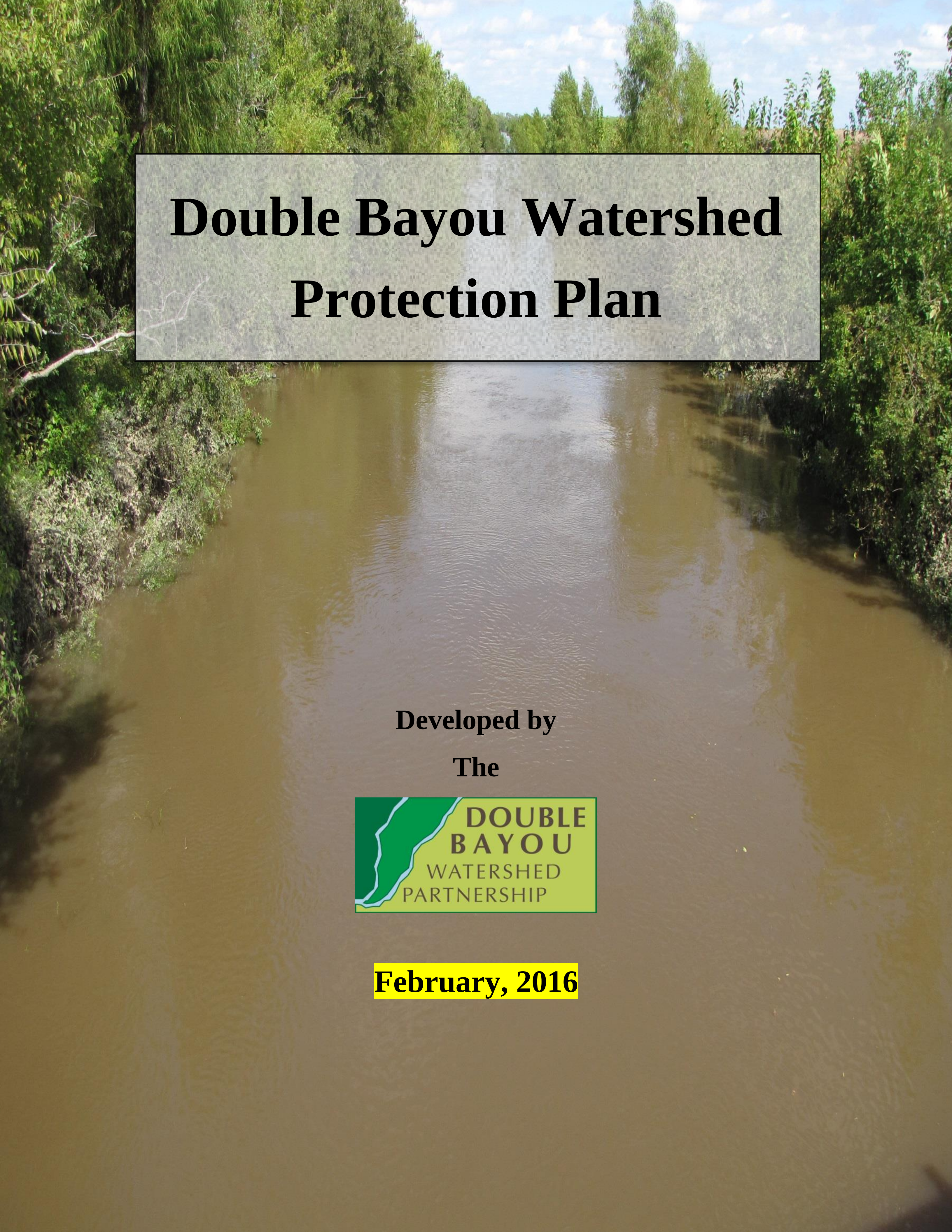

Double Bayou Watershed Protection Plan

Developed by

The

DOUBLE BAYOU WATERSHED PARTNERSHIP

February, 2016

Cover photo of East Fork Double Bayou at Sykes Road Sampling Station.

Double Bayou Watershed Protection Plan

Prepared for the Double Bayou Watershed Partnership

By

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Statement of Purpose

A healthy Double Bayou is vital to support regional commerce, while providing native riparian habitat and recreation opportunities in Chambers County. The land surrounding the West and East Forks of Double Bayou provide excellent grazing and farming. In 2012, the West Fork of Double Bayou was listed by the State of Texas for elevated levels of bacteria and low dissolved oxygen. The East Fork of Double Bayou was identified as a concern for near-nonattainment of water quality standards for elevated levels of bacteria and as a water quality concern based on screening levels for low dissolved oxygen. In response, the Double Bayou Watershed Protection Plan was developed using a stakeholder process driven by public participation to provide a foundation for restoring and maintaining water quality in the Double Bayou Watershed. Development of the Plan involved assessing key water quality issues in the Double Bayou Watershed and determining nonpoint sources of pollution that contribute to these issues. With this knowledge, management programs and public outreach efforts have been developed to restore and protect the vital water resources of the watershed.

Stakeholders are any individual or group that may be directly or indirectly affected by activities implemented to protect water quality such as citizens, businesses, municipalities, city and county governments, nonprofit organizations and state agencies. This document is a means by which stakeholders can become familiar with the Double Bayou Watershed and be active watershed stewards by making a difference in the quality and health of their streams through voluntary management practices. The document is a starting point to focus restoration efforts and enable financial and technical assistance to facilitate improvements in the Double Bayou Watershed. The Double Bayou Watershed Protection Plan is intended to be a living document, adjusted to include new data and modified as conditions in the watershed change over time. It will evolve as needs and circumstances dictate and will be guided by stakeholders as they undertake active stewardship of the watershed.

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Executive Summary

The Double Bayou Watershed is located on the Upper Texas Gulf Coast and is part of the Galveston Bay Watershed. Situated in the eastern portion of the Lower Galveston Bay watershed, it is comprised of two main subwatersheds: East Fork Double Bayou and West Fork Double Bayou, which are the primary waterways in the watershed. The Double Bayou Watershed drains 98 square miles (61,445 acres) of predominantly rural and agricultural land. The Double Bayou Watershed drains directly into the Trinity Bay system and ultimately into Galveston Bay. Today, the lands and waters in and around Double Bayou support: rice farming, cattle grazing, oil production, small town and country living, industry and commercial navigation, sailing, paddling, crabbing, oystering, recreational fishing and wildlife watching.

The West Fork of Double Bayou (Segment 2422B) was listed as impaired (not meeting its water quality standards) on the 2012 Texas Integrated Report 303(d) for low dissolved oxygen for aquatic life usage (listed as impaired since 2004) and for elevated levels of bacteria for contact recreation (listed as impaired since 2006). The East Fork of Double Bayou (Segment 2422D) was identified as a concern for near-nonattainment of the standards for elevated levels of bacteria and as a concern for water quality based on screening levels for low dissolved oxygen.

The Texas State Soil and Water Conservation Board (TSSWCB) provided funding to develop a Watershed Protection Plan (WPP) for the Double Bayou Watershed based on criteria that included the ongoing activities and level of stakeholder interest, presence on the Texas Integrated Report (303(d) list), and the potential for success. Public meetings were held in Anahuac and Double Bayou. Shortly thereafter, the Double Bayou Watershed Partnership was formed to guide the WPP development process. The Partnership is working with citizens, businesses, public officials and state and federal agencies to improve water quality in the Double Bayou Watershed. The Partnership recognizes that success in improving and protecting water resources depends on the people who live, work and recreate in the watershed. The Double Bayou WPP will serve as a guidance document for restoring and protecting local water quality.

The Partnership and members of the Agriculture, Feral Hogs and Wildlife Workgroup, the Recreation and Hunting Workgroup and the Wastewater and Septic Workgroup dedicated significant time and effort to identify the potential bacteria sources in the Double Bayou Watershed. Potential sources of bacteria identified through the process were: feral hogs, cattle, goats, horses, deer and wastewater. Through scientific analysis using sampled bacteria concentrations and flow measurements, researchers supporting the Partnership determined a load reduction goal in bacteria loads in order to meet the state water quality standard. This information was used to set goals and milestones for the implementation of management measures aimed at reducing bacteria levels in the watershed. Based on data analysis, including water quality data and watershed characteristics, the workgroups recommended management measures to reduce bacteria levels in the watershed.

The Wastewater and Septic Workgroup and the Partnership worked closely with local government personnel to identify wastewater management measures. Extending sanitary sewer service to areas not currently served will be a specific target for improvements, as will reducing infiltration and inflow to the City's wastewater system. The Partnership's Watershed Coordinator will work with Texas A&M AgriLife Extension to provide education programs for homeowners with septic systems, as well as seek funding to provide financial assistance to those who are unable to repair failing systems.

The Agriculture, Feral Hogs and Wildlife Workgroup along with the Partnership identified management measures, which include the development and implementation of voluntary site-specific conservation plans. Technical and financial assistance can be provided to farmers and ranchers for development of conservation plans that address potential sources of bacteria and nutrients and meet the needs of each operation.

The Recreation and Hunting Workgroup along with the Partnership identified management measures, which include the possible installation of a boater waste pump out station at Oak Island and potentially adding restrooms in the watershed for people who recreate along the bayous.

To address feral hog concerns in the watershed, the Partnership will rely on Texas A&M AgriLife Extension for technical assistance, education and assistance with management of feral hogs. In addition, the Partnership will support continued employment of a full-time, regional feral hog management position for direct technical assistance in the Double Bayou Watershed.

Outreach and education will play a significant role in successful WPP implementation. All of the workgroups identified key outreach and education management measures that help improve water quality by increasing understanding and engaging the community in stewardship of Double Bayou.

The implementation phase may begin once the WPP document is stakeholder approved and accepted by the EPA. Continued routine water quality monitoring at four mainstem stations will be essential to support adaptive management of the WPP and allow for on-the-ground corrections, if needed. Management measures will be tailored to specific sources and land uses, and will incorporate an adaptive implementation approach that will continually process water quality data, stakeholder experiences and watershed information.

Double Bayou Watershed bacteria reduction goals were developed to be achieved after the full 10-year implementation phase. Interim reduction and programmatic goals were developed for the 3, 6 and 10-year marks to serve as milestones and progress indicators. To meet 10-year reduction goals, progress will be assessed at years 3 and 6 to determine if resource allocation is adequate or needs to be redistributed. Other factors may influence water quality of the Double Bayou Watershed over the 10-year implementation phase; not all factors can be controlled. However, the Double Bayou WPP was designed to guide the implementation of management measures that can help to achieve water quality standards in the watershed.

The Double Bayou Watershed Partnership will continue to meet quarterly, or on an as-needed basis, to receive updates on implementation progress and efforts. The goal of the Partnership is to improve and protect water quality in the Double Bayou Watershed so it is preserved for future generations of stakeholders.

1 Watershed Management

1.1 What is a Watershed?

The simple definition of a watershed is the area of land that catches rain and drains the runoff into a stream, marsh, bayou, river, lake or ocean. Watersheds can be large or small – as small as the area of land that drains to a neighborhood stream – to those that drain into a major river. Each watershed can be part of a larger watershed (Figure 1-1 Double Bayou Watershed System). A smaller watershed, part of a larger one, is known as a subwatershed. Watershed boundaries often cross municipal, county and state borders because the watershed is determined by physical geography, not political boundaries.

Everyone lives in a watershed. Because a water body “catches” the runoff from land in its watershed, the water quality and quantity of the water body is affected by what we do on the land. The overall function and health of the watershed and water body are the result of these cumulative effects.

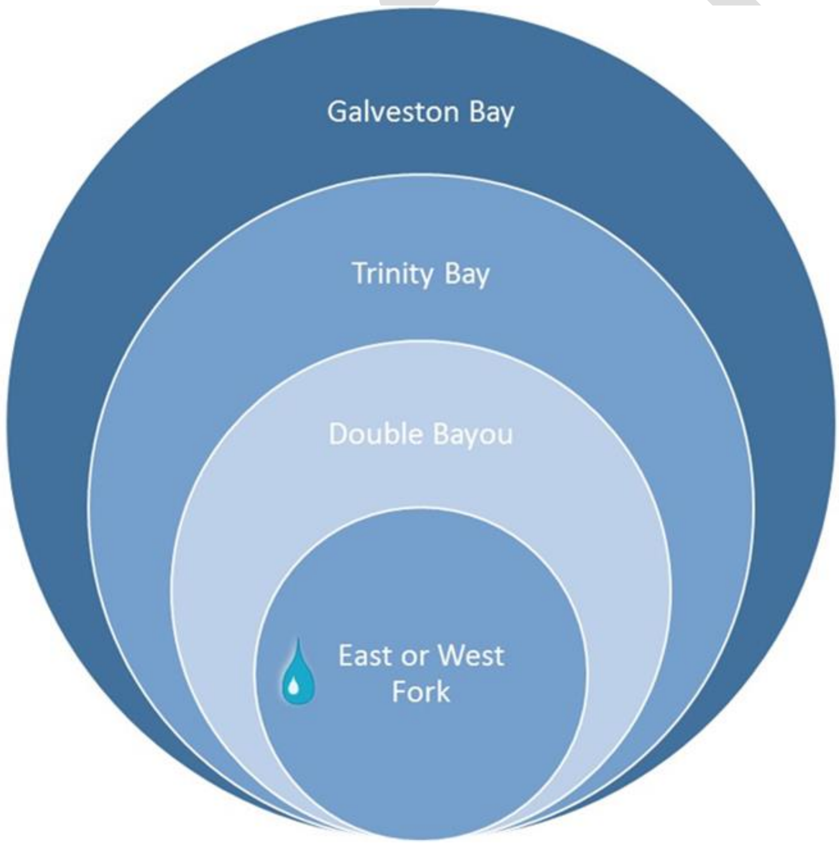


Figure 1-1 Double Bayou Watershed System

1.2 Watersheds and Water Quality

Water quality describes the chemical, physical and biological characteristics of water. Due to surface runoff, activities in the watershed can affect in-stream water quality. Water quality criteria, or thresholds, are established to evaluate the suitability of a waterbody for particular uses. Substances that make water unsuitable for its assigned uses are known as water quality pollutants. Pollutants may be man-made, or they may be natural, but are present in harmful concentrations.

Pollutant sources that can affect water quality are from two main categories – point or nonpoint sources. Runoff from the land to a stream starts as rainfall flowing over agricultural, urban, residential, industrial and/or undeveloped areas in a watershed. This runoff can carry with it pollutants washed from the surrounding landscape. This type of pollution, coming from numerous diffuse sources, is called ***nonpoint source pollution***. Examples of different types of nonpoint source pollution include fertilizer in runoff from residential lawns or agricultural fields, pet waste from urban runoff and wastes from wildlife, feral hogs, or livestock. Nonpoint source pollution is more challenging to manage since it does not originate from a single source.

On the other hand, ***point source pollution***, as the name suggests, comes from a single source that is discharged directly into a water body, such as a pipe, storm sewer or outfall. Point source pollution is subject to regulation by permit. Discharges from wastewater treatment facilities are an example of point source pollution.

1.3 Water Quality Standards

The federal Clean Water Act (CWA) of 1977 required that all states establish standards for measuring the health of surface water bodies. States must develop standards that describe how water bodies are used, establish water quality criteria and develop programs to monitor the state's water quality. The Texas Commission on Environmental Quality (TCEQ) is charged with managing the quality of Texas's waterbodies and water resources, including establishing the state's surface water quality standards and setting the surface water quality criteria.

TCEQ evaluates surface water quality for the state through water quality monitoring, laboratory analysis and data analysis. Stream segments are evaluated based on a seven-year assessment period for various established water quality criteria. Every two years, the TCEQ must report to the Environmental Protection Agency (EPA) on the extent to which the State's waterbodies meet the surface water quality standards. The Texas Integrated Report is developed by the TCEQ and submitted to the EPA. This report describes the status of all surface water bodies in Texas according to the water quality standards. The 303(d) list, an important management tool produced as part of the Texas Integrated Report, identifies all surface waterbodies that do not meet Texas surface water quality standards (i.e., are impaired).

As part of the standards-setting process, TCEQ established designated uses for Double Bayou's water quality, including uses for: Aquatic Life, Primary Recreation, Swimming, General and Fish Consumption (Figure 1-2 West Fork Double Bayou recreation). These designated uses require certain levels of water quality to maintain their associated standards.

Figure 1-2 West Fork Double Bayou recreation

1.4 A Watershed Approach to Water Quality Management

1.4.1 Watershed Approach

The planning for improved health of a stream can be optimized by assessing the watershed system as a whole; watersheds are an integrated system of land and water. State and federal water resource management and environmental protection agencies have embraced the watershed approach for managing water quality. In Texas, the TCEQ manages programs to prevent and abate urban nonpoint source pollution and the Texas State Soil and Water Conservation Board (TSSWCB) manages programs to prevent and abate agriculture/silvicultural nonpoint source pollution.

The watershed approach involves assessing sources and causes of impairments at the watershed level and utilizing this information to develop and implement watershed management plans. A watershed perspective allows all potential sources of pollution entering a waterway to be identified and evaluated. A key reason for success of the watershed approach is that watershed stakeholders bring together their collective knowledge, expertise and experience to preserve, protect and improve water quality. A stakeholder is anyone who lives, works, or has an interest within the watershed.

1.4.2 Watershed Protection Planning for Double Bayou

Using the watershed approach, the TSSWCB has supported the development of a Watershed Protection Plan (WPP) for Double Bayou (Figure 1-3 Double Bayou confluence of East Fork and West Fork). The idea of a WPP is to work with local stakeholders to improve water quality through voluntary participation. Stakeholder involvement is critical to select, design and implement management measures that improve water quality. Stakeholder stewardship guides successful WPP development and implementation.

Figure 1-3 Double Bayou confluence of East Fork and West Fork

The goal of the Double Bayou WPP is to provide a roadmap to improve the water quality of Double Bayou through a voluntary, collaborative approach that incorporates stakeholder ideas in the planning process. The Double Bayou WPP presents the current state of the watershed, discusses water quality sampling efforts and results, describes stakeholder-identified causes and sources of pollution, outlines stakeholder-recommended management measures and includes specifications for the technical and financial framework required for implementation. The Double Bayou WPP was developed using EPA’s nine key elements for successful watershed based plans (see Appendix C: Nine EPA Criteria for a Successful Watershed Protection Plan and Location of Elements in the Plan).

2 State of the Double Bayou Watershed

2.1 Double Bayou Watershed Overview

The lands and waters in the Double Bayou watershed provide a snapshot of the much-prized rural Chambers County life: rice farming, cattle grazing, oil production, small town and country living, industry and commercial navigation, sailing, paddling, crabbing, recreational fishing and wildlife watching. In addition, the waters of Double Bayou drain into Trinity Bay, just up-current from the largest oyster harvesting operation in Texas. This chapter describes the relationship between the lands and waters of the Double Bayou Watershed.

2.1.1 Double Bayou Landscape

The Double Bayou Watershed is located on the Upper Texas Gulf Coast and is part of the Galveston Bay watershed (Figure 2-1 The Double Bayou Watershed). Situated in the eastern portion of the Lower Galveston Bay watershed, it is comprised of two main subwatersheds: East Fork Double Bayou and West Fork Double Bayou, which are also the primary waterways in the watershed. The Double Bayou Watershed drains directly into the Trinity Bay system and ultimately into Galveston Bay. The majority (93%) of the watershed lies within Chambers County, Texas. The remaining 7% of the watershed is located in Liberty County, Texas. The Double Bayou Watershed drains 98 square miles (61,445 acres) of predominantly rural and agricultural land. However, several residential centers are located in the watershed.

The City of Anahuac, Texas is located on the Trinity River and the northeast bank of Trinity Bay. This rural community is the largest area of developed land in the watershed. Anahuac has a total area of 1,344 acres (2 square miles) and is nine feet above sea level (District 2013). Anahuac is the Chambers County Seat, with a 2010 U.S. Census population of 2,243. Much of the middle portion of Chambers County drains into Double Bayou. The unincorporated community of Oak Island is identified by the U.S. Census as a designated place. Oak Island is located at the confluence of the East and West forks of Double Bayou and Trinity Bay. Approximately half of Oak Island is located in the Double Bayou Watershed. A third smaller community in the watershed is called Double Bayou and is located near the East Fork and FM 562 (Figure 2-1 The Double Bayou Watershed).

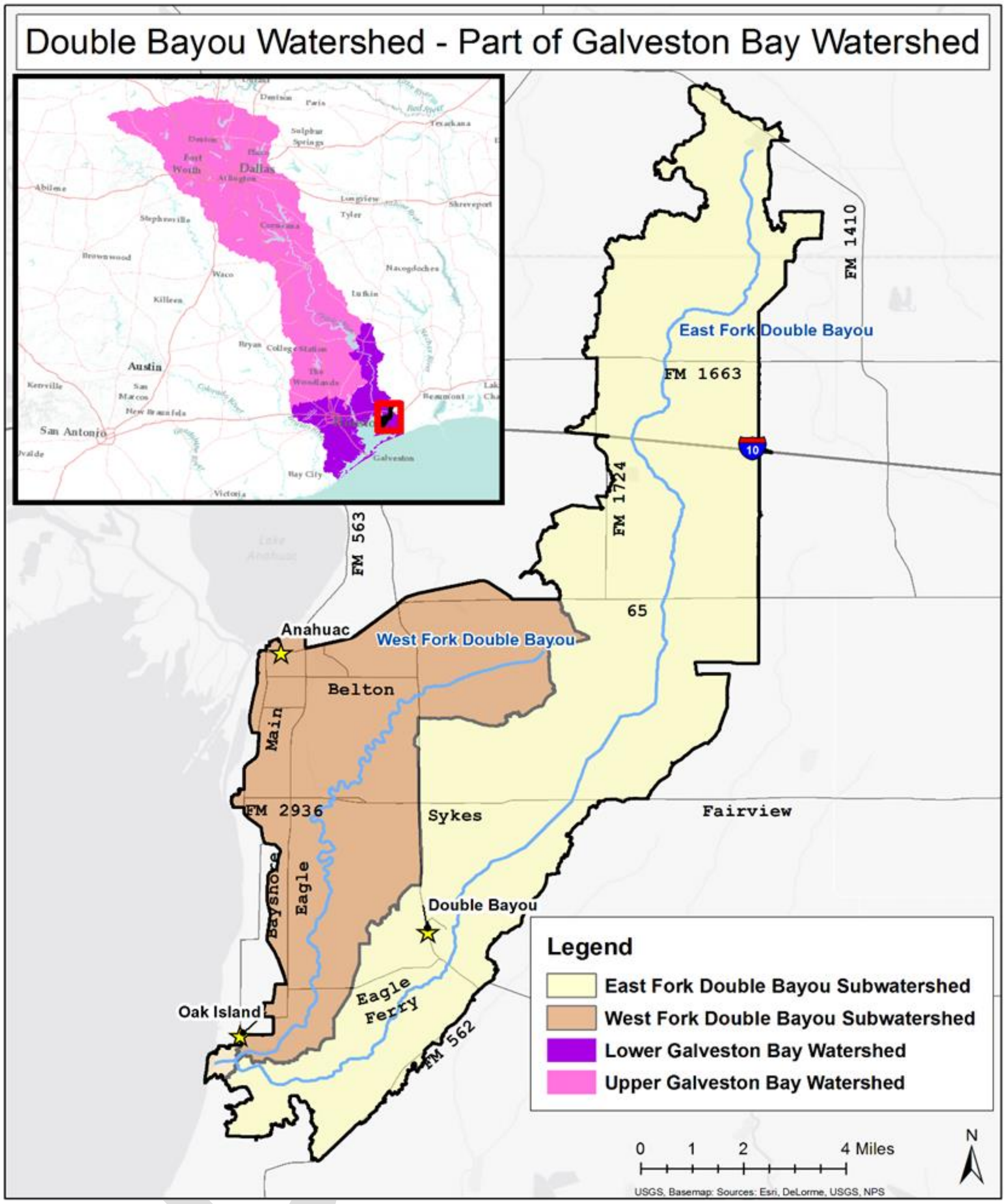


Figure 2-1 The Double Bayou Watershed

2.1.2 Double Bayou Watershed Climate

The climate of the Double Bayou Watershed is Humid Subtropical, defined by hot humid summers and mild winters. The annual peak of rainfall typically occurs in July. However, this peak summer rainfall is dependent on the hurricane season and can reach a maximum in September during hurricane-intensive years.

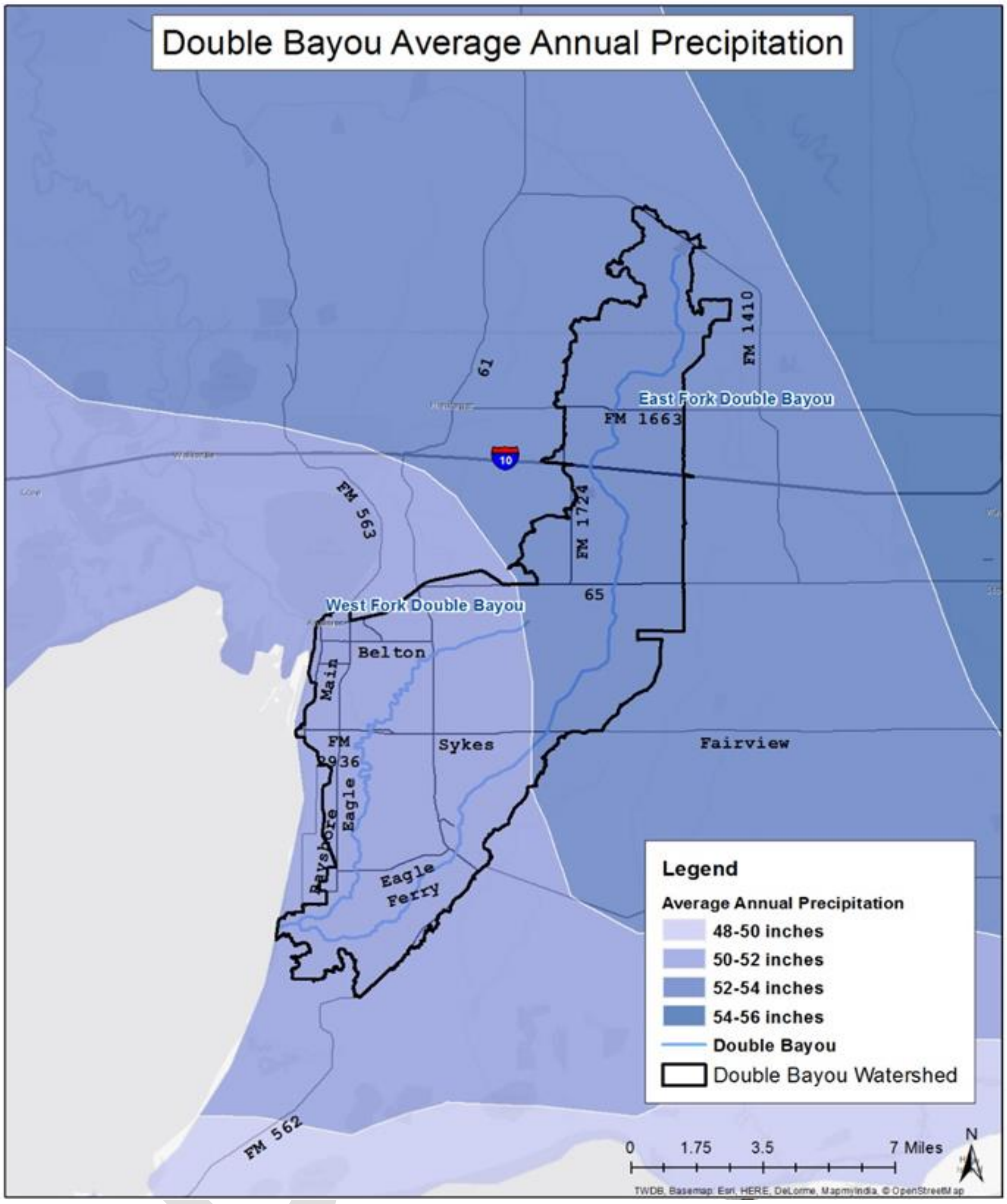


Figure 2-2 Double Bayou Watershed average annual precipitation

Typically, the average annual rainfall for the southeastern portion of the watershed ranges from 50-52 inches, while the average annual rainfall for the northern portion ranges from 52-54 inches (Figure 2-2 Double Bayou Watershed average annual precipitation). The total annual rainfall in the Double Bayou Watershed during calendar year 2014 was 43.3 inches. The average temperature ranges from a high of 92˚F in August to a low of 42˚F in January. The absolute high temperature for the calendar year 2014 was 97˚F and the lowest temperature was 20˚F.

2.1.3 Double Bayou

The East Fork of Double Bayou originates in Liberty County slightly south of FM 1410 (Figure 2-1 The Double Bayou Watershed). The East Fork follows a relatively straight channel southwest towards Trinity Bay for a total of 27 miles. The only named tributary, Chimney Bayou, joins the East Fork of Double Bayou slightly northeast of FM 562 and Eagle Ferry Road. Originating just south of State Highway 65 and FM 1724, the West Fork of Double Bayou is approximately half the length (14 miles) of the East Fork and is characterized by a meandering channel (Figure 2-1 The Double Bayou Watershed). The two bayous form their confluence a quarter of a mile before joining Trinity Bay at Oak Island, Texas (Figure 2-3 Confluence of East and West Forks at Job Beason Park). The lower portions of both bayous are tidally influenced. The bayous' estuary, Trinity Bay, is designated as unclassified oyster waters and as a classified estuary (see Chapter 4.2 for a discussion on classifications). According to the TCEQ, the area of Trinity Bay is 123 square miles. There are also many channelized water-delivery canals and drainage ditches in the watershed.

Figure 2-3 Confluence of East and West Forks at Job Beason Park

Natural drainage patterns in the Double Bayou Watershed have been altered by an extensive network of waterways for drainage and agriculture. For example, the Anahuac Ditch is classified as an unimpaired, perennial freshwater stream that is 3 miles in length and flows south from Belton Lane in the town of Anahuac to its confluence with the West Fork of Double Bayou just upstream of FM 2936 (Sykes Road). The Double Bayou Watershed's natural drainage is further characterized by a shallow water table and a weakly dissected alluvial plain with deep saline soils (HARC 2011).

2.2 Human History of the Watershed

The Double Bayou Watershed's rich history of human activity is often connected to milestones in the history of Chambers County, as well as Texas. Double Bayou itself, similar to many tributaries of the Galveston Bay system, lays claim to pirates sailing its waters around 1820, during the time of Jean Lafitte. Mexican land grants had been conveyed in the Anahuac area by the early 1830s, followed by Anglo settlers in the mid-1830s. The early draws to the region were its waterways, relatively mild climate and wide-open prairies, well suited for raising cattle.

In 1831, the Mexican government surveyed the site of Anahuac as a seat of government, and the construction of a brick fort was initiated. In the build-up to the war for Texas independence (1832 and 1835), Fort Anahuac became the scene of the first Anglo armed resistance to the Mexican government. By 1850, James Jackson founded the JHK Ranch (also known as the Jackson Ranch) in the lower East Fork watershed. The JHK Ranch went on to become one of the largest in the county, with 26,000 acres and 6,000 head of cattle by Jackson's death in 1895.

By 1900, large-scale rice production had been introduced to the watershed area. Two canal companies formed in the first decade of the 20th century, to bring irrigation water east from Turtle Bay (later closed off to form Lake Anahuac). By 1902, the Hankamer-Stowell Canal Company was delivering water to 10,000 acres north and east of the bay, including northern parts of the watershed and the East Fork of Double Bayou. By 1906, the Lone Star Canal Company was delivering irrigation water to 10,000 acres to the southeast, mostly within the Double Bayou Watershed.

In 1907, the City of Anahuac experienced a rise to prominence when Chambers County voters approved moving the County Seat from Wallisville to Anahuac (Chambers County had been created out of Liberty County in 1858). In 1909, a rice warehouse was established in Anahuac. The first rice dryer established in the watershed was between Anahuac and the community of Double Bayou. Previously, rice had to be hauled to Devers to the north or Beaumont to the east for drying.

Meanwhile, the Sterling family had settled on the West Fork of Double Bayou, where Ross Sterling was born in 1875. Truck farming had begun to play a prominent agricultural role by the 1890s, and Sterling ran produce boats to Galveston. Sterling went on to form Humble Oil Company in 1911 and become Texas governor in 1931. Humble Oil Company became Humble Oil and Refining Co. in 1917, which evolved into ExxonMobil. The first oil discovery in the watershed was found accidentally while drilling a water well on the Jackson Ranch in 1925. In 1935, oil was purposely struck, at a well on land owned by Archie Middleton and leased by Humble Oil & Refining Company. This site became the Anahuac field at Monroe City.

City and County revenues from the Anahuac field also provided the funds to help Anahuac grow with the burgeoning demands from development of the field. In 1937, these revenues supported construction of a new county courthouse. It was the first courthouse in the state built with central air conditioning. Revenues from the oil field also provided 90% of the cost for a state-of-the-art school in Anahuac in 1938, to accommodate the growing student population.

The late 1940s saw formation of two public entities that continue to play a key role in the watershed and surrounding areas. The Texas Legislature created the Chambers-Liberty Counties Navigation District in 1944. The district purchased the Lone Star Canal system in 1947. Irrigation water was provide within a service area of 128,559 acres in Chambers County, much of it in the Double Bayou Watershed. The Trinity Bay Conservation District was created at the suggestion of the Trinity Bay Soil Conservation District to improve drainage for agricultural land use. Its functions have expanded to providing drinking water and wastewater service within its jurisdiction, including areas of the Double Bayou Watershed outside Anahuac's service area.

The community of Double Bayou, located between the two forks, was settled by African-Americans, who came to the area as slaves of the families that began the large ranching and farming operations. Many went on to become farmers and ranchers in their own right. One of the oldest churches in the county, St. Paul's United Methodist Church (formerly AME) has been a community focal point for nearly 150 years, including housing a school for area African-American youth, from the mid-1880s until a new school was built in 1920, which then went on to consolidate with the nearby white school in 1951.

The Oscar Mayes store in Double Bayou originally operated on the East Fork of Double Bayou. It became the Jackson Grocery on Eagle Ferry Road and served this community from 1932 until the early 2000s. Renowned blues musician Pete Mayes came from Double Bayou and his first guitar was purchased from Jackson Grocery. After playing across the U.S., South America and Europe, he returned to keep alive the musical tradition at the Double Bayou Dance Hall for several decades. That musical heritage dated back to the late 1920s, with a largely African-American clientele, but entertaining audiences of all backgrounds. The dance hall is soon to be commemorated with a State historical marker.

The community of Oak Island located at the confluence of the East and West Forks of Double Bayou just upstream of Trinity Bay, has long served as a maritime hub for the watershed. Commerce was primarily waterborne until the mid-1930s; boats carried products to Galveston and brought back essential supplies. Before navigation channels were dredged to improve marine transportation around the bay, trips to Galveston could take a week or more by rowboat. Oyster reefs that ran across Galveston Bay between Smith Point and San Leon were navigational hazards that extended the trip time.

As the oil industry became established, the importance of the bayous for transportation grew. In the late 1940s, Brown & Root began operating on the West Fork, just upstream of Oak Island near Trinity Bay, to service more than 100 rigs located in the waters of the Galveston Bay system. They also constructed pipelines that transported oil from Trinity Bay (and beyond) to the plants at Monroe City, where it underwent preliminary processing, before being piped to the Exxon facility in Baytown for further refining. The Brown & Root shipyard was closed by the mid-1980s, but smaller industrial facilities remain near the confluence. A marine salvage operation and a rig servicing business operate there to this day.

Shrimp boats and crabbing boats hail from Double Bayou at Oak Island and upstream. Crabbing boomed with the influx of Vietnamese refugees in the 1980s. Although devastated by Hurricane Ike in 2008, the crabbing industry has experienced a strong comeback with the help of a dedicated community. The harbor at Oak Island is also a center for recreational fishing, hunting and boating. Of additional commercial importance, waters from Double Bayou are a source of inflows to the highly productive oyster-harvesting region just down the bay from the mouth of Double Bayou.

2.3 Geography

2.3.1 Ecoregion

The entire Double Bayou Watershed lies within the Northern Humid Gulf Coastal Prairies Ecoregion (Figure 2-4 Level Four Ecoregions of Double Bayou; from EPA Level IV Ecoregion). The original vegetation of the Northern Humid Gulf Coastal Prairies Ecoregion was mostly grasslands with a few clusters of oaks (oak mottes or maritime woodlands). Little bluestem (*Schizachyrium scoparium*), yellow indiangrass (*Sorghastrum nutans*), brownseed paspalum (*Paspalum plicatulum*), gulf muhly (*Muhlenbergia capillaris*) and switchgrass (*Panicum virgatum*) were the dominant grassland species. The Northern Humid Gulf Coastal Prairies Ecoregion has been mostly converted to land classes that include cropland, rangeland, pasture and urban land uses (Griffth, Bryce et al. 2007). Some loblolly pine (*Pinus taeda*) forest occurs in the northern part of the region. Common tree species in the TBCD area of Chambers County, as well as nearby southwest Jefferson County include live oak (*Quercus virginiana*), bald cypress (*Taxodium distichum*), pine (*Pinus* spp.) and cedar (*Cedras* sp.) trees, accompanied by hardwood species on riparian corridors (Figure 2-5 Riparian corridor along West Fork Double Bayou) (District 2013).

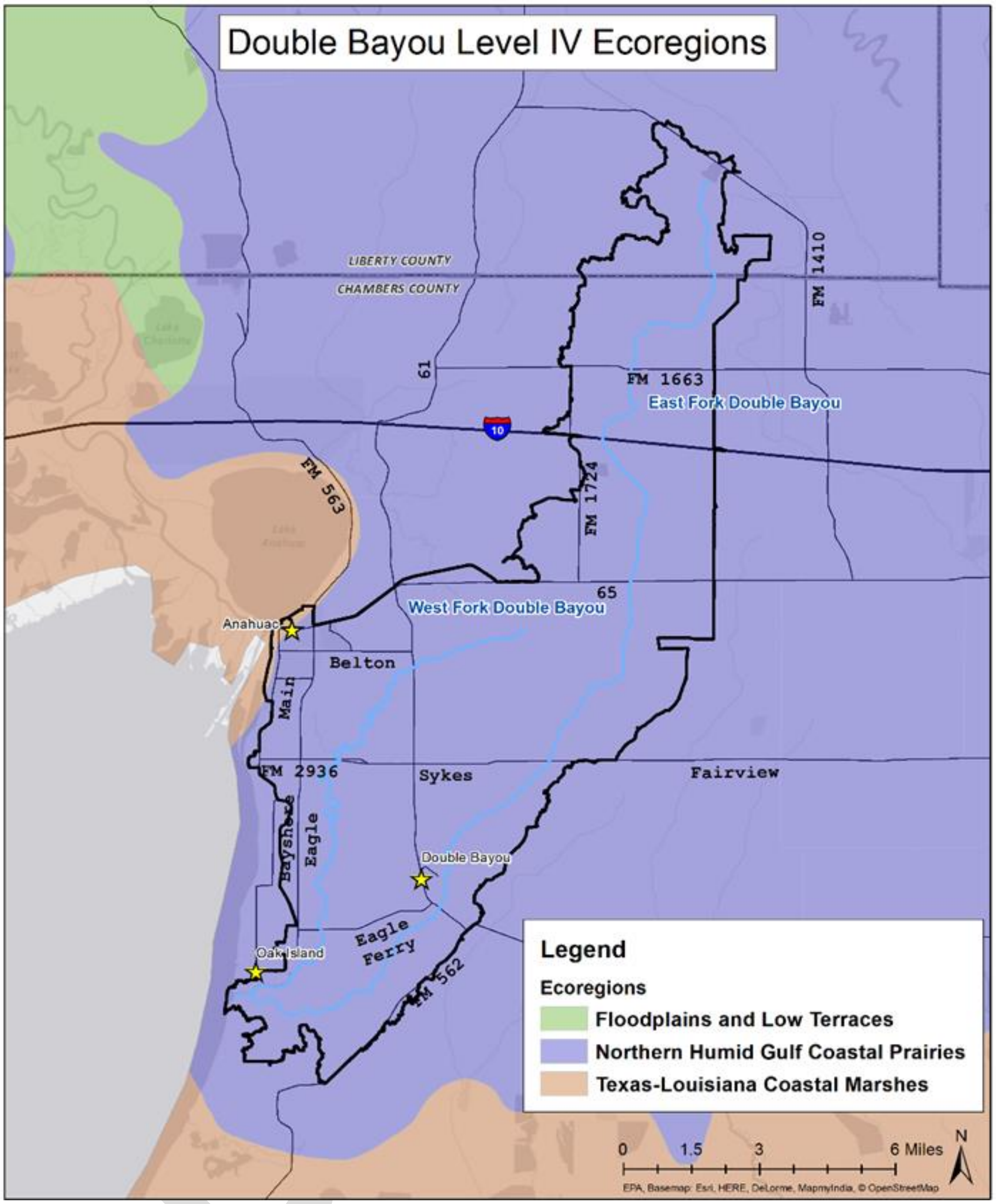


Figure 2-4 Level Four Ecoregions of Double Bayou

Figure 2-5 Riparian corridor along West Fork Double Bayou

2.3.2 Soils

Within the Double Bayou Watershed, there are different soil formations including the higher Lissie Formation and the lower Beaumont Formation (both of Pleistocene age). The Lissie Formation has lighter colored soils, mostly Alfisols, with sandy clay loam surface texture, while darker, clayey soils associated with Vertisols are typical of the Beaumont Formation (Griffth, Bryce et al. 2007). The soils remain homogenous throughout the watershed and are mostly fine-textured: clay, clay loam, or sandy clay loam.

2.3.3 Topography

Typical for the Northern Humid Gulf Coastal Prairies Ecoregion, the northern portion of the watershed has the highest elevation at 23 meters (74.5 feet). The topography of this flat coastal prairie gently slopes south toward Trinity Bay and ends at an elevation of -3 meters (9.8 feet) below sea level for a change of 26 meters (85.6 feet) in elevation (across approximately 20 miles). The average elevation within the Double Bayou Watershed is just over 6 meters (19.7 feet) above sea level.

2.4 Fish and Wildlife

2.4.1 Wildlife and Habitat

Common Double Bayou fish species include the Western mosquitofish (*Gambusi affins*), bluegill (*Lepomis macrochirus*), longear sunfish (*Lepomis megalotis*), spotted sunfish (*Lepomis punctatus*), warmouth (*Lepomis gulosus*) and bay anchovy (*Anchoa mitchilli*). Less common fish species include the pirate perch (*Aphredoderus sayanus*), pugnose minnow (*Opsopoeodus emiliae*) and the hogchocker (*Trinectes maculatus*). Largemouth bass (*Micropterus salmoides*) have been reported and represent a recreational opportunity in the bayous. Common species of birds around Trinity Bay include the reddish egret (*Egretta rufescens*), roseate spoonbill (*Platalea ajaja*) and white-tailed hawk (*Buteo albicaudatus*) (HARC 2011)(data from TPWD).

Figure 2-6 Riparian habitat in Double Bayou

Figure 2-7 Overhanging vegetation East Fork Double Bayou

Other wildlife that is native to the Double Bayou Watershed include coyote (*Canis latrans*), river otter (*Lutra canadensis*), swamp rabbit (*Sylvilagus aquaticus),* American alligator (*Alligator mississippiensis),* Texas blind snake (*Leptotyphlops dulcis*), Gulf coast toad (*Bufo nebulifer)* and diamondback terrapin (*Malaclemys terrapin)* (Turco 2006-07).

In-stream cover is ample along the bayous and primarily consists of woody debris, root wads, macrophytes, algae and overhanging vegetation (Figure 2-7 Overhanging vegetation East Fork Double Bayou). Riparian corridor analysis of the East and West forks of Double Bayou shows approximately 32% canopy cover on the East Fork and 39% canopy cover on the West Fork (calculated using approximately 20 meter (65 feet) riparian corridor buffer around the bayous from 2011 satellite imagery data). The amount of cover varies widely by bayou and depends on whether the floodplain is forested and how the riparian area is managed.

2.4.2 Invasive Exotic Species

Nonnative invasive species are also in the watershed such as feral hog (*Sus scrofa*) (also called wild pig), Chinese tallow (*Triadica sebifera*), Chinese privet (*Ligustrum sinense*), water hyacinth (*Eichhornia crassipes*), giant salvinia (*Salvinia molesta*) and alligator weed (*Alternanthera philoxeroides*).

Feral hogs are largely unmanaged opportunistic generalists that exhibit a high affinity for riparian habitats (Figure 2-8 Feral hog in corral trap). Stakeholders have observed that the feral hog population has increased in the watershed. Stakeholder estimates of the feral hog population in the watershed vary, from approximately 1,300 to 1,500 individuals. Feral hogs lack sweat glands, which leads them to congregate in and around waterways, to wallow and keep cool. Feral hogs can traverse the watershed and spread rapidly, due to the extensive network of natural and channelized waterways, canals and ditches.

Research suggests that the feral hog's reproductive capabilities are more than 4 times higher than that of native ungulates such as white-tailed deer. Sows can become reproductively capable at 6 to 10 months of age and have the potential for bi-annual recruitment (i.e. the rate at which individuals are added to the feral hog population through births and/or immigration) of 4-6 piglets annually – both of which are factors in rapidly increasing feral hog populations. With few natural predators, feral hog populations can grow virtually unregulated in the wild (Tyson 2015).

Due to their affinity for water, feral hogs deposit bacteria-laden fecal waste directly into the waterways of the watershed. Their unrelenting appetite also has a negative impact on future seed recruitment and seed abundance of riparian oak (*Quercus* sp.) and hickory (*Carya* sp.) trees. Feral hogs damage native riparian plant communities and compete with native wildlife for food sources. Additionally, feral hogs cause an average of $52 million in damage annually to Texas agriculture industries (Timmons, Alldredge et al. 2012).

Figure 2-8 Feral hog in corral trap

The Chinese tallow tree (*Sapium sebifera*) and the Chinese privet (*Ligustrum sinense*) have invaded large areas of the watershed. The Chinese tallow tree is considered the most established invasive species in the Lower Galveston Bay Watershed (Chilton, Robinson et al. 2011). The Double Bayou Watershed is particularly vulnerable to this tree because it thrives in the coastal prairie wetlands and ample riparian stream habitat provided by the bayous. The Chinese tallow tree is toxic to livestock, wildlife and humans, which increases the risk of health concerns when managing this invasive species (handling or burning). The Chinese privet is also an aggressive invasive species that can establish rapidly in and around waterways and fence lines. Both species outcompete native riparian plant communities for space, sunlight and nutrients.

In addition to terrestrial invasive plant species, aquatic plant invaders directly impact Double Bayou waterways. Water hyacinth (*Eichhornia crassipes*) is considered the most detrimental nonnative aquatic plant species (Figure 2-9 Water hyacinth East Fork Double Bayou). It can spread quickly on the surface of waterways and dominate native submerged vegetation. These large aquatic mats inhibit light and oxygen diffusion and impede water movement, leading to low dissolved oxygen levels. The low dissolved oxygen concentration can kill native populations of fish (Chilton, Robinson et al. 2011).

