. Environmental Protection Agency. 2021. Enforcement and Compliance History Online (ECHO). Available online at: http://echo.epa.gov/.

Wagner, K. L. Moench, E. 2009. Education Program for Improved Water Quality in Copano Bay Task Two Report. College Station, TX: Texas Water Resources Institute. TR-347. https://oaktrust.library.tamu.edu/handle/1969.1/93181.

Appendix B: Calculations for Potential Bacteria Load Reductions

Estimates for bacteria load reductions in the La Nana Bayou watershed are based on the best available information regarding the effectiveness of management measures agreed upon by local stakeholders. The real-world conditions where implementation is completed will ultimately determine the actual load reduction achieved, which might differ from estimated values. Stakeholders determined the types and numbers of management measures to be implemented over a 10-year period based on perceived local acceptability, effectiveness, and available resources.

Agricultural Nonpoint Source Load Reductions

The potential load reductions that are achieved through conservation planning will depend on the specific management practices implemented by landowners. The load reduction will vary based on the type of practice, existing land condition, number of cattle in each operation, and proximity to water bodies. Substantial research has been conducted on bacteria reduction efficiencies of practices. We reviewed literature to assess the median effectiveness of practices likely to be used in the watershed (Table 32) and used a mean 62.8% load reduction effectiveness rate for conservation planning.

Table 32. Estimated effectiveness of conservation practices.

Effectiveness			
Conservation Practice	**Low**	**High**	**Median**
Exclusionary Fencing*	30%	94%	62%
Prescribed Grazing[1]	42%	66%	54%
Watering Facility[2]	51%	94%	73%

* Includes the following sources: (Brenner et al. 1996; Cook 1998; Hagedorn et al. 1999; Line 2002, 2003; Lombardo et al. 2000; Meals 2001; Peterson et al. 2011)

[1] Includes the following sources: (Tate et al. 2004; EPA 2010)

[2] Includes the following sources: (Byers et al. 2005; Hagedorn et al. 1999; Sheffield et al. 1997)

Table 33. Bacteria load reduction assumptions for livestock.

Assumptions	
Number of operations in the watershed	48.8 estimated
Head of cattle per operation	59.4 estimated
Fecal coliform production rate for cattle	8.55×10^9 cfu per animal unit per day*
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform
Conservation practice effectiveness rate	62.8%
Proximity factor	25%

Colony forming units, cfu; *Escherichia coli, E. coli;*

*Wagner and Moench 2009

Potential bacteria load reductions for livestock management measures were calculated based on the assumed average number of cattle per operation, average fecal coliform production rates, standard conversions, conservation practice effectiveness, and proximity factor of practice to water body (Table 32). The proximity factor is an estimated impact factor that accounts of an assumed stream impact factor based on the location of a practice to the stream. Practices closer to the stream are assumed to have a higher potential load reduction impact while those further away are assumed to have a lower impact. Since actual practices and locations are unknown, a proximity factor of 25% was assumed, similar to proximity factors used in other WPPs.

Using the above assumptions, the potential annual load reduction was estimated by:

$$LR_{cattle} = N_{plans} \times \frac{AnU}{Plan} \times FC_{cattle} \times Conversion \times 365\frac{days}{year} \times Efficacy \times Proximaty\ Factor$$

Where:

LR_{cattle} = Potential annual load reduction of *E. coli*

N_{plans} = Number of WQMPs and CPs, 25 are proposed in this WPP

AnU/Plan = Animal Units of cattle per management plan

FC_{cattle} = Fecal coliform loading rate of cattle

Conversion = Estimated fecal coliform to *E. coli* conversion rate

Efficacy = Median BMP efficacy value

Proximity Factor = Percentage-based factor based on the assumed proximity of the management measure to the water body

The WPP recommends the implementation of 25 WQMPs or CPs across the watershed, resulting in a total potential annual load reduction of 3.77×10^{14} cfu *E. coli* per year. Additionally, nutrient reductions can be anticipated with each WQMP or CP. The Tres Palacios and Carancahua Bay WPPs estimated annual load reductions ranging from 733 to 983 pounds of nitrogen and 276 to 511 pounds of phosphorus per WQMP or CP depending on presumed size and type of agricultural operation (Schramm et al., 2017; Schramm et al., 2019).

Feral Hog Load Reductions

Load reductions for feral hogs assume that existing feral hog populations can be reduced and maintained by a certain amount on an annual basis. Removal of a feral hog from the watershed is assumed to also completely remove the potential bacteria load generated by that feral hog. Therefore, the total potential load reduction is calculated as the population reduction in feral hogs achieved in the watershed.