Figure 2-9 Water hyacinth East Fork Double Bayou

In addition, giant salvinia (*Salvinia molesta*) replaces native forage and is regarded as the second most harmful aquatic invasive species behind water hyacinth. Alligator weed (*Alternanthera philoxeroides*), another invasive species, can out compete aquatic and terrestrial native vegetation and reduce the recreational quality of waterways. Alligator weed is also associated with low dissolved oxygen concentrations. These aquatic invasive species increase the rate of evapotranspiration and reduce the amount of water retained in the bayous (Chilton, Robinson et al. 2011).

2.4.3 Parks and Recreational Lands

Three municipal parks are located in the Double Bayou Watershed, totaling 87 acres. Double Bayou Park (about 37 acres) is located near the intersection of FM 562 and Eagle Ferry Road. The park provides birding, fishing, picnicking and camping opportunities, as well as a kayak launch site. The historical Fort Anahuac Park (also about 37 acres) is located on South Main Street about a mile south of Hwy 61 in Anahuac. It provides ample recreational opportunities, including fishing, ball fields and nature trails. Job Beason Park (approximately 13 acres) is located at the confluence of the East and West forks of Double Bayou. Job Beason Park's unique location provides an opportunity to highlight the ecology at the confluence of both bayous and Trinity Bay.

Figure 2-10 East Fork at Double Bayou Park

2.5 Land Use

2.5.1 Land Cover

Land cover for the Double Bayou Watershed is shown in Figure 2-11 Land Cover and habitat in Double Bayou Watershed (land cover data set adapted from the National Oceanic and Atmospheric Administration (NOAA) 2010 Coastal Change Analysis Program). The most abundant land use/land cover class in the Double Bayou Watershed is Pasture/Hay (34,853 acres), while the least dominant land use/land cover class is Estuarine Aquatic Bed (about 1.5 acres).

A dominant habitat land cover in the Double Bayou Watershed is the Palustrine wetland system; this is not further defined by subsystems, but is represented by four classes of wetlands: Palustrine Forested Wetland, Palustrine Emergent Wetland, Palustrine Scrub-Shrub Wetland and Palustrine Aquatic Bed.

Palustrine Forested Wetlands are typically tidal and nontidal wetlands that are dominated by trees greater than or equal to 5 meters in height, shrubs and persistent emergent vegetation. Palustrine Forested Wetlands are wetlands that occur in tidal areas where the salinity is below 0.5% (Cowardin, Carter et al. 1979). The majority of the Palustrine Forested Wetlands in the Double Bayou Watershed are located along the East and West Forks.

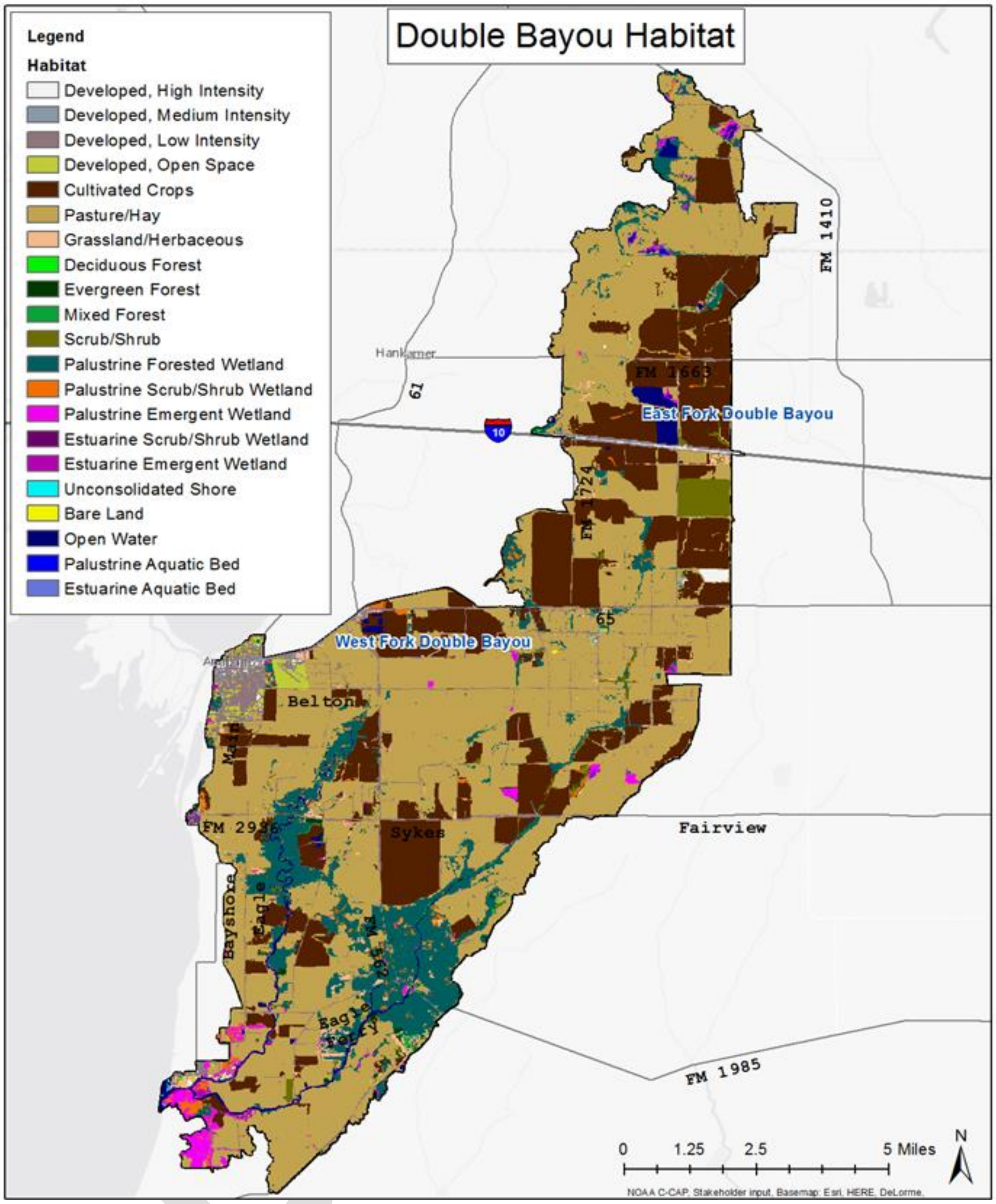


Figure 2-11 Land Cover and habitat in Double Bayou Watershed

Palustrine Emergent Wetlands differ from forested wetlands because they include mosses, lichens and vascular plants. Palustrine Emergent Wetlands are further characterized by having erect, rooted herbaceous hydrophytes and are dominated by perennial plants. Palustrine Scrub-Shrub Wetlands contain woody vegetation less than 5 meters in height and can consist of all water regimes except sub-tidal. Finally, Palustrine Aquatic Bed Wetlands contain plants that grow mainly on or below the surface of the water the majority of the growing season and have permanently standing surface water (Cowardin, Carter et al. 1979).

The present Estuarine wetland subsystems include two Intertidal and one Subtidal system in the watershed. Subsystems can be further classified as Estuarine Emergent Wetland, Estuarine

Scrub-Shrub Wetland and Estuarine Aquatic Bed habitat. However, Estuarine wetlands total only 114 acres of the Double Bayou Watershed (61,445 acres) and are not dominant on the landscape.

Land Cover/Land Use Type	Acres	% of Total Watershed Acres
Pasture/Hay	34,853	57.4%
Cultivated Crops	12,993	21.4%
Palustrine Forested Wetland	6,132	10.1%
Developed, Low Intensity	2380	3.9%
Palustrine Emergent Wetland	781	1.3%
Grassland/Herbaceous	684	1.1%
Palustrine Scrub/Shrub Wetland	669	1.1%
Open Water	653	1.1%
Developed, Open Space	380	0.6%
Scrub/Shrub	374	0.6%
Developed, Medium Intensity	267	0.4%
Evergreen Forest	147	0.2%
Mixed Forest	146	0.2%
Estuarine Emergent Wetland	111	0.2%
The following classes comprise 30 acres or less (0.05% or less) per category: Bare Land, Deciduous Forest, Palustrine Aquatic Bed, Unconsolidated Shore, Estuarine Scrub/Shrub Wetland and Estuarine Aquatic Bed		

Table 2-1 Double Bayou Land Cover/Land Use type

The land cover classes were consolidated into seven categories, due to the small percentage of certain land cover classes present in the Double Bayou Watershed and the stakeholders' desire to streamline land cover classes for subsequent analysis, modeling and management measure decision processes. Stakeholders wanted to focus on groupings of vegetative heights (as opposed to soil type or wetland category) due to familiarity with location in the watershed. Each of the land cover classes is represented in one of the seven categories.

Stakeholder Approved Land Cover	NOAA Coastal Change Analysis Program (C-CAP) Land Cover			
Grassland and Pasture	Bare Land	Grassland/Herbaceous	Pasture/Hay	----
Cultivated Crops	Cultivated Crops	----	----	----
Mixed Forest and Forested Wetlands	Deciduous Forest	Evergreen Forest	Mixed Forest	Palustrine Forested Wetland
Developed	Developed, High Intensity	Developed, Medium Intensity	Developed, Low Intensity	Developed, Open Space
Water	Open Water	Palustrine Aquatic Bed	Estuarine Aquatic Bed	Unconsolidated Shore
Marsh and Emergent Wetland	Palustrine Emergent Wetland	Estuarine Emergent Wetland	----	----
Scrub/Shrub Variety	Scrub/Shrub	Palustrine Scrub/Shrub Wetland	Estuarine Scrub/Shrub Wetland	----

Table 2-2 Land Cover Class Groupings in the Double Bayou Watershed consolidated from the NOAA Coastal Change Analysis Program (C-CAP)

2.5.2 Geographic Task Force

Estimated watershed boundaries were determined via local knowledge of the watershed and drainage system. A United States Geologic Survey (USGS) Hydrologic Unit Code (HUC) watershed boundary was used to define a larger watershed area. Local knowledge, developed through several stakeholder meetings, site visits and iterations of the watershed boundary and land cover, was applied to create a better representation of the Double Bayou Watershed. Different flow patterns from the intricate drainage ways were reviewed by the stakeholder geographic task force and incorporated into the boundary. Stakeholder input was used to ground-truth the land cover and ensure that the ground cover of land-use blocks was accurate, for the seven grouped categories of: Grassland/Pasture, Cultivated Crops, Mixed Forest/Forested Wetlands, Developed Land, Water, Marsh/Emergent Wetlands and Scrub-Shrub variety.

Due to the nature of crop rotations, sometimes a block of land designated as Cultivated Crops one year may be Grassland/Pasture the next year and vice versa. Cattle are moved from Grassland/Pasture to Cultivated Crop land, and then that pasture land is once again cultivated. Because of this dynamic relationship the land cover classifications represents a “snapshot” in time. The stakeholders agreed that the same land use areas are typically traded back and forth between cultivation and pasture and are generally adjacent or nearby to each other (and thus likely in the same subwatershed), the finalized land cover represents the land cover categories to the best extent possible.

2.5.3 Demographics

The smallest U.S Census unit, the block level, was used to estimate the population of the watershed for each decade from 1970 to 2010 (Figure 2-12 Double Bayou Watershed population 2000 (3,535) and 2010 (3,335)). To account for instances when a block boundary fell partially in the watershed, a ratio of block land percentage in and out of the watershed was used. According to this methodology, the 2010 Double Bayou Watershed population is estimated to be 3,335 people (Table 2-3 Population of Double Bayou Watershed and Anahuac, TX).

Year of Census	Population of Double Bayou Watershed	Percent Change of Watershed Population	Population of Anahuac, TX	Percent Change of Anahuac, TX Population
1970	2,299	X	1,881	X
1980	3,117	26%	1,840	-2%
1990	2,923	-7%	1,993	8%
2000	3,535	17%	2,210	10%
2010	3,335	-6%	2,243	2%

Table 2-3 Population of Double Bayou Watershed and Anahuac, TX

In 1970, Anahuac had a population of 1,881. After a 2% decline in population the total number of residents in 1980 was 1,840. In 1990, Anahuac had a population of 1,993 individuals. A 10% increase of population occurred from 1990 to 2000 with the addition of 217 people and a 1.5% increase occurred from 2000 to 2010 with the addition of 33 persons. The 2010 Census reports that Anahuac had a population of 2,243 persons. In 2010, the population by age in Anahuac was 1,397 people between the ages of 18 and 64, 456 people between the ages of 5 and 17, 246 people over 65, and 144 people under 4 years old.

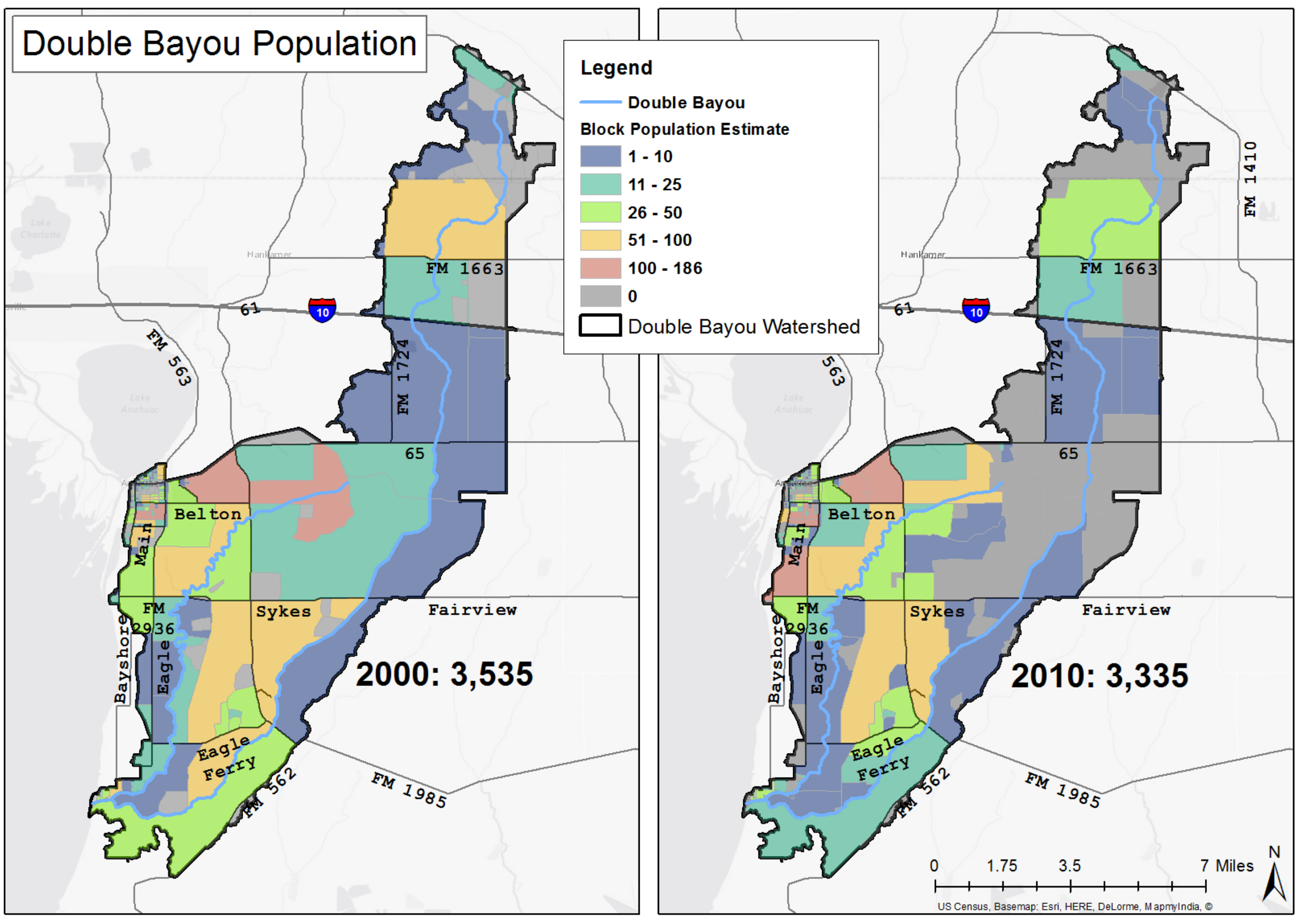


Figure 2-12 Double Bayou Watershed population 2000 (3,535) and 2010 (3,335)

2.5.4 *Existing Land Management Practices*

The 2012 agricultural census reports that forage, including hay, haylage, grass silage and greenchop and rice are the top crop items in Chambers County. Sorghum for grain and wheat for grain also make up a portion of the farming operations (USDA 2012). These trends are also reflected in the Double Bayou Watershed, where rice farming and cattle ranching are the main types of agriculture. Accordingly, predominate watershed land cover is 12,993 acres of cultivated crops (21.4%) and 34,853 acres of Hay or Pasture (57.4%). (Figure 2-13 Rice Farming along the East Fork). The presence of rice farming requires a canal and irrigation system to support operations. In 2012, the average farm size in Chambers County was 346 acres. Since 2007 there has been a 16% reduction in the average farm size in the County (USDA 2012).

Figure 2-13 Rice Farming along the East Fork

The City of Anahuac, the residential community of Oak Island, and pockets of oil/gas drilling and exploration activities are the largest developed areas of land cover in the watershed. The largest concentration of oil/gas wells is located south of FM 65 and FM 1724 in the historic Anahuac oil field, which centers on the Anahuac oil gathering system and pipeline operated by the Texas Petroleum Company. Natural gas pipelines are also prevalent in the watershed along with active and plugged wells. The oil/gas operations, combined with the community of Oak Island and the City of Anahuac, result in 3,127 acres of developed land (5%) in the watershed.

The watershed is not highly fragmented by commercial and residential development. Landowners, farmers and ranchers own large tracks of the Double Bayou Watershed and their participation is paramount to the success of implemented management measures. The rural nature of the watershed creates the potential for an effective implementation of management measures.

The seafood industry also has a presence in the Double Bayou Watershed, primarily in the community of Oak Island (Figure 2-14 Commercial fishing vessel near Oak Island, TX). Crabbers, shrimpers and oystermen make use of tidal waters near Oak Island and Trinity Bay to harvest these natural resources. Outside of the watershed boundaries, extensive oystering occurs just south of Oak Island at Smith Point.

Figure 2-14 Commercial fishing vessel near Oak Island, TX

Along with commercial operations, recreational opportunities are abundant along the bayous. Job Beason Park and Fort Anahuac Park are equipped with full access boat ramps, while Double Bayou Park has a canoe/kayak launch. Kayaking and sailing are popular forms of recreational boating. The three parks located within the watershed could serve as education centers to increase watershed awareness. The Double Bayou Watershed is also a popular destination for wildlife viewing, birding and recreational fishing.

The Trinity Bay Conservation District (TBCD) actively manages the bayou's riparian corridors, through easements along the East and West Forks, to improve drainage and reduce the impacts of flooding. The application of herbicide and dredging of the bayous are common management practices that affect the riparian vegetation of the East and West Forks of Double Bayou.

2.6 Water Quality

The Double Bayou Watershed consists of the TCEQ stream segments 2422A (Anahuac Ditch), 2422B (Double Bayou West Fork) and 2422D (Double Bayou East Fork). The TCEQ began monitoring the water quality of Double Bayou in 1969. The Texas Integrated Report, formerly known as the Texas Water Quality Inventory and 303(d) list, is a document that describes the status of all surface waterbodies of the State evaluated for the given assessment period. A waterbody can be listed for a water quality parameter of concern if the constituent does not meet the water quality standards set by the TCEQ. The West Fork of Double Bayou was listed as impaired (not meeting its water quality standards, as assessed by numerical criteria) on the 2012 Texas Integrated Report for low dissolved oxygen (listed as impaired since 2004), and elevated levels of bacteria (listed as impaired since 2006). West Fork Double Bayou was also identified as a concern for water quality (concern for use based on numerical screening levels, rather than criteria) of chlorophyll-a. The East Fork of Double Bayou was identified as a concern for elevated levels of bacteria (since 2012) and as a concern for water quality based on screening levels for low dissolved oxygen (since 2010). Low dissolved oxygen is a concern for aquatic life because they require a certain amount of dissolved oxygen to live and reproduce (see Sections 4.4 and 4.5 for more information). Elevated levels of bacteria can be a concern for people using a waterway for recreational use, because elevated concentrations can indicate the presence of human disease-causing pathogens (see Chapter 4.6).

All of Galveston Bay and its tidal tributaries, including the East and West Forks of Double Bayou, are on the State's impaired waters list for PCBs and Dioxin. Most of the contamination stems from the Houston Ship Channel sediments and is transferred up the food chain to fish. A TCEQ project is under way to figure out how to address the sediment contamination so that the concentrations in fish tissue will be reduced. No actions in the Double Bayou Watershed will affect fish tissue, but stakeholders can participate in the larger Galveston Bay project.

2.7 Wastewater Infrastructure

2.7.1 Permitted Wastewater Treatment Facilities

The Anahuac Wastewater Treatment Facility (WWTF) is the only municipal wastewater treatment facility in the Double Bayou Watershed that discharges into the bayou, via the Anahuac Ditch. The effluent from this facility is considered the only point source (pollutant attributable to one specific source) in the watershed. Located just south of Anahuac the facility is owned by the City of Anahuac and the Trinity Bay Conservation District and is operated by the City of Anahuac.

The operators are required to report effluent sampling results to the CWA's National Pollutant Discharge Elimination System (NPDES) program. Currently, the wastewater treatment facility operates under the minor NPDES individual permit number TX0033944. The facility is permitted to discharge 0.6 million gallons per day of treated effluent.

The most recent compliance inspection was on 05/16/2013. The Anahuac WWTF has been out of compliance for 11 of 12 quarters from 10/01/2011 to 09/30/2014. However, the non-compliances have not resulted in significant violations. Chlorine, as total residual, fell below the monthly minimum on 4 occasions and it exceeded the monthly maximum once. Nitrogen, as total ammonia, resulted in five violations including 2 daily maximum and 3 daily average exceedances. Exceedances of the pH minimum limit criterion have also occurred.

Typically, the WWTF's *E. coli* effluent concentrations are well under the required 126 cfu/100 milliliter (mL) limit. Intense rainfall can cause problems with Infiltration and Inflow (I&I) to the City of Anahuac's sewage collection system pipes, which also contributes to the overflow of the pond and to potential elevated levels of bacteria. TBCD's collection system that feeds this plant is a force main sewer system and is not vulnerable to I&I. During periods of intense rainfall, an increase of *E. coli* is evident in the receiving waters (Anahuac Ditch) of the WWTF. Both the daily maximum and daily average *E. coli* criteria levels were exceeded on 10/31/2013, after a rainfall of 2 inches over a 5-day period.

A second facility, the Oak Island WWTF (owned and operated by the Trinity Bay Conservation District) is located near the community of Oak Island inside the Double Bayou Watershed. However, the Oak Island WWTF's effluent is discharged into Trinity Bay and is not a point source contribution to the watershed. As with the Anahuac WWTF, portions of the force main collection system for the Oak Island WWTF are within the Double Bayou Watershed. While force main sewers do not have the I&I problems that gravity sewers have, leaky or failing pipes and joints in force main sewers are possible.

2.7.2 On-Site Sewage Facilities

On-site sewage facilities (OSSF) are possible sources of bacteria and dissolved oxygen impairments in the Double Bayou Watershed. It is estimated that there are more than 450 OSSFs in the Double Bayou Watershed. This number was determined from OSSF permit data and local knowledge (stakeholder knowledge of homes not on public sewer systems). Septic systems in the Double Bayou Watershed range in age from new to over thirty years old. The majority of the septic systems in the Double Bayou Watershed range from twenty to more than thirty years in age.

3 Public Participation

3.1 Project History and Development

3.1.1 Early Project Interest and Activity

As part of its initiative to improve water quality in Galveston Bay, the Galveston Bay Estuary Program (GBEP) became interested in the collection of additional data to better assess the water quality of both forks of Double Bayou, because the forks are tributaries of Galveston Bay. GBEP also wanted to explore whether a voluntary WPP could be beneficial for the Double Bayou Watershed. A Double Bayou WPP could help prevent further water quality degradation and restore watershed health through a voluntary, community-driven process.

Public participation began in 2009, when GBEP facilitated funding for an initial study, from grants under the American Recovery and Reinvestment Act, the EPA, state sources and USGS. The funding provided resources for HARC to: (a) assemble and analyze existing water quality data for the watershed, (b) collect new water quality samples for both forks of Double Bayou and analyze the data and (c) share the information with key stakeholders, as well as the general public.

3.1.2 The Watershed Protection Plan Project

Since 2012, HARC has worked with the USGS and Shead Conservation Solutions to develop a WPP for Double Bayou. Funding is provided by the TSSWCB/EPA (federal Clean Water Act §319(h) grant) and the GBEP/TCEQ. The goal of the funded project was to develop a nine-element WPP for the Double Bayou Watershed by:

1) Establishing and providing direction for a stakeholder group that would serve as a decision-making body,
2) Conducting routine and targeted water quality sampling and analysis,
3) Identifying and analyzing spatial and temporal patterns in watershed data, and
4) Increasing education among the targeted audience.

3.2 Partnership Development, Structure and Meetings

3.2.1 Development of the Partnership

Local involvement is crucial for the successful development and implementation of a WPP. Funding for the development of the Double Bayou WPP opened the door for public participation. Multiple stakeholder categories were considered such as officials, community members with vested interest, landowners, recreational users, technical resource providers and any other person who may be affected by the Double Bayou WPP. The list was continuously updated over the course of the WPP process and was used to inform stakeholders of project and meeting updates and to bring stakeholders together for workgroup sessions.

From the outset, stakeholder interest in the Double Bayou WPP project was high. An invitation letter was sent to approximately 170 people. Thirty-seven stakeholders attended the first kick-off meeting on May 21, 2013. UPDATE AT END: A total of XX individuals have participated in at least one meeting during the development of the Double Bayou WPP.

3.2.2 Stakeholder Structure

Stakeholders preferred that the Double Bayou Watershed Partnership operate informally, as a "committee of the whole," rather than have a limited number of representatives serve on a Steering Committee. Stakeholder meetings were typically held every 2-3 months, with workgroup meetings and/or workshops held in between. In total, fifteen general meetings, seven sets of workgroup meetings and five informational workshops were held during the WPP development process.

3.2.3 General Stakeholder Meetings

General stakeholder meetings were held to share data, information and workgroup results that aided stakeholder decision-making. Over the project period, general meeting topics included in-stream water quality, water quality monitoring results, land use/land cover in the watershed and modeling of potential bacteria sources. In addition, all stakeholders were presented with the specialized knowledge and results decided on in each individual workgroup meeting. Any objections or concerns were resolved before an informal consensus was reached. During the final six months of the WPP process, general meetings were held more frequently (Figure 3-1 Double Bayou Watershed Partnership general stakeholder meeting). These final meetings provided a forum for the Project Team to present and explain chapter content, while collecting feedback from stakeholders.

Figure 3-1 Double Bayou Watershed Partnership general stakeholder meeting

3.2.4 Workgroup Meetings

To develop in-depth discussions of specific topics, stakeholders suggested forming four workgroup categories: Agriculture/Wildlife/Feral Hogs, Recreation/Hunting, Wastewater/Septic and Residential. The workgroups were based on groupings of potential pollutant sources identified during an early general meeting. Based on their interest and expertise, stakeholders chose the workgroup(s) in which they wished to participate. All workgroup recommendations were reached by informal consensus.

Each workgroup focused on the potential pollution sources for which they were formed. All workgroups started with reviewing basic concepts of watershed protection planning. The workgroups focused primarily on potential sources of bacteria pollution and dissolved oxygen impairments, but also considered other water quality issues. After identifying specific potential pollutant sources, the groups discussed the following topics: evaluation of source data, the location of sources in the watershed, development of SELECT modeling scenarios (which included their input on location and amount of sources) and potential management measures associated with the pollutant source (see Chapter 6). Each workgroup also developed a set of outreach and education programs that could address their particular category of pollution sources (see Chapter 7). Stakeholders provided input on implementation schedules, milestones and indicators for management measures.

A formal Residential Workgroup did not materialize in the same manner as the other groups. Instead, the watershed coordinator conducted one-on-one interviews with stakeholders and provided a residential breakout group during a general meeting, to identify and discuss potential residential pollutant sources and management measures.

The Agriculture/Wildlife/Feral Hogs Workgroup identified agricultural categories of potential bacteria pollution sources such as livestock (cattle), goats and horses. Combined with the work of the Geographic Task Force (see Chapter 2.5.2), they used extensive local knowledge to create a current (summer 2014) snapshot of land cover/land use in the watershed, particularly as it relates to agricultural production. They also were able to define current estimated grazing densities of livestock, based on the specific land cover (Figure 3-2 Agriculture/Wildlife/Feral Hogs Workgroup meeting).

Figure 3-2 Agriculture/Wildlife/Feral Hogs Workgroup meeting

The workgroup’s discussion of wildlife bacteria sources settled on source categories for which population data could be obtained. Native wildlife sources (deer) were considered background bacteria sources, as they occur naturally (i.e., were not specifically introduced by humans for agricultural production). Other pollution sources/issues discussed were feral hogs, game and livestock carcasses, fish kills and vegetation collecting on the water.

The Recreation/Hunting Workgroup first identified the recreation/hunting activities common in the watershed. Then the bacteria or water pollution issues associated with those activities were discussed, including: boater waste, the concentration of scavengers, disposal of game carcasses and the lack of public sanitation facilities available to recreationists in the watershed.

Other water pollution issues that this workgroup developed recommendations for were: vehicle maintenance, litter, oil sheen from motorboats and boat engines, lead (from hunting, shooting ranges and fishing weights), invasive species and sediment and loss of vegetation from erosion caused by ATVs and motorboats. This workgroup also identified feral hogs as a source of bacteria and riparian/shoreline erosion.

The Wastewater/Septic Systems Workgroup spent time identifying and learning about the public and private wastewater infrastructure of the watershed. The workgroup gained a better understanding of what public wastewater systems are located in the watershed and how the infrastructure is operated and maintained. The following questions were addressed: how many wastewater treatment facilities operate in the watershed, which of these wastewater treatment facilities discharge to Double Bayou or its tributaries and what types of collection systems are used in the watershed.

The private onsite sewage facilities (OSSFs) were also evaluated by stakeholders as potential sources. The type of septic systems in the watershed, their locations and the age of the systems were identified. Stakeholder expertise was critical in developing the OSSFs data set. Straight pipe discharges were also discussed.

3.2.5 Workshops

To bring additional resources to local stakeholders, specialty workshops on a variety of topics were held in the watershed. The workshops often combined lectures and field excursions to enhance stakeholder knowledge of common watershed issues and introduced practical solutions to watershed problems (Figure 3-3 Texas Riparian & Stream Ecosystem workshop). Many of the workshops also provided Continuing Education Credits (CEUs) needed by the stakeholders for various certifications. Workshops held for stakeholders during the Double Bayou WPP project were:

- Texas Watershed Steward Training: June 25th, 2013
- Feral Hog Management Workshop: June 27th, 2014
- Texas Riparian & Stream Ecosystem Workshop: September 24th, 2014
- Septic System Workshop: March 31st , 2015
- Texas Well Owner Network Workshop: May 28th , 2015

Figure 3-3 Texas Riparian & Stream Ecosystem workshop

3.2.6 Project Team

The Double Bayou WPP Project Team was comprised of representatives from the funding agencies (TSSWCB, GBEP/TCEQ and EPA) and from the participating organizations of HARC, Shead Conservation Solutions and USGS. The Project Team's primary role was to provide the stakeholders with data and information needed to develop the WPP. This included providing descriptions of watershed conditions, water quality data analysis and modeling results, and suggestions for management measure implementation.

In addition to their specific roles of providing funding and of approving the direction and documentation of the project, the TSSWCB and GBEP representatives provided insight and experience from other WPP projects in Texas and the region.

HARC developed the water quality data analysis and SELECT modeling, prepared graphs and exhibits of water quality data and SELECT modeling results and prepared drafts of the WPP document chapters for stakeholder review and comment. Shead Conservation Solutions was responsible for the public participation component of the project, including maintaining communications with stakeholders through email and/or U.S. mail, preparing and distributing media items, providing notices of meetings and events, facilitating meetings and preparing meeting documents. USGS was responsible for the collection of quality-assured water quality data.

3.3 The Future and Watershed Protection Plan Implementation

Watershed protection plans guide implementation of holistic water management solutions that are developed by watershed stakeholders. They are adaptive documents that evolve as new data, partners, funding and stakeholders become available. New information is continually identified through tracking and monitoring of the WPP. As with any watershed protection plan, implementation of the Double Bayou Watershed Protection Plan is entirely dependent on voluntary participation and availability of funding. Continued stakeholder involvement in the implementation phase of the WPP is crucial to accomplish the plans goals (see Chapter 8 for the stakeholder-identified implementation process).

4 Water Quality

4.1 Water Quality Sampling

Physical and chemical water quality sampling was conducted to assess water quality impairments and current conditions of the Double Bayou Watershed. All water quality sampling was conducted under an approved Quality Assurance Project Plan (QAPP). Four mainstem sampling station, two each on the West Fork and the East Fork, and one wastewater treatment facility sampling station were identified through a process of stakeholder input and scouting for safety/feasibility of sampling (Figure 4-1 USGS sampling station).

Figure 4-1 USGS sampling station

The wastewater treatment facility sampling station was incorporated into the sampling design to characterize a possible point source contribution in the watershed by analyzing the water quality of the effluent discharge of the WWTF. The sampling stations, with their associated abbreviation, numerical designation and approximate location, are displayed in Table 4-1 Double Bayou sampling stations. Figure 4-2 Double Bayou sampling stations shows the exact location of all the sampling stations in the watershed.

Station Name	**Abbreviation**	**Location** (*crossing*)	**USGS Designation**
Wastewater Treatment Facility	WWTF	Anahuac Ditch	294443094401100
East Fork Upper	EFU	FM 1663	08042546
East Fork Lower	EFL	Carrington Road	08042548
West Fork Upper	WFU	Sykes Road	08042554
West Fork Lower	WFL	Eagle Ferry Road	08042558

Table 4-1 Double Bayou sampling stations

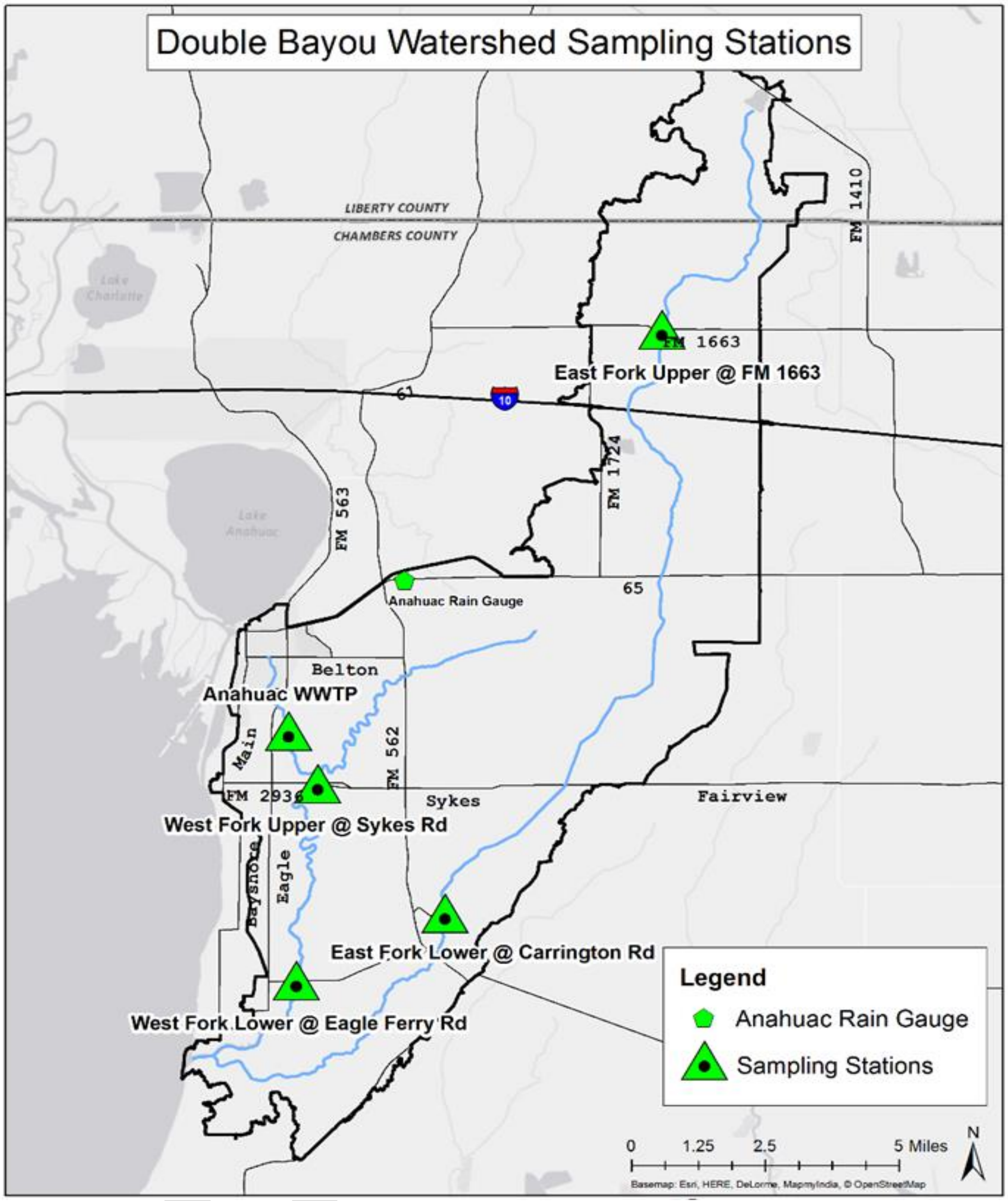


Figure 4-2 Double Bayou sampling stations

Water quality sampling was conducted under two different conditions – routine and targeted. Sampling conducted under "routine" conditions were scheduled events that monitor standard ambient (common or prevailing) conditions. Water quality sampling conducted under "targeted" conditions took place during predicted rain events, to monitor the impact of rainfall on water quality. The routine samples were collected approximately twice per month at each station over a twenty-month sampling period (10/22/2013-06/08/2015), while targeted samples were dependent on rainfall events (Table 4-2 Total Samples collected during WPP sampling period). All water quality samples are surface samples collected at 0.3 meters (about 1 foot) in depth below the surface. Note that not all sampling events provided valid results for every constituent. For example, even though the total number of sampling events for the EFU station is 39, only 36 total dissolved oxygen results are accounted for, due to equipment malfunction or sample instability. This is why the quality assured practices of field blanks or replicates are so crucial in water quality sampling, to ensure valid results.

Station (*Abbr.*)	**Number of Routine Samples**	**Number of Targeted Samples**	**Total Number of Samples**
EFU	32	7	39
WWTF	31	7	38
EFL	32	7	39
WFU	33	7	39
WFL	32	7	38
Total	**159**	**35**	**194**

Table 4-2 Total Samples collected during WPP sampling period

Targeted sampling is focused on analyzing water quality in the bayous during a wet weather event (Table 4-3 Targeted sampling dates). This analysis provides insight on how increased nonpoint source runoff affects the bayous during rain events. These samples often show the "worst-case" scenario for water quality indicators such as bacteria. Targeted samples are not considered to be representative of the bayous' water quality during normal flow patterns and are not used to determine listings on the Texas Integrated Report. All other sampling events are considered routine regardless of the amount of precipitation that occurred on or before the sampling day.

Targeted Sampling Date	**Amount of Rainfall**
10/31/2013	0.53
2/26/2014	2.50
5/13/2014	1.10
5/27/2014	0.16
9/17/2014	1.40
3/10/2015	0.40
4/17/2015	2.80

Table 4-3 Targeted sampling dates

4.2 Stream Type Designations and Tidal Mixing

The water quality sampling stations and their corresponding tidal/nontidal stream type, as designated by TCEQ, are displayed in Table 4-4 Stream type designations. The indicator bacteria *E. coli* is used for analysis at the nontidal stations EFU and WWTF; the tidal stations are assessed using Enterococci (see Section 4.6, for details). The Anahuac Ditch, where the WWTF sampling station is located, joins with the main tidal portion of the West Fork of Double Bayou. However, the ditch itself is designated as a nontidal freshwater stream. The only other nontidal sampling station selected for monitoring is the EFU station; the remaining three sampling stations are designated as tidal.

Sampling Station	Stream Type
Wastewater Treatment Facility	Nontidal
East Fork Upper	Nontidal
East Fork Lower	Tidal
West Fork Upper	Tidal
West Fork Lower	Tidal

Table 4-4 Stream type designations

The WFL station had the strongest negative flow measured during the sampling period. Over the 20-month study period, the strongest tidally influenced negative flow recorded at the WFL station was -511 cubic feet per second (cfs). A negative flow is defined as flow moving from downstream towards upstream, caused by an incoming tide from Trinity Bay (see Chapter 5.8.1 Trinity Bay for a detailed discussion on the influence of wind and freshwater inflows on tides in Trinity Bay). Average salinity regime varies widely at the different sampling stations, with WFL average at 6.35 practical salinity units (PSU), EFL at 0.84 PSU and EFU and WFU both under 0.20 PSU. See Chapter 5.8, Tidal Mixing, for a detailed discussion of tidal mixing and how it affects constituents in the water compared to typical nontidal flow.

4.3 Precipitation

Precipitation analysis is crucial to consider when analyzing water quality data, because rain events can affect water quality results. In the Double Bayou Watershed, precipitation data are collected at the Anahuac rain gauge and was downloaded from NOAA's Online Climate Data Portal for analysis (Figure 4-3 Precipitation in Double Bayou). The Anahuac rain gauge has been operational since March of 1931 and is located east of the City of Anahuac (near FM 562 and SH 65) (Figure 4-2 Double Bayou sampling stations).

Precipitation data were analyzed to determine the number of days since last rainfall, which provides valuable insight on the effects of rainfall and nonpoint source runoff into the bayou. Typically, as the number of days since last rainfall (DSLR) increases, the pollutants accumulate on the ground and higher levels of nonpoint source pollutants may be washed into the bayou during the next rain. High intensity or frequent rain events also increase surface runoff, which can result in larger amounts of nonpoint source pollutants flowing into the bayous. A combination of greater length of DSLR, followed by an intense wet weather event, can intensify the impact on the concentrations of nonpoint source pollutants in the bayous.

An example of this in Double Bayou was the sampling event on 5/13/2014. Prior to this targeted sampling event, 27 days had passed since the last rainfall. On 5/13/2014, 1.10 inches of rain fell at the Anahuac rain gauge. The combination of the large wet weather event and highest recorded DSLR can lead to high bacteria contributions that are quickly flushed into the bayous because the bacteria were allowed to build on the landscape before being effectively flushed by the large precipitation event.

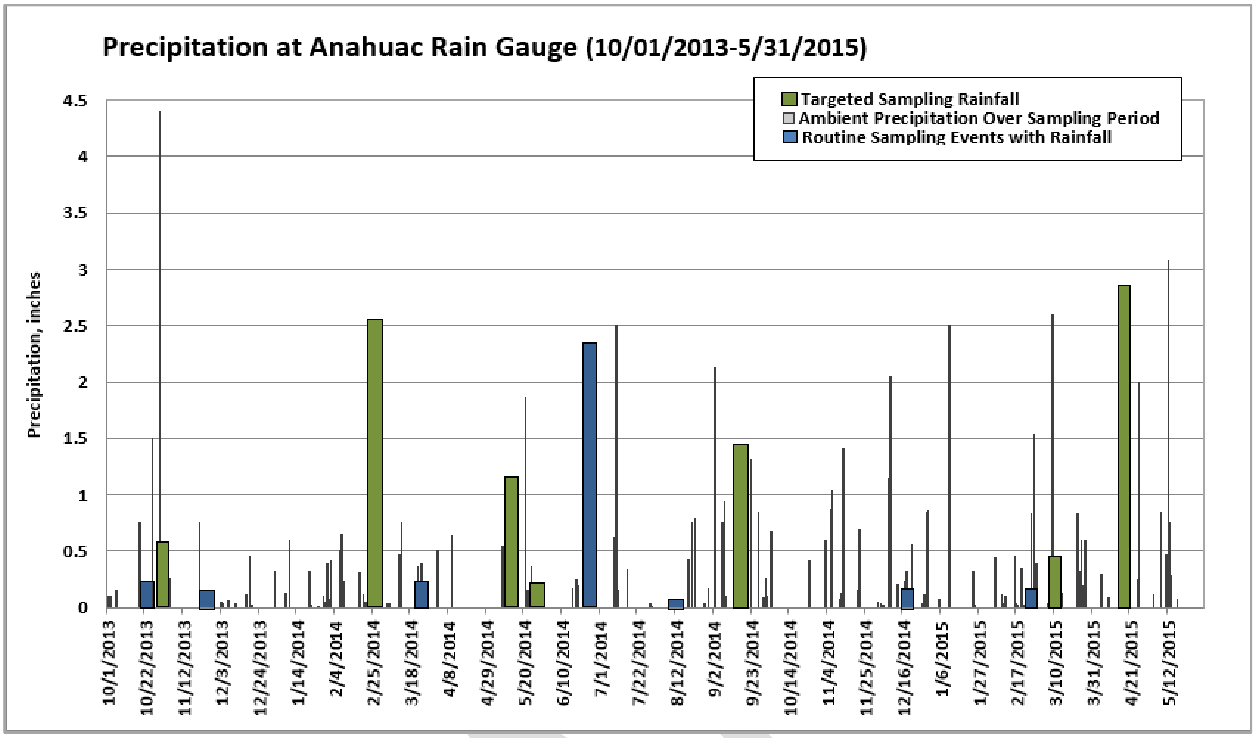


Figure 4-3 Precipitation in Double Bayou

4.4 Dissolved Oxygen

Dissolved oxygen (DO) is a water quality parameter that is commonly monitored because it is crucial for the survival of aquatic life. DO in a waterbody is typically considered optimal for aquatic life at concentrations above 6 mg/L; aquatic organisms will become stressed at DO concentrations between 4 and 5 mg/L; and the loss of aquatic life is probable when the DO concentration is below 3 mg/L. To determine if a waterbody is impaired, the TCEQ established a screening level for grab samples (a sample that is taken once, with a literal "grab" or scoop of the water – as opposed to continuous sampling) of 3 mg/L for tidal and nontidal waters. Note that for DO, the concentration must be *less* than the threshold of 3 mg/L to be considered as an exceedance, compared to most other water quality indicators that have to be *greater* than the designated criterion to be considered an exceedance.

The concentration of DO in a waterbody can fluctuate depending on several environmental factors, including the temperature and salinity of the waterbody and the time of day. DO can also fluctuate from season to season. The lowest DO levels are typically observed during the hottest months of the year while the highest DO levels occur during the coldest months of the year. Colder water can hold more DO. Over the sampling period (10/22/2013-06/08/2015), the average concentration of DO in the Double Bayou Watershed (all stations) was 6.3 mg/L. The highest DO concentration was 12.6 mg/L and the lowest was 0.8 mg/L. During the sampling period, 16 routine and targeted samples (9% of the total) were below the TCEQ criterion of 3 mg/L (Figure 4-4 Double Bayou dissolved oxygen results). The EFU station had the highest percentage (25%) of samples below the TCEQ criterion. No DO samples below the criterion were recorded at the

WWTF station, while 2 were recorded at the EFL station, 4 at the WFU station and 1 at the WFL station.