Based on GIS analysis, 1,188 feral hogs were estimated to exist across the La Nana Bayou watershed (see Appendix A for details). The established goal is to reduce and maintain the feral hog population to 10% below current population estimates, thus resulting in a 10% reduction in potential loading that is attributable to feral hogs.

Table 34. Bacteria load reduction assumptions for feral hogs.

Assumptions	
Number of feral hogs removed per year	118.8 (10% of total estimated population)
Animal Unit conversion factor	0.125*
Fecal coliform production rate for feral hogs	1.21×10^9 cfu per animal unit per day*
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform
Proximity factor	25%

Colony forming units, cfu; *Escherichia coli, E. coli;*
*Wagner and Moench 2009

Load reductions were calculated based on the following:

$$LR_{fh} = N_{fh} \times AnUC \times FC_{fh} \times Conversion \times 365\frac{days}{year} \times Proximaty\ Factor$$

Where:

LR_{fh} = Potential annual load reduction of *E. coli* attributed to feral hog removal

N_{fh} = Number of feral hogs removed

AnU= Animal Unit conversion factor

FC_{fh} = Fecal coliform loading rate of feral hogs

Conversion = Estimated fecal coliform to *E. coli* conversion rate

Proximity Factor = Percentage based factor based on the assumed proximity of the management measure to the water body

The estimated potential annual load reduction across the La Nana Bayou watershed based on reducing and maintaining the feral hog population by 10% is 1.03×10^{12} cfu *E. coli* per year. Additionally, nutrient reductions can be anticipated for each feral hog removed. The Tres Palacios and Carancahua Bay WPPs estimated annual load reductions were six pounds of nitrogen and two pounds of phosphorus per hog removed (Schramm et al. 2017; Schramm et al. 2019).

Pet Waste Load Reductions

Potential load reductions for pet waste depend on the number of pets that contribute loading and the amount of pet waste that is picked up and disposed of properly. Assessing the number of dog owners who do not pick up waste or who would change behavior based on education or availability of pet waste stations is inherently difficult. It is estimated that 12% of dog owners that do not currently pick up after their pets would be willing to change their behavior (Center for Watershed Protection 1999).

Table 35. Bacteria load reduction assumptions for dogs.

Assumptions	
Number of dogs in the watershed	11,080
Percent of dogs managed	12%*
Fecal coliform production rate for dogs	5.0×10^9 cfu per animal per day[1]
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform[2]
Practice efficiency	75%

Colony forming units, cfu; *Escherichia coli, E. coli;*
* Center for Watershed Protection 1999
[1] EPA 2001
[2] Wagner and Moench 2009

The resulting reductions are calculated by:

$$LR_d = N_d \times DM\% \times FC_d \times Conversion \times 365 \frac{days}{year} \times Practice\ efficiency$$

Where:

LR_d = Potential annual load reduction of *E. coli* attributed to proper dog waste disposal

N_d = Number of dogs

$DM\%$ = Percent of dogs managed

FC_d = Fecal coliform loading rate of dogs

Conversion = Estimated fecal coliform to *E. coli* conversion rate

Practice Efficiency = Assumption of efficiency of proper dog waste disposal

If we assume that 50% of dog owners walk their dogs, 40% of those walkers do not pick up pet waste, and of those 40%, about 60% would be willing to change their behavior (Center for Watershed Protection, 1999) then 12% (0.5 *0.4 *0.6 = 0.12) of dog walkers change their behavior to begin picking up after their pets, and that 75% of the waste was disposed of properly, the estimated potential load reduction attributed to this management measure in the watershed is 1.15×10^{15} cfu *E. coli* annually. Additionally, nutrient reductions can be anticipated for every additional dog managed. The Tres Palacios and Carancahua Bay WPPs estimated annual load reductions between 0.8 and 1.0 pounds of nitrogen and 0.2 pounds of phosphorus per additional dog managed (Schramm et al. 2017; Schramm et al. 2019).

OSSF Load Reductions

OSSF failures are factors of system age, soil suitability, system design, and maintenance. The Nacogdoches County DR estimated a 30% failure rate in the watershed. Load reductions can be calculated as the number of assumed failing OSSFs replaced (Table 36).

Table 36. Bacteria load reduction assumptions for OSSFs.