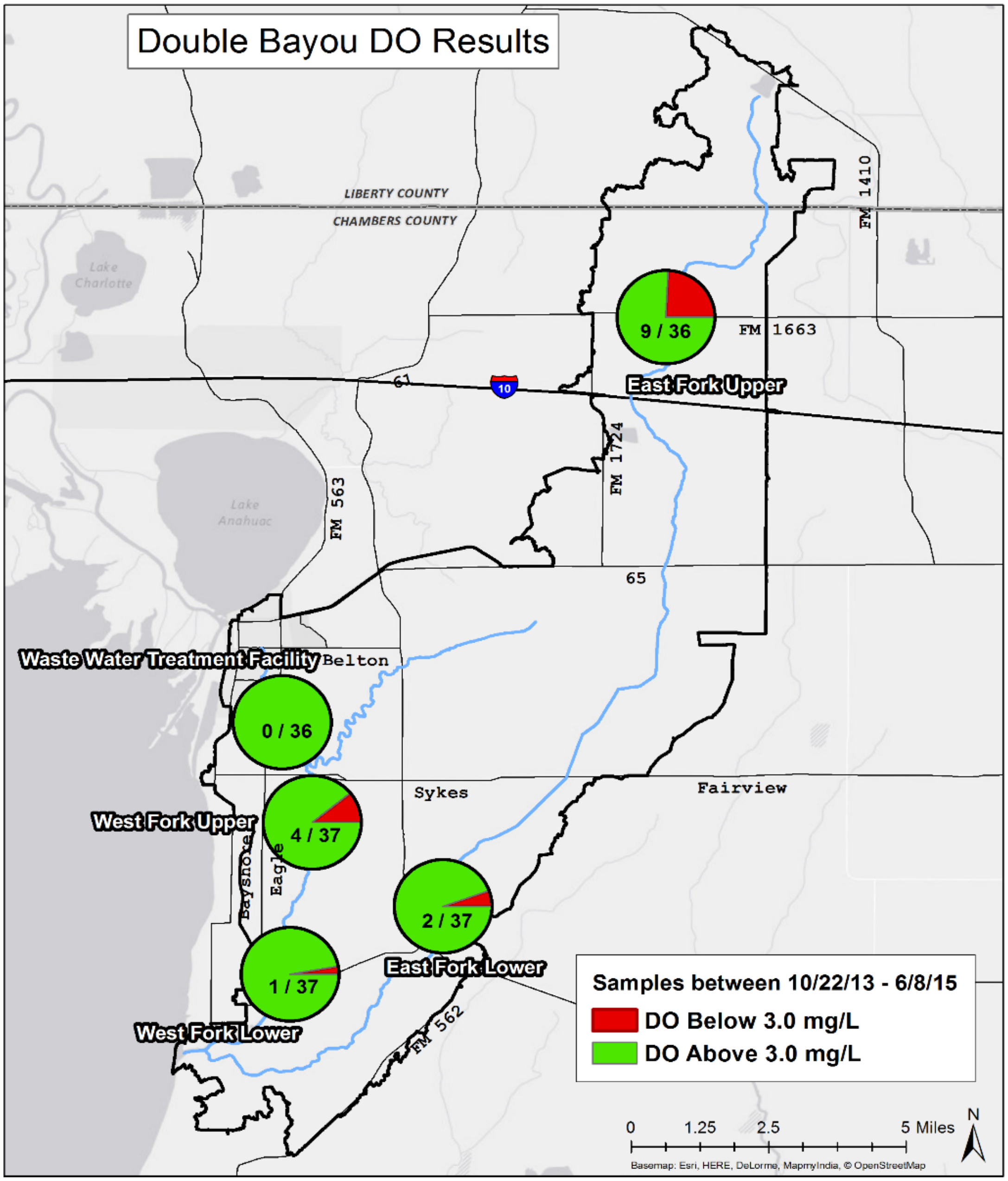


Figure 4-4 Double Bayou dissolved oxygen results (routine and targeted)

DO is a not a pollutant but rather a marker to indicate water quality and health for aquatic life. Low DO is caused by a number of factors in the bayous. One of these factors can be high bacteria levels, because an increase in bacteria will often lead to higher consumption of oxygen that can result in lower DO levels. The water quality management measures discussed in Chapters 6 and 7 will be targeted towards bacteria, but their benefits will also extend to mitigating lower DO levels.

4.5 24-hour Dissolved Oxygen Sampling

In addition to targeted and routine sampling, twelve 24-hour continuous sampling gages were deployed at the mainstem sampling stations: EFU, EFL, WFU and WFL. Continuous (24-hour) monitoring data (for water temperature, specific conductance, dissolved oxygen, and pH) were collected at 15-minute intervals at each bayou sampling station during 24-hour events. Monitoring of 24-hour DO is measured to determine compliance with aquatic life use designations and to support biological modeling, as well as to aid with the analysis of short-term fluctuations. The 24-hour monitoring can show the variation of DO throughout the course of the day and reveal high and low DO concentrations.

To assess the 24-hour DO sampling results, a separate set of criteria and analyses are used than those for grab samples. These include the absolute minimum and average DO values over a continuous 24-hour monitoring event. The TCEQ also requires a minimum number of samples to be taken during specific seasons (index periods) to accurately represent seasonal DO variations. These values must then meet certain TCEQ requirements to determine if the waterbody is impaired. Conducting 24-hour sampling events is resource intensive and, therefore, 24-hour data are not always available at all streams during the index period necessary for criteria analysis. If the 24-hour sampling events are not available, TCEQ relies on grab sample DO data for screening level assessment as described in Section 4.4 Dissolved Oxygen. Both 24-hour data and grab samples have been used for West and East fork assessments.

When the index period requirement is met, the TCEQ criteria to assess the aquatic life use are 5.0 mg/L average DO for 24-hour nontidal (freshwater) and 4 mg/L average DO for 24-hour tidal (saline water). The 24-hour DO minimum for tidal and nontidal waters is 3.0 mg/L. The 24-hour data discussed below represent sampling efforts *not* specifically within the TCEQ criteria for index periods; yet the data analyzed represent DO patterns which are important in assessing the health of the watershed.

Figure 4-5 24-hour Dissolved Oxygen displays the results of the 24-hour DO sampling events. The top of the black lines represent the maximum DO concentration during the event; the bottom of the black lines represents the minimum DO concentration during the event and the colored shape represents the average of all DO concentrations sampled during the event. All three of the East Fork Upper nontidal 24-hour monitoring events had DO concentrations below the average and minimum criteria. The East Fork Lower 24-hour monitoring event on 12/3/2014 had DO concentrations below the minimum. Two of the West Fork Upper 24-hour monitoring events had DO concentrations below the minimum and average criteria on 8/20/2014 and 9/17/2014. None of the West Fork Lower 24-hour monitoring events resulted in samples below the TCEQ criteria for DO.

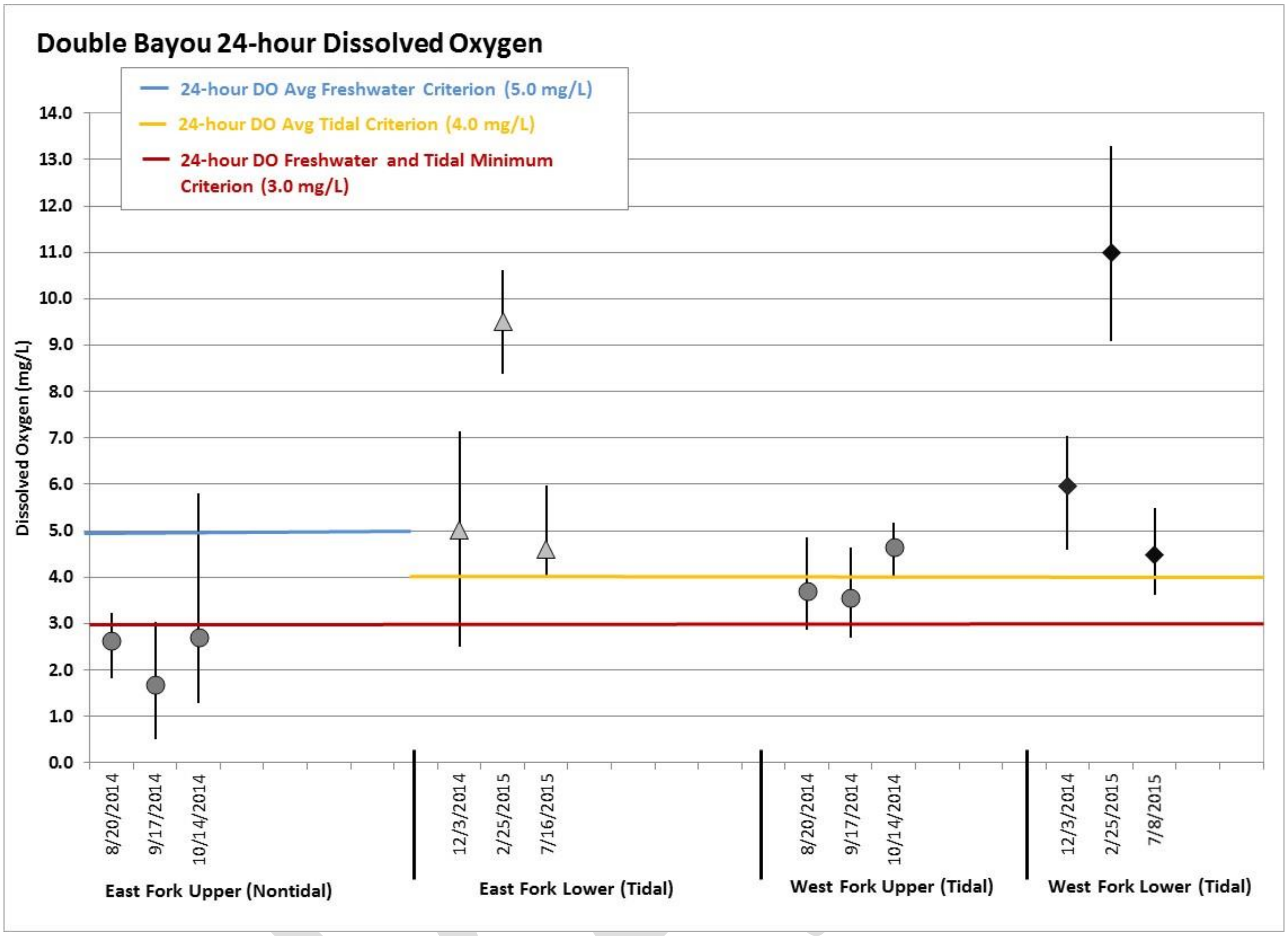


Figure 4-5 24-hour Dissolved Oxygen

4.6 Bacteria

Another critical indicator of nonpoint and point source pollution is bacteria; specifically, the fecal indicator bacteria *E. coli* and Enterococci. *E. coli* is the preferred fecal indicator bacteria for nontidal waters (freshwater) and was used for analysis in the upper nontidal reaches of the East Fork and at the nontidal WWTF to assess bacteria concentrations. *E. coli* was utilized at the WWTF station instead of Enterococci because the WWTF's operation permit has a self-reporting requirement for *E. coli* concentrations; a direct comparison can be made. The preferred fecal indicator bacteria for tidal (saline) waters is Enterococci (TCEQ 2010). These bacteria are used to determine the level of health risk from fecal contamination and associated pathogens in their respective waterbodies. The fecal indicator bacteria are not a primary threat to human health, but serve as an indicator for potential harmful pathogenic microorganisms and fecal waste contamination.

Note that bacteria units are typically identified as colony forming units (cfu) or as most probable number (MPN) according to the lab method used for analysis. During our sampling period, bacteria were identified in units of MPN and the discussion here will reflect that. The SELECT model uses cfu for bacteria units. These units (MPN and cfu) are comparable in terms of the quantity of bacteria.

TCEQ uses criteria based on the geometric mean to indicate bacteria impairments for recreational waterbodies. The geometric mean is a type of average that normalizes the sampling data over a period of time (no one number dominates the average). The geometric mean criterion for *E. coli* is 126 MPN/100 mL while the geometric mean criterion for Enterococci is 35 MPN/100 mL (TCEQ 2012). These criteria are based on the TCEQ's standards for primary contact (i.e. swimming, water skiing and surfing) in recreational waterbodies. Targeted samples are not included in geometric mean calculations.

All three Double Bayou tidal monitoring stations exceeded the geometric mean criterion for Enterococci (35 MPN/100 mL) (Figure 4-6 Bacteria geometric means). Of the three tidal stations, the WFU station had the highest geometric mean, while the EFL station had the lowest. The EFU station did not exceed the geometric mean criterion for *E. coli* (126 MPN/100 mL) and the WWTF station had a geometric mean significantly lower.

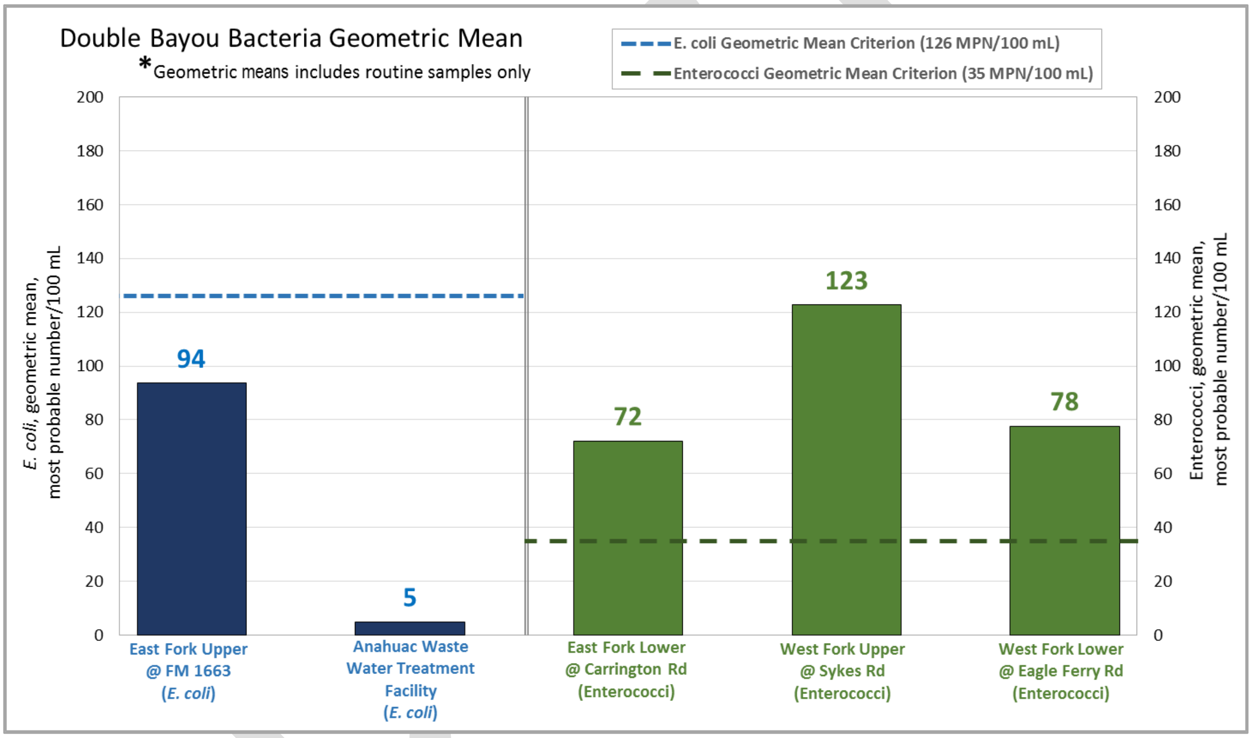


Figure 4-6 Bacteria geometric means

During rain events, bacteria can be transported to the bayou in associated surface runoff. Typically, the amount of bacteria transported to the bayou is dependent on the intensity of the rain event and the number of days since the last rain event. Longer periods between rain events can allow more fecal material to build up on the landscape and be washed into the bayou. However, not all of the bacteria that are deposited reach the bayou because die-off and absorption occurs from natural mechanisms such as exposure to sunlight and vegetative uptake. The bacteria that are not removed during these processes may be carried to the bayou during a rain event. This can be mitigated by implementing appropriate management measures that will help to remove some of the remaining bacteria before runoff reaches the bayous (see Chapter 6 for management measures discussion).

The largest targeted rainfall event (2.80 inches) occurred on 4/17/2015; however, 0 days had passed since the last rainfall. In addition, 2.50 inches of rain had fallen over the five days just prior to the 4/17/2015 rain event (Figure 4-7 Targeted Event Bacteria Sampling Results). During this rain event, the highest concentration of *E. coli* from targeted sampling was recorded at the WWTF (49,000 MPN/100 mL) and at the EFU (9,600 MPN/100 mL) sampling stations. There were not enough data for geomean analysis for the targeted rainfall events; only single sample results are shown in Figure 4-7 Targeted Event Bacteria Sampling Results.

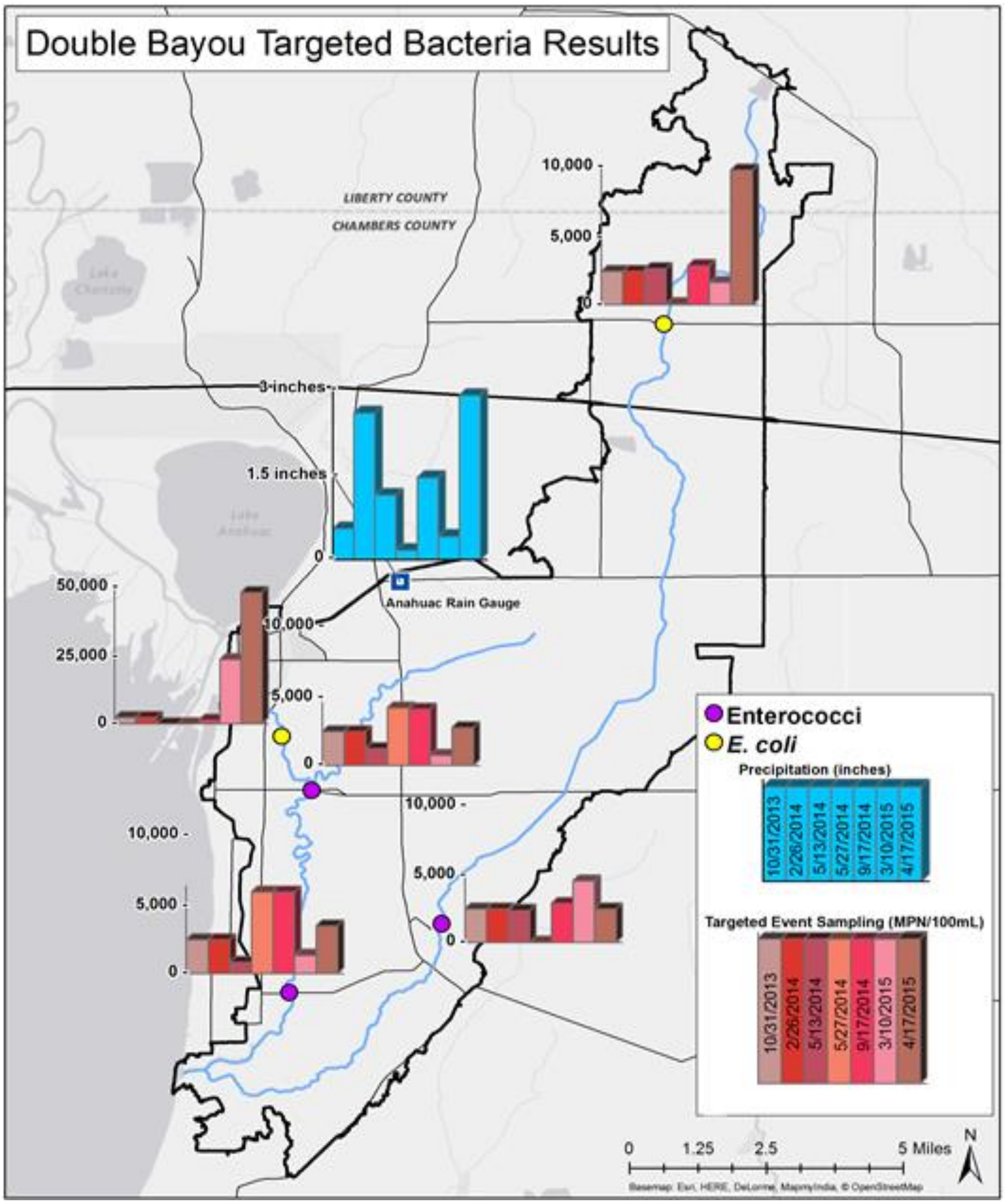


Figure 4-7 Targeted Event Bacteria Sampling Results

4.7 *Nutrients and Chlorophyll-a*

Nutrients and chlorophyll-a, which is the associated indicator of algae biomass, were the third class of indicator used to determine if excessive nonpoint source pollution is prevalent in the Double Bayou Watershed. Chlorophyll-a is a green pigment found in plants, which absorbs sunlight and converts it to sugar during photosynthesis using nutrients such as phosphorus and nitrogen. High levels of chlorophyll-a often indicate poor water quality and low levels often suggest good conditions, but it is the overall cycle that is important. However, long-term persistence of elevated levels can be problematic. Chlorophyll-a is often used as an indicator of the abundance and quantity of phytoplankton (microscopic plants) in coastal and estuarine waters.

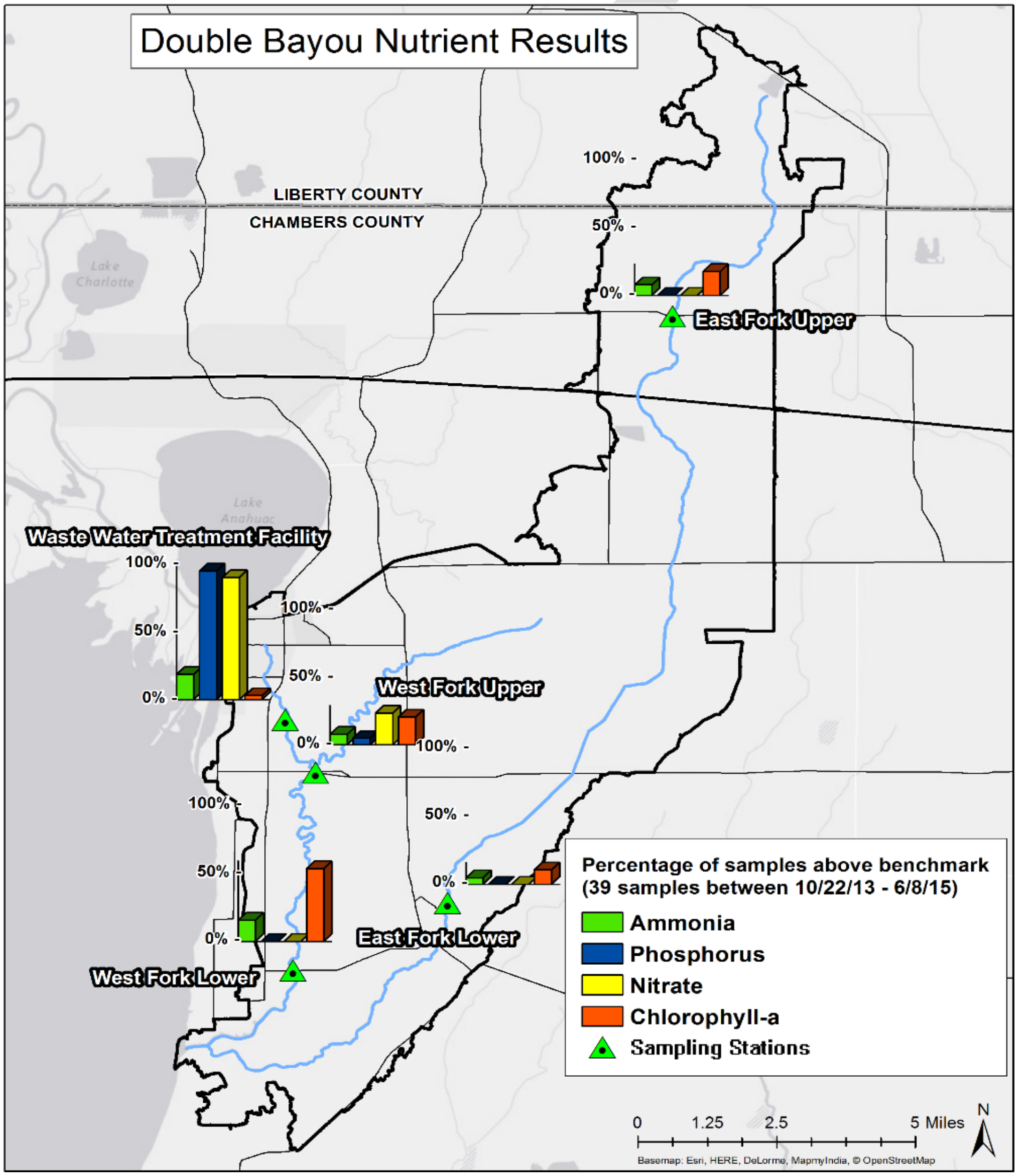


Figure 4-8 Nutrient percent of exceedance

Among the various forms of nutrients sampled by the USGS, nitrate, orthophosphate, total phosphorus and ammonia were chosen for analysis. It is important to monitor these nutrients because excess concentrations can lead to eutrophication (excessive plant growth). Eutrophication occurs when excessive nutrients fuel a phytoplankton bloom. This bloom can only be supported for a short period of time until large amounts of phytoplankton die off in unison and sink to the bottom of the water column. Their subsequent decomposition uses up available DO which depresses oxygen levels. The decreased oxygen levels can lead to die-off of organisms such as fish and invertebrates. These organisms then sink to the underlying hypoxic (low DO) zone (at the bottom) and use more oxygen as they decompose. This exacerbates the hypoxic conditions and continues to suppress oxygen levels eventually rendering the water body unsuitable for life.

Concerns for attainment of general uses are identified using screening levels for nutrients and chlorophyll-a. TCEQ screening levels for nutrients and chlorophyll-a are statistically derived from monitoring data. Double Bayou West Fork was identified as a concern for water quality based on screening levels for chlorophyll-a in the 2012 Texas Integrated Report (TCEQ 2012). It is important to monitor the nutrient and chlorophyll-a levels in Double Bayou to assess long term trends. Tracking of these indicators can serve as early detection such as if the number of exceedances starts to increase or if a new activity in the watershed is causing an excessive amount of nitrogen. Over the 20-month study period, the WWTF station had the highest percent of exceedances of ammonia, phosphorus and nitrate (Figure 4-8 Nutrient percent of exceedance). The WFL station had the highest percent of exceedance for Chlorophyll-a.

5 Pollutant Sources and Loads

5.1 Modeling and Analysis Approach

5.1.1 Land Use/Land Cover

Land use/land cover is a crucial input to the modeling and analysis approach used for determining pollutant sources and loads. A pollutant load is the total amount of pollutant entering a waterbody from one or multiple sources. Pollutant load is measured as a rate, as in weight per unit time or weight per unit area. Determining land use/land cover in the Double Bayou Watershed was accomplished by starting with land cover data from the 2010 NOAA Coastal Change Analysis Program (C-CAP) based upon 30-meter Landsat imagery. Stakeholders with local knowledge worked with this data set to ground truth the land cover as well as consolidate 25 land classes into 7. The consolidation was based on local stakeholder expertise of land cover locations in the watershed. The details of this process are discussed in Chapter 2, Sections 2.5.1 and 2.5.2.

5.1.2 SELECT

The SELECT (Spatially Explicit Load Enrichment Calculation Tool) model was used to estimate potential pollutant loadings from bacteria across the Double Bayou Watershed. SELECT was developed by the Department of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University. SELECT modeling for the Double Bayou Watershed was performed to estimate bacteria loadings from various sources and to identify critical loading areas within the watershed. SELECT works within an ArcGIS environment and spatially characterizes the bacterial loads in the watershed. For this WPP, the distribution of livestock, wildlife, wastewater treatment facilities and septic systems along with the contributions from each were quantified through source-specific bacterial production rates. Rankings of each contribution source were assessed for the entire watershed. A refined model was created by taking into account the data availability and watershed characteristics to modify point sources based on stakeholder input. All model inputs as well as model results were discussed with stakeholders and outputs were assessed for management measure implementation. SELECT results are based on subwatersheds, which are smaller watersheds within the Double Bayou Watershed that are determined using elevation and hydrological characteristics.

To maximize potential pollutant reduction and the efficiency of available funding, SELECT results will support implementation of on-the-ground management measures. For example, a riparian herbaceous buffer, coupled with cross fencing and alternate water sources for livestock, was suggested to reduce bacteria contributions from feral hog and livestock fecal waste. SELECT provides insight to stakeholders as they select voluntary management strategies.

5.1.3 Developing a Load Duration Curve

A Load Duration Curve (LDC) is used for evaluating water quality data when trying to determine pollutant loadings under different flow conditions. LDC analysis results in a graph representing the percentage of time during which the value of the load is equaled or exceeded. The first step in developing a load duration curve is to calculate a Flow Duration Curve. To do this, flow data are sorted and ranked from highest flow to lowest flow and then used to develop a graph of flow rate versus frequency (Figure 5-1 Example flow duration curve - stream flow data are used to determine how frequently stream conditions exceed certain flows). The LDC analysis for the Double Bayou WPP was performed using flow measurements and bacteria samples that were obtained as part of the overall sampling plan (see Chapter 4.1). Stakeholders consider the LDC analysis for bacterial loads when making decisions on load reduction goals. The LDC analysis will also help to guide the implementation of the plan and management strategies.

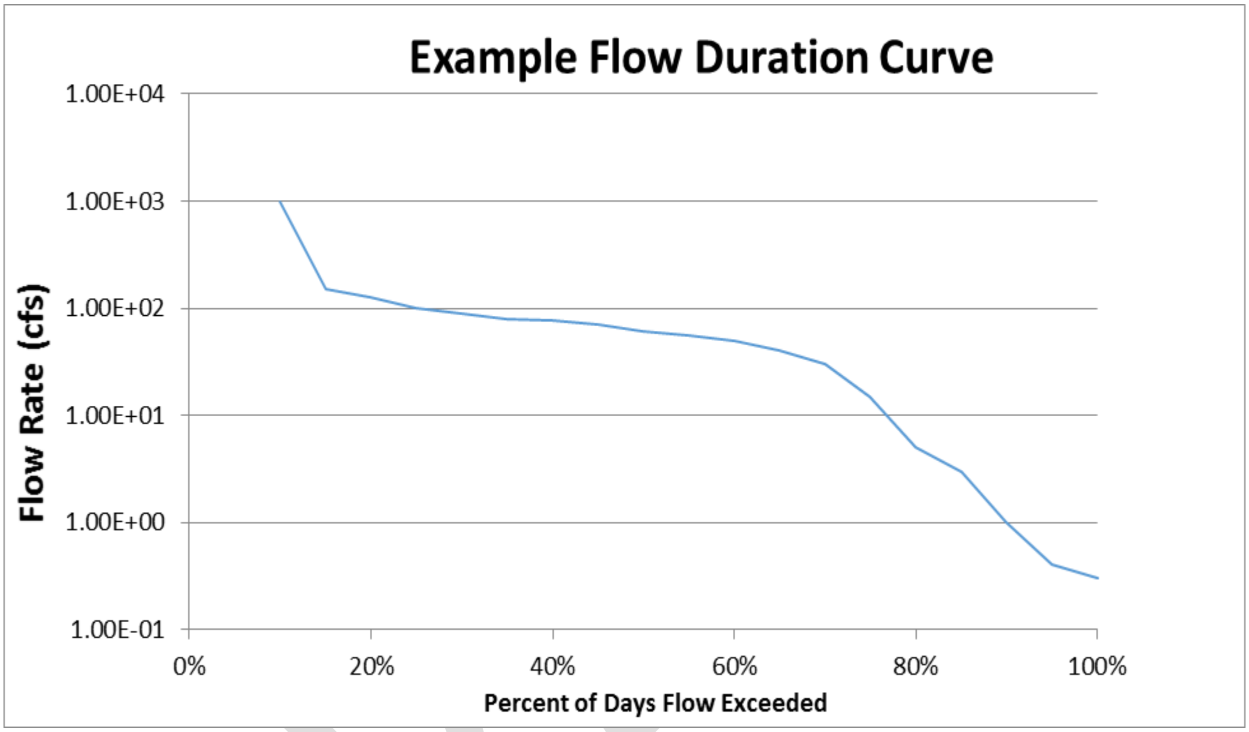


Figure 5-1 Example flow duration curve - stream flow data are used to determine how frequently stream conditions exceed certain flows

Flow data from the flow duration curve are multiplied by the concentration of the water quality standard for the pollutant in question (in Double Bayou's case, bacteria) to produce the LDC. The "load" is expressed as amount of pollutant per unit time – for bacteria, this would be bacteria cfu/day. The resulting curve reflects the maximum load (again, bacteria in this case) a stream can carry across the regime of flow conditions (low, medium, and high flows) in the bayou without exceeding the water quality standard. Typically, a margin of safety (MOS) is applied to the pollutant concentration to allow for possible variations in loading from potential sources, stream flow, management measures and other types of uncertainty. For this WPP, stakeholders selected a 10% MOS for bacteria. The regulatory standard for *E. coli* bacteria as established by TCEQ for contact recreation is 126 cfu/100 mL; the applied 10% MOS results in a more conservative threshold concentration of 113 cfu/100 mL.

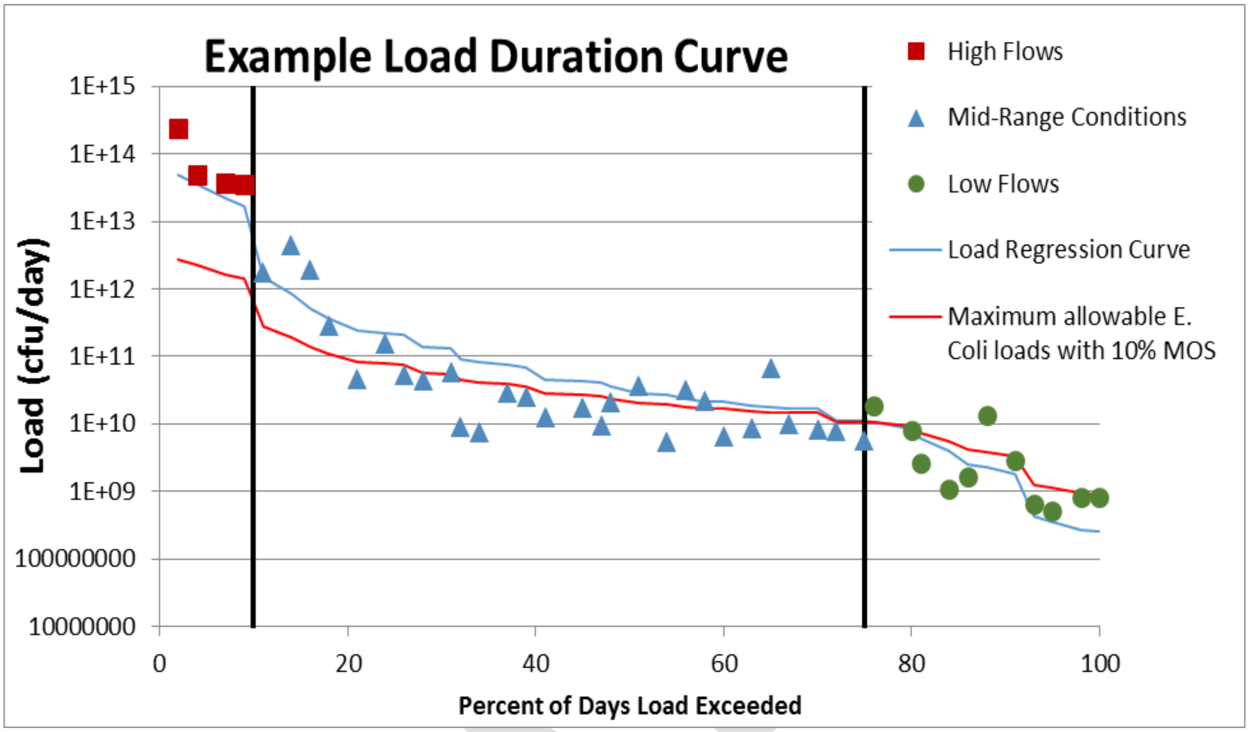


Figure 5-2 Example Load Duration Curve

Different flow regimes are identified in the LDC as areas where the slope of the curve changes significantly – indicating a significant change in flow. In the example (Figure 5-2 Example Load Duration Curve) and in the actual Double Bayou LDC (see Section 5.7), there are three flow regimes: high, mid-range and low. The monitored constituent data can then be plotted on the curve to show the frequency and magnitude of exceedances. In the example, the red squares indicate the data collected under high flow conditions, the blue triangles indicate data collected under mid-range conditions and the green circles indicate data collected in low flow conditions. In Figure 5-2, the red line "maximum allowable *E. coli* loads with 10% MOS" indicates the maximum allowed load for *E. coli* bacteria with the 10% MOS discussed above. When the monitored data points are above the red line, the actual (measured) stream load has exceeded the water quality standard. Monitored data points on or below the red line indicate that the actual (measured) stream load is in compliance with the water quality standard.

The blue regression line is the statistical "best fit" line for the monitored data (Figure 5-2 Example Load Duration Curve). When the blue regression line is on or below the red line, the monitoring data are in compliance with the water quality standard. When the blue line is above the red line, the monitoring data are not in compliance with the water quality standard. Regression analysis aids in determining the estimated percent reduction needed to achieve pollutant loads.

The LDC analysis provides information about pollutant concentrations and flows. In general, if exceedances observed on the LDC only occur during high flow conditions, nonpoint sources of pollution are likely to be the primary causes of impairment. High flow conditions usually indicate high rainfall events which would increase surface runoff and therefore cause more surface pollutants to be carried to the bayou. On the other end of the LDC, in general, if exceedances observed only occur during low flow conditions, point sources of pollution are likely to the primary causes of impairment. Low flow conditions usually indicate no runoff, which would mean only direct discharges (point source) into the bayou are contributing to the load.

Tidal mixing was analyzed to determine the extent of influence that tidal forces have on bacteria loadings in the lower tidal portion of the watershed. A critical component of the tidal mixing analysis was the Index Velocity Site Gauge that was in operation throughout the project period at the West Fork Lower sampling station. The Index Velocity Site Gauge is a continuous operating flow meter that measures both positive and negative flows. Using this continuous flow data set, comprehensive tidal analysis was performed.

5.1.4 Identifying Point and Nonpoint Pollutant Sources

The Anahuac WWTF is a point source in the Double Bayou Watershed (Figure 5-20 WWTF SELECT results). The effluent that is discharged to the Anahuac Ditch does not change location and comes from a single identifiable source (see Chapter 2.7.1 for compliance details). Many nonpoint pollutant sources also contribute to the bacteria and nutrient concentrations of the bayous. To identify the diffuse nonpoint sources of pollution, the Double Bayou Partnership workgroups first discussed all possible contributions (see Chapter 3 for details on all sources). As discussed in Chapter 3, there were three main Workgroups: the Wastewater/Septic Workgroup, the Recreation/Hunting Workgroup and the Agriculture/Wildlife/Feral Hogs Workgroup. Feral hogs were discussed in both the Agriculture/Wildlife/Feral Hogs and the Recreation/Hunting Workgroups because both sets of stakeholders have experience with the potential pollution and management issues associated with feral hogs.

A consensus on a subset of primary point and nonpoint sources with known loading rates was reached for use in the SELECT analysis. These sources included input from each of the three workgroups. Chapter 3.2.4 has a detailed discussion on the workgroups and the possible sources and pollutants that were discussed. The following analyses - SELECT, LDC and tidal mixing - are focused on bacteria pollutant loading because high bacteria counts are the main pollutant of concern in the East and West Forks of Double Bayou. The potential sources from each workgroup discussed in the following sections are: the Anahuac WWTF and septic systems (from the Wastewater/Septic Workgroup); cattle, horses, goats and deer (from the Agriculture/Wildlife/Feral Hogs Workgroup) (Figure 5-3 Cattle in the Double Bayou Watershed); and feral hogs (from the Agriculture/Wildlife/Feral Hogs Workgroup and the Recreation/Hunting Workgroup). Note that dogs, which often are considered as a contributing source, were determined not to be a potential bacteria source of great concern due to the rural nature of the watershed and the low density dispersal of dogs.

Figure 5-3 Cattle in the Double Bayou Watershed

5.2 SELECT Analysis Overview

High and low bacteria loading scenarios were generated by stakeholder workgroups for sources that had ranges in population inputs; that is, septic systems, cattle and feral hog. High, medium and low scenarios were generated for the WWTF. Single scenarios were generated for horse, goat and deer sources because their population inputs were fixed values. The high and low scenarios can provide insight on the approximate range of the potential load from a given source. The low scenarios provide a threshold for periods of low rainfall and a baseline for comparison. The stakeholders decided to use the high loading scenarios for all possible sources to determine the priority and placement of management measures within the watershed. This will allow the maximum effectiveness of management measures because the highest possible loads are targeted for reduction and the management measures can be designed to handle the worst case scenario. Reduction of bacteria loading rates will require a combination of management measures across the subwatersheds to have the greatest impact. The high scenario results from the SELECT analysis will be discussed in this chapter; for low and medium scenario loading rates see Appendix D: In-depth SELECT Approach.

The stakeholder-established land cover presented in this chapter should be considered as a June 2014 (month of development) snapshot of the land use in the watershed because agriculture is dynamic and may vary depending on the growing season and livestock grazing requirements (Figure 5-4 Land cover of Double Bayou Watershed). In some cases, this arrangement may shift the distribution of the associated nonpoint source pollutants to different subwatersheds from year to year (Figure 5-5 Double Bayou subwatersheds). For example, rice crops are typically rotated to different fields and alternated with other agricultural crops, cattle, or left fallow. The alternating fields typically remain in the same subwatershed because they are in close proximity to the original field. However, the overall number of cattle and acres of crop land in the watershed will not change significantly even when they are occasionally rotated between subwatersheds.

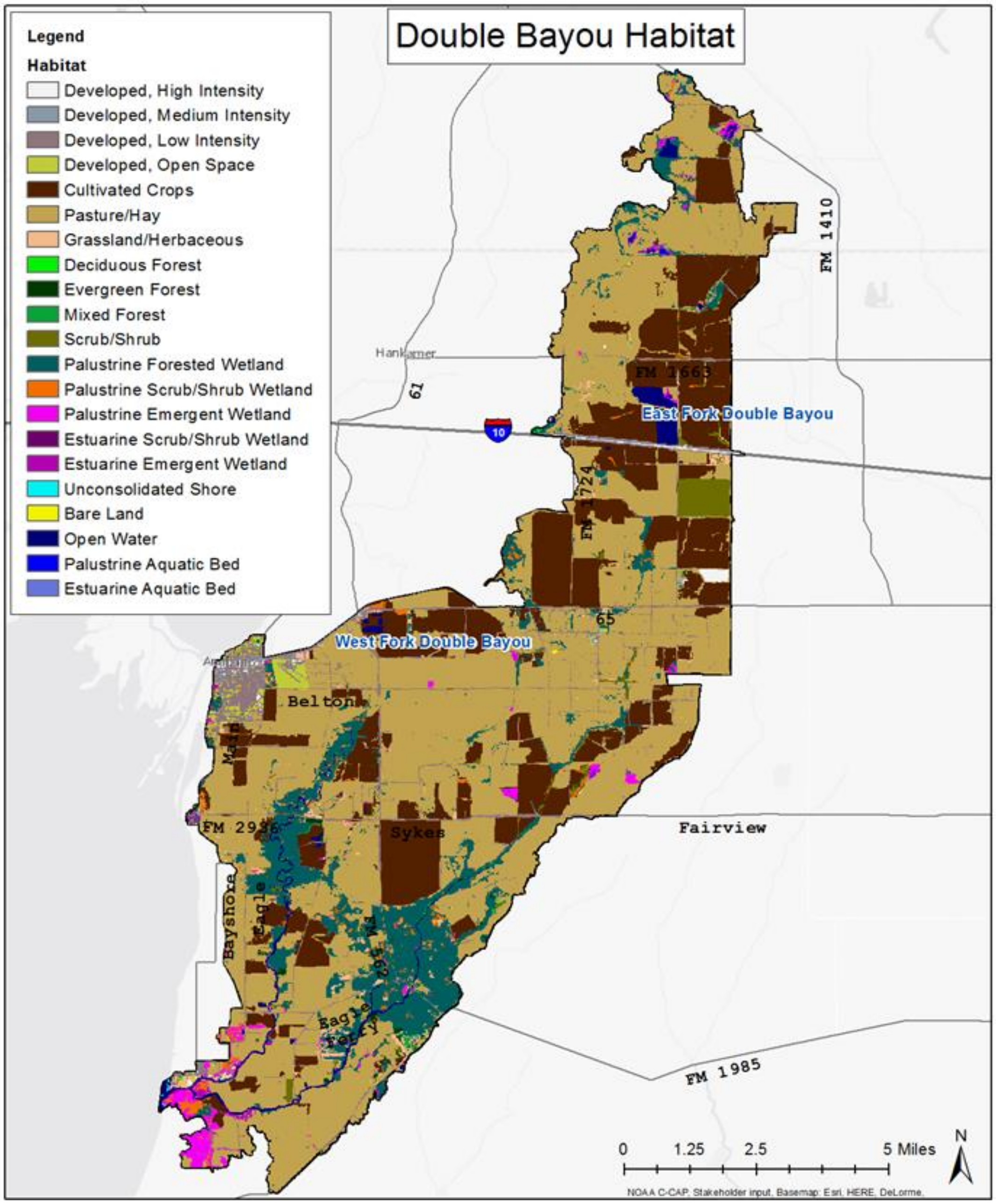


Figure 5-4 Land cover of Double Bayou Watershed

The output of the SELECT model is *E. coli* load per subwatershed per day (for each input source) (Figure 5-5 Double Bayou subwatersheds). To achieve this, the SELECT model distributes the animal population for each source through the watershed based on input population as well as on the suitable habitat area (including land cover). The bacteria loading rate is another input to the model, and is the total cfu per day per animal. The EPA has created a standardized set of known daily bacterial loading rates from a variety of nonpoint sources (U.S. EPA 2001). These loading rates are based on the rate of excretion, diet, species of animal and other environmental factors. The SELECT model then multiplies the loading rate by the population to get the total load for each subwatershed. To convert the total load to the *E.coli* load, the total load is multiplied by the *E.coli* conversion factor of 0.63 (See Appendix D: In-depth SELECT Approach for load equations).

The SELECT results represent the concentration of bacteria that is potentially on the ground and does not necessarily depict the amount of bacteria that reaches the bayous. Important factors in this context include the distribution of the loadings, proximity of the source to the bayou, the amount and location of vegetative material that may filter bacteria contributions before they reach the bayou and the variation in the inputs (which is dependent on factors such as animal diet).