Assumptions	
Number of OSSFs repaired/replaced	85
Average number of people per household	2.49*
Assumed sewage production rate	70 gallons per person per day[1]
Fecal coliform concentration in sewage	1.0×10^6 cfu/100 mL[2]
Fecal coliform to *E. coli* conversion rate	0.63 *E. coli* per cfu fecal coliform

Colony forming units, cfu; *Escherichia coli, E. coli;* milliliter, mL;
* US Census Bureau 2010
[1] Borel et al. 2015
[2] EPA 2001

Using the assumptions in Table 36, the potential annual load reduction was estimated by:

$$LR_{ossf} = N_{ossf} \times N_{hh} \times \ Production \ \times FC_s \ \times Conversion \times 3{,}578.2 \ \frac{mL}{gallon} \times 365 \frac{days}{year}$$

Where:

LR_{ossf}= Potential annual load reduction of *E. coli* attributed to OSSF repair/replacement

N_{ossf}= Number of OSSFs repaired/replaced

N_{hh} = Average number of people per household

Production = Assumed sewage discharge rate

FC_s = Fecal coliform concentration in sewage

Conversions = Estimated fecal coliform to *E. coli* conversion rate

In the watershed, stakeholders decided that at least 30 OSSFs will be remediated which results in a potential annual load reduction of 4.52×10^{13} cfu *E. coli* per year. Additionally, nutrient reductions can be anticipated for every OSSF replaced. The Tres Palacios and Carancahua Bay WPPs estimated annual load reductions between 11.6 and 20.5 pounds of nitrogen and 2.9 and 4.8 pounds of phosphorus per additional OSSF repaired or replaced (Schramm et al. 2017; Schramm et al. 2019).

Appendix B. References

Borel, K., Gregory, L., Karthikeyan, R. 2012. Modeling Support for the Attoyac Bayou Bacteria Assessment using SELECT. College Station, TX: Texas Water Resources Institute. TR-454. https://twri.tamu.edu/publications/technical-reports/2012-technical-reports/tr-454/.

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 (6): 2293-2300. https://doi.org/10.2134/jeq2004.0335.

Center for Watershed Protection. 1999. A Survey of Residential Nutrient Behaviors in the Chesapeake Bay. Prepared for Chesapeake Research Consortium. Ellicot City, MD: Center for Watershed Protection. https://cfpub.epa.gov/npstbx/files/UNEP_all.pdf.

Cook, M. N. 1998. Impact of animal waste best management practices on the bacteriological quality of surface water. Master's Thesis. Virginia Polytechnic Institute and State University. http://hdl.handle.net/10919/36762.

Hagedorn, C., Robinson, S. L., Filts, 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. https://doi.org/10.1128/aem.65.12.5522-5531.1999.

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 (6): 1691-1701. https://doi.org/10.1111/j.1752-1688.2002.tb04374.x.

Line, D. E. 2003. Changes in a stream's physical and biological conditions following livestock exclusion. Transactions of the ASAE. 46 (2): 287-293. https://doi.org/10.13031/2013.12979.

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. Raleigh, NC: North Carolina State University Water Quality Group, Biological and Agricultural Engineering Department, North Carolina State University. https://www.epa.gov/sites/default/files/2015-10/documents/nmp_successes.pdf.

Meals, D. W. 2001. Water quality response to riparian restoration in an agricultural watershed in Vermont, USA. Water Science & Technology. 43 (5):175-182. https://doi.org/10.2166/wst.2001.0280.

Peterson, J. L., Redmon, L. A., McFarland, M. L. 2011. Reducing Bacteria with Best Management Practices for Livestock: Heavy Use Area Protection. College Station, TX: Texas A&M AgriLife Extension Service. ESP-406. https://agrilifeextension.tamu.edu/library/ranching/reducing-bacteria-heavy-use-area-protection/.

Schramm, M., Berthold, A., Entwistle, C. 2017. Tres Palacios Watershed Protection Plan. TR-500. College Station, TX: Texas Water Resources Institute. http://matagordabasin.tamu.edu/media/1247/tr-500.pdf.

Schramm, M., Ruff, S., Jain, S., Berthold, A., Mohandass, U. 2019. Carancahua Bay Watershed Protection Plan. TR-514. College Station, TX: Texas Water Resources Institute. https://twri.tamu.edu/media/4974/tr-514.pdf.

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 (3): 595-604. https://doi.org/10.13031/2013.21318.