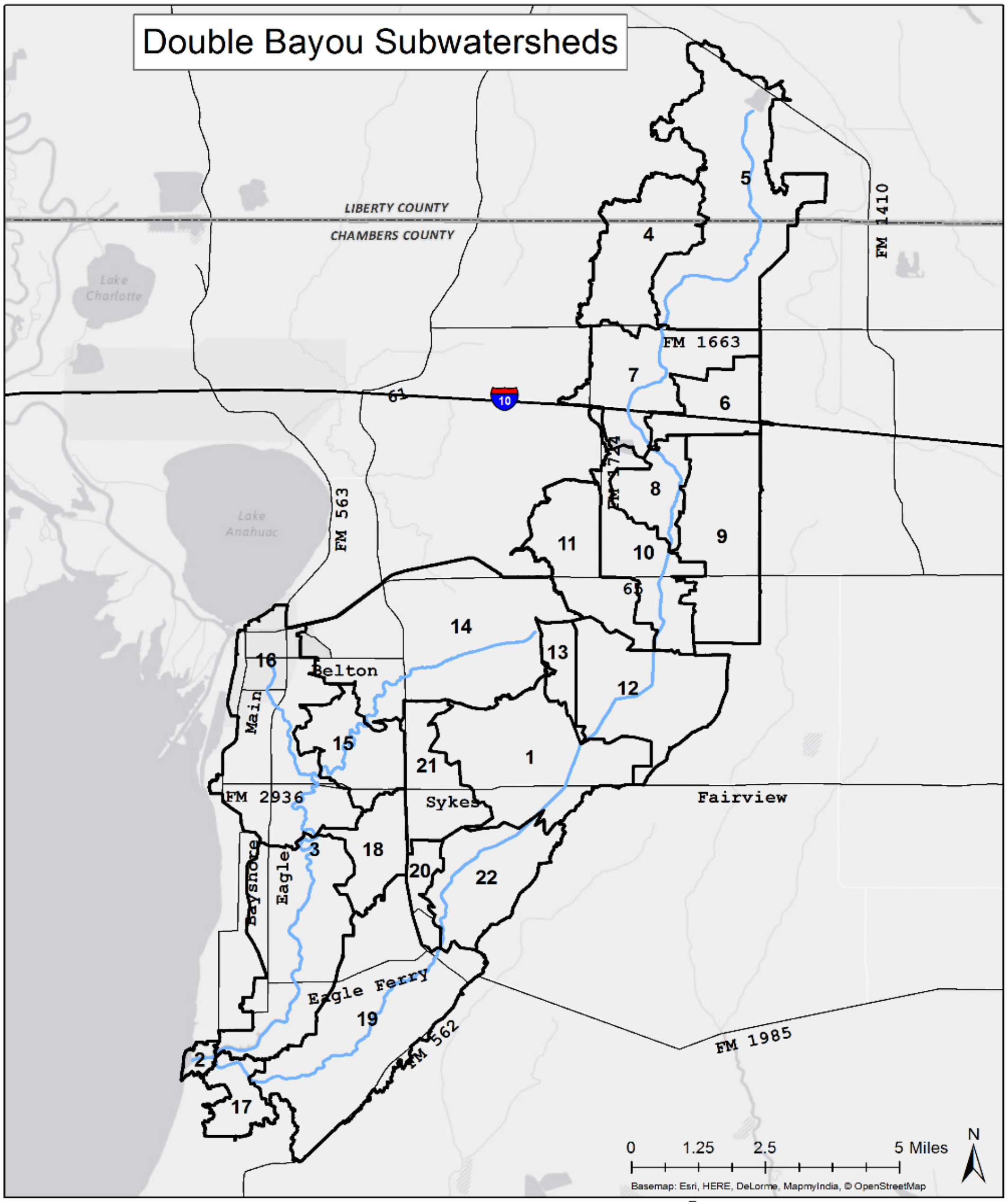


Figure 5-5 Double Bayou subwatersheds

A total estimated load scenario was generated for analysis by adding the potential loads from the 22 subwatersheds (Figure 5-6 Total output (all sources) bacteria loads). The subwatershed color scheme shows the relative potential bacteria load in the different subwatersheds. The subwatersheds with the highest potential load are yellow (larger number in the legend). Dark blue represents the subwatersheds with the lowest potential load (smaller number in the legend). The color scheme will remain the same for all SELECT output figures. Although the color scale remains the same, the high and low legend scale of the loading rates changes depending on the source. All units of bacteria are reported as colony forming units (cfu) per day (cfu/day). The analysis of total estimated loads provides insight on the prioritization of management measures to have the greatest reduction of pollutants possible.

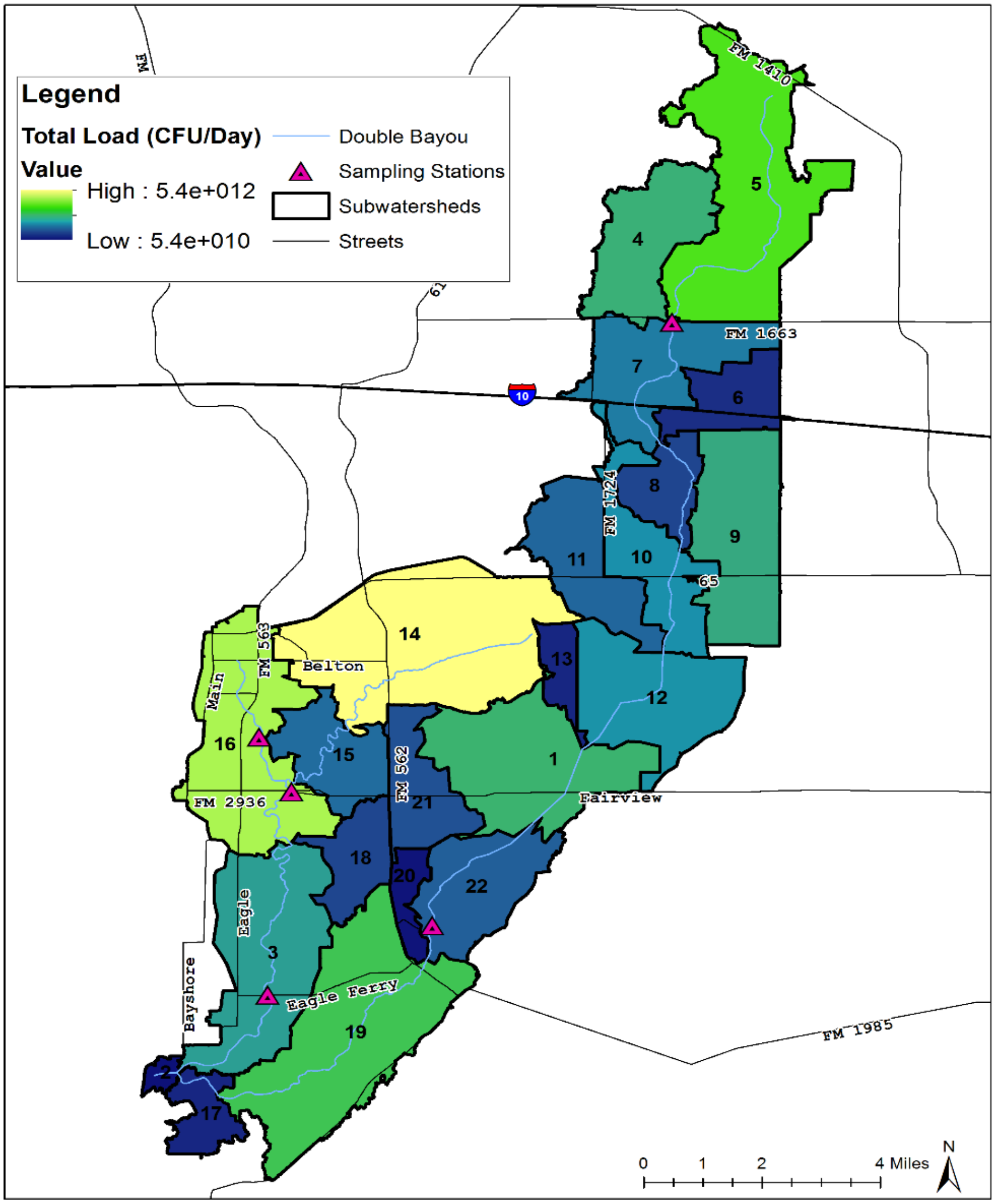


Figure 5-6 Total output (all sources) bacteria loads

The SELECT analysis resulted in total loads that ranged from 5.4×10^{10} (54,000,000,000 or 54 billion) to 5.4×10^{12} (5,400,000,000,000 or 5.4 trillion) cfu of bacteria per day. To have the greatest impact, management measures could be prioritized in the subwatersheds with the highest potential daily bacteria loads. We recognize that wildlife is a tremendous contributor to bacteria loads across the state. However, the only native wildlife analyzed in the Double Bayou Watershed SELECT results is deer.

5.3 SELECT Results: Wildlife

SELECT focuses on known quantifiable sources that may have the largest impact on bacteria loading of Double Bayou. Although the Double Bayou Watershed supports large flocks of migratory birds and background populations of wildlife, their potential bacteria contributions are unknown. Data to support SELECT modeling of the potential wildlife sources is not yet available. Therefore, the SELECT modeling focused on deer as the only known native wildlife source with adequate data.

A total deer population estimate was based on the Texas Parks and Wildlife (TPWD) estimate of deer density for Resource Management Unit 13 (RMU 13), where Chambers and Liberty County are both located. RMU 13 currently has an estimated deer density of 5.15 deer/1000 acres, with a 95% confidence interval of 2.2-12.3 deer/1000 acres. The stakeholders agreed that this was a reasonable estimate. The Mixed Forest/Forested Wetland land class was determined by the stakeholders to be the only land class suitable for deer (Figure 5-7 Deer associated land cover). Using the 5.15 deer/1000 acres number applied to the 6,321 acres of suitable habitat in the watershed gives a total watershed deer population of 33. The SELECT default standard for deer bacteria contributions of $3.5x10^8$ cfu per deer per day was used to generate the estimated deer bacteria loadings.

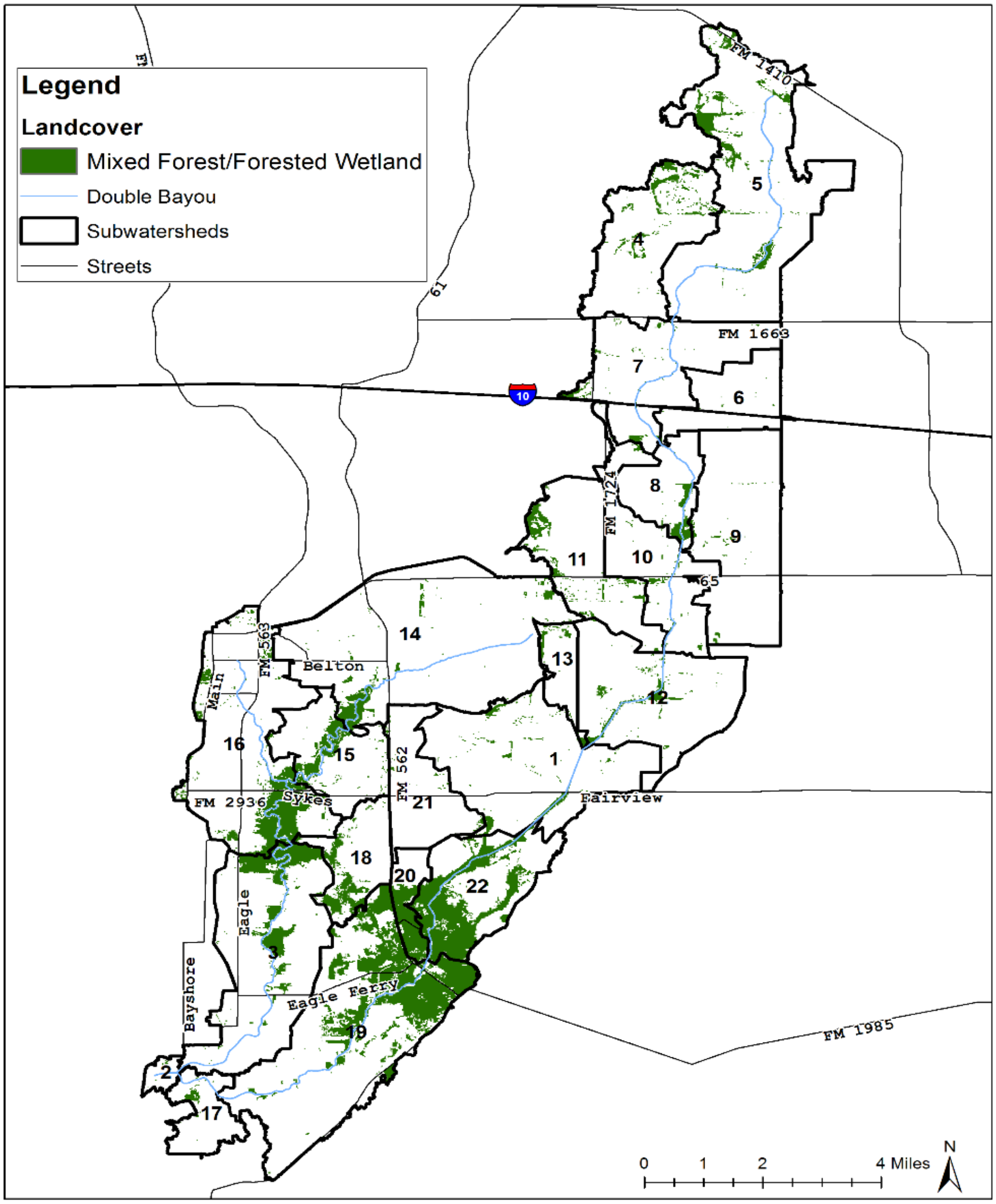


Figure 5-7 Deer associated land cover

The subwatersheds with the majority of the remaining mixed forested and forested wetlands are in the southern portion of the watershed. These subwatersheds also contain the largest deer populations (Figure 5-7 Deer associated land cover). However, deer contribute a small amount to the total daily potential bacteria load in the watershed. Their highest potential to contribute is $3.3x10^6$ cfu/day, while the lowest is $1.9x10^9$ cfu/day (Figure 5-8 Deer SELECT results). Deer will not be actively managed by the Double Bayou Partnership. The TPWD actively manages deer populations in the state of Texas (see Chapter 6.3).

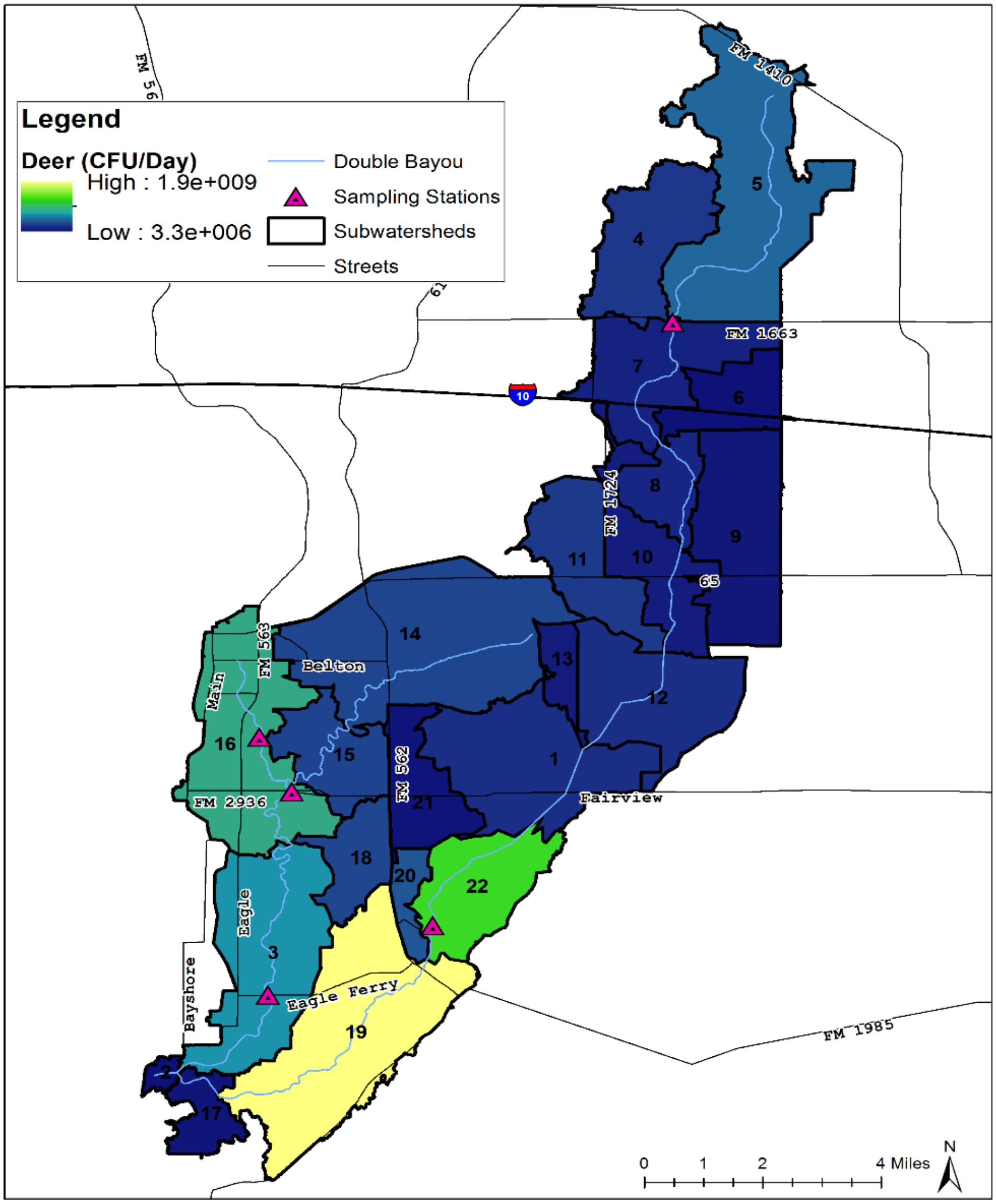


Figure 5-8 Deer SELECT results

5.4 SELECT Results: Feral Hog

Feral hogs significantly contribute to the nonpoint source bacteria concentrations of the Double Bayou watershed. They also cause other environmental and agricultural issues (See 2.4.2 for a detailed assessment of feral hogs in the watershed).

Figure 5-9 Feral hogs (Sus scrofa)

Studies from the Texas Water Resource Institute and Texas A&M University provide an estimated high density of feral hogs to be 33.3 acres per hog, medium density of 50.7 acres per hog and low density of 70.1 acres per hog. Based on these estimates, the maximum Double Bayou Watershed feral hog population was estimated to be 1,519 hogs. It was determined through stakeholder experience that feral hogs have a higher potential to utilize the most land classes in the watershed and are more likely to contribute bacteria directly to the bayous, due to the amount of time they spend in and around waterways. Taking into consideration that feral hogs lack sweat glands and spend a lot of time in and around water, the upper input scenario for SELECT applied the 33.3 acres per hog value to the land cover categories of Grassland/Pasture, Scrub/Shrub variety, Mixed Forest/Forested Wetland and Cultivated Crops, plus a 100-meter (328 foot) buffer zone from any water source, including flooded rice fields (Figure 5-10 Feral hog land cover with 100m buffer). (A buffer in ArcGIS (the software for SELECT) is a zone around a map feature measured in units of distance or time. A buffer is useful for proximity analysis).

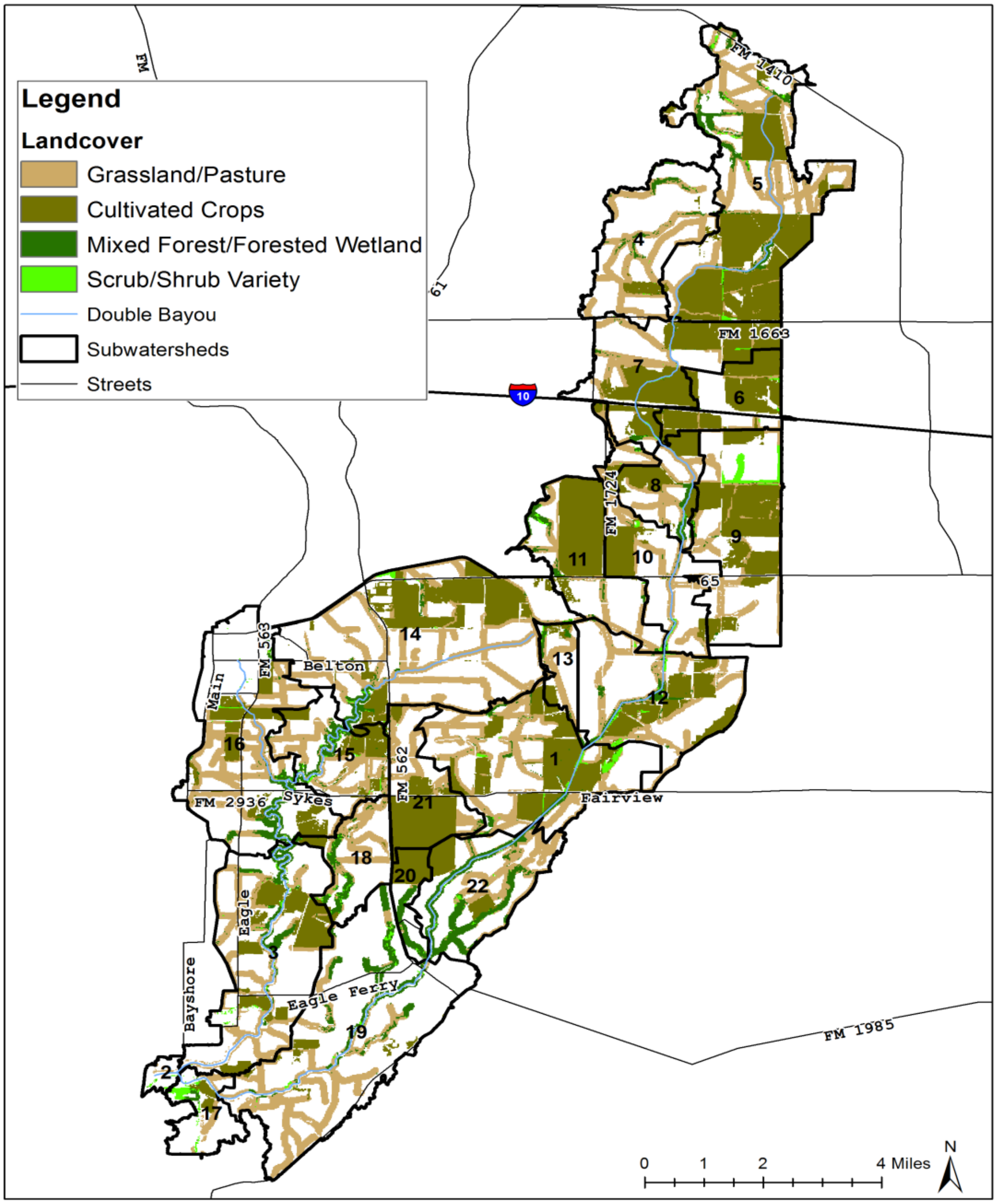


Figure 5-10 Feral hog land cover with 100m buffer

The density of 50.7 acres per hog was applied to the remaining appropriate land classes in the watershed. The EPA SELECT default loading rate for pigs of $1.1\text{x}10^{10}$ cfu/day/pig was applied to the feral hog source class (Figure 5-11 Feral hog SELECT results).

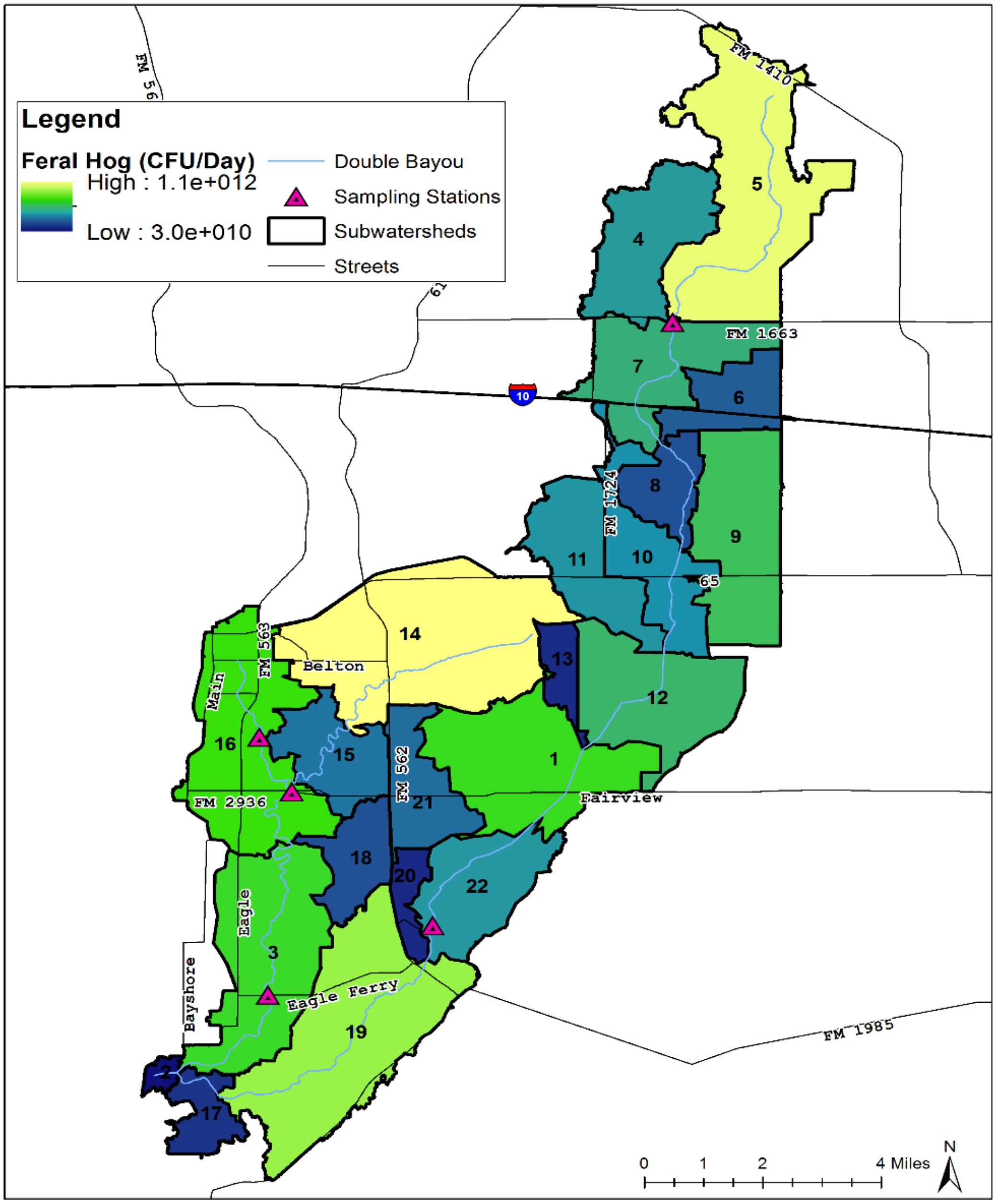


Figure 5-11 Feral hog SELECT results

5.5 SELECT Results: Livestock

The stakeholders assigned all livestock (cattle, horses and goat) to the same types of land cover for SELECT analysis (Figure 5-12 Livestock land cover classes). They determined that the land cover classes of Grassland/Pasture and Scrub/Shrub were the best fit to apply these potential sources. Furthermore, the stakeholders recognized that some Grassland/Pasture is strictly hay (not fenced, so it cannot hold livestock) and some Scrub/Shrub land is left fallow without cattle. These unsuitable areas were removed from the SELECT model input. The resulting SELECT analysis will be discussed in the following sections.

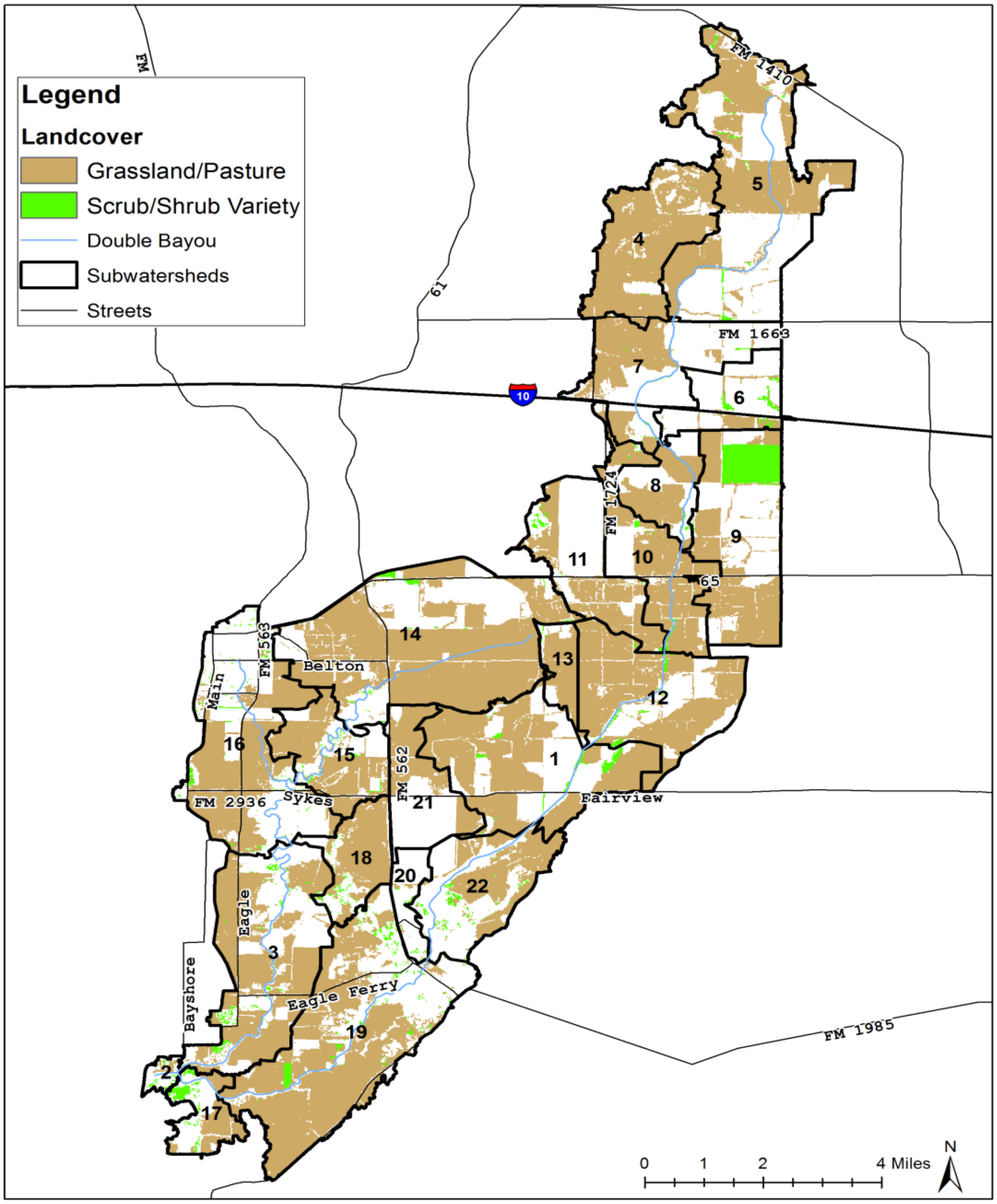


Figure 5-12 Livestock land cover classes

5.5.1 Cattle

Along with rice, cattle are the primary agricultural product of the watershed and are traditionally part of the Double Bayou Watershed's heritage (Figure 5-13 Cattle along the West Fork). Most of the cattle operations within the watershed are cow-calf and there are no confined animal feeding operations (CAFO). However, at least one stocker operation is based in the watershed.

Figure 5-13 Cattle along the West Fork

An Animal Unit (AU) is a standardized unit of measure typically used for agricultural management and planning. One AU is equivalent to one adult cow and a nursing calf. Using local knowledge, the stakeholders generated estimates of approximate stocking rates. The stakeholders applied the specific stocking rates of 1 ac/AU, 7-8 ac/AU, 9 ac/AU and 12-15 ac/AU to sections of the watershed where these rates were known to exist (Figure 5-14 Cattle stocking rates).

The total number of cattle was calculated based on these stocking rates. The total estimate of cattle in the watershed is 4,074. This population represents the maximum number of cattle that may contribute to nonpoint source pollutant loading in the watershed. This stakeholder estimate of cattle population compared favorably with county estimates from Texas Agricultural Statistics and the USDA Census of Agriculture.

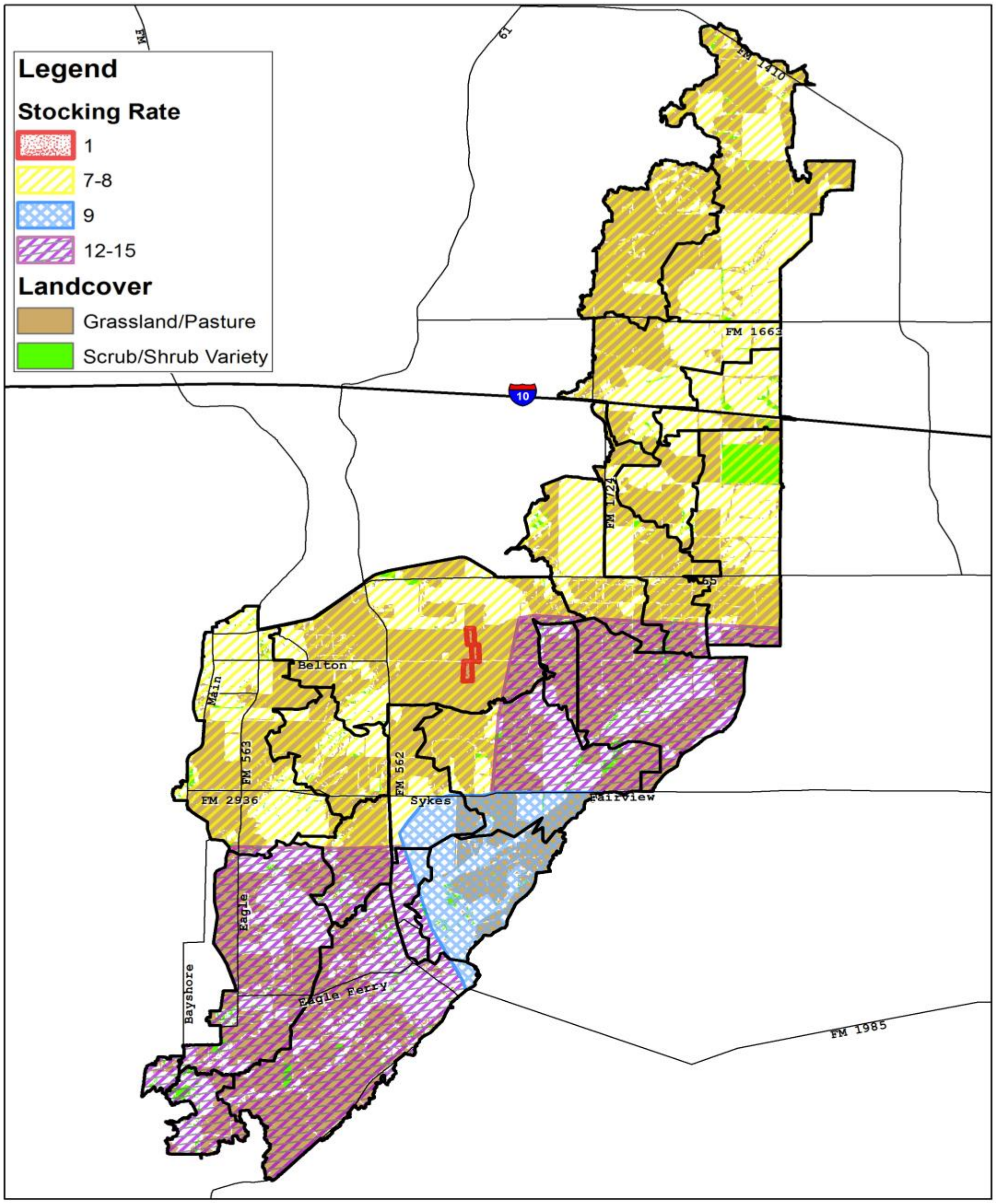


Figure 5-14 Cattle stocking rates

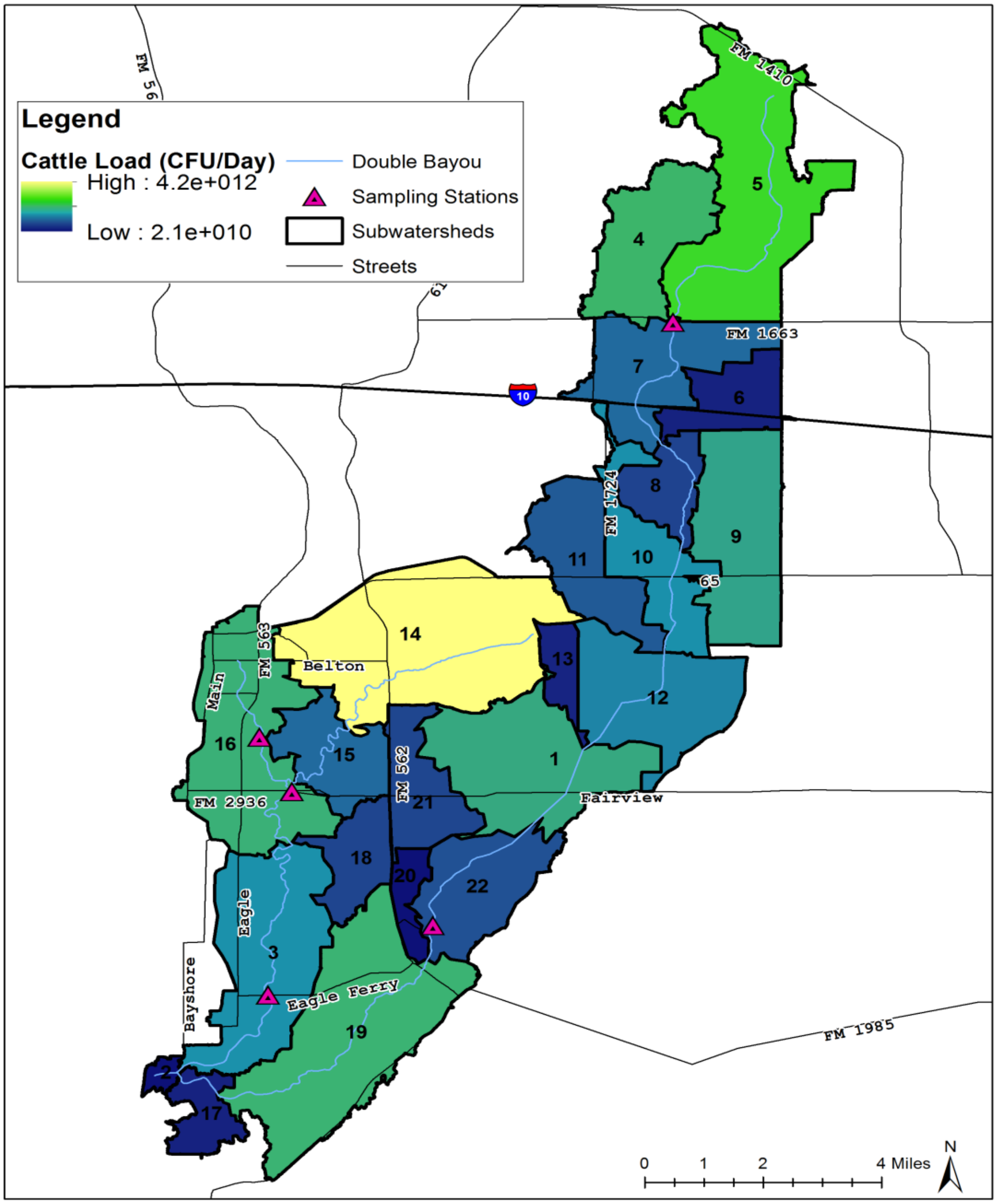


Figure 5-15 Cattle SELECT results

The standard potential bacteria loading rate for cattle of $10x10^9$ per head of cattle per day was used to generate the SELECT cattle potential load scenarios (Figure 5-15 Cattle SELECT results).

5.5.2 Horses

The bacteria nonpoint source contributions from horses were modeled based on an estimated population of 294 horses in the Double Bayou Watershed (Figure 5-16 Horses in the Double Bayou Watershed). This estimate came from a combination of the 2012/2013 Census of Agriculture and the percent of suitable land in watershed/county, with input from the Agriculture/Wildlife/Feral Hogs Workgroup.

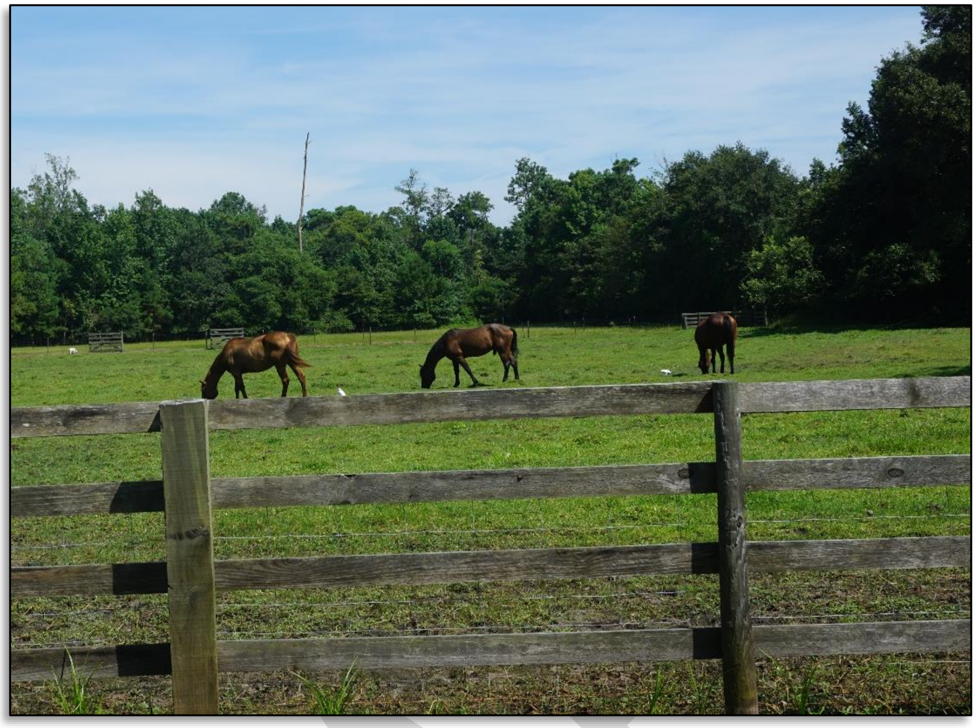


Figure 5-16 Horses in the Double Bayou Watershed

The land cover categories to which horses were applied are the same as cattle (Grassland/Pasture and Scrub/Shrub). The stakeholders noted that horses are typically used to support cattle ranching operations and are spread out over the watershed (not concentrated for agricultural production). The SELECT default bacteria loading rate for horses of 4.2×10^8 cfu per horse per day was used for SELECT modeling (Figure 5-17 Horses SELECT results).

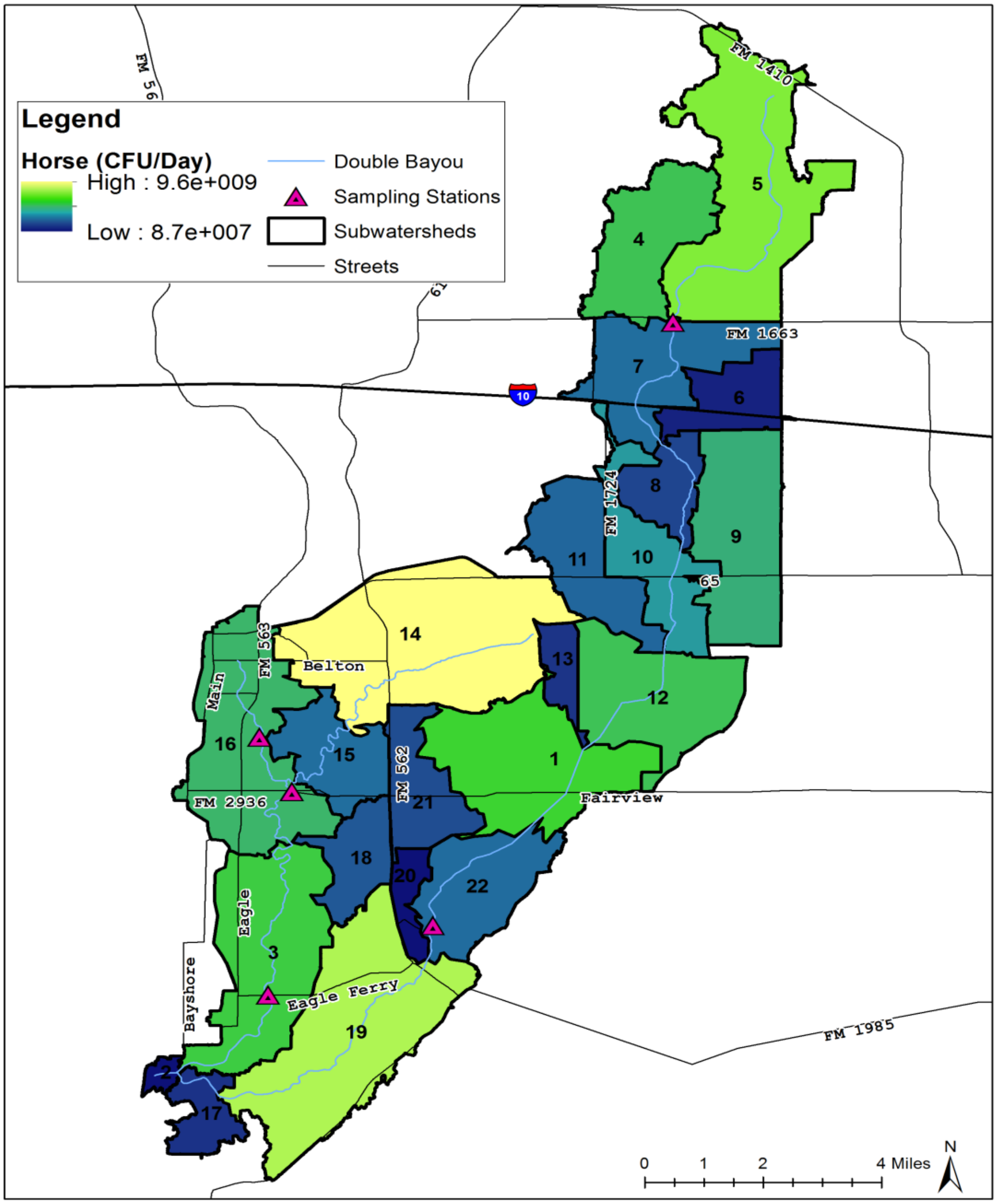


Figure 5-17 Horses SELECT results

5.5.3 Goats

Stakeholders stated that goats are not used for agricultural production but are kept by some landowners for subsistence use (Figure 5-18 Goats in the Double Bayou Watershed). Although goats are not typically concentrated in the watershed, they can potentially contribute to the bacteria loading of the bayous. However, goats are not likely to enter the bayou and directly deposit fecal material that cause elevated concentrations of bacteria. Based on Texas Agricultural Statistics, 11 goats were identified in the Liberty County portion of the watershed.

Figure 5-18 Goats in the Double Bayou Watershed

The Texas Agricultural Statistics stated that there are no goats in Chambers County. However, the stakeholders determined that an estimated 200 goats are known to exist in the Chambers County portion of the watershed. A total of 211 goats was determined to be a reasonable watershed estimate for inclusion in SELECT (Figure 5-19 Goat SELECT results). The bacteria loading rate for sheep of $1.2x10^{10}$ cfu per sheep per day was used as a proxy for the goat SELECT input because no SELECT bacteria loading rate for goats is available (Borel, Karthikeyan et al. 2012).

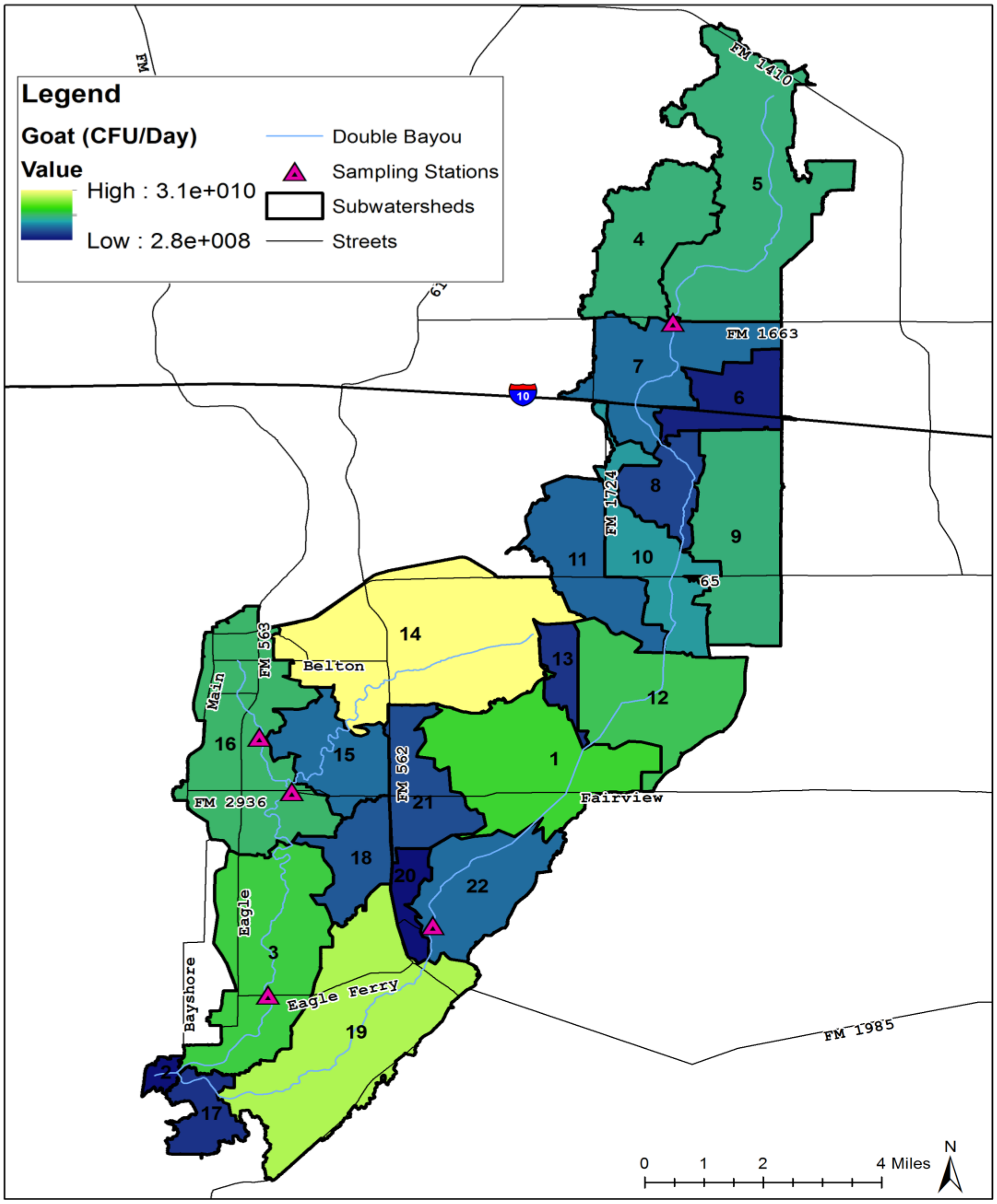


Figure 5-19 Goat SELECT results

5.6 SELECT Results: Wastewater and septic

5.6.1 WWTF

The Wastewater/Septic Workgroup identified the Anahuac WWTF, along with its public sewer line collection system and the collection system for the Oak Island WWTF, as potential point and nonpoint sources of bacteria in the watershed. Because the Anahuac WWTF is a point source, the bacteria contributions are from a fixed location and can be traced back to one subwatershed (Figure 5-20 WWTF SELECT results).

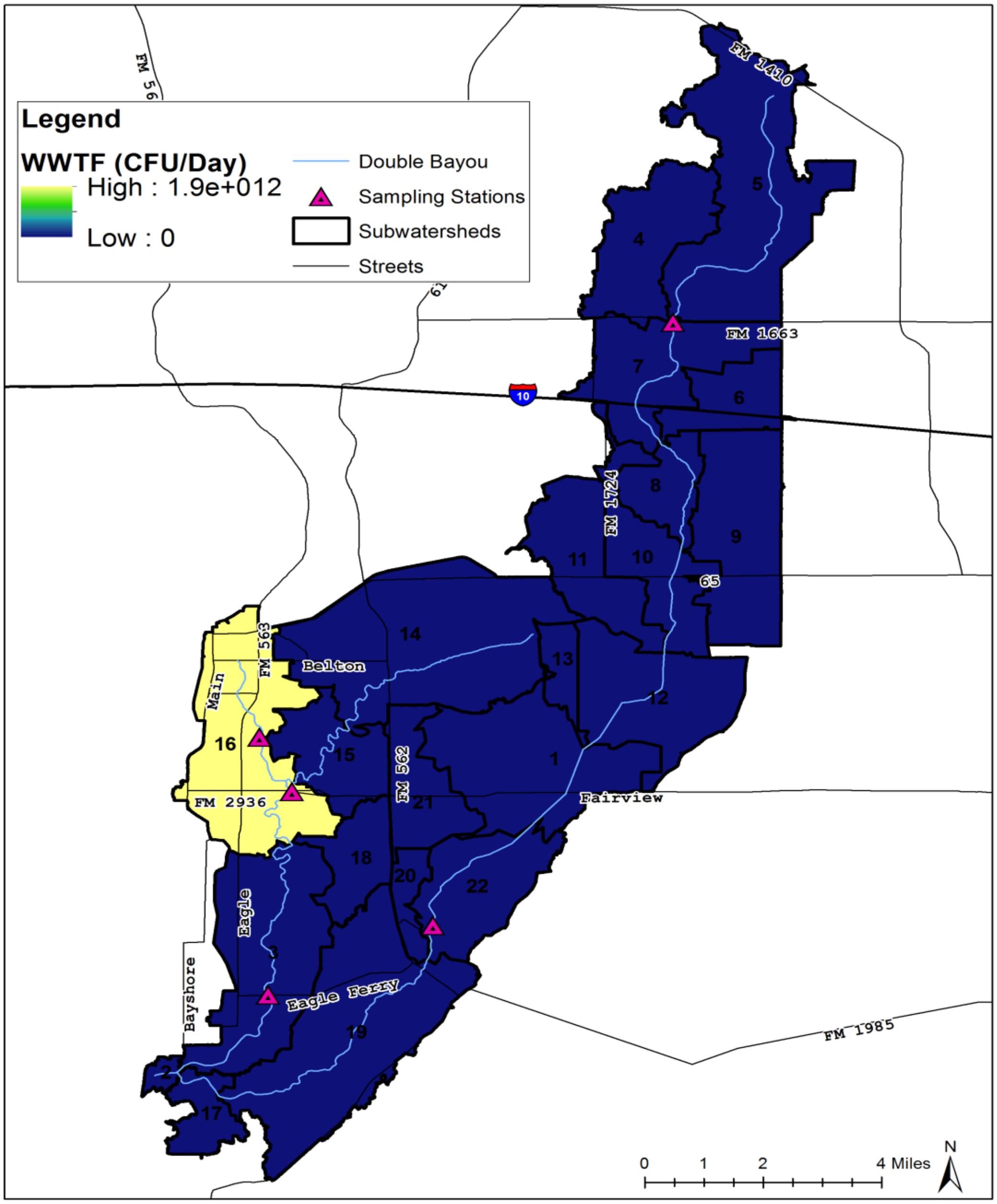


Figure 5-20 WWTF SELECT results

The potential loading rate of 49,000 cfu/100 mL and the approximate flow of 1,000,000 MGD (million gallons per day) were the SELECT model inputs used to generate the maximum scenario for the facility. This value is based on the highest recorded targeted bacteria sample collected at the outfall of the WWTF.

5.6.2 OSSF

The Wastewater/Septic Workgroup identified septic systems as potential nonpoint sources of bacteria. To generate the SELECT input, locations of 91 of the estimated 465 septic systems in the watershed were obtained from the H-GAC OSSF database. The remaining systems were identified by a stakeholder who has in-depth local knowledge of OSSF placement. Stakeholders then refined and developed quality assurance for this information. They discussed and generated septic system age, based on a neighborhood-by-neighborhood analysis. The age ranges established for septic systems were assigned to one of three groups: 0-15 years old, 16-30 years old and greater than 31 years old. The Wastewater/Septic Workgroup also assigned approximate failure rates to the systems, based on age and known failure rates. A failure rate of 10% was applied to the 0-15 age group; 30% to the 16-30 age groups; and a 50% failure rate was applied to the 31+ age group. Stakeholders noted that aerobic systems are less likely to contribute bacteria to the watershed than conventional anaerobic systems, because aerobic systems are typically newer and more efficient. In the watershed, soil conditions are generally not suitable for conventional systems. They also stated that proper septic system maintenance is key to limit potential bacteria contributions.

The best available data from the H-GAC OSSF database and stakeholder input were combined; the identified systems were overlaid and filtered to eliminate the possibility of double counting septic systems. In Figure 5-21 OSSFs in Double Bayou Watershed, the green dots represent septic systems less than 15 years old; the yellow dots are for septic systems between 16-30 years old; and the red dots are septic systems greater than 31 years of age. The majority of the identified septic systems are distributed in subwatersheds 19 and 20 to the southeast and 16 and 14 in the northwest portion of the watershed.

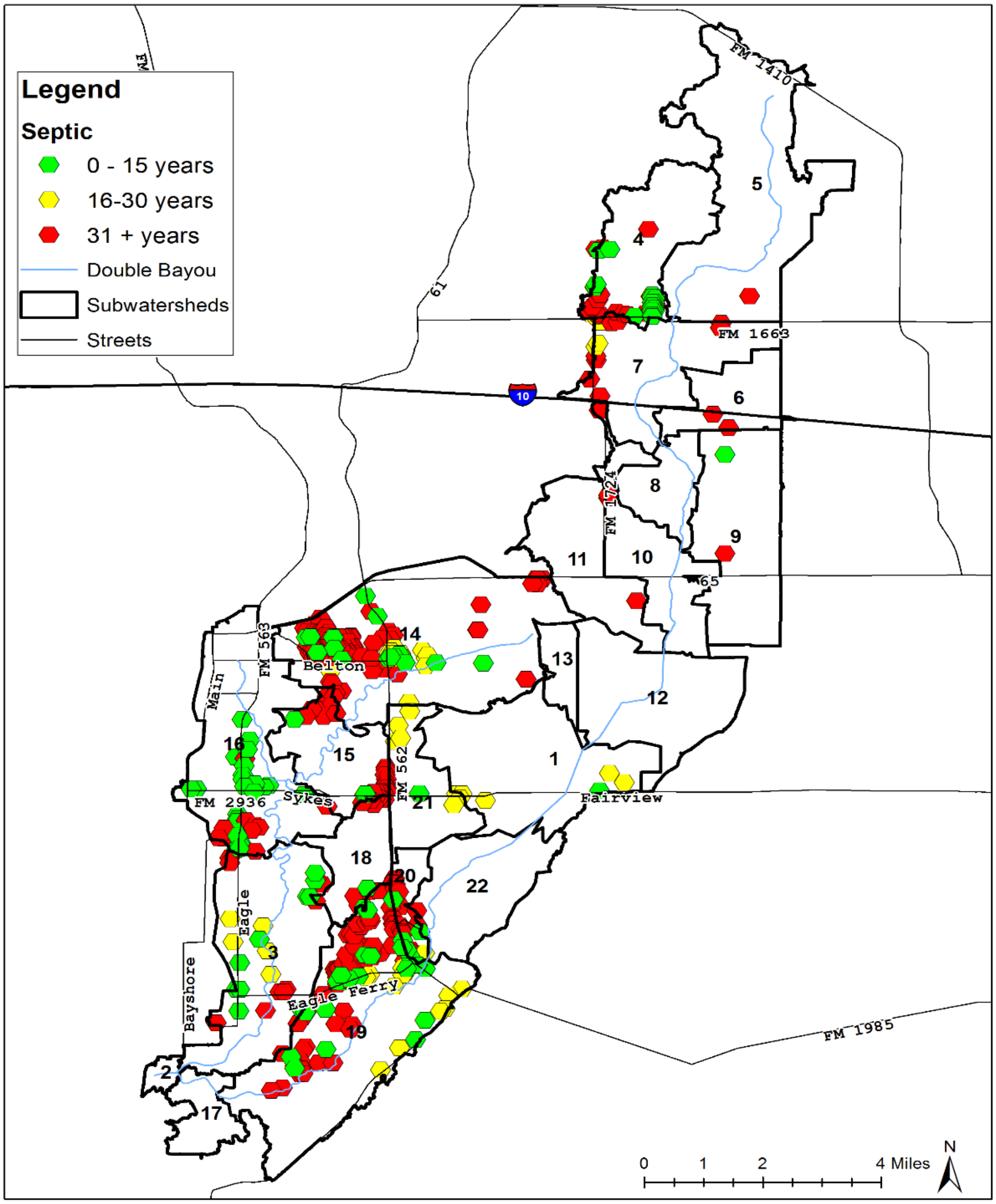


Figure 5-21 OSSFs in Double Bayou Watershed

The SELECT model considers the effectiveness of septic systems based on the soil type (different types of soils would have different rates of wastewater absorption), by accounting for the age of the system and by estimating a failure rate. The soils in the watershed have a poor absorptive capacity and are 98% homogeneous throughout the watershed. The soils are particularly poor for septic systems because their poor absorption means that the effluent from the septic tank cannot be treated by the soil microorganisms. The effluent may contaminate the groundwater or back up on the soil and be washed into the bayou with stormwater runoff. The age of the systems was estimated in clusters by the workgroup, based on their extensive local knowledge.

The primary subwatershed that displays a high bacteria loading potential from septic systems aligns with the subwatersheds where septic systems are concentrated (Figure 5-22 Septic SELECT results). In these areas, there are simply more septic systems that are older and have higher failure rates that allow more bacteria to be leached from the systems. However, it is not a guarantee that these nonpoint source contributions reach the stream.

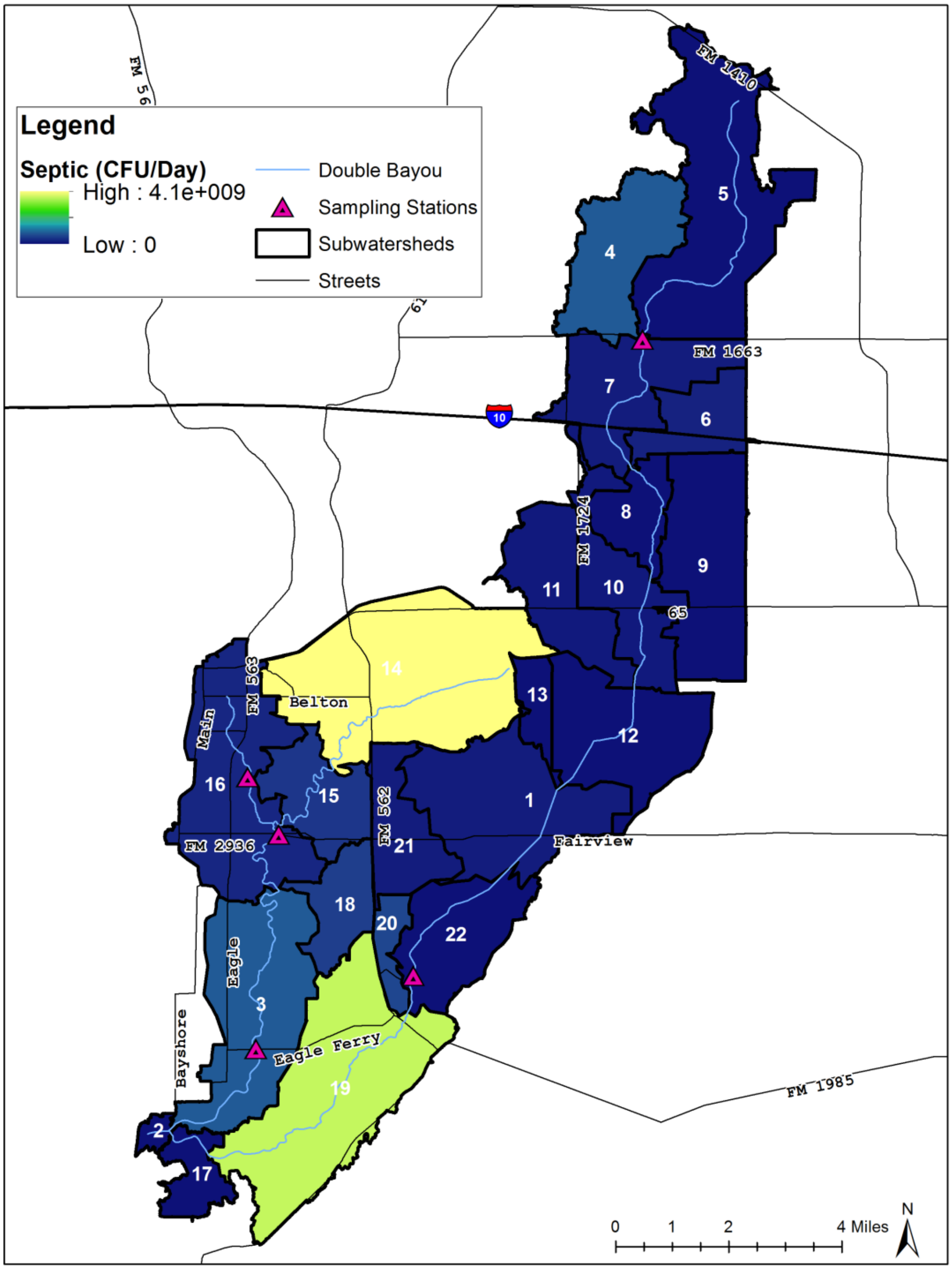


Figure 5-22 Septic SELECT results

5.7 *Double Bayou Watershed Load Duration Curve*

Traditionally, LDCs are developed for nontidal stations due to the way the flow is represented and visualized in the LDC. East Fork Upper is the only sampling station that is not designated as tidally influenced (freshwater) in the watershed. There are no stream flow gages on East Fork. However, stream flow data samples were measured each time a bacteria grab sample was collected. In this manner, enough flow data were collected to develop a flow duration curve and the resulting LDC for the East Fork Upper sampling station.

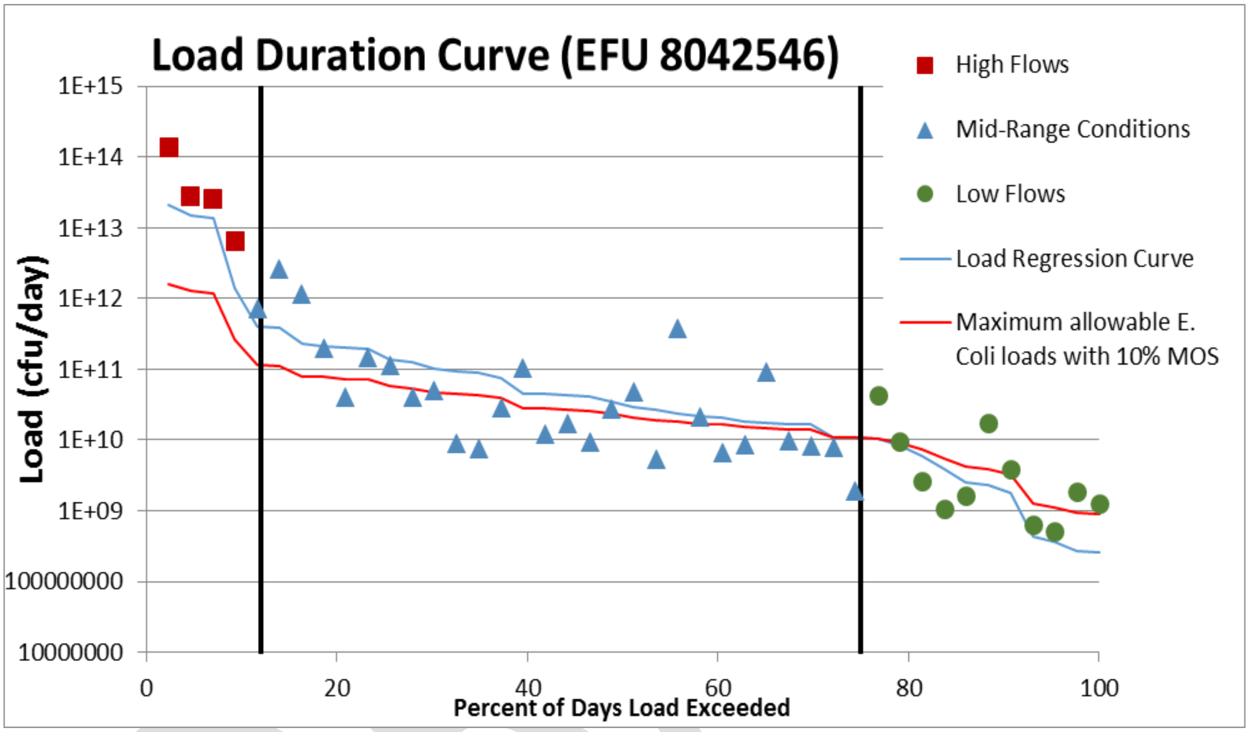


Figure 5-23 Load Duration Curve for Double Bayou East Fork Upper

LOAD ESTimator (LOADEST), a software program developed by the USGS, is a FORTRAN program for estimating constituent loads in waterways. Given a time series of flow, additional data variables, and constituent concentration, the LOADEST program assists the user in developing a regression model for the estimation of constituent load. LOADEST was used for the LDC and regression analysis for the Double Bayou East Fork Upper Station.

LDC analysis for the Double Bayou East Fork Upper station (Figure 5-23 Load Duration Curve for Double Bayou East Fork Upper) suggests that the bacteria water quality standard is met under low-flow conditions, but is not supported for mid-range and high-flow conditions. Percent exceedance categories for the flow regimes were developed; these helped determine the amount of load reduction necessary to meet regulatory standards in the flow regime categories that had exceedances (in our case, high and mid-range flows). Based on the analysis used to develop the LDC, *E. coli* load reductions of 84% at high-flows and 30% at mid-range flows would be necessary to meet the water quality standard for primary contact recreation. With a 10% margin of safety factored in, this would be 85% at high-flows and 38% at mid-range flows. Based on the

LDC analysis for Double Bayou East Fork Upper, the stakeholders decided to use a load reduction goal of 38% for mid-range flow conditions in the upper watershed. This more conservative approach will guide WPP implementation efforts to meet water quality standards under current conditions, as well as allow for future load capacity planning.

5.8 Tidal Mixing

5.8.1 Trinity Bay

The Galveston Bay system is largely enclosed by Bolivar Peninsula and Galveston Island (Figure 5-24 Galveston Bay system). Galveston Bay is not strongly influenced by oceanic tidal patterns due to these protective barriers and the shallow nature of the system. Trinity Bay, a shallow basin that ranges in depth from approximately 2 to 3 meters (6.6 to 9.8 feet), is part of the larger Galveston Bay estuary system. Although oceanic tides are weak in Galveston and Trinity Bays, diurnal (one high and one low tide per day) and semidiurnal (two high tides and two low tides per day) patterns exist.

Winds are the dominate factor causing water level fluctuations and circulation patterns in the Galveston Bay system; tides and freshwater inflows are also factors of influence (Ward 1991) (Kennish 1999). The Trinity and San Jacinto rivers are major tributaries of Galveston Bay and deliver the majority of freshwater inflows (54% and 28%, respectively) (TWDB 2000). The strength of the inflows varies by season. Spring rains typically provide the largest volume of freshwater inflows during April and May. Salinity in Trinity Bay can drop to 0 psu, during this time. Under normal conditions, salinity in Trinity Bay is approximately 10 psu (Lester 2011). (On average, freshwater is typically 0 psu and seawater is typically 35 psu).Typically a low-flow season occurs July to October. Wind driven tides along with freshwater inflows dominate the circulation patterns of Trinity Bay and ultimately influence tidal patterns of Double Bayou.

Figure 5-24 Galveston Bay system

5.8.2 Tidal Influence

Trinity Bay tides moving up or down the bayou influence water quality through tidal mixing - as the tide comes in (due to direct tidal flow or wind), water flows up the bayou (See Appendix E for flow and salinity graphs). Due to the shallow nature of Trinity Bay and winds being a dominant force, with relatively weak tides, tidal effects in the bayous are dampened and irregular. The West and East forks of Double Bayou are slow moving streams. The bayous around the Galveston Bay system mainly have precipitation-driven flow and are generally slow moving.

To determine the extent of tidal influence and mixing on the Double Bayou Watershed, an Index Velocity Site Gauge (continuous operating flow meter that measures both positive and negative flows) was installed at the site of the West Fork Lower station. The gauge was installed here because the West Fork Lower station is closest to Trinity Bay and has the strongest tidal response. The Index Velocity Site Gauge operates continuously, measuring flow in cubic feet per second (cfs) every fifteen minutes. “Positive flow”, or ebb tide, indicates times at which the flow is going from upstream (north) towards downstream (south). “Negative flow”, or flood tide, indicates times at which the flow is going from downstream (south) towards upstream (north), as a result of tidal or wind influence from Trinity Bay.

The gauge is maintained by the USGS and began recording data in February of 2012. Data used for the gauge flow analysis are from the sampling period of 2/24/2012-7/6/2015. Over this time period, the average flow measured at West Fork Lower (WFL) was 71 cfs. The maximum recorded positive flow was 1,020 cfs and the minimum recorded negative flow was -511 cfs (Table 5-1 Sample flow measurements). The maximum, minimum and average flow measured at the mainstem stations is shown in Table 5-1 Sample flow measurements. The WFL data is from the Index Velocity Site Gauge while the East Fork Upper (EFU), East Fork Lower (EFL) and West Fork Upper (WFU) measurements are grab samples.

Station	**Flow (cfs)**		
	Min	**Max**	**Average**
EFU	-6	572	49
EFL	-49	1,390	106
WFU	-70	940	71
WFL	-511	1,020	71

Table 5-1 Sample flow measurements

Three 24-hour periods (April 15-17, 2014) from the West Fork Lower continuous sampling gauge show how unpredictable Double Bayou tidal patterns can be due to wind and other tidal variables (Figure 5-25 Tidal variance at West Fork Lower). Within this three-day period, tidal patterns include diurnal, semidiurnal and irregular flows.

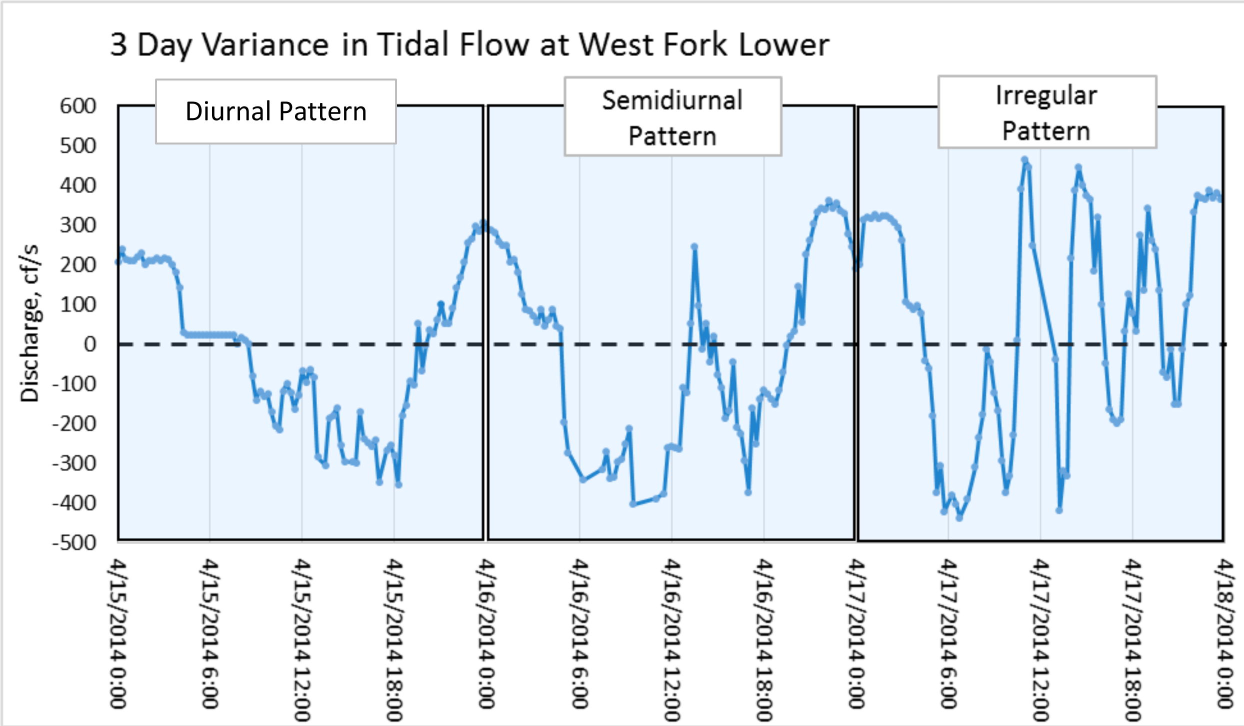


Figure 5-25 Tidal variance at West Fork Lower

Statistical analysis was conducted on bacteria samples from two groups of data, those taken during positive and negative flow. This analysis showed that Enterococci concentrations during negative and positive flows at WFL are statistically different. Percent exceedance of negative flow samples was 18%, while percent exceedance of positive flow samples was 94% (Enterococci single sample criterion 89 cfu/100 mL). The geomean of the negative samples was 38 cfu/100 mL and the geomean of the positive samples was 106 cfu/100 mL (Enterococci geomean criterion 35 cfu/100 mL). The negative sample set is slightly above the criterion. However, the negative sample size is 16, which is under the minimum sample size of 20 that TCEQ prefers for assessment. In addition, the negative sample set is skewed by a high outlier. The percent exceedance is an important reference in this case. Tidal mixing dilutes the concentration of bacteria causing bacteria loads to not exceed the regulatory load, during negative flow sample periods.

Negative flow measurements in Double Bayou West Fork indicate flow coming from Trinity Bay due to tidal and/or wind effects. There are four estuary water quality monitoring stations in close proximity to the mouth of Double Bayou with Enterococci data from 2001-2014 (Figure 5-26 Water quality stations in Trinity Bay closest to the mouth of Double Bayou). The geomean of the Enterococci from these years (46 samples) is 7.6 cfu/100 mL. Of these, the most recent samples (20 of the 46) have a geomean of 6.6 cfu/100 mL. Trinity Bay's waters around the mouth of Double Bayou are not considered a source of bacteria. The volume of water brought into the bayou from the Bay will impact bacteria concentrations through dilution. The dilution effect of bay water is further demonstrated by the tidal variance analysis because negative flow time periods were associated with loads meeting the regulatory criteria.

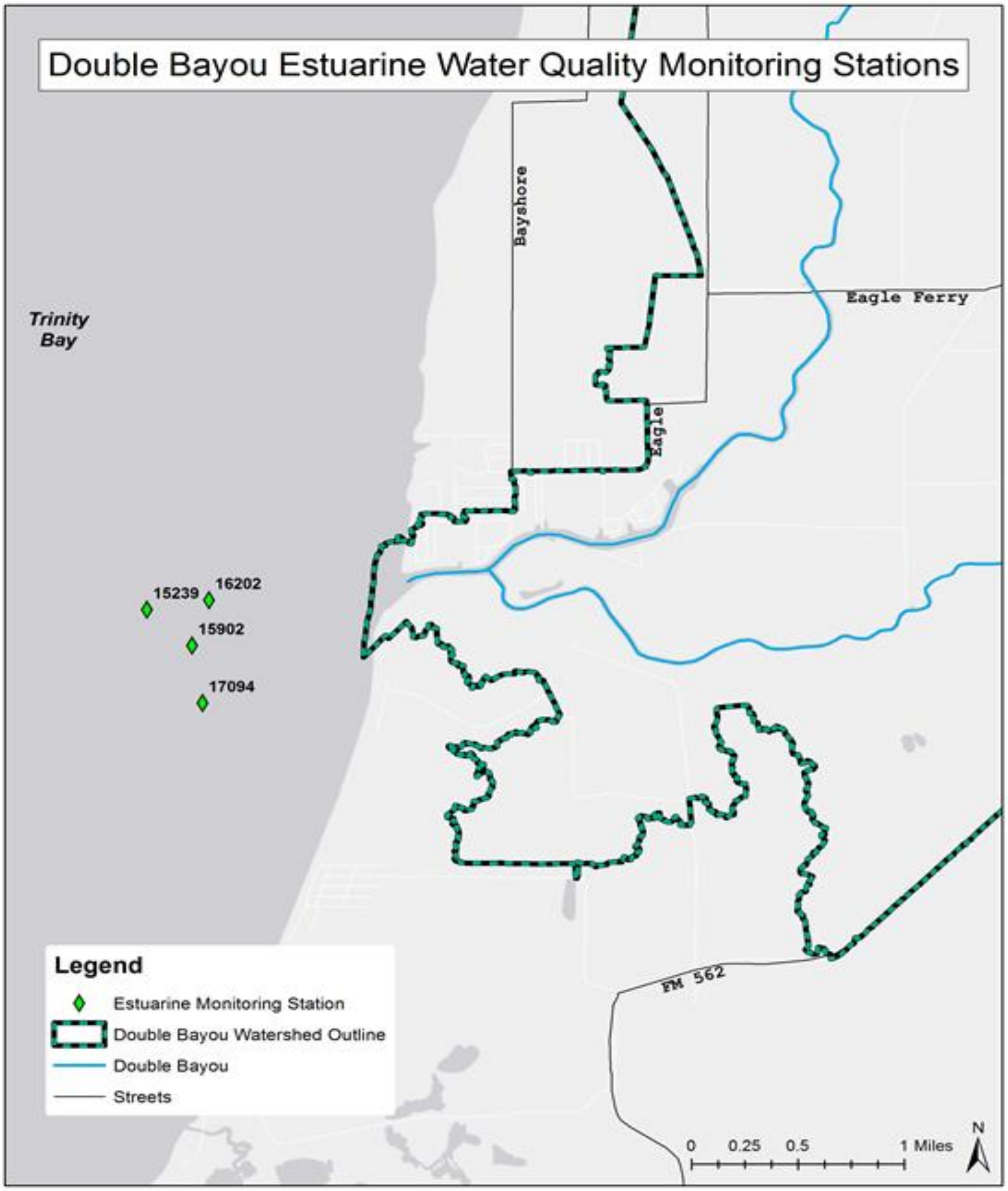


Figure 5-26 Water quality stations in Trinity Bay closest to the mouth of Double Bayou

5.8.3 Bacteria Loadings

Typically, LDCs are calculated for nontidal stations due to the way the flow data are analyzed for this process (see Section 5.8). Continuous gauges are more often established at nontidal stations rather than tidal stations due to the technology involved. Since a majority of the Double Bayou Watershed is tidally influenced, the automatic gauge was established at the West Fork Lower station to assist with analyzing tidal pollutant loadings.

Due to the irregular flow pattern of West Fork Lower, the LDC approach will not work in this case. There is little correlation between positive flow and bacteria concentrations at West Fork

Lower. This is likely due to the wind-driven nature of the system – periods of intense rainfall will often be accompanied by high winds, causing erratic flow patterns. Because of the weak correlation between flow and bacteria, analysis based on flow regimes would be difficult.

It is important to note that there is a strong connection between bacteria results for targeted rain events compared to non-rain event samples. The Enterococci targeted rainfall samples had a 100% exceedance rate. It is the correlation between targeted rain events and flow itself that is relatively weak – some rain events had negative flow or weak flow, due to the reasons discussed above. But the magnitude of difference for Enterococci samples on targeted rain event days does suggest non-point sources as potential contributors.

Loadings for the West Fork Lower station were analyzed based on volumetric calculations (analysis based on volume of water, as opposed to flow, which was used for the LDC analysis). As stated above, the Index Velocity Site Gauge measured flow in cubic feet per second (cfs) every 15 minutes. Each flow measurement could then be converted to volume represented during those 15 minutes. (15 minutes x 60 seconds = 900 seconds; each rate was multiplied by 900 seconds resulting in cubic feet). Integrating the flow (combining all the 15 minute discrete measurements of water) gives the volume of water for that day (cubic meters, or $m^{3)}$. The Enterococcus sample multiplied by this volume results in the calculated daily load for each sample (units of cfu/day). See Appendix E: Flow and Salinity Graphs and Tidal Mixing for a detailed discussion on this analysis.

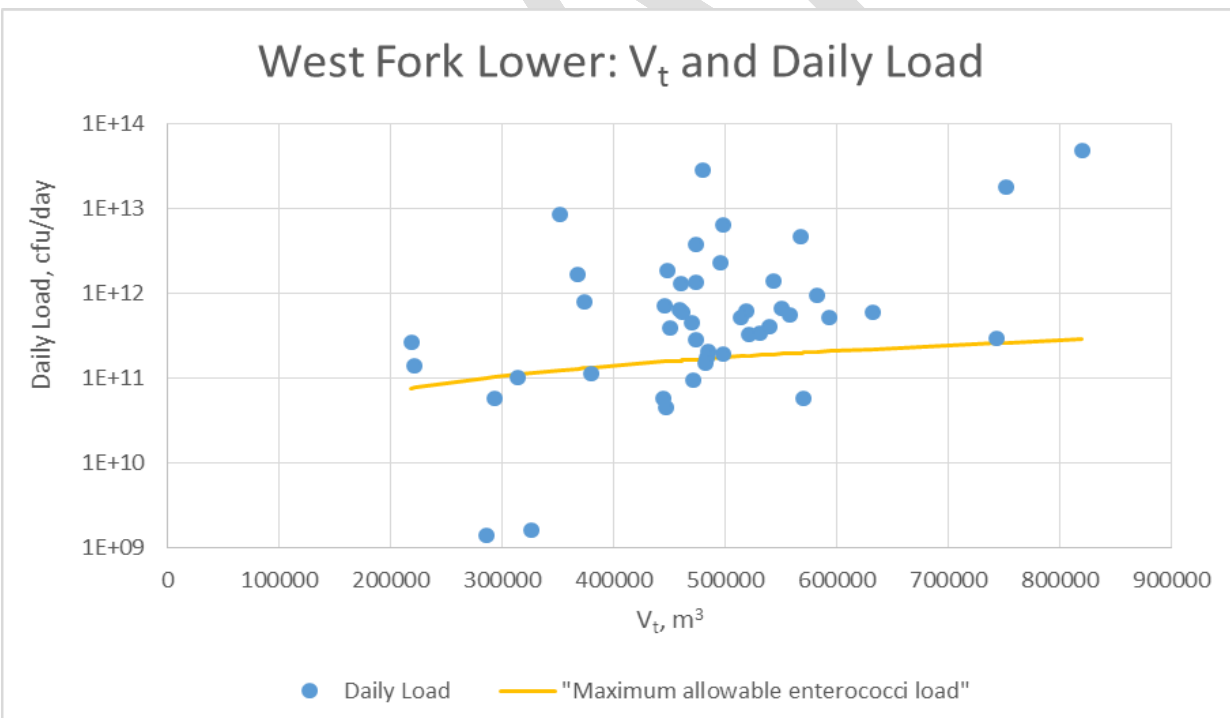


Figure 5-27 West Fork Lower calculated Daily Load

Once daily load had been calculated for each sample date, a maximum allowable load was calculated in the same manner, using the maximum allowable Enterococci standard of 35 cfu/100 mL (Figure 5-27 West Fork Lower calculated Daily Load, where V_t = Daily total volume (m^3/day), which is defined as the volume of bayou water (m^3/day) plus the volume of bay water (m^3/day)). Analysis of the calculated daily load versus the maximum allowable Enterococci load resulted in amount of exceedance by sample. The percent exceedance calculated for these samples represents the percent decrease necessary for daily load to be at or under the maximum allowable Enterococci load. In Figure 5-27 West Fork Lower calculated Daily Load, the blue dots on or below the yellow line are meeting the maximum allowable Enterococci load; the blue dots above the line are exceeding the maximum allowable Enterococci load. As with the percent reduction goal determined by LDC analysis, the percent exceedance categories were evaluated (see section 5.7 Double Bayou Watershed Load Duration Curve for the LDC percent reduction goal and percent exceedance discussion). As opposed to categorizing by flow, such as with the LDC analysis, the focus was on the categories themselves and frequency distribution of samples within each category (Table 5-2 West Fork Lower percent exceedances and reduction).

Percent Exceedance Category	Number of % exceedances in each category	Percent Reduction
75-100%	17	90%
40-74%	15	59%
Under 0 (meeting criteria) - 39%	14	-1044%

Table 5-2 West Fork Lower percent exceedances and reduction

The load reduction goal should then focus on percent exceedance categories that are highly achievable. The 75-100% percent exceedance category is heavily populated by rain event samples. Therefore, it is not a desirable scenario for typical load planning. Based on the load calculation analysis at the West Fork Lower station, Enterococci load reductions of 59% at mid-range conditions would be necessary to meet the primary contact recreation water quality standard. With a 5% margin of safety (see Appendix E for the details) a load reduction of 61% for mid-range conditions would be required.

A load reduction goal of 38% was selected for the upper watershed, based on the LDC results for the East Fork Upper sampling station. Considering, the load calculation analysis for Double Bayou West Fork Lower, a load reduction goal of 61% was selected for the lower watershed. Since the upper watershed that drains into East Fork Upper was a smaller representation of the overall watershed (subwatersheds 4 and 5 only, Figure 5-5 Double Bayou subwatersheds), stakeholders decided to use the load reduction goal of 61% for the entire Double Bayou Watershed. This conservative approach will guide WPP implementation efforts to meet water quality standards and allow for future load capacity planning.

6 Management Measures

This chapter details water quality management measures suggested by stakeholders to address water quality issues in the watershed. Water quality issues were identified through stakeholder interviews, workgroups, stakeholder meetings and water quality monitoring. The suite of stakeholder recommended management measures presented in this chapter can be applied to the diverse categories of potential pollutant sources in the Double Bayou Watershed. The management measures discussed here and employed in conjunction with the outreach and education programs in Chapter 8 will create a holistic, watershed approach to improve the water quality of Double Bayou. Proposed management measures are primarily targeted to address bacteria concerns in the Double Bayou Watershed. However, most measures that reduce bacteria will also reduce other nonpoint source pollutants. All management measures are voluntary and contingent on available funding.

As discussed in Chapter 5, the Spatially Explicit Load Enrichment Calculation Tool (SELECT) was used to estimate the distribution of potential pollutant sources across the watershed and the degree of contribution per each source. Each potential pollutant source identified by stakeholders was spatially defined based on the best available data and information available. SELECT analysis identified subwatersheds with the greatest potential for impacting water quality, which are ideal locations for management measures that are discussed below.

During general meetings and workgroups stakeholders discussed possible water quality management measures that could be implemented in the Double Bayou Watershed. Workgroups suggested possible management measures appropriate to their workgroup. The three main workgroups for the Double Bayou WPP were Agriculture/Wildlife/Feral Hogs, Wastewater/Septic and Recreation/Hunting; see Chapter 3 for more information. Residential measures were identified through stakeholder interviews and a stakeholder meeting break-out session. Outreach and education measures were combined from all sources and are discussed in Chapter 8.

Throughout the discussion, there are several broad-based management measures that will serve several categories of pollution sources. For example, buffer zones will be discussed at length, but may be applicable to multiple categories including agriculture nonpoint source and wildlife and non-domestic plant/animal management measures.

6.1 Wastewater

The WWTF wastewater management measures suggested by the Wastewater/Septic Workgroup can be further subdivided into two types of wastewater improvements – public wastewater systems and private systems.

6.1.1 Public Wastewater Systems

Public wastewater systems are comprised of two components: the sanitary sewage collection system and the WWTF (the treatment plant itself). The collection system includes sewer pipes and lift (pump) stations that keep wastewater flowing through pipes, where gravity flow is not sufficient. Treatment of wastewater occurs at the WWTF, in sequential treatment steps and includes a lift station to pump wastewater to the WWTF treatment units.

The City of Anahuac and the Trinity Bay Conservation District (TBCD) each provide and maintain infrastructure for public wastewater systems in the Double Bayou Watershed. The primarily clay pipe gravity sewer system that collects wastewater within Anahuac is maintained by the City and that wastewater is treated at the Anahuac WWTF. It was noted by stakeholders that the clay pipe collection system is outdated and likely to cause I&I and should be a high priority for replacement. TBCD collects wastewater from outside the watershed through a force main sewer system and delivers it to the Anahuac WWTF for treatment. Treated wastewater from the Anahuac WWTF is discharged to the Anahuac Ditch, a tributary of the West Fork of Double Bayou.

TBCD also collects other wastewater from within the Double Bayou Watershed, through a force main sewer system, but that wastewater goes to the Oak Island WWTF for treatment, and the treated wastewater is then discharged to Trinity Bay (outside of the watershed). The Oak Island collection system consists of modern PVC pipe and is not likely to be associated with the I&I issues that cause significant bacteria contributions to the bayous.

6.1.2 Private Septic Systems

The two types of private septic systems in the Double Bayou Watershed are conventional and aerobic. These systems, also called onsite sewage facilities (OSSFs), provide minimal treatment in a tank and then discharge the wastewater through soil or onto the ground for additional "natural" treatment. The Wastewater/Septic Workgroup consisted of personnel from the City of Anahuac, the TBCD, Chambers County and other interested citizens who were knowledgeable about the watershed's various wastewater systems. Together, they developed the proposed management measures that stakeholders approved for this WPP.

6.1.3 Wastewater Collection System Infrastructure Improvements

A number of management measures would facilitate infrastructure improvements for the Anahuac wastewater collection system. The City of Anahuac was suggested as the lead entity to implement these management measures, which would be addressed by the Watershed Coordinator working with the WWTF system operator. The key to sewer system improvement will be to determine what is needed and where it is needed. A Collection System Study campaign was suggested as a first step to identify issues and sources of leaks in the City's sanitary sewer system, including a sewer line test.

As part of this campaign, grants for homeowner implementation of low-flow devices will be sought. Stakeholders noted that use of low-flow devices should be coordinated with the sewer line size and slope so there is enough flow to convey solids. Otherwise, I&I during rain events would cause problems.