Tate, K. W., Pereira, M. D. G., Atwill, E. R. 2004. Efficacy of vegetated buffer strips for retaining Cryptosporidium parvum. Journal of Environmental Quality. 33 (6): 2243-2251. https://doi.org/10.2134/jeq2004.2243.

USCB (U.S. Census Bureau). 2021. County Quick Facts from the American Community Survey. https://www.census.gov/quickfacts/fact/table/US/PST045221.

U.S. Environmental Protection Agency (EPA). 2001. Protocol for Developing Pathogen TMDLs: Source Assessment. First Edition. U.S. Environmental Protection Agency Office of Water. 841-R-00-002. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=20004QSZ.txt.

U.S. Environmental Protection Agency (EPA). 2010. Implementing Best Management Practices Improves Water Quality. Washington D.C.: U.S. Environmental Protection Agency Office of Water. 841-F-10-001F. https://www.epa.gov/sites/production/files/2017-07/documents/va_robinson_508.pdf.

Wagner, K. L., Moench, E. 2009. Education Program for Improved Water Quality in Copano Bay Task Two Report. College Station, TX: Texas Water Resources Institute. TR-347. https://hdl.handle.net/1969.1/93181.

Appendix C: Elements of Successful Watershed Protection Plans

EPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (EPA 2008) describes the nine elements critical for achieving improvements in water quality that must by sufficiently included in a WPP for it to be eligible for implementation funding through CWA Section 319(h) funds. These elements do not preclude additional information from being included in the WPP. This Appendix briefly describes the nine elements and references the chapters and sections that fulfill each element.

A: Identification of Causes and Sources of Impairment

Identify the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this watershed-based plan (and to achieve any other watershed goals identified in the watershed-based plan). 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. Information can be based on a watershed inventory or extrapolated from a subwatershed inventory, aerial photos, GIS data, or other sources.

B: Estimated Load Reductions

Estimate the load reductions expected for the management measures proposed as part of the watershed plan.

C: Proposed Management Measures

Describe the management measures that will need to be implemented to achieve the estimated load reductions and identification (using a map or description) of the critical areas in which those measures will be needed to implement the plan. Proposed management measures are defined as including BMPs and measures needed to institutionalize changes. A critical area should be determined for each combination of source BMP.

D: Technical and Financial Assistance Needs

Estimate the amounts of 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 that allows, prohibits, or requires an activity.

E: Information, Education and Public Participation Component

Information/education components will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the appropriate nonpoint source pollution management measures.

F: Implementation Schedule

Schedule implementing the nonpoint source pollution management measures identified in the plan that is reasonably expeditious.

G: Milestones

Provide a description of interim, measurable milestones for determining whether nonpoint source pollution management measures or other control actions are being implemented. Milestones should be tied to the progress of the plan to determine if it is moving in the right direction.

H: Load Reduction Evaluation Criteria

Determine a set of criteria that can be used to determine whether loading reductions are being achieved over time and if substantial progress is being made toward attaining water quality standards. If not, it is also the criteria for determining if the watershed-based plan needs to be revised. The criteria for the plan needing revision should be based on the milestones and water quality changes.

I: Monitoring Component

Include a monitoring component to evaluate the effectiveness of the implementation efforts over time that is measured against the evaluation criteria. The monitoring component should include required project-specific needs, the evaluation criteria, and local monitoring efforts. It should also be tied to the state water quality monitoring efforts.

Name of Water Body	La Nana Bayou
Assessment Units	0611B_01, 0611B_02, and 0611B_03
Impairments Addressed	Bacteria
Concerns Addressed	Nitrate nitrogen, total phosphorus