Another component of the campaign would be the elimination of illicit connections. The Guidance Manual for Identifying and Eliminating Illicit Connections to Municipal Separate Storm Sewer Systems (MS4), prepared by the Galveston County Health District Pollution Control Division in cooperation with H-GAC, GBEP and TCEQ, could be used to seek appropriate low budget solutions for potential high cost infrastructure issues.

Straight pipe discharges were also discussed as a possible source of bacteria and to be included in the Collection System Study campaign. Stakeholders suggested working with homeowners, within Anahuac and other residential communities in the watershed, to route straight pipe discharges (identified through the above methods) into the main city sewer line.

TCEQ's Sanitary Sewer Overflow (SSO) initiative helps cities address problems with their collection system (https://www.tceq.texas.gov/field/ssoinitiative). A sanitary sewer overflow occurs when sewer lines are blocked, broken or aged to the point of allowing rain and groundwater to infiltrate into pipes. This I&I can then contribute to flows that exceed the design capacity of the pipes, causing the system to overflow with untreated sewage. The City of Anahuac is already enrolled in the SSO program. A benefit of targeting I&I is that it helps to reduce the number and intensity of sanitary sewer overflows. The key wastewater recommended management measures are:

- ***Collection System Study Campaign**:* A campaign to identify issues and sources of leaks in the sanitary sewer system; this could include components such as: a) smoke test and other sewer line testing (such as the use of video lines) to identity priority areas for repair or replacement, b) seeking grants for homeowner implementation of low-flow devices, c) elimination of illicit connections, and d) elimination of straight pipe discharges.
- ***Upgrade Collection System**:* Sanitary sewer line and manhole replacement to prevent I&I from overwhelming the sanitary sewer system.
- ***Lift Station Upgrades**:* Includes work on pumps; pump motors at 2 lift stations have been replaced, more are planned.
- ***Pump Repair and Replacement**:* Replacement of pumps with ones that are less likely to fail in a peak flow condition – work on this is currently underway.

6.1.4 Septic Systems Management Measures

Stakeholders recommended the following septic system management measures be implemented under a septic system review and inspection initiative:

- ***Identify OSSFs in the watershed; develop and maintain an OSSF database**:* This database was begun with the help of stakeholders and the geographic task force (see Chapter 2.5.2). The database includes the location and general ages of septic systems in the watershed.
- ***Increase Septic System Inspection Capacity**:* Expand inspection capacity to include relief lines and ensure current program response expands with population growth.
- ***Expand Sewer System to Serve Septic Homes:*** Stakeholders also suggested that connecting more homes that are currently on septic systems to a public WWTF could

reduce nonpoint source bacteria pollution from aging septic systems. TBCD was identified as lead entity for this initiative in the Double Bayou Watershed.

Subwatershed	Total Systems per Subwatershed	Potential Number of Failing Systems	Systems within 1,000 feet of Bayous or Anahuac Ditch
1	5	1	0
2	0	0	0
3	25	7	6
4	44	12	0
5	1	0	0
6	2	1	0
7	11	5	0
8	0	0	0
9	2	1	0
10	3	2	0
11	1	0	0
12	0	0	0
13	0	0	0
14	147	64	7
15	22	10	0
16	40	8	3
17	0	0	0
18	12	5	0
19	117	46	17
20	24	10	4
21	8	2	0
22	1	0	0
Total	**465**	**174**	**37**

Table 6-1 Double Bayou Watershed septic systems

In order to identity priority subwatersheds for the maintenance and replacement of septic systems the total number of septic systems per subwatershed was identified using ArcGIS (Table 6-1 Double Bayou Watershed septic systems). The number of failing systems per subwatershed was derived from the system age established by stakeholders. Septic systems that are in close proximity (within 1,000 feet) to the bayous and the Anahuac Ditch were identified because these systems are considered a high risk of contributing bacteria to waterways (see Chapter 5.6.2 for detailed discussion on age and placement of septic systems).

6.2 Agriculture

6.2.1 Agricultural Nonpoint Source Management Measures

The Agriculture/Wildlife/Feral Hog Workgroup recommended many agricultural management measures that could reduce agriculture related sources of bacteria. It was agreed that voluntary site specific management plans are the best way to implement management measures on local farms and ranches. Water Quality Management Plans (WQMPs) are site-specific plans that include conservation practices designed to reduce nonpoint source runoff from silvicultural and agricultural land uses. The plans are developed and approved by the Trinity Bay Soil and Water Conservation District #434 (SWCD) and TSSWCB. To receive financial incentives from TSSWCB, the landowner must develop a WQMP with the SWCD that is customized to fit the needs of their operation. The Natural Resources Conservation Service (NRCS) also offers guidance and options for development and implementation of both individual practices and whole farm conservation plans. The landowners, in partnership with the SWCD and the WQMP Technician, would be lead entities for implementing the management measures detailed in each WQMP. One benefit of the WQMPs is that an individual management measure can help to reduce contributions from several different pollution sources. Each WQMP must be developed and certified in order to receive funding to implement the described management measures.

Stakeholders suggested that the creation of a WQMP Technician position would support conservation plan development in the Double Bayou Watershed. This position would be dedicated to assisting landowners in the creation and implementation of the WQMPs. A number of WQMPs are already certified in the watershed. The WQMP Technician would focus on enrolling new landowners in the program and updating existing WQMPs. The technician would be involved in writing, planning and promotion of the WQMPs. In addition, the WQMP technician would help secure potential WQMP funding. Working together, the WQMP Technician and Watershed Coordinator would organize and host workshops and coordinate with Texas A&M AgriLife Extension on relevant programs. The WQMP Technician could be stationed in Anahuac and employed by the Trinity Bay SWCD.

6.2.2 Livestock Operations

SELECT identified cattle from livestock operations as one of the potential major contributors of bacteria in the Double Bayou Watershed (Figure 6-2 Livestock along West Fork Double Bayou). Horses were identified by SELECT as having a moderate potential.

The average farm in Chambers County is 346 acres, according to the 2012 USDA National Agricultural Statistics Service (NASS) census of agriculture. An average of 38 animal units per farm was calculated for Chambers County, based on the number of farming operations and the cumulative number of cattle, calves and horses per operation.

The number of total animal units (cattle and horses) in each subwatershed of Double Bayou was generated using the analysis of inputs for the SELECT model (Figure 6-1 Double Bayou subwatersheds). The total number of animal units per subwatershed was divided by the number of animal units per farm in Chambers County (38 AU). From this calculation, the number of farms per subwatershed was derived.

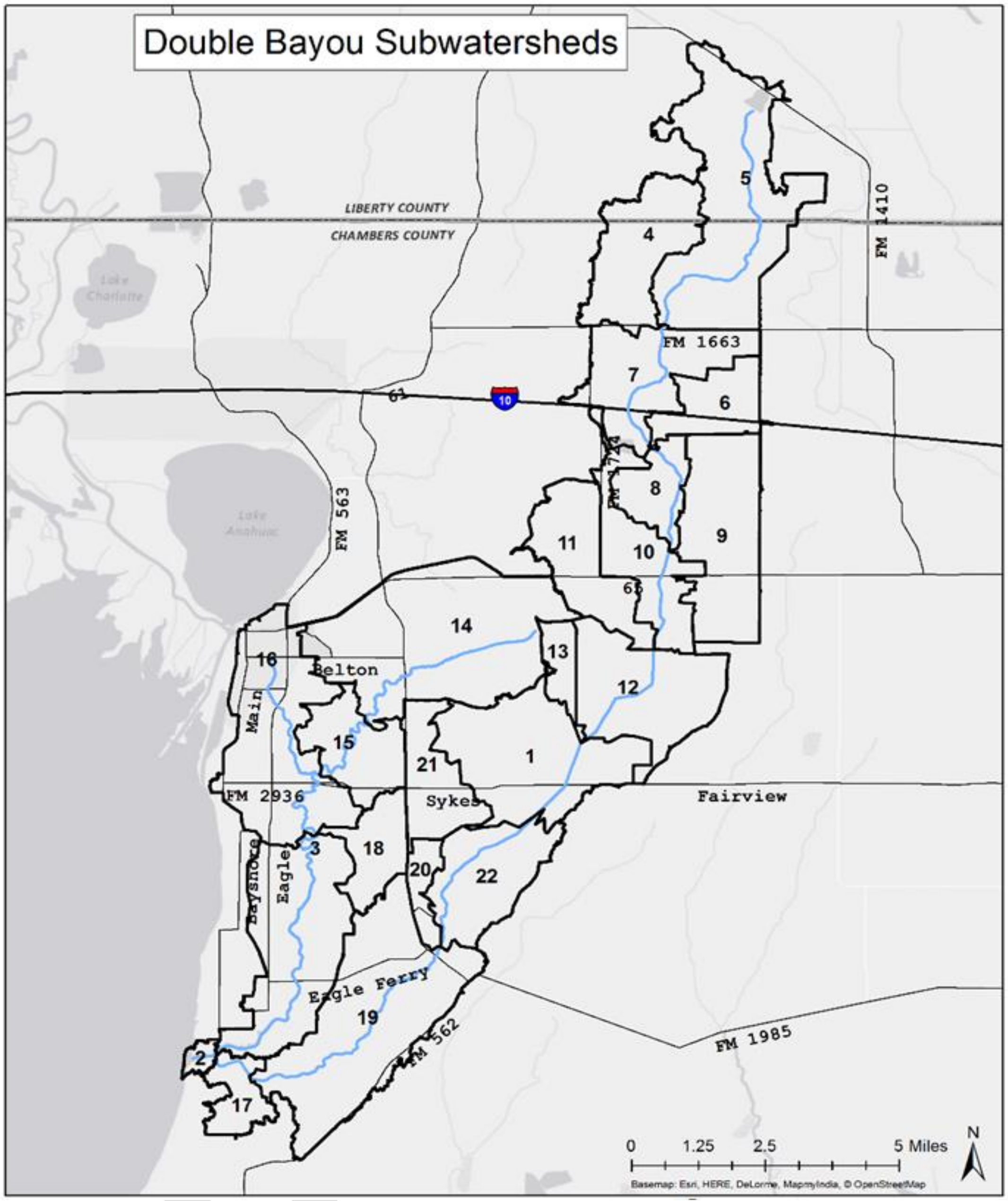


Figure 6-1 Double Bayou subwatersheds

To achieve the load reduction goals set by the WPP, the number of livestock operations in each subwatershed and the number of existing WQMPs were evaluated to determine the number of recommended WQMPs needed (Table 6-2 Recommended number of WQMPs). The recommended number of WQMPs accounts for the WQMPs that are already in place by subtracting the existing plans from the recommended number of new plans. A total of 52 new WQMPs are recommended, ranging from 0 to 8 plans per subwatershed.

Subwatershed	Animal Units	Number of Farms per Subwatershed	Recommended Number of WQMPs*
1	320	8	3
2	4	0	0
3	243	6	1
4	353	9	3
5	457	12	7
6	39	1	1
7	175	5	3
8	105	3	2
9	299	8	2
10	237	6	4
11	149	4	2
12	226	6	4
13	45	1	1
14	712	19	8
15	174	5	2
16	332	9	0
17	43	1	1
18	110	3	2
19	356	9	3
20	4	0	0
21	115	3	2
22	134	4	2
Total	**4631**	**122**	**52**

* Recommended number of WQMPs equals number recommended minus existing plans.

Table 6-2 Recommended number of WQMPs

Note that in the following sections, the "high" scenarios (see Chapter 5 for the SELECT scenarios discussion) were used for analyzing load reductions so that management measures minimize loads for the worst case scenarios.

Figure 6-2 Livestock along West Fork Double Bayou

Stakeholders suggested that the following management measures, which could be part of a WQMP, would address nonpoint source runoff from agriculture and livestock in the Double Bayou Watershed (Technical reference for agricultural management measures (Peterson, Jordan et al. 2012)):

- ***Prescribed Grazing***: The controlled harvest of vegetation by grazing animals to facilitate stable plant communities that improve surface and subsurface water quality.
- ***Alternative Water Sources***: Can be a permanent or semi-permanent off-stream structure such as a trough, pond or similar vessel that allows livestock to drink ample supplies of fresh water away from the bayou. At this distance they are less likely to distribute fecal waste directly into the receiving waters. The alternative water sources often provide a shade structure as an additional incentive for use by livestock.
- ***Stream Crossings***: A safe stream crossing for livestock, grazing animals and people. Stream crossings are more stable than the bayou's bank, which can be eroded by livestock causing sedimentation of the waterways. The crossings give livestock an opportunity to drink while reducing the overall instream loafing time. Stream crossings can also prevent injury to livestock that must cross steep banks when seeking a water source or crossing the bayou.
- ***Grade Stabilization Structures***: A structure used to control the grade and head cutting in natural or artificial channels. These structures stabilize the grade and control erosion, prevent the formation or advancement of gullies, and enhance environmental quality, while reducing pollution hazards.

- ***Cross Fencing***: Is used to promote rotational grazing and makes the task of maintaining healthy grass heights with prescribed grazing easier, thus promoting infiltration and slowing runoff.
- ***Shade Structures***: Can be used in conjunction with an alternative water source or as a lone standing structure that will provide shade to grazing animals. Shade structures are most effective when placed away from the bayou, offering shade to entice livestock away from the cool, shaded riparian corridor along the bayou.
- ***Riparian Herbaceous Buffers***: Improve water quality in the bayou by filtering surface runoff, which reduces sediment load and allows the natural absorption process time to remove the nutrient load from runoff. These buffers also inhibit fecal indicator bacteria from reaching the waterway. Riparian buffers would also provide more shading, which lowers the water temperature, allowing for a higher concentration of dissolved oxygen, and helping to prevent fish kills.
- ***Buffer Zones***: Are buffers between flooded fields and bayous, i.e. vegetative filter strips and streamside buffers, reduce nutrient and bacteria loading from wildlife and livestock. In forested areas, 50 feet on either side of the channel is a common minimum for riparian buffer zones.
- ***Nutrient Management***: Can reduce bacteria and nutrient loading to the bayou by providing a plan to apply the correct amount of fertilizers and manure at the optimal time. This management measure is best used in conjunction with the soil testing campaign described in Section 7.2.5.

Implementation priority will be given to multipurpose management measures which reduce bacteria runoff into the bayous.

For example, direct deposition of fecal waste by cattle into streams or the bayou is the most concentrated delivery mechanism of bacteria to instream water quality from this source. The amount of bacteria cattle may contribute to the bayou correlates with the stocking rate of the adjacent land, distance from the bayou and the amount of time cattle spend near or in the bayou. In Larsen, Buckhouse et al. 1988, a manure deposition distance of 2 feet and 6.9 feet from a stream showed an 83% and 95% reduction of bacteria compared to fecal waste that is directly deposited into the stream. Providing cattle with alternative water sources has been shown (Wagner, Redmon et al. 2013) to reduce the overall loading rate from 1.11×10^7 cfu/day to 6.34×10^6 cfu/day. The amount of time cattle spent instream was also reduced by 43% with alternative water sources.

6.3 Wildlife and Non-Domestic Plant/Animal Management Measures

In addition to livestock, native wildlife such as deer, raccoons, opossums and bird species, can contribute bacteria to the bayous. However, these sources are considered to be background contributors of nonpoint pollution sources. TPWD actively manages the White-tailed deer populations in Texas, including the deer population that is in the watershed. They consider many factors when deciding how to manage the deer populations of the state such as carrying capacity, population trends, hunting, population densities and competition with other native wildlife, domestic and exotic animals (TPWD 2002). In the State of Texas, further deer management for water quality purposes is not promoted. Deer ranked last, among all sources run in SELECT for their potential contribution to the nonpoint source pollution of the watershed. The stakeholders elected to count deer as part of the background bacteria concentrations, along with other wildlife, due to the small amount of bacteria contributions from deer and the fact that they are native to the watershed.

Stakeholders remarked that some of the WQMP practices such as vegetative buffers (i.e. filter strips and streamside buffers areas) between flooded fields and the bayou could help to reduce the amount of bacteria from native wildlife populations although this management measure isn't intended for that purpose.

GBEP has educational material on invasive species, which is a potential resource for the Double Bayou Partnership. The manual removal of aquatic and terrestrial invasive species during volunteer physical removal days, similar to trash bash events, could be coupled with the riparian area outreach and education measures. Masses of non-native vegetation that has collected in the bayous could also be removed during these events. Large scale mechanical removal equipment should also be employed in conjunction with the event to remove large quantities of invasive aquatics.

SELECT results highlighted feral hogs as the second highest potential source of bacteria contributions to the watershed. Stakeholders agreed that feral hogs and their bacteria contributions are a high management priority. Similar to the livestock discussion in Section, 6.2.2 the direct deposition of fecal waste by feral hogs into streams or bayous is the most concentrated delivery mechanism of bacteria to instream water quality from this source. To determine an estimate of feral hogs that should be removed, the number of hogs for each subwatershed was analyzed according to the bacteria load reduction goal (Table 6-3 Recommended number of feral hogs to be removed by subwatershed).

Subwatershed	Total Hogs	Hogs to be removed
1	107	65
2	4	2
3	105	64
4	63	38
5	157	96
6	38	23
7	77	47
8	32	20
9	88	54
10	56	34
11	60	37
12	82	50
13	16	10
14	164	100
15	47	29
16	110	67
17	21	13
18	33	20
19	135	82
20	16	10
21	45	27
22	63	38
Total	**1519**	**927**

Table 6-3 Recommended number of feral hogs to be removed by subwatershed

SELECT identified the bacteria contributions from the feral hog population of the Double Bayou Watershed as large enough to create a Feral Hog Management Plan. The plan would be comprised of feral hog management measures discussed in this section. Stakeholders expressed the concern that an effective feral hog management plan in the Double Bayou Watershed may simply drive feral hogs across neighboring borders where management measures are not in place. Due to transboundary management requirements for feral hogs, stakeholders explicitly suggested that the Double Bayou Watershed Partnership form relationships with neighboring watersheds and counties to eradicate feral hogs from the region. Furthermore, the stakeholders also suggested holding a workshop to discuss the potential for a statewide feral hog management program. Until a statewide program can be discussed, the Agriculture/Wildlife/Feral Hog Workgroup suggested the following feral hog management measures for the Double Bayou Watershed:

- ***Feral Hog Management***: The creation of a County Feral Hog Control position that would assist stakeholders and allow them to borrow trapping equipment and tools.

Management measures may include: trapping, aerial shooting, exclusionary fencing and increased hunting and removal.

Stakeholders also expressed a desire for the County to implement a program that would issue feral hog bounties. They suggested that the bounty would provide an incentive to increase the hunting and control of feral hogs.

6.4 Recreation Management Measures

The Recreation/Hunting Workgroup discussed management measures to reduce the amount of nonpoint source bacteria from recreational activities in the Double Bayou Watershed. To address the boater waste issue, stakeholders suggested the creation of a pump-out station at Job Beason Park or nearby, for pumping out sewage holding tanks on recreational boats. The installation and maintenance of a pump-out station could be handled by Chambers County, or by a private business in the area. The goal is to promote the use of the pump-out station, which would be in a readily accessible area. This will result in more recreational boaters using the pump-out station, and less boater waste being discharged into the bayous and adjacent Trinity Bay.

Compared to the abundant recreational activities in the watershed, relatively few sanitation facilities exist for recreationalists. The potential creation of restrooms was noted as a possible management measure by the stakeholders although it was recognized that other management measures are higher priorities. ChambersWild is one organization that may be able to facilitate this management measure.

Another recreational issue in the watershed is the sedimentation of the bayous from stream bank erosion caused by ATVs and motorboats. The stakeholders stated that damage caused by these recreational activities and the subsequent loss of vegetation should be addressed. Another boating issue of concern is oil sheen from boat engines. To address oil sheen, stakeholders recommend the creation of an incentive program. The program would incentivize people to either replace their older boat engines or keep them in proper working order. The stakeholders expressed interest in developing and facilitating this initiative.

7 Outreach and Education Management Measures

7.1 Outreach and Education Approach

7.1.1 Role of Outreach and Education

The watershed approach and subsequent implementation phase are stakeholder driven processes. This chapter details outreach and education management measures suggested and agreed upon by stakeholders for successful communication and implementation of this WPP's management measures. It is crucial to inform stakeholders how different choices impact water quality. Outreach and education management measures will be vital to the success of the implementation of the Double Bayou WPP. These measures will provide the awareness upon which the success of all other management measures will be built.

7.1.2 Initial Outreach and Education Activities

Throughout the WPP process, outreach and education activities have included: general meeting presentations, workshops, the project website, fact sheets, brochures, newsletters and outreach to public officials.

Informational presentations by agency partners were incorporated into general stakeholder meetings on the topics of: Lone Star Health Streams, PCBs and Dioxins in the Galveston Bay system, Onsite Wastewater Treatment Systems, TCEQ Assistance for Local Governments and Small Businesses, GBF's Cease the Grease campaign and the Galveston Bay Report Card.

Also, in cooperation with Texas A&M AgriLife Extension, public workshops were organized during development of the WPP to bring specialized training to stakeholders and the general public on watershed-related topics:

- Texas Watershed Steward Training held on June 25th, 2013 (36 participants)
  - This training was a statewide comprehensive program provided by the TSSWCB and Texas A&M AgriLife Extension to educate local stakeholders on watersheds and water issues. The program provides knowledge to allow community members to take on leadership roles and proactively improve and protect water resources in their watershed.

- Double Bayou Watershed/Chambers County Feral Hog Management Workshop held on June 27th, 2014 (57 participants)
  - This workshop was sponsored by Texas A&M AgriLife Extension and provided information on feral hog biology, laws and regulations, interactions with native wildlife and management measures, along with up-to-date research efforts regarding feral hog disease concerns, interactions with native wildlife and management measures.

- Double Bayou Watershed Texas Riparian & Stream Ecosystem Workshop held on September 24th, 2014 (34 participants)
  - This workshop provided Double Bayou stakeholders with classroom presentations and field demonstrations to highlight the hydrology, natural and healthy riparian functions and possible causes of riparian degradation. The program was

sponsored by the TSSWCB, Texas A&M AgriLife, NRCS, USGS and the Texas A&M Forest Service.

- Septic System Maintenance Workshop for Homeowners held on March 31st, 2015 (15 participants)
    - This informational program was sponsored by Texas A&M AgriLife Extension to raise awareness of how everyday activities can affect septic system operation. Homeowners that have anaerobic or aerobic septic systems learned about how septic systems function, care and feeding of the system and proper maintenance procedures.

- Texas Well Owner Network Workshop held on May 28th, 2015 (26 participants)
    - This workshop was sponsored by Texas A&M AgriLife Extension and the TSSWCB to provide private water well owners with affordable water quality testing along with an educational program centered on groundwater resources, well maintenance and well water treatment.

The Double Bayou Watershed Partnership website (http://www.doublebayou.org/) was developed to provide a vehicle for updating stakeholders on the WPP process and to organize content such as meeting announcements, notes and presentations (Figure 7-1 Double Bayou Partnership website).

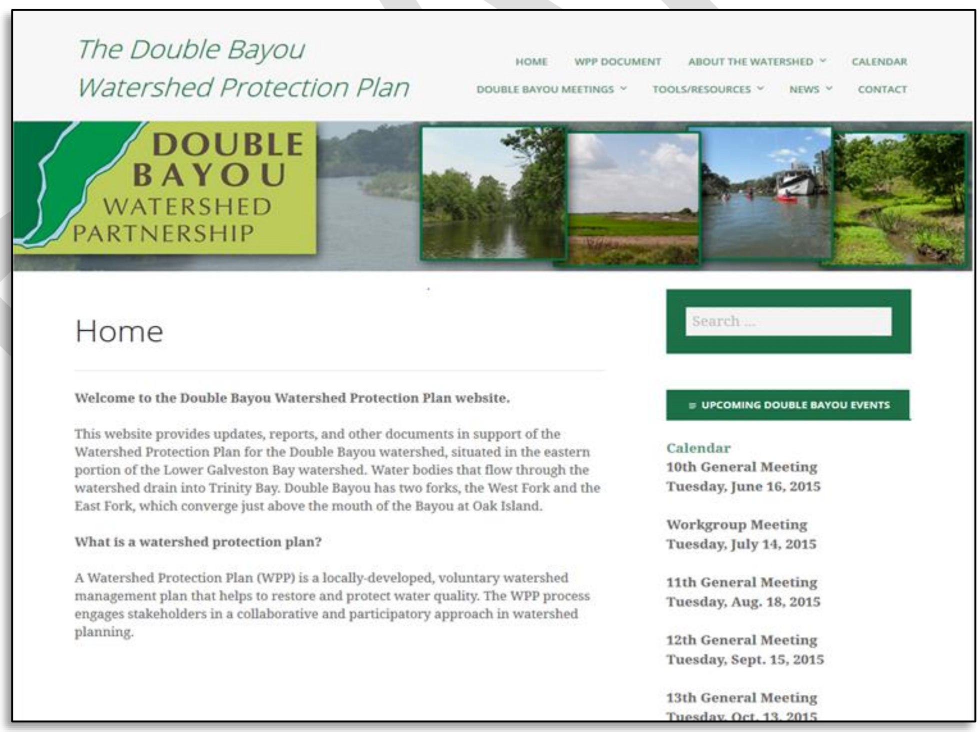
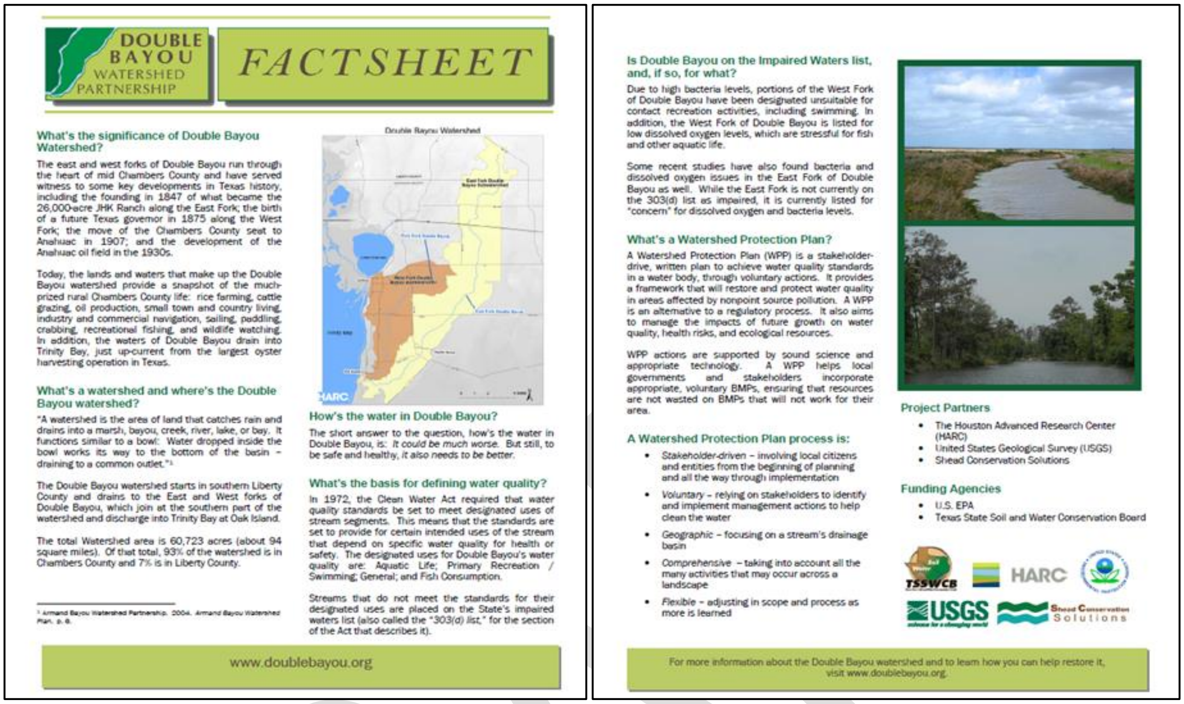


Figure 7-1 Double Bayou Partnership website

The Double Bayou Watershed Fact Sheet (Figure 7-2 Double Bayou Watershed factsheet) and the Double Bayou Watershed Partnership Brochure (Double Bayou Watershed Partnership brochure (front and back) were created to educate stakeholders and the general public about the Double Bayou Watershed, the watershed protection planning process and water quality issues in the watershed.


DOUBLE BAYOU WATERSHED PARTNERSHIP

FACTSHEET

What's the significance of Double Bayou Watershed?

The east and west forks of Double Bayou run through the heart of mid Chambers County and have served witness to some key developments in Texas history, including the founding in 1847 of what became the 26,000-acre JHK Ranch along the East Fork; the birth of a future Texas governor in 1875 along the West Fork; the move of the Chambers County seat to Anahuac in 1907; and the development of the Anahuac oil field in the 1930s.

Today, the lands and waters that make up the Double Bayou watershed provide a snapshot of the much-prized rural Chambers County life: rice farming, cattle grazing, oil production, small town and country living, industry and commercial navigation, sailing, paddling, crabbing, recreational fishing, and wildlife watching. In addition, the waters of Double Bayou drain into Trinity Bay, just up-current from the largest oyster harvesting operation in Texas.

What's a watershed and where's the Double Bayou watershed?

"A watershed is the area of land that catches rain and drains into a marsh, bayou, creek, river, lake, or bay. It functions similar to a bowl: Water dropped inside the bowl works its way to the bottom of the basin – draining to a common outlet."[1]

The Double Bayou watershed starts in southern Liberty County and drains to the East and West forks of Double Bayou, which join at the southern part of the watershed and discharge into Trinity Bay at Oak Island.

The total Watershed area is 60,723 acres (about 94 square miles). Of that total, 93% of the watershed is in Chambers County and 7% is in Liberty County.

[1] Armand Bayou Watershed Partnership. 2004. Armand Bayou Watershed Plan. p. 6.

Double Bayou Watershed

HARC

How's the water in Double Bayou?

The short answer to the question, how's the water in Double Bayou, is: *It could be much worse.* But still, to be safe and healthy, *it also needs to be better.*

What's the basis for defining water quality?

In 1972, the Clean Water Act required that water quality standards be set to meet designated uses of stream segments. This means that the standards are set to provide for certain intended uses of the stream that depend on specific water quality for health or safety. The designated uses for Double Bayou's water quality are: Aquatic Life; Primary Recreation / Swimming; General; and Fish Consumption.

Streams that do not meet the standards for their designated uses are placed on the State's impaired waters list (also called the "*303(d) list*," for the section of the Act that describes it).

www.doublebayou.org

Is Double Bayou on the Impaired Waters list, and, if so, for what?

Due to high bacteria levels, portions of the West Fork of Double Bayou have been designated unsuitable for contact recreation activities, including swimming. In addition, the West Fork of Double Bayou is listed for low dissolved oxygen levels, which are stressful for fish and other aquatic life.

Some recent studies have also found bacteria and dissolved oxygen issues in the East Fork of Double Bayou as well. While the East Fork is not currently on the 303(d) list as impaired, it is currently listed for "concern" for dissolved oxygen and bacteria levels.

What's a Watershed Protection Plan?

A Watershed Protection Plan (WPP) is a stakeholder-drive, written plan to achieve water quality standards in a water body, through voluntary actions. It provides a framework that will restore and protect water quality in areas affected by nonpoint source pollution. A WPP is an alternative to a regulatory process. It also aims to manage the impacts of future growth on water quality, health risks, and ecological resources.

WPP actions are supported by sound science and appropriate technology. A WPP helps local governments and stakeholders incorporate appropriate, voluntary BMPs, ensuring that resources are not wasted on BMPs that will not work for their area.

A Watershed Protection Plan process is:

- *Stakeholder-driven* – involving local citizens and entities from the beginning of planning and all the way through implementation
- *Voluntary* – relying on stakeholders to identify and implement management actions to help clean the water
- *Geographic* – focusing on a stream's drainage basin
- *Comprehensive* – taking into account all the many activities that may occur across a landscape
- *Flexible* – adjusting in scope and process as more is learned

Project Partners

- The Houston Advanced Research Center (HARC)
- United States Geological Survey (USGS)
- Shead Conservation Solutions

Funding Agencies

- U.S. EPA
- Texas State Soil and Water Conservation Board

TSSWCB HARC USGS Shead Conservation Solutions

For more information about the Double Bayou watershed and to learn how you can help restore it, visit www.doublebayou.org.

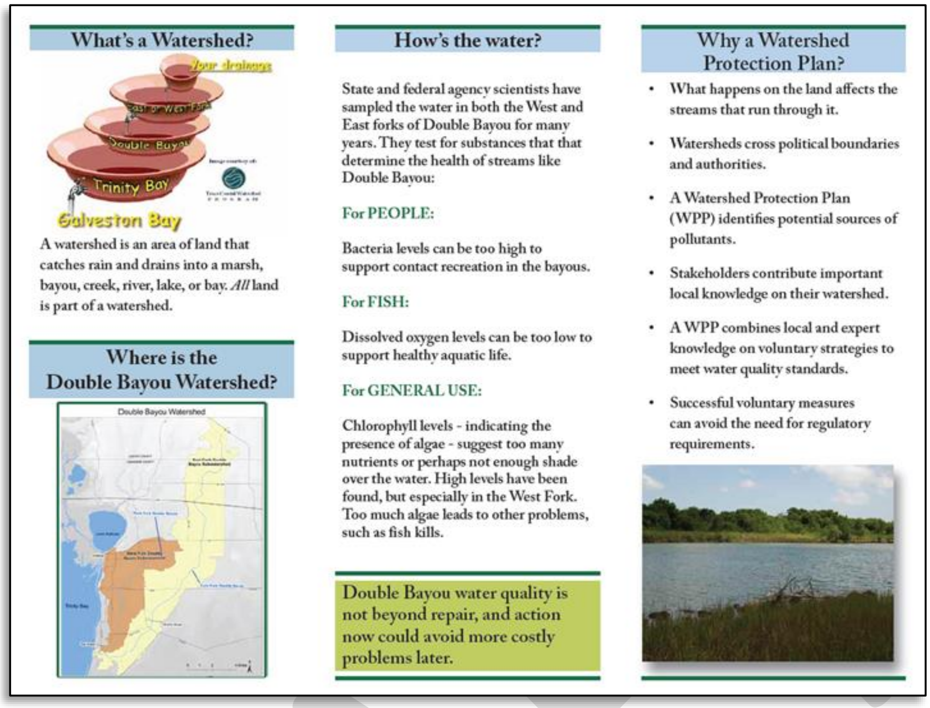
Figure 7-2 Double Bayou Watershed factsheet

During the watershed protection planning process, four informational newsletters were developed and distributed for the Double Bayou Watershed Partnership. The newsletters served as outreach and education materials and highlighted watershed activities, helped inform stakeholders of current programs and provided information on water quality issues. The June 2014 newsletter introduced the WPP concept, describing some key elements and highlights of the planning process for the Double Bayou Watershed; provided information on an upcoming feral hog workshop; and offered a local stakeholder's perspective. The December 2014 newsletter included features on the importance of riparian areas, ways to prevent clogging of sewer pipes by fats, oils and grease and biological drivers of feral hog behavior. The May 2015 newsletter highlighted award-winning stakeholders, presented a new Double Bayou Watershed Partnership partner, provided an update on the WPP project and on the "Cease the Grease" campaign, offered a second local stakeholder perspective and presented additional feral hog management resources for stakeholders. The November 2015 newsletter featured a Texas WPP project that has resulted in de-listing of stream segments, offered a third local stakeholder perspective, presented an overview of the WPP document, explained some of the science behind proposed bacteria load reductions, and continued to present information on what residents and homeowners can do to help keep bacteria out of Double Bayou.

Press releases were developed and distributed throughout the development of the WPP development to inform stakeholders of upcoming meetings, or to give details of workshops and

WPP events.

Figure 7-3 Double Bayou Watershed Partnership brochure (front and back)


What's a Watershed?

A watershed is an area of land that catches rain and drains into a marsh, bayou, creek, river, lake, or bay. *All* land is part of a watershed.

Where is the Double Bayou Watershed?

How's the water?

State and federal agency scientists have sampled the water in both the West and East forks of Double Bayou for many years. They test for substances that that determine the health of streams like Double Bayou:

For PEOPLE:

Bacteria levels can be too high to support contact recreation in the bayous.

For FISH:

Dissolved oxygen levels can be too low to support healthy aquatic life.

For GENERAL USE:

Chlorophyll levels - indicating the presence of algae - suggest too many nutrients or perhaps not enough shade over the water. High levels have been found, but especially in the West Fork. Too much algae leads to other problems, such as fish kills.

Double Bayou water quality is not beyond repair, and action now could avoid more costly problems later.

Why a Watershed Protection Plan?

- What happens on the land affects the streams that run through it.
- Watersheds cross political boundaries and authorities.
- A Watershed Protection Plan (WPP) identifies potential sources of pollutants.
- Stakeholders contribute important local knowledge on their watershed.
- A WPP combines local and expert knowledge on voluntary strategies to meet water quality standards.
- Successful voluntary measures can avoid the need for regulatory requirements.

7.1.3 Implementation Phase Overview

To facilitate outreach and education management measures, stakeholders recognized the need for and recommended the creation of a Watershed Coordinator position. The primary duty of the Watershed Coordinator is to oversee the implementation of the outreach and education measures detailed in this chapter. The Watershed Coordination will routinely interact with stakeholders, local city councils, county commissioner courts, Extension, GBF, TCEQ, TSSWCB and other watershed interest groups to keep them informed and involved in implementation activities. The Watershed Coordinator will work to secure external funding to facilitate stakeholder-recommended implementation activities outlined in the Double Bayou WPP. The stakeholders also suggested that educational materials printed in both English and Spanish would maximize the number of residents who would benefit and help implement the WPP.

Stakeholders recommended that the Watershed Coordinator develop or utilize current age-encompassing materials to target different school grades. Stakeholders noted that this will be an effective form of outreach, because the youth will then share materials and knowledge with their parents. One possible school-age group to target is the Roots and Shoots Club at Anahuac High School, which is oriented towards environmental activities.

Also, each of the outreach and education methods described in this chapter will continue during the implementation of this plan: general meeting presentations, workshops, fact sheets and brochures, project website, newsletters and outreach to elected officials.

In summary, based on stakeholder recommendations, outreach and education during implementation of the Double Bayou WPP will be based on three key strategies:

- Create a Watershed Coordinator position to oversee and integrate the outreach and education measures,

- Partner with other entities both for securing funding and for on-the-ground management measure implementation, and
- Utilize existing materials and programs wherever applicable and possible, developing and/or adapting them to be specific for the Double Bayou Watershed, as appropriate.

7.2 Stakeholder Recommended Outreach and Education Management Measures

7.2.1 Stakeholder Management Measures Overview

Stakeholders met during general public meetings and workgroup meetings (the three main workgroups for Double Bayou were Agriculture/Wildlife/Feral Hogs, Wastewater/Septic and Recreation/Hunting) to discuss possible management measures to improve water quality in Double Bayou. Workgroups suggested possible management measures appropriate to their workgroup focus. All workgroups recommended a significant number of outreach and education management measures as part of their overall management measures. The lists of workgroup recommendations were then discussed and accepted, with some modifications, at a general stakeholder meeting.

Many workgroup recommended manage measures often overlapped. As a result, they were merged into one collective stakeholder-recommended list of outreach and education management measures and are discussed in the following sections.

7.2.2 Broad-Based Programs

Workshop programs, such as the ones discussed in Section 7.1.2, will continue to be offered to the Double Bayou stakeholders during WPP implementation (Figure 7-4 Double Bayou Texas Riparian & Stream Ecosystem Workshop). These workshops benefit the watershed as a whole and encompass many nonpoint source pollution issues that are present in the watershed.

Figure 7-4 Double Bayou Texas Riparian & Stream Ecosystem Workshop

The Texas Watershed Steward program is a statewide, comprehensive water resource training program sponsored by Texas A&M AgriLife Extension and the TSSWCB. This program informs stakeholders of watershed and water quality issues. Its purpose is to: "promote healthy watersheds, increase understanding of the potential causes of water resource degradation and give people the knowledge and tools they need to prevent and/or resolve water quality problems." The program specifically targets nonpoint sources of pollution and provides stakeholders with the knowledge to enable implementation of management measures that will preserve, protect and enhance the Double Bayou Watershed.

The Texas Riparian & Stream Ecosystem Workshop is a collaboration of the Texas Water Resources Institute, TSSWCB and numerous state, local and federal resource agencies. This day-long workshop is part of a program to "promote healthy watersheds and improve water quality through riparian and stream ecosystem education." This workshop increases citizen awareness and understanding of the nature, function and benefits of riparian zones and how to manage them to minimize nonpoint source pollution.

The Feral Hog Management Workshop sponsored by Texas A&M AgriLife Extension and TSSWCB provides information on feral hog biology, population dynamics, effects on water quality, regulations and feral hog controls/management through methods such as trapping. Feral hogs are a state wide issue that has water quality impacts in numerous watersheds. The Texas A&M AgriLife Extension Feral Hog Specialists who run the workshop will also be available to provide technical assistance and insight to manage the feral hog population.

The Texas Well Owner Network Workshop sponsored by Texas A&M AgriLife Extension and the TSSWCB is a one-day workshop for private well owners and provides resources on well maintenance, water quality, water treatment, water supply and groundwater resources. This workshop provides well owners the opportunity for affordable well water screening; well owners can bring in samples of their well water to be screened for common contaminants including fecal coliform bacteria, nitrates, arsenic and high salinity

The NEMO (nonpoint source education for municipal officials) program sponsored by Texas A&M AgriLife Extension and Texas Sea Grant is another broad-based outreach and education initiative that provides factsheet resources for municipal officials about management measures that reduce the impacts on water quality from stormwater and nonpoint source runoff.

The Galveston Bay Foundation has implemented an interactive web and mobile application, the Galveston Bay Action Network (GBAN), which is funded through the Texas Coastal Management Program by NOAA and EPA. It will be promoted during implementation. GBAN is an application for submitting and viewing water related pollution reports across the four counties around Galveston Bay, including the Double Bayou Watershed. GBAN pollution reports are sent directly to the appropriate authorities, making it easy for stakeholders to report concerns. These pollution events can range from boat sewage to trash and debris.

Broad-based outreach and education activities also include those that are less structured around a specific program. Providing displays of educational materials on watershed topics could be rotated at local events, depending on the aspect that needs greater awareness. Watershed roadway signs will be utilized to increase the public's awareness that what they do on the land can affect water in the bayou and to promote general watershed awareness. Stakeholders suggested that a test-your-watershed-knowledge game be developed for distribution through social media and the ChambersWild website. A continuous advertisement or regular article submission in the Anahuac newspaper will help to promote awareness of the Double Bayou Watershed Partnership in general, along with upcoming outreach and education workshops as well as provide targeted campaign information, such as illegal dumping.

7.2.3 Wastewater Programs

Stakeholders recommended outreach and education activities that build on existing programs, applied to the Double Bayou Watershed. First, residents and homeowners will be the target audience. The Watershed Coordinator will lead watershed-wide campaigns and build partnerships to educate residents on how they affect their wastewater infrastructure at an individual level.

The Watershed Coordinator will work with the Galveston Bay Foundation to bring their Cease the Grease program (http://galvbay.org/ceasethegrease/) to local residents. This program details the problems that fats, oils and grease create for wastewater infrastructure and offers alternatives to dumping fats, oils and grease down the drain.

To aid in this outreach measure, stakeholders also agreed that the No Wipes in the Pipes/ Patty Potty Patrol Campaign (http://www.pattypotty.com/) maintained by the San Jacinto River Authority would also be a reasonable outreach and education tool to implement watershed-wide.

Additionally, providing information about homeowner responsibilities for maintenance of their lateral lines (the sewer pipe from the home to the public sewage system) and keeping clean-out caps closed would serve as another preventive measure to increase the effective operation of the Anahuac WWTF.

A second target audience will be wastewater professionals. The Watershed Coordinator will work to include options for financing or organizing classes and training opportunities. The Texas A&M Engineering Extension Service (TEEX) courses were recommended by stakeholders for the Anahuac WWTF wastewater professionals who have not already taken the courses. These could include TEEX water and wastewater bacteria troubleshooting and operations training classes. The training opportunities offered by the Trinity Valley District of the Texas Water Utilities Association were also recommended for local wastewater professionals.

7.2.4 Septic Systems Programs

Stakeholders suggested two methods of effective outreach and education through utility connections. One method could be education marketed to new homeowners at the time of connections. The other method could be to include educational information with utility bills such as an introduction to OSSFs (including a homeowner's septic system responsibilities). Notifications about educational programs (including an aerobic system workshop) for existing homeowners could also be offered through this mechanism.

Different types of outreach programs, such as workshops, help inform homeowners about improved septic system maintenance and about alternatives for those who may have a relief line from their septic tank. Materials on the proper use of gray water will be offered to inform homeowners about the need for a filter on their gray water line. Another recommended outreach program is to develop a process for boaters to report straight pipe discharges (Figure 7-5 Straight pipe discharge East Fork).

The Septic System Maintenance Workshop is sponsored by Texas A&M AgriLife Extension and covers the septic system treatment processes, health and safety considerations for homeowners, and how to inspect and maintain the system. This workshop also provides answers to the most frequently asked septic system questions, including the best schedule for pump-out of a tank and what should or should not go down the drain. The existing workshop focuses on conventional (anaerobic) septic systems. Stakeholders recommended continuing to hold this workshop in the watershed. Stakeholders also suggested a workshop that focuses on the operation and maintenance of aerobic septic systems.

Figure 7-5 Straight pipe discharge East Fork

7.2.5 Agricultural Programs

Stakeholder-recommended outreach and education activities for agriculture would focus on partnering with Texas A&M AgriLife Extension to bring existing programs to the watershed, including education campaigns/events and materials. Workshops and events are generally recommended once per year. Educational materials are recommended to be made available at workshops and other events.

The Watershed Coordinator will work with the existing Lone Star Healthy Streams (LSHS) program, Texas A&M AgriLife Extension and TSSWCB to bring their nonpoint source education materials to the Double Bayou Watershed. The LSHS program focuses on the protection of Texas waterways from nonpoint source bacteria runoff from livestock and feral hogs.

This program has specific materials that detail management of bacteria and nutrients from nonpoint source runoff, specifically animal production and feral hogs. The recommended management measure is to have copies of the Lone Star Healthy Streams materials for horses, feral hogs and cattle available for distribution in the Double Bayou Watershed. Stakeholders also suggested that similar educational materials be developed for goats. The Watershed Coordinator will work with Texas A&M AgriLife Extension to provide stakeholders with existing educational materials for goat management and determine if additional materials need to be developed. The existing Lone Star Healthy Streams manuals and the materials on goats should be available for both Spanish and English-speaking audiences.

Stakeholders recommended that soil testing and nutrient management be management measures, led by the Watershed Coordinator, partnering with Texas A&M AgriLife Extension. The soil testing campaign may offer soil testing at a reduced rate. An analysis of the soil's nutrient content will guide proper fertilizer application rates for a specific pasture or hay field. The soil testing provides knowledge for the landowner, but it is up to the landowner to decide how to use that knowledge. The nutrient management campaign will provide information on proper agricultural nutrient management through the use of existing Texas A&M AgriLife Extension materials. This program highlights the importance of proper fertilizer application to reduce the amount of nutrients that runs off into the bayous. Agriculture field days will also be hosted by the Watershed Coordinator and Texas A&M AgriLife Extension.

Stakeholders recommended that agriculture waste pesticide collection days be held. These would be organized by the Watershed Coordinator in partnership with the TCEQ. The agricultural waste pesticide days would allow land-owners to bring in their extra pesticides and fertilizers for disposal, without facing any penalties or cost. The waste collection days would also provide an outreach opportunity to share educational materials with stakeholders. In addition, the stakeholders suggested that materials or a workshop on proper and targeted use of herbicides be implemented. To increase effectiveness of the program, stakeholders recommended that the waste pesticide collection days be coordinated with a workshop on proper and targeted herbicide use and that CEUs be offered for participation in the combined event.

The Watershed Coordinator will be able to promote many of the agricultural initiatives in partnership with the WQMP Technician (see Chapter 6: Management Measures for a discussion on the WQMP Technician). The two positions could organize and host workshops, including some of the activities that Texas A&M AgriLife Extension offers.

7.2.6 Recreation Programs

To reduce the amount of water pollution stemming from recreational activities in the watershed, three outreach and education programs were recommend by the stakeholders to target management of human waste from recreational uses. First, an Illegal Boater Dumping Awareness campaign will be implemented through a partnership with GBF, to promote proper recreational boat pump-out practices. This would include working with GBF on informing boaters who embark from the west side of Galveston Bay and come to recreate in the Double Bayou Watershed. Another management measure to aid in this process will be to add icons to local maps and websites to identify locations of existing park restrooms in and near the watershed. The Watershed Coordinator, along with GBF, will also promote the Galveston Bay Action Network to prevent and report illegal boater discharges.

To reduce bacteria pollution from the dumping of carcasses in or near waterways, an awareness event and a campaign signage program for proper disposal of carcasses was recommended as another focus for the recreational outreach and education measures. This program will inform stakeholders of alternate/proper carcass disposal sites. The program will highlight the proper disposal of carcasses away from waterways to prevent fecal bacteria from entering the waterways. The Watershed Coordinator will organize an educational event and provide educational materials on the proper disposal of carcasses to hunters at point-of-sale locations for hunting supplies and licenses. The point-of-sale displays will also promote the Operation Game

Thief program and hunter education. Since many hunters buy their supplies and licenses outside the watershed, coordination with TPWD will be needed for this program to be effective.

Stakeholders recommended that the Watershed Coordinator organize efforts to raise awareness of the pollution potential of older boat engines and encourage use of newer boat motors when opportunities arise. Additionally, the Watershed Coordinator will organize efforts to raise awareness on how to reduce the amount of sedimentation stemming from erosion caused by the loss of vegetation from unauthorized use of ATVs in and near waterways.

In order to meet all of the recreational outreach and education objectives in this chapter, stakeholders recommended that the Watershed Coordinator work with the TPWD officers of Chambers and Liberty counties to bring attention to the “Illegal Boater Waste Dumping” and “Proper Disposal of Carcasses” campaigns. In addition to these outreach and education measures, stakeholders suggested that a continuous advertisement or regular stories be submitted to the *Anahuac Progress* and *Liberty Vindicator* newspapers to inform residents about the impacts that dumping carcasses and illegal boater waste has on the water quality of the bayous. To further market and promote proper recreational activities in the watershed, all information and developed materials will be made available on the ChambersWild website. Stakeholders also recommended that younger residents be included in these campaigns and that age-encompassing and appropriate materials be developed and distributed to local schools.

7.2.7 Residential Programs

Stakeholders agreed that the promotion of County landfill facilities available for residents could help to reduce the amount of solid waste dumped in the bayou. As an incentive they suggested a program that includes funding to subsidize the tags required by the County for a household to use the landfill.

Stakeholders recommended demonstrations of rain gardens and rain water harvesting. These promote the use of drain chains or similar features at gutter downspouts to drain into rain gardens and thus decrease bacterial loads into the bayous from concentrations of scavengers on rooftops.

7.2.8 Wildlife and Non-domestic Plant/Animal Programs

The Watershed Coordinator will work with Texas A&M AgriLife Extension to bring outreach and education materials covering the management of feral hog populations to the Double Bayou Watershed. The materials will be displayed at local events such as the Texas Rice Festival and the Double Bayou Boat Parade and be made available on the ChambersWild and Double Bayou Watershed Partnership websites. In addition, Texas A&M AgriLife Extension’s Feral Hog Management Workshop will be offered for the Double Bayou Watershed. The Feral hog outreach and education materials focus on providing information that highlights how feral hogs contribute to nonpoint source bacteria pollution in the bayous.

A “Don’t Treat or Feed as Pets” campaign will incorporate watershed signage at public access points and possibly a billboard to inform the public not to feed wildlife to reduce their concentrations, especially waterfowl (Figure 7-6 Example signage Example signage). Other outreach and education materials will be developed to inform the public of the potential pathways that invasive species are spread. One such pathway is transfer by boats when they are used in multiple waterbodies without washing them in between.

Figure 7-6 Example signage

7.2.9 Litter and Dumping Programs

Stakeholders recommended that an Illegal Solid and Hazardous Waste Dumping Campaign be launched watershed-wide (Figure 7-7 Illegal dumping in the watershed). The campaign will incorporate no littering or dumping signs at parks and other recreational hotspots in the watershed. It will also include an informational exhibit at the public library in Anahuac. A major component of the Illegal Solid and Hazardous Waste Dumping Campaign will be promoting the use of the Galveston Bay Action Network to report illegal dumping.

Figure 7-7 Illegal dumping in the watershed

As part of the Illegal Solid and Hazardous Waste Dumping Campaign, the stakeholders suggested that clean-up days be held for the Double Bayou Watershed in the form of Trash Bash. The cleanup event provides an opportunity for watershed awareness and stakeholder education. An Adopt-a-Beach program was recommended in the watershed for stakeholders or local businesses to participate and be responsible for picking up litter along a stretch of waterway. Monofilament collection receptacles at bridges and popular fishing destinations could help to educate the public and to collect excess monofilament line. The Texas Sea Grant program already installs and maintains receptacles around Galveston Bay. The Double Bayou Watershed Partnership would attempt to include the Texas Sea Grant as a partner of the campaign.

8 Project Implementation

8.1 Project Implementation Overview

The project schedule, milestones and estimated cost of management measures are primary components to consider prior to the implementation phase of a WPP. In addition, project implementation cannot be undertaken with on-the-ground management measures without securing adequate project funding. This chapter details the financial and technical assistance needed to successfully implement the nonpoint source reduction management measures previously discussed in Chapters 6 and 7. Expected load reductions are presented along with a water quality monitoring plan. An adaptive implementation approach will allow for contingencies if the implementation progress of the Double Bayou WPP is falling short or ahead of schedule. All management measures are voluntary and contingent on available funding. See Tables 8-1 and 8-2 for lists of all stakeholder-recommended management measures.

8.2 Technical Assistance

The successful implementation of the Double Bayou WPP relies on a number of entities including stakeholders, local government agencies, nonprofits, municipalities, counties and Texas A&M AgriLife Extension agents. Stakeholders possess motivation and local knowledge, but will require technical expertise, personnel and resources from supporting entities to improve Double Bayou water quality on a watershed scale. The implementation phase will require the further support of two full-time positions that will help fulfill the criteria set out in this chapter. Resources will be targeted to stakeholder-selected high-priority management measures. Project implementation will require a collaborative effort between stakeholders and other land and natural resource management entities.

8.3 Wastewater Management Measures

Wastewater management measures that have been recommended by stakeholders will require the expertise and input of the City of Anahuac staff, including WWTF plant operators, as well as technical resources from TCEQ and Texas A&M AgriLife Extension, to advise and coordinate the implementation of the collection system infrastructure improvements and WWTF operations management measures. Funding will be sought to facilitate the stakeholder-recommended improvements to the public wastewater systems, including potential expansion to areas currently not served by the public systems.

8.4 Septic Systems Management Measures

An initial component of the septic system management measures is to maintain and expand the OSSF database started by stakeholders. The database will be the responsibility of Chambers County to manage. The active involvement of County personnel will be imperative for continued success of OSSF operations with population growth. Funding will be targeted to aid the County in the oversight of these operations. To optimize load reductions, high priority subwatersheds identified with SELECT will be targeted.

8.5 Agricultural Management Measures

Support and technical guidance from the Trinity Bay SWCD, TSSWCB, USDA-NRCS, and the Texas A&M AgriLife Extension will be crucial for the selection and placement of appropriate agricultural management measures. Many of the stakeholders in Double Bayou are landowners/agriculture producers who already operate under WQMPs and effectively execute agricultural conservation practices. Stakeholders who have a WQMP in place represent a valuable resource for the watershed. Their experience will provide essential insight to aid the selection and placement of management measures.

In order to support WQMP development, stakeholders recommended that a WQMP Technician position be created. This position would be dedicated to assisting landowners in the creation and implementation of the WQMPs. Because a number of WQMPs are certified in the watershed, the WQMP Technician would focus on enrolling more landowners while also emphasizing WQMP status reviews. The technician would be involved in writing, updating/planning and promotion of the WQMPs. In addition, the technician would help secure potential funding to implement WQMPs.

8.6 Wildlife and Non-Domestic Plant/Animal Management Measures

Active stakeholder participation will be required to implement Wildlife and Non-Domestic Plant/Animal Management Measures because assistance will be required for invasive species physical removal days and the trapping of feral hogs. Management of the feral hog population will require a large-scale regional effort. The existing Texas A&M AgriLife Extension Feral Hog Specialist for South Texas will provide technical assistance and insight for trapping and managing the feral hog population. County feral hog personnel will provide guidance and coordination of the feral hog removal effort. The County feral hog position will assist stakeholders with technical advice while providing valuable resources such as traps and equipment.

8.7 Recreation Management Measures

The Galveston Bay Foundation will provide technical expertise on recreational boater waste issues. A boater waste pump-out station is recommended for Oak Island. It might be at Job Beason Park, and either County-run or managed/maintained by a contractor. Another option might be for another business opportunity at a private facility at the Double Bayou confluence with Trinity Bay. The ChambersWild website will serve as a platform and outreach tool for implementation updates and information to stakeholders.

8.8 Project Schedule, Milestones, Estimated Cost

The implementation schedule will be described for short-term (1-3 years), mid-term (4-6 years) and long-term (7-10 years) milestones (Table 8-1 Management measures). Milestones are project goals used to keep the implementation phase on track. Depending on specifics of the management measure, some will be adopted early on in the process and may not require extensive maintenance and monitoring, while others will require ample time for research and development, funding and personnel. The three project phases help spread funding, resources and personnel over the 10-year timeline. Progress indicators provide quantifiable benchmarks that will be used to assess implementation of management measures and nonpoint source load reductions outlined in this WPP. The estimated costs consider initial requirements and long term maintenance costs of management practices.

Management Measures	Lead Entity	Unit Cost	Number Implemented per Year Range			Total Cost
			Years			
			1 to 3	4 to 6	7 to 10	
Wastewater Management Measures						
Collection system study (*smoke test and video lines*) (*high priority*)	City of Anahuac	$75,000/study	1	---	---	$75,000
Upgrade collection system line and manhole replacement	City of Anahuac	$375,000/biennium	2	1	1	$1,500,000
Lift station upgrades	City of Anahuac	$520,000/lift station	1	2	---	$1,560,000
Pump repair and replacement (*high priority*)	City of Anahuac	$120,000/pump	1	1	---	$360,000
Septic Systems Management Measures						
Identify OSSFs in watershed and maintain OSSF database	Chambers/ Liberty Counties	Cost contributed*	1			$0
Expand sewer system to serve septic homes	TBCD	$3,200/home	1			$TBD
Increase septic system review and inspection capacity (*including relief lines and plan for population growth*)	Chambers/ Liberty Counties	$42,000/year for inspection	1			$420,000
Agricultural Management Measures						
Water Quality Management Plans (WQMP)	SWCD/ Landowner	$15,000/plan	12 (3,4,5)	18 (6/yr)	22 (7,7,8)	$780,000
WQMP Technician (*new position-shared with Cedar Bayou*)	SWCD	$75,000/year	1			$750,000**

*The OSSFs were identified and developed into a database as part of the Double Bayou WPP; the database will be maintained as part of a current salaried position.

**Total includes salary, benefits (health insurance, annual/sick leave, etc.) office rental, communications (fax, phone), travel expenses, and computer cost.

Table 8-1 Management measures

Management Measures	Lead Entity	Unit Cost	Number Implemented per Year Range			Total Cost
			Years			
			1 to 3	4 to 6	7 to 10	
Wildlife and Non-Domestic Plant/Animal Management Measures						
Feral Hog County Position	Chambers/ Liberty Counties	$90,000/year	1			$900,000*
Feral Hog Control (*equipment*)	County Position	$500/trap	20	15	20	$27,500
Feral hog bounties (*county*)	Chambers/ Liberty Counties	$5/bounty	1			N/A
Physical and mechanical removal of invasive species day(s)	Watershed Coordinator	$TBD	1	0	1	$TBD
Recreation Management Measures						
Boater waste pump out station (possibly Job Beason Park)	County and/or Private Entity	$12,000/unit	---	1	---	$12,000**
Potential additional restrooms throughout watershed	Chambers Wild	$TBD	---	---	1	N/A
Monitoring Component						
Targeted water quality monitoring	USGS	$3,125/event***	96	63	63	$693,750
Bacterial source tracking	Texas A&M University	$200,000	1	----	----	$200,000

*Total includes salary, benefits (health insurance, annual/sick leave, etc.) office rental, communications (fax, phone), travel expenses, and computer cost.
**Cost includes unit price, installation parts and labor; eligible for 75% reimbursement from TPWD See 8.10.
***Sampling event includes travel time, salary and benefits, sampling equipment, laboratory transport equipment, and laboratory analysis; the amount is a rough estimate for the collection and analysis of one sample at one site for the constituents listed in Chapter 8.13.

Table 8-1 Management measures (continued)

8.9 Outreach and Education

As detailed in Chapter 7, an extensive outreach and education campaign will be vital to raise awareness and stakeholder participation in the Double Bayou Watershed. This initiative will require support and collaboration from stakeholders, TSSWCB, Texas A&M AgriLife Extension, Galveston Bay Foundation, City of Anahuac and Chambers County. The watershed coordinator will facilitate communication with these entities and act as a liaison to ensure that information is provided throughout the watershed. This section provides lead-entity and financial details of stakeholder-identified outreach and education management measures (Table 8-2 Outreach and education management measures). Stakeholders also suggested the number of outreach and education programs to be implemented per year over the 10-year project term. Tracking of the implementation of these programs, which may include the number of people reached, will provide quantifiable metrics for evaluation of the implementation of the outreach and education measures.

Outreach and Education Management Measures	Lead Entity	Number of Programs per Year Range — Years: 1 to 3	4 to 6	7 to 10	Total Cost
Broad-Based Programs					
Watershed Coordinator	Partnership/ TSSWCB	1			$950,000*
Texas Watershed Steward Trainings	TSSWCB/AgriLife Extension	1	1	1	N/A
Watershed Texas Riparian & Stream Ecosystem Workshop	TSSWCB/AgriLife Extension	1	1	1	$24,000
Feral Hog Management Workshop	TSSWCB/AgriLife Extension	1	1	1	$24,000
Texas Well Owner Network Workshop	TSSWCB/AgriLife Extension	1	1	1	N/A
Nonpoint Source Education for Municipal Officials (NEMO) Workshop	TCEQ/AgriLife Extension	1	---	1	$10,000
Galveston Bay Foundation Action Network (GBAN) application	Galveston Bay Foundation	1			N/A
Educational displays at local events	Watershed Coordinator	5	5	5	$3,000
Rain gardens and rain water harvesting education/ demonstration	AgriLife Extension	2	1	2	$25,000

*Total includes salary, benefits (health insurance, annual/sick leave, etc.) office rental, communications (fax, phone), travel expenses, and computer cost.

Table 8-2 Outreach and education management measures

Outreach and Education Management Measures	Lead Entity	Number of Programs per Year Range			Total Cost
		Years			
		1 to 3	4 to 6	7 to 10	
Watershed roadway signage*	Watershed Coordinator	60	---	---	$6,000
Development and promotion of test-your-watershed knowledge game	Watershed Coordinator/ ChambersWild	1			$TBD
Wastewater Programs					
Galveston Bay Foundation's Cease the Grease Campaign	Galveston Bay Foundation	3	3	4	$0
San Jacinto River Authority No Wipes in the Pipes/ Patty Potty Campaign	San Jacinto River Authority	1	1	1	N/A
Wastewater operator training programs	TEEX/ Texas Water Utilities Association	1	1	1	N/A
Awareness programs: • Homeowner education on lateral line maintenance (including clean-out caps) • Education/opportunities for homeowner implementation of low-flow devices • Mechanism for reporting illicit connections	Watershed Coordinator	1**			$TBD
Septic Systems Programs					
Awareness programs: • Education for new homeowners • Education with utility bills • Materials on proper use of gray water (filter) • Mechanism for reporting straight pipe discharges	Watershed Coordinator	1**			$1,000
Septic System Maintenance Workshop, exploring aerobic component addition	AgriLife Extension	3	3	4	$25,000

*The implementation of Watershed Roadway Signage will involve coordination with TXDOT to explore feasibility of roadway signage and ensure compliance with appropriate numbers of signs, scale of signs and colors of signs.

**Ongoing provision/development of materials to be distributed/promoted at workshops and events.

Table 8-2 Outreach and education management measures (continued)

<table>
<tr><th rowspan="3">Outreach and Education Management Measures</th><th rowspan="3">Lead Entity</th><th colspan="3">Number of Programs per Year Range</th><th rowspan="3">Total Cost</th></tr>
<tr><th colspan="3">Years</th></tr>
<tr><th>1 to 3</th><th>4 to 6</th><th>7 to 10</th></tr>
<tr><td colspan="6">Agricultural Programs</td></tr>
<tr><td>Lone Star Healthy Streams (LSHS) program materials for distribution (feral hogs, horse and cattle)</td><td>TSSWCB/ AgriLife Extension</td><td colspan="3">1**</td><td>N/A</td></tr>
<tr><td>Development of material similar to LSHS program materials for goat (in both English and Spanish)</td><td>Watershed Coordinator</td><td colspan="3">1**</td><td>$TBD</td></tr>
<tr><td>Agriculture Field Days</td><td>AgriLife Extension</td><td>3</td><td>3</td><td>4</td><td>$1,000</td></tr>
<tr><td>Nutrient Management Campaigns</td><td>AgriLife Extension</td><td>3</td><td>3</td><td>4</td><td>$1,200</td></tr>
<tr><td>Agriculture Waste and Pesticide Collection Days</td><td>TCEQ</td><td>1</td><td>1</td><td>1</td><td>$75,000</td></tr>
<tr><td>Herbicide Targeted Use and Application Education</td><td>AgriLife Extension</td><td>3</td><td>3</td><td>4</td><td>N/A</td></tr>
<tr><td colspan="6">Recreation Programs</td></tr>
<tr><td>Awareness Programs:
• Add Icons for restrooms in and near the watershed to existing maps
• Material to inform and encourage newer boat motors
• Education on sedimentation from ATVs
• Newspaper information
• Age-encompassing local school materials</td><td>Watershed Coordinator</td><td colspan="3">1**</td><td>$TBD</td></tr>
<tr><td>Illegal Boater Dumping Awareness Campaign/Galveston Bay Action Network</td><td>GBF</td><td>1</td><td>---</td><td>1</td><td>$TBD</td></tr>
</table>

**Ongoing provision/development of materials to be distributed/promoted at workshops and events.

Table 8-2 Outreach and education management measures (continued)

Outreach and Education Management Measures	Lead Entity	Number of Programs per Year Range			Total Cost
		Years			
		1 to 3	4 to 6	7 to 10	
Proper Disposal of Carcasses Awareness Event and Campaign Signage Program	Watershed Coordinator	1	---	---	N/A
Reinforce hunter education at point of sale for license and supplies	Watershed Coordinator/ TPWD	---	---	1	$TBD
Wildlife and Non-domestic Plant/Animal Programs					
Feral Hog Management Workshop	AgriLife Extension	2	1	2	$40,000
Don't treat or feed wildlife as pets signage	Watershed Coordinator	20	15	20	$250/sign*
GBEP invasive species materials for distribution	Watershed Coordinator/GBEP	1**			N/A
Litter and Dumping Programs					
No littering/dumping Signage	Watershed Coordinator	20	15	20	$250/sign*
Monofilament educational signage with collection receptacles	Texas Sea Grant	10	5	5	N/A

*Includes sign, post, hardware, concrete and sign maintenance.

Table 8-2 Outreach and education management measures (continued)

8.10 Watershed Coordinator

To support the technical and financial assistance outlined in this chapter stakeholders recommended the creation of a Watershed Coordinator position. The Watershed Coordinator will oversee and coordinate implementation activities while routinely interacting with stakeholders, the city council, county commissioner courts, Extension, GBF, TCEQ, TSSWCB and interest groups, to keep them informed and involved. The Watershed Coordinator will be crucial to facilitate collaboration and actively ensure that a quality outreach and education campaign is maintained watershed-wide. Working with the WQMP Technician, the Watershed Coordinator will organize and host workshops. The Watershed Coordinator will secure external funding to facilitate stakeholder-recommended implementation activities outlined in the Double Bayou Watershed Protection Plan. See Chapter 7 for a detailed discussion of the Watershed Coordinator's primary responsibilities under each of the respective workgroup categories.

8.11 Sources of Funding

A crucial aspect of implementation is to secure funding that supports the personnel, equipment and resources behind this phase. Project funding can be acquired from a variety of state and federal programs. Typically, funds for project and program development are issued in the form of a grant or loan. Grant proposals will be given priority. Funds may also be secured through county or city resources. For example, the county would pay for the Feral Hog Coordinator management measure, possibly through a grant from Texas Department of Agriculture. Another example might be coordinating with Texas A&M AgriLife Extension to work with the Texas Animal Health Commission to implement a Proper Disposal of Carcasses Awareness Campaign or the Reinforce Hunter Education at Point of Sale management measures. Often, a management measure can be secured by promoting existing resources. For example, the Inform and Encourage New Boat Motors management measure – in this case, material exists on the West side of the Bay to inform recreational boaters; the watershed coordinator will work to bring these materials to the East side of the Bay.

Project funding sources that may be applicable to the Double Bayou Watershed can also include broader based programs or sources. Outlined below are some examples of funding sources that the Partnership will seek for specific management measures.

Section 319(h) Federal Clean Water Act

Section 319 of the Federal Clean Water Act covers the Nonpoint Source Management Program. States are eligible to receive grants through the EPA that support a variety of initiatives that assess the success of specific nonpoint source implementation projects. State funding sources for 319 dollars include TSSWCB and TCEQ. Management measures proposed for the Double Bayou Watershed that would request 319 funds for implementation include the Watershed Coordinator position, water quality monitoring, WQMPs and WQMP technician, watershed roadway signage, feral hog specialist, soil testing campaign, nutrient management and agricultural field days. Many of these management measures will also seek other sources of funding or promote existing resources to fully support the implementation of the management measure across the full project timeline. The Partnership plans to seek support for the water quality monitoring management measure from state agencies such as GBEP/TCEQ to share costs.

Texas State and Soil Water Conservation Board

TSSWCB supports and manages programs to prevent and abate agriculture/silvicultural nonpoint source pollution across the State of Texas. Management measures proposed for the Double Bayou Watershed that would seek support from TSSWCB for implementation include many of the workshops, including Watershed Texas Riparian & Stream Ecosystem, Feral Hog Management, Texas Well Owner Network; the LSHS program materials for distribution, soil testing campaign, nutrient management, agricultural field days, WQMPs and WQMP technician, feral hog specialist and water quality monitoring. Texas A&M Agri-life Extension would help support the costs of the LSHS program materials for distribution, soil testing campaign, nutrient management and agricultural field days.

Water Quality Management Plan Program

Water Quality Management Plans (WQMPs) are site-specific voluntary plans designed to reduce nonpoint source runoff from silvicultural and agricultural land uses. The plans are supported by the Trinity Bay Soil and Water Conservation District #434 (SWCD) and TSSWCB. To receive financial incentives from TSSWCB, the landowner must develop a WQMP with the SWCD that is customized to fit the needs of the landowner's operation, WQMPs include appropriate treatment practices, management measures, and technologies, and allow financial incentives for participation in the program.

TWDB Rural Water Assistance Fund (RWAF) Program

The TWDB's Rural Water Assistance program allows rural political subdivisions to obtain low-cost financing for water and wastewater projects. The financing is often provided with tax-exempt equivalent interest rate loans that have long-term finance options. This program's funding can be applied to water related projects, including water quality enhancements such as the planning, design and construction for wastewater collection and treatment and for nonpoint source pollution abatement. Management measures for the Double Bayou Watershed that would seek assistance from TWDB include the Expand Sewer Systems to Serve Septic Homes.

Although most management measures in the tables have possible funding sources identified, not all do at this time. In addition, a variety of funding programs need to be identified in case the original funding source is unavailable. The following is a list of focused funding programs that may be applicable to the Double Bayou Watershed.

Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program (EQIP) managed through USDA-NRCS provides financial and technical assistance to agricultural producers. The program is oriented towards conservation and requires contracts up to ten years. The contracts provide financial assistance to help plan and implement conservation practices that can improve water quality.

TCEQ Small Business and Local Government Assistance (SBLGA)

The TCEQ's Small Business and Local Government Assistance program is not in itself a grant program, but offers a suite of tools and information to provide confidential assistance to small businesses and local governments without the threat of enforcement. The program also provides possible sources of funding and covers air, water and waste environmental issues.

TWDB State Loan Program Texas Water Development Fund II (DFund)

The Texas Water Development Board (TWDB) focuses on the conservation and responsible development of water, including wastewater and flooding mitigation projects. The Water Development Fund is a state-funded loan program that combines multiple loan opportunities such as water and wastewater into a single loan. The DFund loans can be applied to water supply, wastewater and flood control projects.

Clean Water Act State Revolving Fund

The Clean Water Act State Revolving Fund provides low interest rates and flexible terms that are often well below the national market interest rate. The funds may be used for wastewater collection and treatment systems, nonpoint source pollution control, and estuary protection.

Clean Vessel Act Grant Program (CVA)

The Clean Vessel Act Grant Program (CVA) managed by the U.S. Fish and Wildlife Service provides grants to states for the construction, renovation, operation and maintenance of pump-out stations and waste reception facilities for recreational boaters and for educational programs that inform boaters about the importance of proper disposal of sewage.

USDA Rural Development Program (USDA-RD)

The USDA Rural Development Program (USDA-RD) offers loans, grants and loan guarantees to support essential services such as wastewater infrastructure.

Farm Service Agency – Conservation Reserve Program (CRP)

The Conservation Reserve Program is managed by the Farm Service Agency and is focused on land conservation. The program provides a yearly rental payment to farmers that conserve environmentally sensitive land instead of using it for agricultural production. A typical contract is for 10-15 years. The goal of the program is to re-establish land cover that will help improve water quality, reduce sedimentation and erosion and provide wildlife habitat.

Agricultural Water Conservation Loan Program

The Agricultural Water Conservation Loan Program is administered by the TWDB to provide agriculture water conservations loans to political subdivisions to facilitate water conservation improvements. The loan can be applied under a conservation program as well as to individual conservation projects.

Texas Farm & Ranch Lands Conservation Program

This program assists private landowners in protecting land from development while maintaining the land under the private owner in agricultural production. The program provides cash and tax advantages for financial incentives. A conservation easement is required to protect and preserve the natural resources of the land. The program is currently managed by the Texas General Land Office but will be transferred to Texas Parks and Wildlife ffective January 1, 2016.

Feral Hog Abatement Grant Program

The Feral Hog Abatement Grant Program under the Texas Department of Agriculture is a grant program that strives to manage the damage caused by feral hogs across the state. Currently, Texas AgriLife Extension Service - Wildlife Services and the Texas Parks and Wildlife Department receive funding under this grant program to develop technologies and projects to control the feral hog population.

Outdoor Recreation Grants

Managed by the Texas Parks and Wildlife Department, this program provides 50% matching grant funds to local units of government (municipalities, counties, municipal utility districts (MUD) and others) to acquire and develop parkland or to renovate existing public recreation areas. There are two funding cycles per year with a maximum award of $500,000 for non-urban areas. The projects must be completed within a short-term three year time period.

Environmental Education Grants (EE)

An EPA program that seeks grant proposals to support environmental education projects that will promote environmental awareness and stewardship. Ideal proposals to receive support include the design, demonstration or methods and techniques of environmental education projects.

Landowner Incentive Program (LIP)

The Landowner Incentive Program is a collaborative effort between TPWD and Inland Fisheries Division to support private, non-federal landowners in enacting good conservation practices on their lands for the benefit of healthy terrestrial and aquatic ecosystems.

Economically Distressed Areas Program (EDAP)

The Economically Distressed Areas Program (EDAP) is a TWDB initiative that offers financial assistance to provide water and wastewater services to economically distressed areas where these services are not available or the current system does not meet minimum state standards. This funding can be applied to planning, land acquisition design and construction of first-time service or improvements to water supply and wastewater collection and treatment systems. Grants or a combination of grants/loans are available.

Regional Water Supply and Wastewater Facility Planning Program

This TWDB program offers grants to political subdivisions either working together or for multiple service areas. The program provides funding for studies and analyses to determine the most feasible alternatives to meet regional water supply and wastewater facility needs, plus cost estimates and to identification of institutional arrangements that will provide regional water supply and wastewater services.

Section 106 State Water Pollution Control Grants

The Section 106 State Water Pollution Control Grants of the Clean Water Act provides assistance to states to establish and maintain water pollution control programs. Through this program, TCEQ supports permitting, development of water quality standards and total maximum daily loads, training and public information. This initiative targets the watershed approach at the state level in order to improve water quality. The program is grant based.

Supplemental Environmental Projects (SEP)

Supplemental Environmental Projects Program (SEP) are environmentally beneficial projects that may be undertaken as a result of a negotiated agreement with TCEQ to offset a penalty in an enforcement action. SEP funding supports projects for pollution prevention, pollution reduction and water quality enhancement projects.

8.12 Expected Load Reductions

Expected load reductions of *E. coli* bacteria in nontidal waters and Enterococci in tidal portions of the bayous as a result of full implementation of the Double Bayou WPP are detailed in Table 8-3 Expected load reductions. These load reductions are based on the stakeholder-recommended load reduction goals and are considered estimates due to the dynamic nature of watersheds and of nonpoint source bacteria contamination. Load reductions represent an expected improvement towards meeting the bacteria water quality standards in Double Bayou. The bacteria management measures discussed in this WPP will require implementation and continued support from stakeholders and lead entities to maintain progress and ensure that the expected load reductions are realized (Table 8-3 Expected load reductions).

Management Measure	Expected Bacteria Load Reduction
Wastewater Management Measures	
Collection System Study (*smoke test and video lines*)	1.13×10^{12}
Upgrade Collection System Line and Manhole Replacement	
Lift Station Upgrades (*bypass pumps*)	
Pump Repair and Replacement (*high priority*)	
Septic Systems Management Measures	
Continued Enforcement of Septic System Complaints with Population Growth	7.45×10^{9}
Increase Septic System Review and Inspection Capacity (*including relief lines and laterals*)	
Connect Homes with Septic Systems to Sewer Line (*expand sewer system*)	
Agricultural Nonpoint Source Management Measures	
Water Quality Management Plans (WQMP)	1.66×10^{13}
WQMP Technician (*new position-shared with Cedar Bayou*)	
Wildlife and Non-Domestic Plant/Animal Management Measures	
Physical Removal Days (*aquatic and terrestrial invasive species*)	6.41×10^{12}
Feral Hog Specialist (*existing*)	
Feral Hog Management	
Feral Hog County Position	
Feral Hog Control (*equipment*)	
Feral Hog Bounties (*county*)	

Table 8-3 Expected load reductions

8.13 Monitoring Plan

The objective of the water quality monitoring plan is to provide sufficient data to characterize water quality conditions in support of WPP implementation. Water quality data will be analyzed for short-term and long-term trends. Sampling station locations will remain the same as current water quality monitoring in order to identity long-term trends (Figure 4-2 Double Bayou sampling stations). Enterococci values at tidal stations and *E. coli* values at nontidal stations will be compared to the desired load reductions outlined in Section 8.12. This will assist in the evaluation of the effectiveness of implemented management measures and allow for adaptive WPP management.

Efforts for the initial onset of the monitoring plan will pursue funds appropriate for a 24-month sampling period. Opportunities to fund further monitoring will be pursued as appropriate. For the initial 24-month sampling plan, ambient in-stream data are proposed to be collected at 4 mainstem sites once per month. Field, conventional, flow and bacteria parameter groups will be collected. Ambient monitoring data will be collected at the WWTF site once per quarter. Targeted-flow monitoring data will be collected at 4 mainstem sites plus the WWTF site, during 2 storm events over the sampling period; field, conventional, flow and bacteria parameters will be collected. Funds will also be sought to continue operations and maintenance of the Index Velocity Site Gauge currently installed at Double Bayou West Fork Lower. Further funds will be sought to extend the monitoring plan for the full 10-year implementation period with the idea that using adaptive management and focusing sampling on management measure implementation, the sampling events may occur quarterly in the interest of capturing long-term trends balanced with available funding.

Currently, routine ambient monitoring is conducted once per quarter at one station in the watershed by TCEQ (10657 – by lower West Fork; field, conventional and bacteria parameters only) and at two stations by the Trinity River Authority (18361 – by upper West Fork, 10658 – by Lower East Fork; field and conventional parameters only) through the Clean Rivers Program. This sampling subtask will complement existing routine ambient monitoring regimes.

Field parameters for collection are pH, temperature, specific conductance, turbidity and DO. Conventional parameters to be collected are suspended solids, sulfate, chloride, nitrite+nitrate nitrogen, ammonia nitrogen, total kjeldahl nitrogen, chlorophyll-a, orthophosphorus and total phosphorus. Bacteria parameters to be collected are *E. coli* and Enterococcus. Quantitative flow will be collected by gage, electric, mechanical or Doppler, including severity. The parameters listed here include constituents that are not necessary to assess current impairments or screening level concerns. However, monitoring for this suite of parameters may detect possible development of additional water quality problems as well as characterize trends for overall water quality conditions. Water quality data analysis will provide milestones to gauge the progress of project implementation and will monitor percent of load reductions as management measures are implemented.

8.14 Bacterial Source Tracking

The Double Bayou Watershed Partnership and Work Groups also recommended implementing Bacterial Source Tracking (BST) as a possible management tool for project implementation, if appropriate. BST has evolved greatly as a science over recent years, and advances have been made to refine the technology; even so, separate species profile identification is not always possible. There are currently State bacteria markers in an established BST library (collection of know species or species group profiles) that could help identify and track Double Bayou Watershed bacterial sources. BST could be used to help further refine SELECT results and also adjust implementation efforts, depending on results.

References

Chilton, E. W. I., L. Robinson, et al. (2011). Texas State Comprehensive Management Plan for Aquatic Nuisance Speceis Texas Parks and Wildlife

Cowardin, L. M., V. Carter, et al. (1979). Classification of Wetlands and Deepwater Habitats of the United States, U.S Fish and Wildlife Service.

Daniel Turner, B. K., Paul Heberling, Bobbi Lindberg and G. A. Mike Wiltsey and Ryan Michie (2006). Umpqua Basin Bacteria TMDL. Medford, Oregon, Oregon Department of Environmental Quality.

District, T. B. C. (2013). Trinity Bay Conservation District Hazard Mitigation Action Plan: FY 2013. Stowell, Texas.

Griffth, G., S. Bryce, et al. (2007). Ecoregions of Texas. Austin, Texas.

HARC. (2011). "Gulf Coast Portal; Coastal Waterbird Data From TPWD." Retrieved 2/15/2015, 2015, from http://gulfcoast.harc.edu/Biodiversity/Ecoregions/TexasLouisianaCoastalPlains/tabid/2256/Default.aspx.

Kennish, M. J. (1999). Case study 3. <u>Estuary Restoration and Maintenance</u>, CRC Press**:** 205-254.

Larsen, R., J. Buckhouse, et al. (1988). "Range-land cattle and manure placement: A link to water quality." Proceedings of Oregon Academy of Science 24(7).

Lester, L. J. (2011). Chapter 2: Galveston Bay: An Overview of the System. In <u>The State of the Bay: A Characterization of the Galveston Bay Ecosystem, Third Edition.</u> L. J. L. a. L. A. Gonzalez. Houston, Texas, Texas Commission on Environmental Quality, Galveston Bay Estuary Program**:** 26

Peterson, J., E. Jordan, et al. (2012). Lone Star Healthy Streams Dairy Cattle Manual, Texas A&M AgriLife Extension. Texas A&M University.

TCEQ (2010). 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas, Texas Commission on Environmental Quality

TCEQ (2012). 2012 Guidance for Assessing and Reporting Surface Water Quality in Texas, Texas Commission on Environmental Quality

Texas Parks and Wildlife Department (TPWD). 2002. Annual Report.

Timmons, J. B., B. Alldredge, et al. (2012). Feral Hogs Negatively Affect Native Plant Communities, Texas A&M

Turco, D. W. B. a. M. J. (2006-07). Water-Quality, Stream-Habitat and Biological Data for West Fork Double Bayou, Cotton Bayou and Hackberry Gully, Chambers County, Texas, 2006-07. U.S. Geological Survery Data Series 407.

Tyson, M. A. (2015). Personal Communication; Feral Hog (wild pig) Comments and Insight, Texas A&M AgriLife Research Extension.

TWDB. (2000). "Texas Bays and Estuaries: Basin Wide Inflow Summary for Galveston Bay." 2015, from http://midgewater.twdb.state.tx.us/bays_estuaries/TxEmp/galvtable.htm.

USDA (2012). 2012 Census of Agriculture: County Profile for Chambers County, Texas, US Department of Agriculture

USDA (2012). Aquaculture sales: 2012 and 2007, US Department of Agriculture

U.S. Environmental Protection Agency. Borel, K., R. Karthikeyan, et al. (2012). Workshop Manual: Watershed Modeling Using LDC and SELECT, Texas Water Resources Institute

Wagner, K. L., L. A. Redmon, et al. (2013). "Effects of an off-stream watering facility on cattle behavior and instream E. coli levels." Texas Water Journal 4(2): 1-13.

Ward, G. H. (1991). Galveston Bay Hydrography and Transport Model Validation, Tech. Rept. Rockville, MD, National Oceanic and Atmospheric Administration, Strategic Assessment Branch.

A) Appendix A: List of Acronyms

AU	Animal Unit
C-CAP	Coastal Change Analysis Program
CEU	Continuing Education Credit
CFU	Colony Forming Unit
CRP	Texas Clean Rivers Program
CRP	Farm Service Agency – Conservation Reserve Program
CWA	Clean Water Act
DFund	State Loan Program Texas Water Development Fund II
DO	Dissolved Oxygen
DSLR	Days Since Last Rainfall
E. coli	*Escherichia coli*
EDAP	Economically Distressed Area Program
EE	Environmental Education Grants
EFL	East Fork Lower
EFU	East Fork Upper
EQIP	Environmental Quality Incentives Program
GBAN	Galveston Bay Action Network
GBEP	Galveston Bay Estuary Program
GBF	Galveston Bay Foundation
HARC	Houston Advanced Research Center
H-GAC	Houston Galveston Area Council
HUC	Hydrologic Unit Code
I&I	Infiltration and Inflow
LIP	Landowner Incentive Program
LSHS	Lone Star Healthy Streams
Mg/L	Milligram per Liter
mL	Milliliter

MPN	Most Probable Number
MPN/100 mL	Most Probable Number per 100 milliliter
MS4	Municipal Separate Storm Sewer Systems
NASS	National Agricultural Statistics Service
NEMO	Nonpoint Source Education for Municipal Officials
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	On-site sewage facilities
PSU	Practical Salinity Unit
RWAF	Rural Water Assistance Fund Program
SBLGA	Small Business and Local Government Assistance
SELECT	Spatially Explicit Load Enrichment Calculation Tool
SEP	Supplemental Environmental Projects Program
SJRA	San Jacinto River Authority
SSO	Sanitary Sewer Overflow
SWCD	Soil and Water Conservation District
TBCD	Trinity Bay Conservation District
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
TEEX	Texas A&M Engineering Extension Service
TMDL	Total Maximum Daily Load
TPWD	Texas Parks and Wildlife
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
US EPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USDA-NRCS	United States Department of Agriculture Natural Resources Conservation Service

USDA-RD	USDA Rural Development Program
USGS	United States Geologic Survey
WFL	West Fork Lower
WFU	West Fork Upper
WPP	Watershed Protection Plan
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

B) Appendix B: Glossary

Animal Unit - standardized unit of measure typically used for agricultural management and planning. One AU is equal to one adult cow and a nursing calf.

Chlorophyll-a - a green pigment found in the chloroplasts of algae and higher plants that enables plants to make food through a process called photosynthesis. High levels of chlorophyll-a in water can mean that there is more algae in the water than usual. Too much algae in the water can make the water "cloudy" and decrease the amount of dissolved oxygen in the water, impacting the health of fish and other aquatic life.

Dissolved Oxygen (DO) - dissolved oxygen in water that is freely available for use by fish and other aquatic life. Different aquatic species need different levels of dissolved oxygen in the water in order to survive.

***E. coli* -** a bacterium found in the intestines and feces of warm-blooded animals including humans, livestock, pets and wildlife. When *E. coli* is present in the environment, other disease-causing microbes (pathogens) could be present. *E. coli* is currently called a "fecal indicator bacteria," meaning that if it is present in the water then it indicates that human and/or animal waste is also present.

Ecoregion - major ecological areas or subareas.

Enterococcus - bacteria that are found in the intestines and waste of warm-blooded animals, including humans, livestock, pets and wildlife. When Enterococcus bacteria are present in the environment, other disease-causing microbes (pathogens) could be present. Enterococcus is also a fecal indicator bacteria.

Environmental Protection Agency (EPA) - The EPA is the federal agency that is responsible for maintaining and regulating water quality in the nation's waters under the Clean Water Act.

Fecal Coliform - bacteria found in the intestines and waste of warm-blooded animals, including humans, livestock, pets and wildlife. When fecal coliform bacteria are present in the environment, other disease-causing microbes (pathogens) could be present. Fecal coliform bacteria used to be the standard fecal indicator bacteria but they are not very specific.

Galveston Bay Estuary Program (GBEP) - project partner and a non-regulatory program administered by the Texas Commission on Environmental Quality charged with implementing The Galveston Bay Plan.

Geometric Mean – one type of state standard to determine bacteria impairments of waterbodies.

Houston Advanced Research Center (HARC) - project partner that is responsible for developing water quality data analysis and modeling, preparing graphs and exhibits of those data and modeling results and preparing drafts of the WPP document chapters for stakeholder review and comment.

Invasive Species - non-native, invasive species are plants, animals and microorganisms that are introduced from other parts of the world and successfully establish reproducing populations in ecosystems in which they do not naturally occur.

Load Duration Curve - is useful for analyzing water quality data when trying to determine pollutant loadings under different flow conditions.

Management Measure - water quality management measures suggested by stakeholders to address water quality issues by reducing point or nonpoint source pollutant contributions before the pollutant reaches the bayou.

Nonpoint Source (NPS) Pollution - pollution in water that comes from multiple sources or locations (not just one specific location) that is generally carried to a river, lake, or stream by precipitation runoff over land. Examples of nonpoint sources are agricultural lands, yards, roads and parking lots.

Nutrients - substances that help plants and animals grow. Examples of nutrients in water include nitrogen or phosphorus compounds.

Outreach and Education Management Measures – informational and educational programs and materials that focus on spreading the word of the Double Bayou Partnership and educating stakeholder on watershed issues.

Pathogen - a disease-causing microorganism.

pH - a measurement of how acidic or basic a substance is. pH is measured on a scale of 0 to 14. If measured at 7 the substance is neutral, below 7 is acidic and above 7 is basic. White vinegar is acidic with a pH of 2.4 while Milk of Magnesia is basic with a pH of about 10.

Point Source Pollution - pollution in water that comes from a single identifiable source such as a pipe.

Routine Water Quality Sampling - water quality sample taken regardless of the rainfall on that date to assess water quality under normal conditions.

SELECT Model (Spatially Explicit Load Enrichment Calculation Tool) **-** developed by the Department of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University to spatial identify the sources that contribute to bacteria loading.

Shead Conservation Solutions - project partner that is responsible for the public participation component of the project.

Stakeholder - any person who lives, works or plays in the watershed.

Targeted Water Quality Sampling - planned water quality sample taken on days that have a high amount of rainfall to assess worst case scenarios.

Texas Commission on Environmental Quality (TCEQ) - this is the state agency that is responsible for maintaining and regulating water quality in Texas streams, lakes and estuaries.

Texas State Soil Water Conservation Board (TSSWCB) – project partner that provides insights and experience from other WPP projects in the state, finding and technical expertise.

Total Maximum Daily Load (**TMDL) -** refers to the maximum amount of a contaminant that can be in a body of water and still be considered safe. TMDL also refers to a regulatory process that States, Territories and authorized Tribes of the United States use to determine the maximum limits that are considered safe.

Turbidity - increased "cloudiness" of water caused by floating material, such as silt or organic matter.

United States Geological Survey (USGS) - responsible for the collection and laboratory analysis of the additional water quality samples.

Water Quality - Physical and chemical properties of a give waterbody that can be used to gauge the condition and quality or impairment of a waterway.

Water Quality Criteria - the minimum or maximum limits set for substances found in water depending on the use of a water body. For example, an "aquatic life use" would require a minimum concentration of dissolved oxygen in order for fish to live. Yet, a "recreational use" for a water body does not need to focus on dissolved oxygen. Instead, "recreational use" would require the concentration of fecal indicator bacteria to be below a certain number in order for the water to be safe for human contact.

Water Quality Standards - a set of rules that tell how the water body is to be used, what criteria needs to be met in order to protect the water body and how to prevent actions that would lessen water quality.

Watershed - an area of land that drains to a stream, river or other body of water. Watershed boundaries are determined by analyzing how a drop of rainfall will flow once it hits the land. High areas typically mark the edges of watershed boundaries.

Watershed Protection Plan (WPP) - a locally developed voluntary watershed management plan that helps to restore and protect water quality. The WPP process engages stakeholders in a collaborative and participatory approach in watershed planning.

C) Appendix C: Nine EPA Criteria for a Successful Watershed Protection Plan and Location of Elements in the Plan

A. Identification of Causes of Impairment and Pollutant Sources (see Chapters 3.2.4 Workgroup Meetings and 5.1.4 Identifying Point and Nonpoint Pollutant Sources)

Geographically identify and locate the major causes and sources of impairment in the watershed. These are the pollutant sources that will need to be controlled in order to achieve the established load reductions. At a minimum the TCEQ water quality benchmarks should be met. The analytical methods to identify pollutant sources can include mapping, modeling, monitoring and field assessments to track the link between the sources of pollution and the amount of nonpoint source pollutant loading that they contribute to the water body which may cause exceedances of water quality standards.

B. An Estimate of the Load Reductions Expected from Management Measures (see Chapter 8.12 Expected Load Reductions)

Consist of the reductions that are required to meet the water quality standards. Management measures that will help to reduce the pollutant load will be established and estimated load reductions resulting from implemented management measures will be detailed.