Element	Report Section(s)
Element A: Identification of Causes and Sources of Impairment	
1. Sources identified, described, and mapped	Chapter 4 – Potential Pollution Sources
2. Subwatershed sources	Chapter 4 – Potential Pollution Sources, Point Source Pollution Chapter 4 – Potential Pollution Sources, Nonpoint Source Pollution
3. Data sources are accurate and verifiable	Chapter 4 – Potential Pollution Sources Appendix A: GIS Analysis and Potential Load Calculations
4. Data gaps identified	Appendix A: GIS Analysis and Potential Load Calculations
Element B: Expected Load Reductions	
1. Load reductions achieve environmental goal	Chapter 6 – Management Measures, Expected Load Reduction Summary
2. Load reductions linked to sources	Chapter 6 – Management Measures Appendix A: GIS Analysis and Potential Load Calculations Appendix B: Calculations for Potential Bacteria Load Reductions
3. Model complexity is appropriate	Appendix B: Calculations for Potential Bacteria Load Reductions
4. Basis of effectiveness estimates explained	Appendix A: GIS Analysis and Potential Load Calculations
5. Methods and data cited and verifiable	Appendix A: GIS Analysis and Potential Load Calculations Appendix B: Calculations for Potential Bacteria Load Reductions
Element C: Management Measures Identified	
1. Specific management measures are identified	Chapter 6 – Management Measures
2. Priority areas	Chapter 5 – Pollution Source Assessment, GIS Analysis
3. Measure selection rationale documented	Chapter 6 – Management Measures
4. Technically sound	Chapter 6 – Management Measures
Element D: Technical and Financial Assistance	
1. Estimate of technical assistance	Chapter 8 – Implementation Resources, Technical Assistance
2. Estimate of financial assistance	Chapter 8 – Implementation Resources, Financial Resources
Element E: Education/Outreach	
1. Public education/information	Chapter 7 – Education and Outreach Plan
2. All relevant stakeholders are identified in outreach process	Chapter 1 – The Watershed Approach, Working Together and Partnerships
3. Stakeholder outreach	Chapter 1 – The Watershed Approach, Education and Outreach
4. Public participation in plan development	Acknowledgements Chapter 1 – The Watershed Approach, Working Together and Partnerships
5. Emphasis on achieving water quality standards	Chapter 1 – The Watershed Approach Chapter 3 - Water Quality

Element	Report Section(s)
6. Operation and maintenance of BMPs	Chapter 6 – Management Measures
Element F: Implementation schedule	
1. Includes completion dates	Chapter 6 – Management Measures, Management Measure Summary Table
2. Schedule is appropriate	Chapter 6 – Management Measures, Management Measure Summary Table
Element G: Milestones	
1. Milestones are measurable and attainable	Chapter 6 – Management Measures, Management Measure Summary Table Chapter 9 – Measuring Success
2. Milestones include completion dates	Chapter 6 – Management Measures, Management Measure Summary Table Chapter 9 – Measuring Success
3. Progress evaluation and course correction	Chapter 6 – Management Measures, Management Measure Summary Table Chapter 9 – Measuring Success
4. Milestones linked to schedule	Chapter 6 – Management Measures, Management Measure Summary Table Chapter 9 – Measuring Success
Element H: Load Reduction Criteria	
1. Criteria are measurable and quantifiable	Chapter 6 – Management Measures Appendix A: GIS Analysis and Potential Load Calculations Appendix B: Calculations for Potential Bacteria Load Reductions
2. Criteria measure progress toward load reduction goal	Chapter 6 – Management Measures Appendix A: GIS Analysis and Potential Load Calculations Appendix B: Calculations for Potential Bacteria Load Reductions
3. Data and models identified	Appendix A: GIS Analysis and Potential Load Calculations Appendix B: Calculations for Potential Bacteria Load Reductions
4. Target achievement dates for reduction	Chapter 6 – Management Measures, Management Measure Summary Table
5. Review of progress toward goals	Chapter 9 – Measuring Success, Data Review Chapter 9 – Measuring Success, Interim Measurable Milestones
6. Criteria for revision	Chapter 9 – Measuring Success
7. Adaptive management	Chapter 9 – Measuring Success, Adaptive Management
Element I: Monitoring	
1. Description of how monitoring is used to evaluate implementation	Chapter 9 – Measuring Success, Water Quality Targets
2. Monitoring measures evaluation criteria	Chapter 9 – Measuring Success, Water Quality Targets
3. Routine reporting of progress and methods	Chapter 9 – Measuring Success, Data Review
4. Parameters are appropriate	Chapter 9 – Measuring Success, Water Quality Targets
5. Number of sites is adequate	Chapter 9 – Measuring Success, Additional Data Collection Needs
6. Frequency of sampling is adequate	Chapter 9 – Measuring Success, Additional Data Collection Needs
7. Monitoring tied to QAPP	Chapter 9 – Measuring Success, Additional Data Collection Needs
8. Can link implementation to improved water quality	Chapter 9 – Measuring Success

Appendix C. References

United States Environmental Protection Agency (EPA). 2008. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. Washington, DC: United States Environmental Protection Agency Office of Water, Nonpoint Source Control Branch. EPA 841-B-08-002. https://www.epa.gov/sites/production/files/2015-09/documents/2008_04_18_nps_watershed_handbook_handbook-2.pdf.

July 2023
TWRI TR-547