C. Nonpoint Source Management Measures (see Chapters 6.1.3 Wastewater Collection System Infrastructure Improvements, 6.1.4 Septic Systems Management Measures, 6.2 Agriculture 6.4 Recreation Management Measures and 5.1 Modeling and Analysis Approach to 5.6 SELECT Results: Wastewater and septic)

A description of the nonpoint source management measures that will need to be implemented to achieve load reductions along with the critical area where the measures will be implemented.

D. Estimates of the Financial and Technical Assistance Needed for Implementation (see Chapters 8.2 Technical Assistance to 8.10 Watershed Coordinator)

Estimates of the financial and technical assistance needed to implement the entire plan. Estimates will include implementation and long-term operation and maintenance costs. Relevant authorities and entities who will play a role in implementing the plan.

E. Information and Education Management Measures (see Chapters 7 Outreach and Education Management Measures and 8.9 Outreach and Education)

An information/ education component that identifies the education and outreach activities or programs to support plan adoption and long-term participation. To enhance the public understanding of the project and encourage participation throughout the project life.

F. Schedule for Implementing the Nonpoint Source Management Measures (see Chapters 8.8 Project Schedule, Milestones, Estimated Cost and 8.9 Outreach and Education)

A schedule for plan implementation that will follow the milestones outlined in the plan.

G. Interim Measurable Milestones (see Chapter 8.8 Project Schedule, Milestones, Estimated Cost)

A schedule of interim measurable milestones for determining whether nonpoint source management measures are being implemented. The milestones will measure progress of the implementation phase to gauge success.

H. Criteria to Determine Whether Loading Reductions are Being Achieved (see Chapters 5.7 and 5.8.3 Bacteria Loadings)

Defined criteria that will determine whether loading reductions are being achieved and sustained over time and are heading toward achieving water quality standards. These will be in the form of water quality benchmarks.

I. Monitoring Component to Track Implementation Measures Over Time (see Chapter 8.13 Monitoring Plan)

A monitoring component to evaluate the effectiveness of the implementation progress over time. The monitoring component will determine whether the loading reductions are being achieved and progress is being made towards obtaining the water quality standards.

D) Appendix D: In-depth SELECT Approach

SELECT Approach

The SELECT (Spatially Explicit Load Enrichment Calculation Tool) model was used to estimate potential pollutant loadings from bacteria across the Double Bayou Watershed. SELECT works within an ArcGIS environment and spatially characterizes the bacterial loads in the watershed. Determination of land use/land cover was accomplished by using 2010 NOAA Coastal Change Analysis Program (C-CAP) land cover data based upon 30-meter Landsat imagery. Using the ArcHydro model (a component of ArcGIS), the Double Bayou Watershed was delineated into 22 subwatersheds. The ArcHyrdo model incorporates elevation and hydrological characteristics into the delineation process; stakeholder input was used as local knowledge to better define land cover input. The results of the SELECT model are individual 30-meter grid cell raster files for each source, which were added together spatially to create a total load raster for the entire watershed.

Total Load

Stakeholders decided on initial runs of “lower” and “upper” scenarios for sources to characterize all possible scenarios for potential bacteria loadings. A lower SELECT scenario was also calculated in addition to the upper total daily load scenario discussed in Chapter 5.3. The low scenario was calculated by summing all of the low range scenarios for sources that had multiple scenarios generated (Figure D-1Total low load scenario).

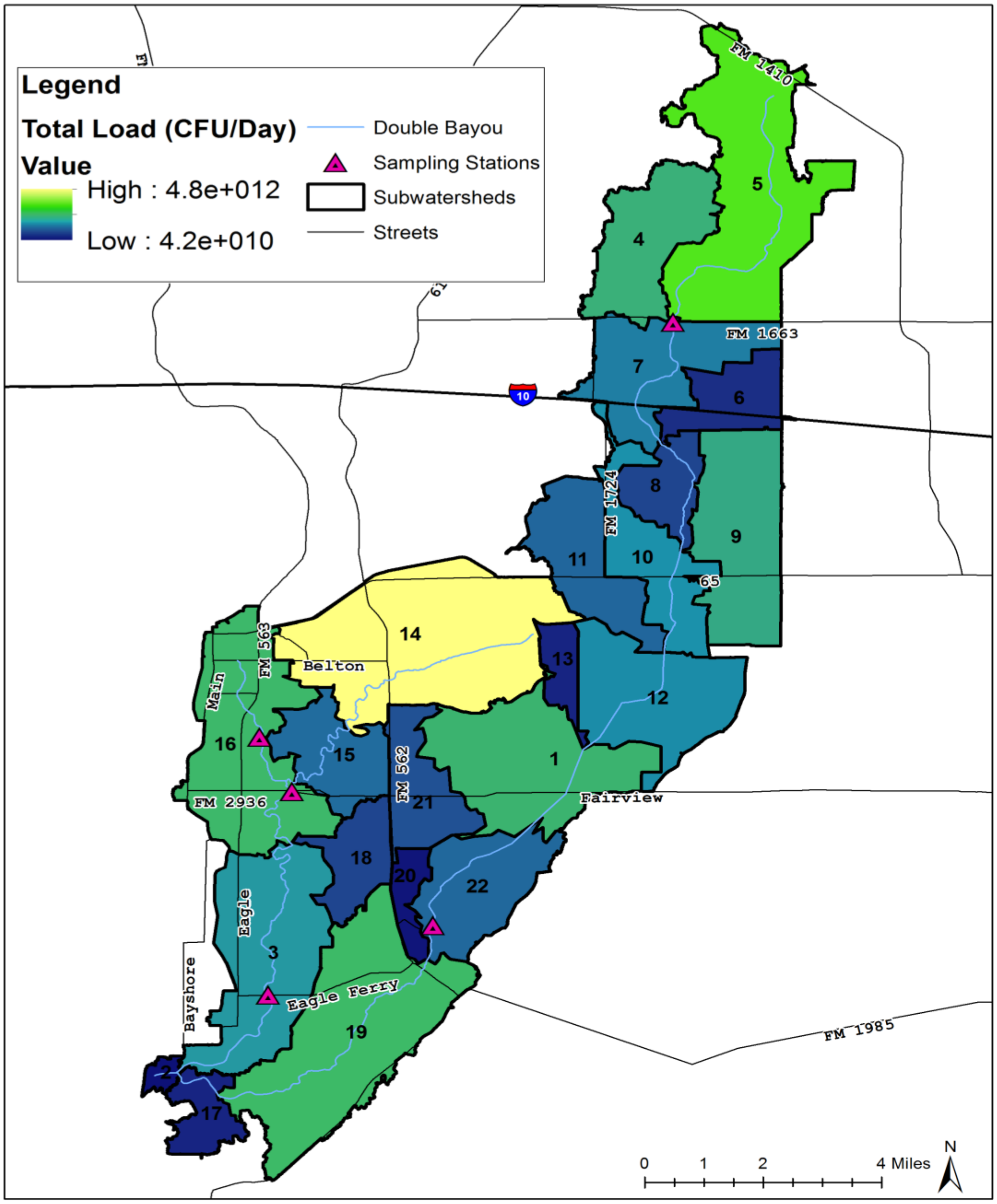


Figure D-1Total low load scenario

Cattle

The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Cattle\ Load\ =\ \#\ Cattle * 1x10^{10}\ cfu/day * 0.63$$

Where $1*10^{10}$ cfu/day *0.63 (*E.coli* conversion factor) is the SELECT model default average daily *E. coli* production per head of cattle.

A minimum SELECT cattle load scenario was calculated in addition to the maximum cattle scenario discussed in Chapter 5.4.1 (Figure D-2 Cattle low scenario). The minimum scenario is based on the low end of the stakeholder assigned stocking rate range (Figure 5-14 Cattle stocking rates) and the area of suitable land cover. The minimum scenario was calculated by substituting the low range stakeholder defined cattle population of 3,494 in place of the maximum scenario input of 4,074 cattle.

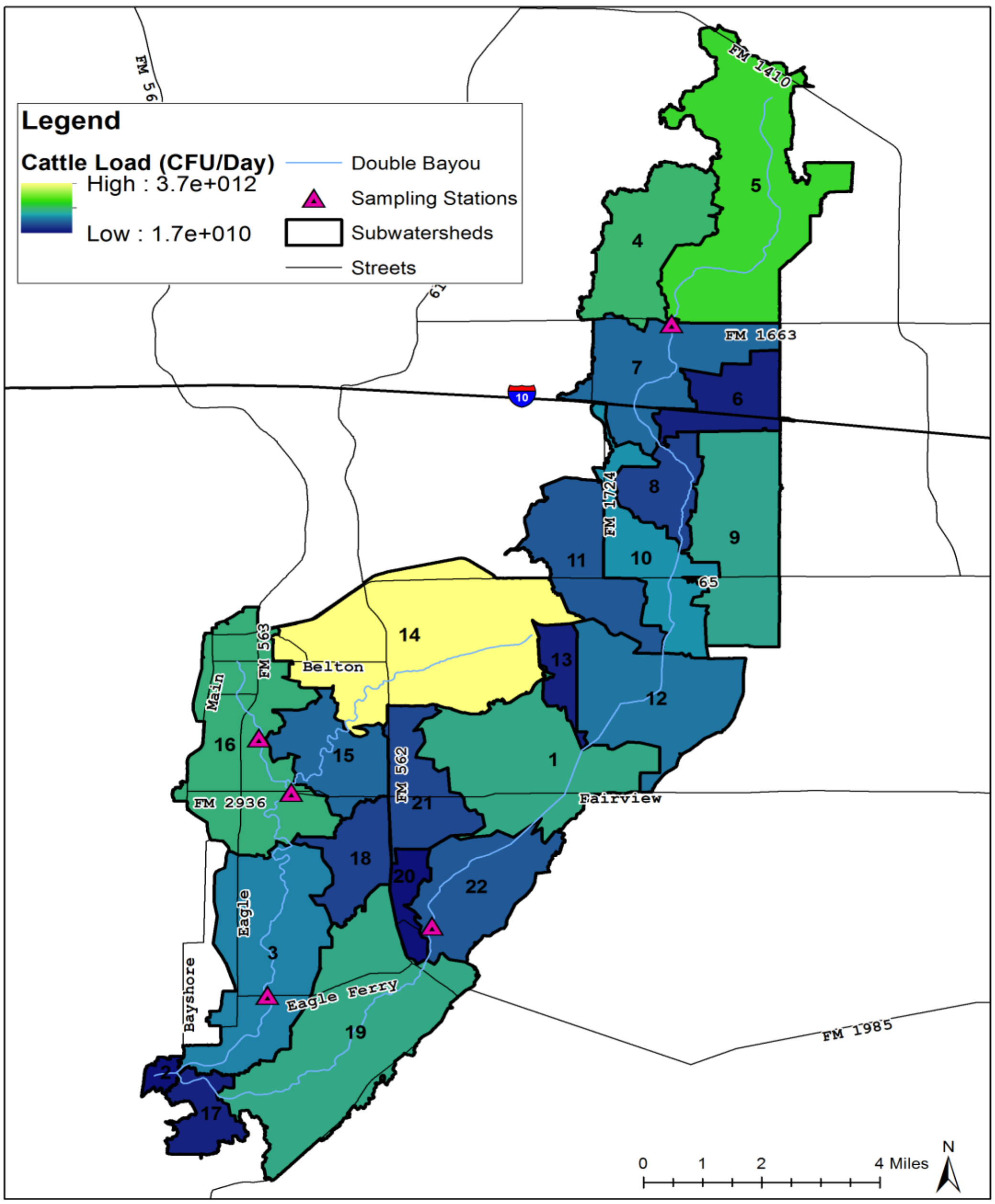


Figure D-2 Cattle low scenario

Horse
The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Horse\ Load\ =\ \#\ Horse * 4.2x10^{8}\ cfu/day * 0.63$$

Where $4.2*10^{8}$ cfu/day *0.63 (*E.coli* conversion factor) is the average daily *E. coli* production per horse (EPA 2001). Only one horse scenario was generated with an input of 294 horses (Chapter 5.5.2).

Goat

The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Goat\ Load\ =\ \#\ Goat * 1.2x10^{10}\ cfu/day * 0.63$$

Where $1.2*10^{10}$ cfu/day *0.63 (*E.coli* conversion factor) is the average daily *E. coli* production per sheep (known goat SELECT loading rate is not available) (EPA 2001). Only one goat scenario was generated with an input of 211 goats (Chapter 5.5.3).

Deer
The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Deer\ Load\ =\ \#\ Deer * 3.5x10^{8}\ cfu/day * 0.63$$

Where $3.5*10^{8}$ cfu/day *0.63 (*E.coli* conversion factor) is the average daily *E. coli* production per deer (EPA 2001). Only one deer scenario was generated with an input of 33 deer (Chapter 5.3).

Feral Hog
The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Feral\ Hog\ Load\ =\ \#\ Hogs * 1.1x10^{10}\ cfu/day * 0.63$$

Where $1.1*10^{10}$ cfu/day *0.63 (*E.coli* conversion factor) is the average daily *E. coli* production per pig (used as a proxy for feral hog) (Chapter 5.6) (EPA 2001).

A minimum SELECT feral hog load scenario was calculated in addition to the maximum feral hog scenario discussed in Chapter 5.6 (Figure D-3 Feral hog low scenario). The minimum scenario was calculated with the same land classes and 100-meter (328 foot) water source buffer zone (Figure 5-18). However, The Texas Water Resource Institute and Texas A&M University recommended low density of 70.1 acres per hog was used to define the approximate minimum feral hog population of 1,352 5.4).

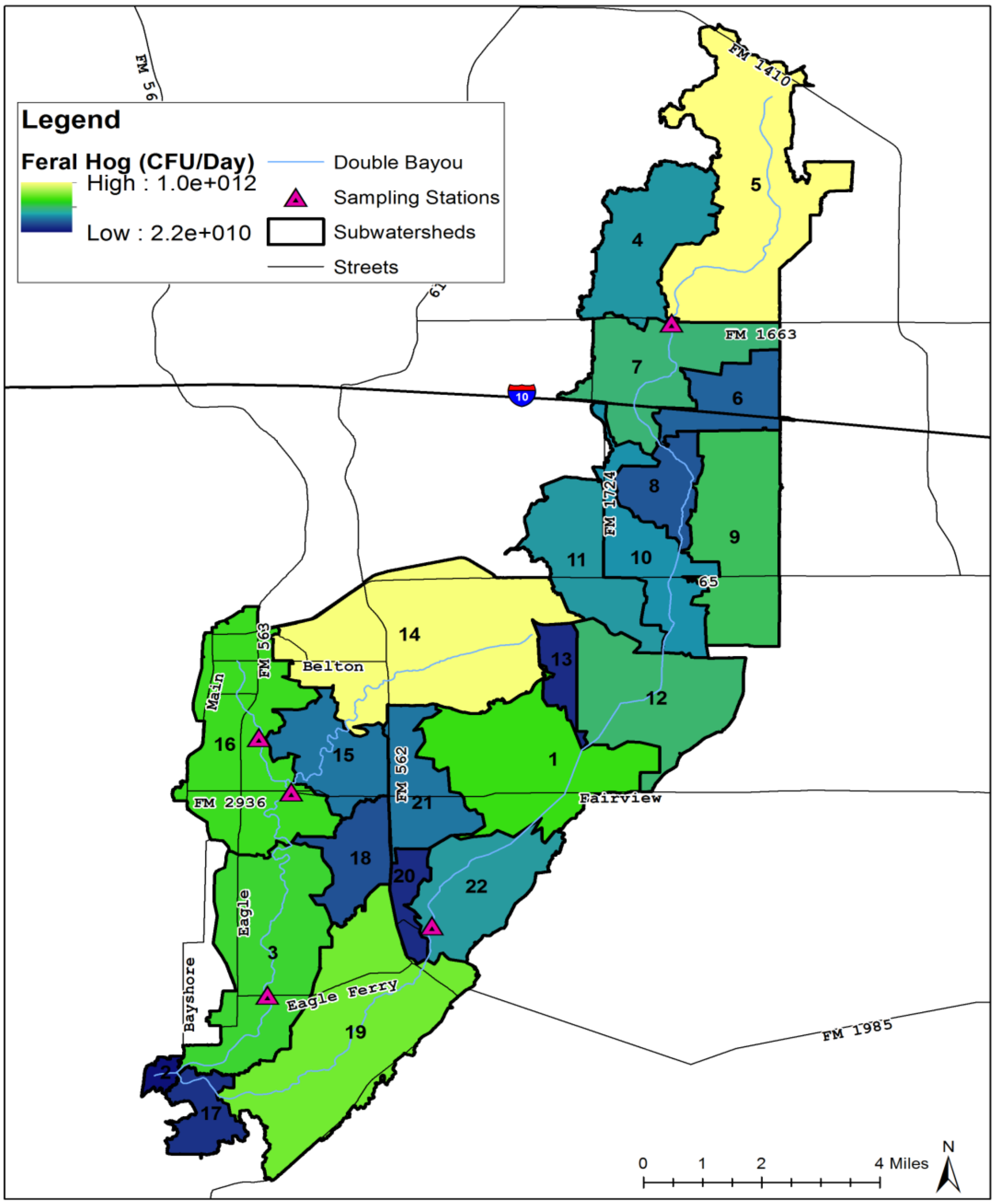


Figure D-3 Feral hog low scenario

Septic Systems
The average potential daily *E.coli* load for each subwatershed was estimated by the following equation:

$$Septic\ Load = Septic\ Systems * Malfunction\ Rate * \frac{10x10^6\ cfu}{100\ mL} * \frac{60gal}{person/day} * 0.63$$

A U.S Census average of 2.4 people per household was used. The malfunction rate is based on age of the septic system and soil type (watershed soils are poor for OSSFs) (Chapter 5.6.2).

The low range scenario was based on a failure rate of 5% applied to the 0-15 age group; 10% to the 16-30 age groups; and a 40% failure rate was applied to the 31+ age group (see Figure D-4 Septic SELECT low scenario).

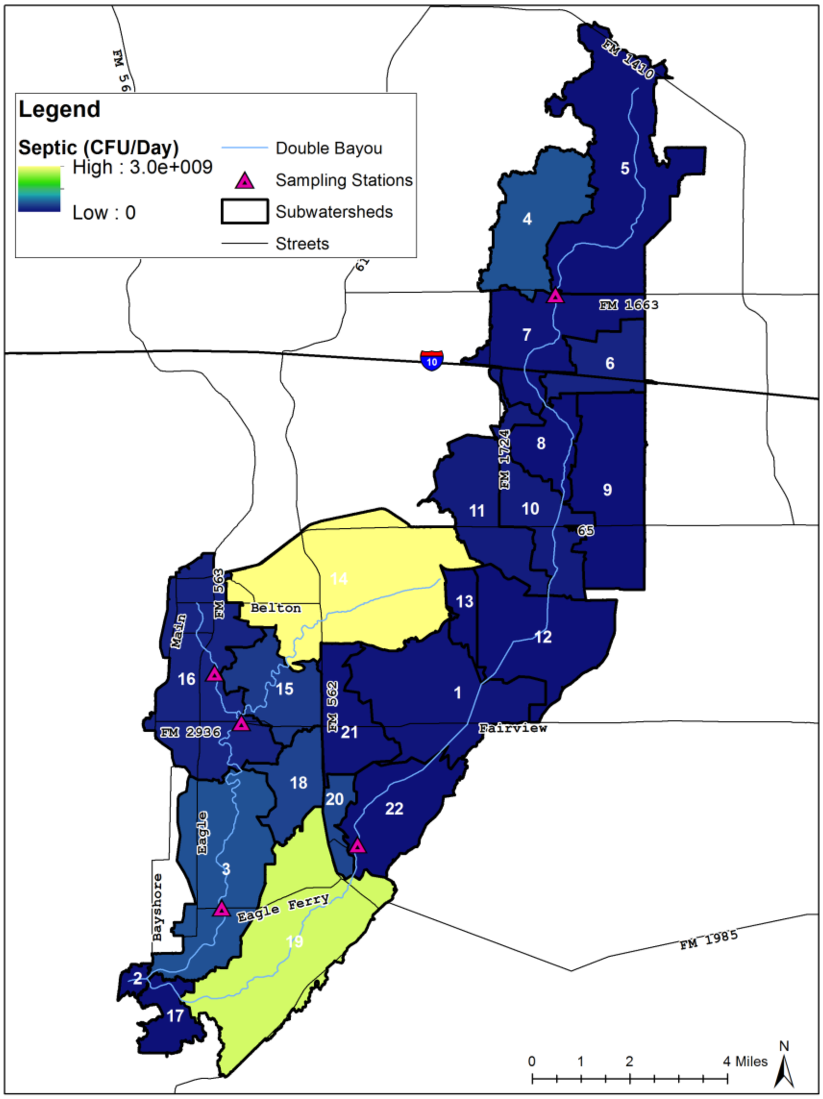


Figure D-4 Septic SELECT low scenario

WWTF
To establish the WWTF's potential bacteria loading rates under a range of conditions, three WWTF SELECT model scenarios were generated. The maximum scenario is discussed in Chapter 5.7.1 and is defined by:

$$WWTF\ Maximum\ Load = \frac{49{,}000\ cfu}{100\ mL} * \frac{3{,}785\ mL}{gallon} * 1{,}000{,}000\ GPD$$

The mid-range scenario is based on the WWTF's daily average NPDES permitted bacteria and flow requirements. Daily average effluent concentration less than 126 cfu/100 mL for *E. coli* and a daily average flow of 600,000 GPD is required (Figure D-5 WWTF mid-range scenario). The WWTF's potential bacteria load under the mid-range scenario is defined by:

$$WWTF\ Mid\text{-}range\ Load = \frac{126\ cfu}{100\ mL} * \frac{3{,}785\ mL}{gallon} * 600{,}000\ GPD$$

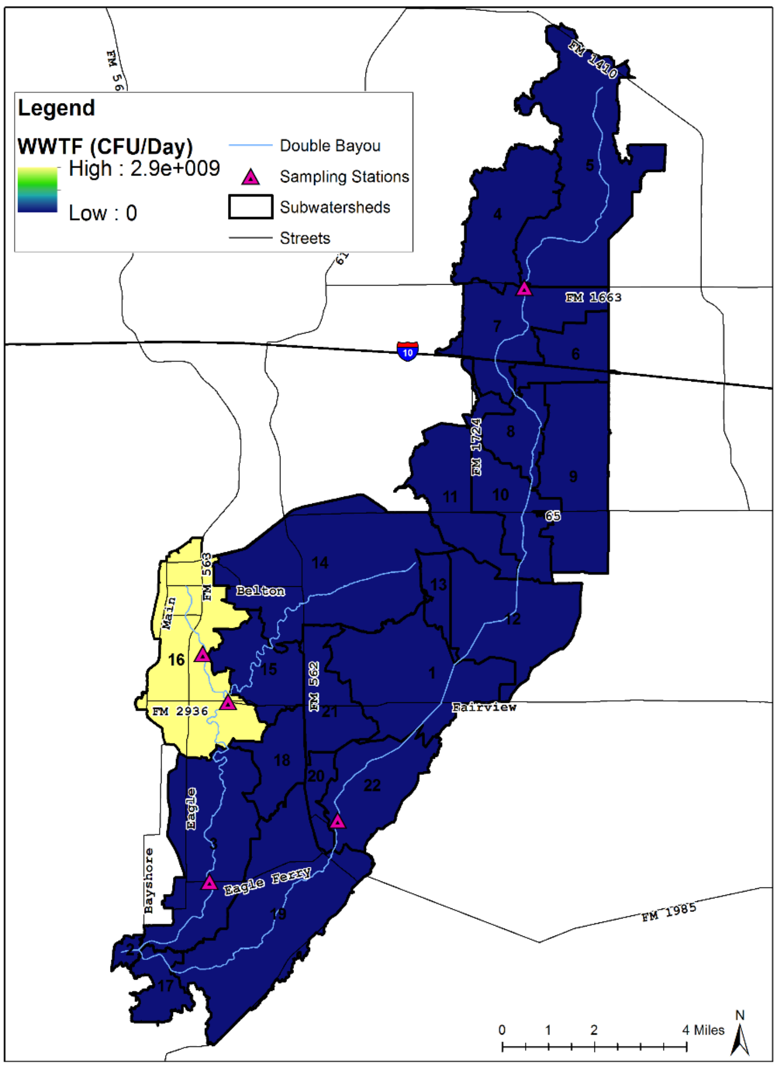


Figure D-5 WWTF mid-range scenario

The minimum loading scenario was derived from 3.51 cfu/100 mL (dry event geomean as reported by WWTF; 9 samples from 9/13-7/14) and the facilities approximate daily average flow of 300,000 GPD and is defined as (Figure D-6 WWTF low scenario):

$$WWTF\ Minimum\ Load = \frac{3.51\ cfu}{100\ mL} * \frac{3{,}785\ mL}{gallon} * 300{,}000\ GPD$$

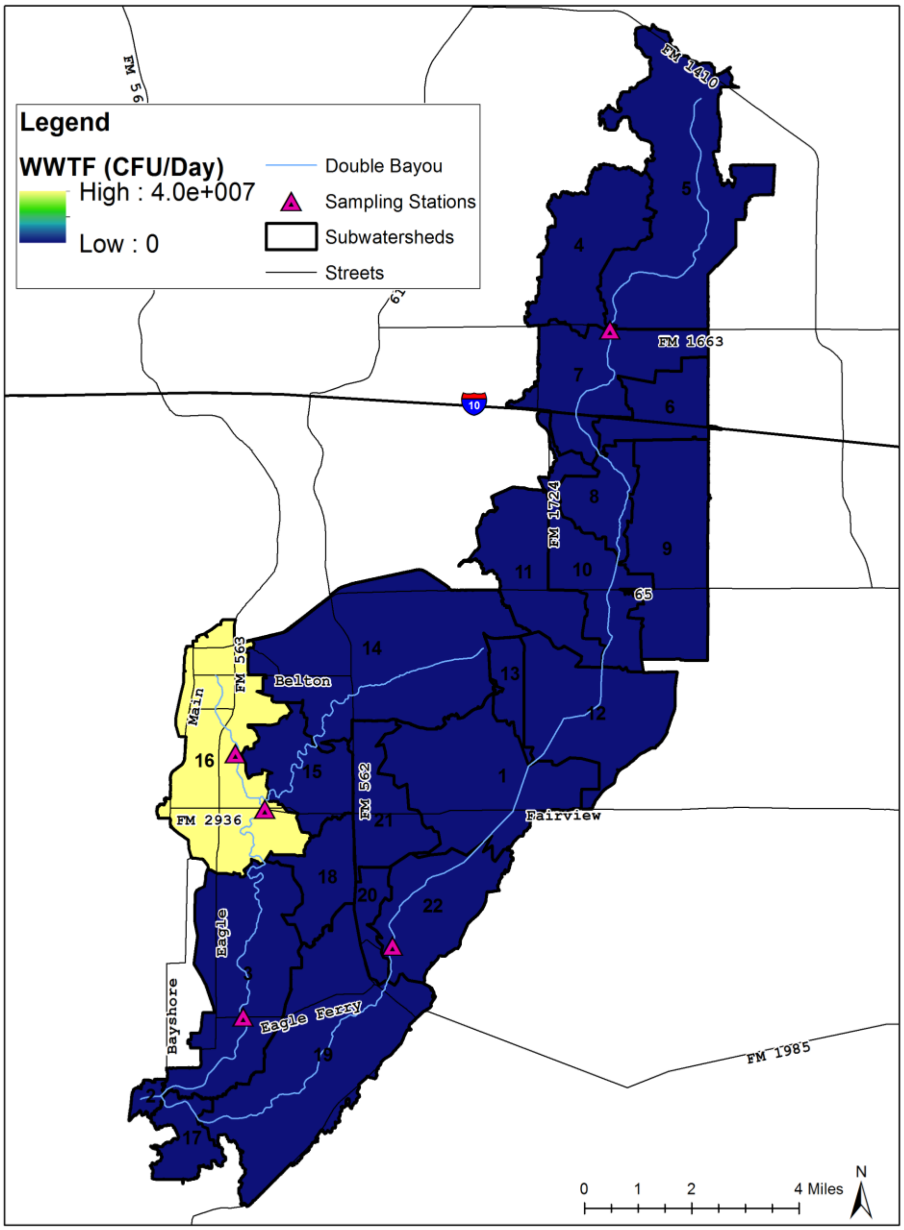


Figure D-6 WWTF low scenario

E) Appendix E: Flow and Salinity Graphs and Tidal Mixing

Flow and Salinity Graphs

The four graphs below show measured flow from each grab sample taken over the sampling period, per station. The differences in obveserved tidal effects are shown. Distances from Trinity Bay to the sampling stations, as the water flows (including all curves and contours of the bayous) are: East Fork Upper - 34.6 km (21.5 miles); East Fork Lower – 11.7 km (7.3 miles); West Fork Upper – 14.3 km (8.9 miles); and West Fork Lower – 4.7 km (2.9 miles).

TCEQ has several criteria for determining the extent of tidal influence in freshwater streams that drain to tidal water bodies. Field measurements (specific conductance and salinity), water quality measurements obtained through sampling (total dissolved solids (TDS) and chloride) and observing water levels upstream over several complete tidal cycles are all important criteria. According to TCEQ a water body is classified as tidally influenced when tidal activity is observed, Total Dissolved Solids (TDS) are greater than or equal to 2,000 mg/L, salinity is greater than or equal to 2 parts per thousand (ppt), or specific conductance is greater than or equal to approximately 3,000 µS/cm (TCEQ 2012). The salinity graph shows the salinity results of the 24-hour sampling from each station (Figure E-5 24-hour sampling Salinity Results Double Bayou).

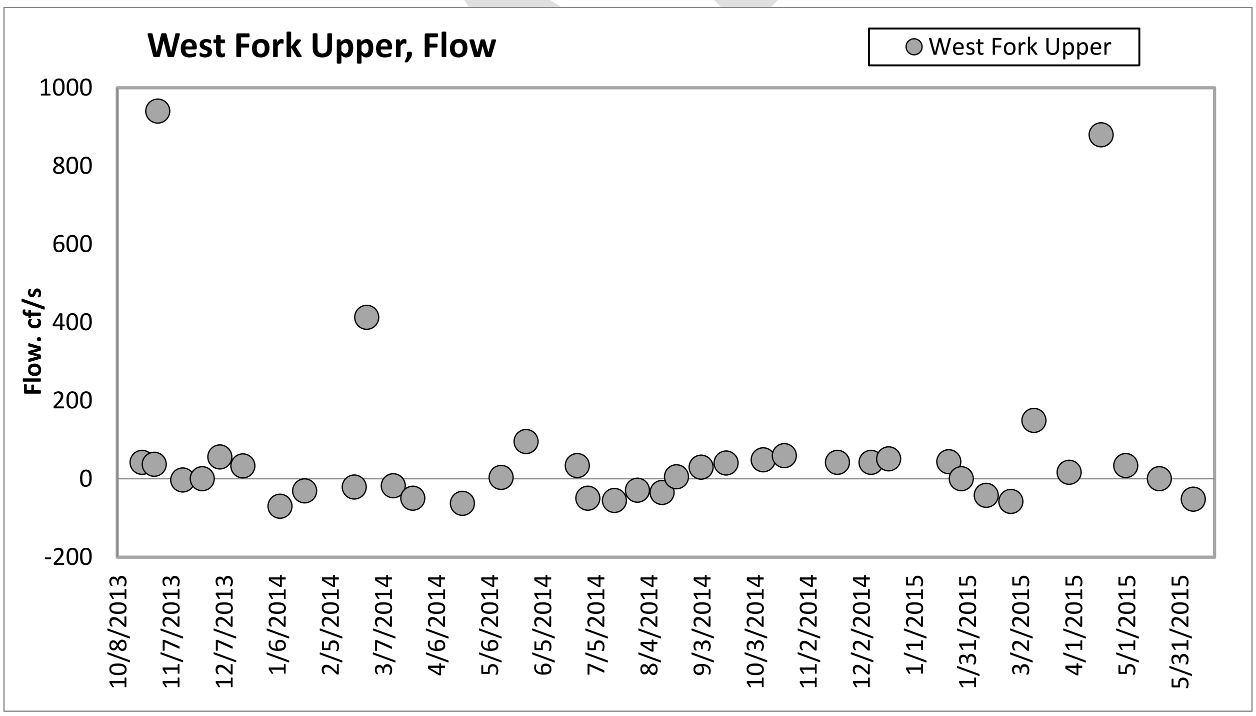


Figure E-1 West Fork Upper Flow

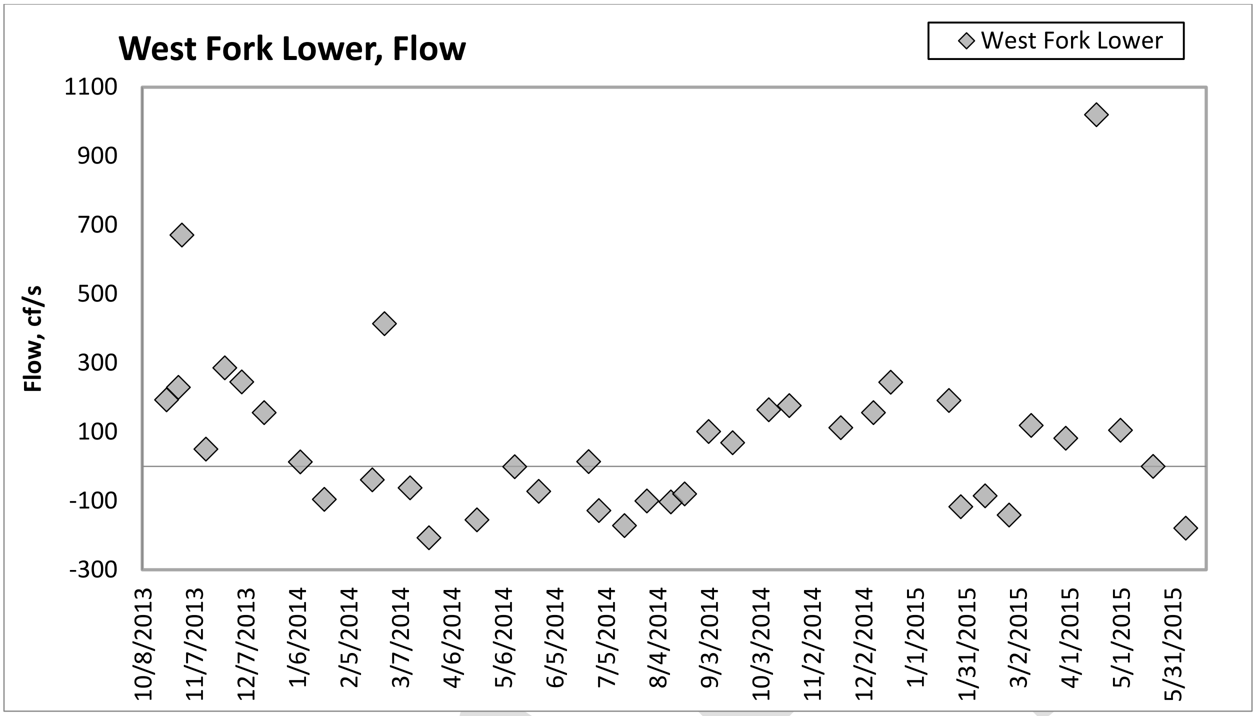


Figure E-2 West Fork Lower Flow

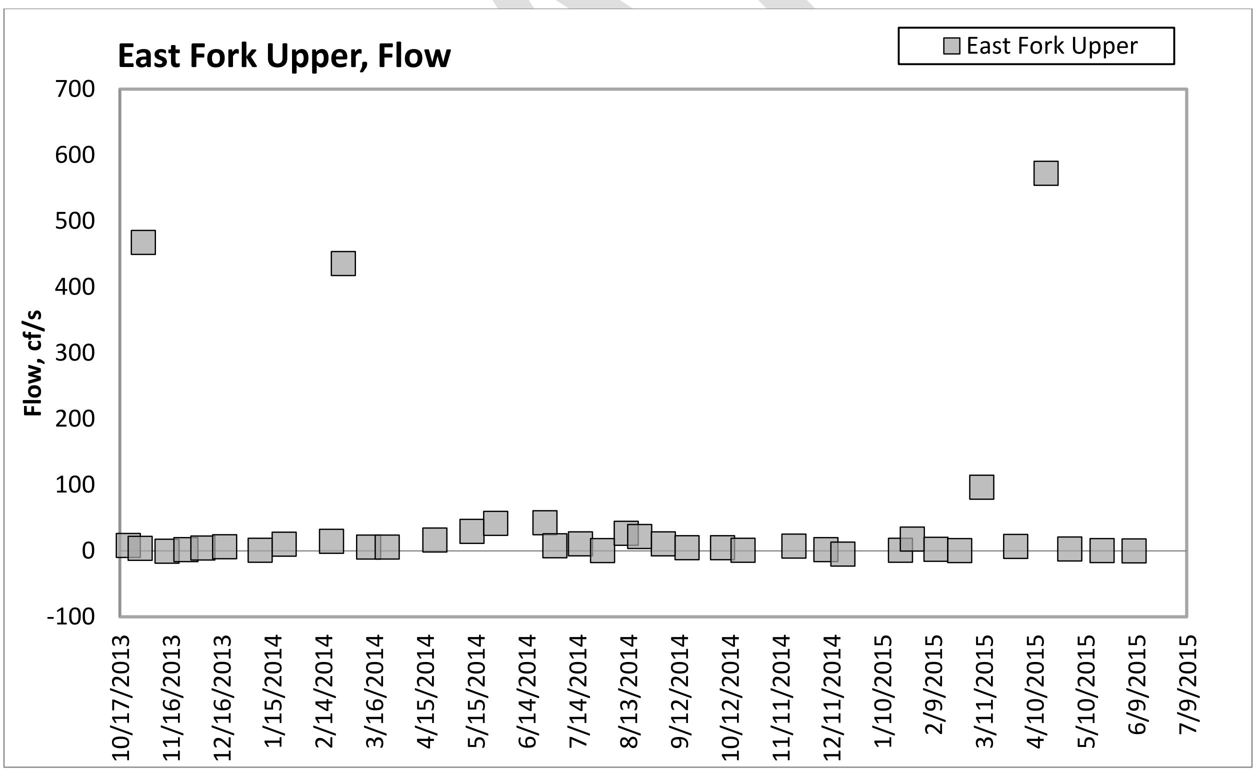


Figure E-3 East Fork Upper Flow

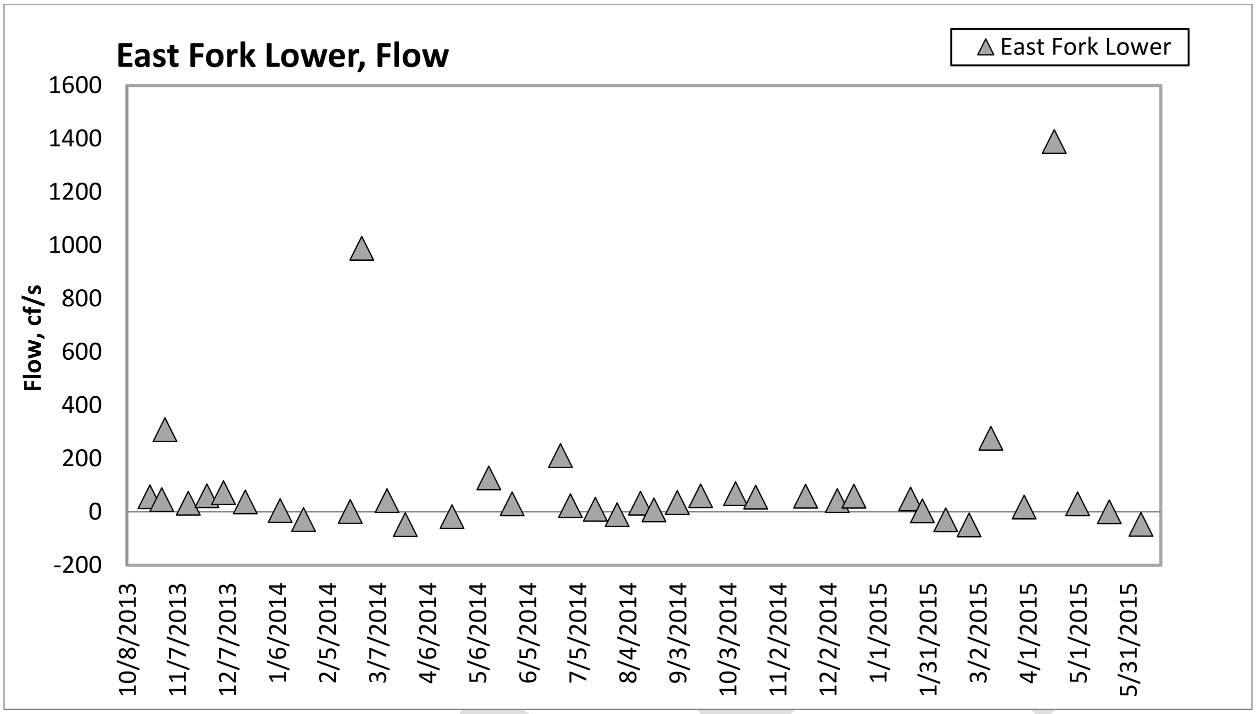


Figure E-4 East Fork Lower Flow

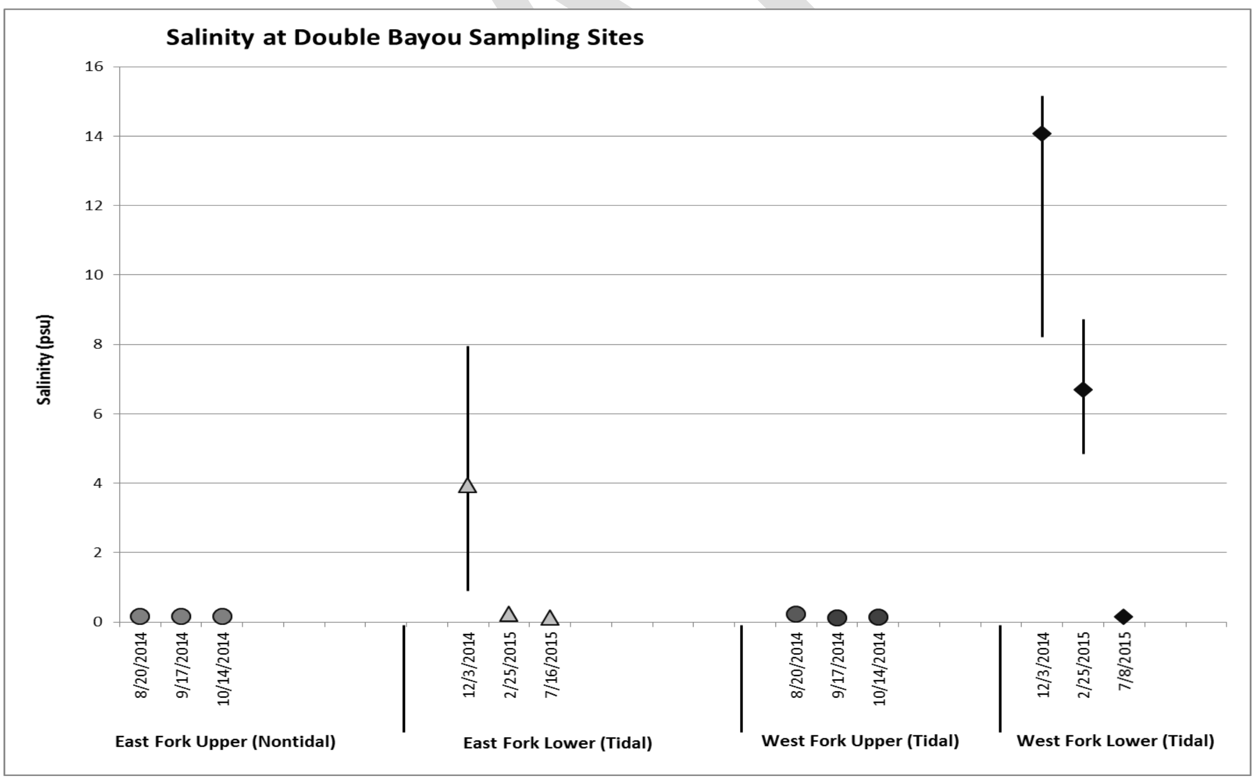


Figure E-5 24-hour sampling Salinity Results Double Bayou

Tidal Mixing Detail

An Index Velocity Site Gauge was installed at the site of West Fork Lower to determine the extent of tidal influence and mixing on the Double Bayou Watershed (see Chapter 5.8.2). The Index Velocity Site Gauge operates continuously, routinely measuring positive and negative flows (discharge) (cubic feet per second (cfs)) every fifteen minutes. As a reminder, "Positive flow", or ebb tide, indicates times at which the flow is occurring from upstream (north) towards downstream (south). "Negative flow", or flood tide, indicates times at which the flow is occurring from downstream (south) towards upstream (north), as a result of tidal or wind influence from Trinity Bay.

The data from the continuous sampling gauge and Enterococci bacteria samples collected show that tidal mixing occurs and dilutes bacteria concentrations at West Fork Lower. An analysis of determination for positive versus negative flow was conducted. For the purpose of this analysis, the point-in-time sample was not enough to be considered positive or negative flow. For bacteria analysis, an important factor to consider is the point in time the sample was taken and if it was during a continuous negative flow (representing tide coming into the bayou) or a continuous positive flow (representing flow downstream into the bayou). To determine this, the time the bacteria samples were collected was compared to the nearest 15 minute parameter flow measurement from the continuous gauge. This single flow sample was not considered representative of the flow– analysis showed that the measurement could represent a single positive flow at the end of a continuous negative flow. Therefore, the sample was actually representative of negative flow. Another example would be "erratic flow" times (erratic flows might be due to slack flows; period of time when tides are about to change) or wind-driven changes in flow and results in positive and negative flow all within an hour.

As a result, the flow data set from the hour before and two hours before each bacteria sample was analyzed to determine the representative tidal variance for the sample time. Bacteria samples collected under the Double Bayou Watershed Protection Plan sampling period as well as bacteria samples collected by the CRP during the time period when the continuous gauge was operated were used for analysis. Targeted rain events were not used for this analysis, which resulted in an initial sample size of 43. The method of analyzing flow from the hour before and two hours before collection of each bacteria sample was applied. If the average of the previous one hour and two hour flow samples was positive, as well as the sample itself, then the flow for the sample was considered positive. If the average of both the previous one hour and two hour flow samples was negative, as well as the sample itself, then the flow for the sample was considered negative. In the event that these were inconsistent (i.e., one negative and two positives), the sample was evaluated for slack flow or tip of tide change situations. In this manner, 39 samples were selected, with each sample categorized as positive or negative flow.

Using this analysis for tidal effect, it was determined, with a Mann-Whitney-Wilocoxon test (non-normal data) at 0.05 significance level ($p=0.0086$), that the Enterococci concentrations of negative and positive flows at WFL are non-identical data distributions. Chapter 5 Section 5.8.3 discusses the detailed results of the geomeans and percent exceedances of both sample distributions. It was determined that tidal mixing dilutes the bacteria concentration and the resulting bacteria loads would not exceed the regulatory load, during negative flow sample periods.

Precedence has been established for calculating tidal LDCs (typically called "modified LDCs") by regression using salinity as a proxy for flow (Daniel Turner and Mike Wiltsey 2006). In the case of Double Bayou West Fork, there is little correlation between salinity and flow (r^2 = 0.1079, Figure E-6 West Fork Lower Salinity versus Flow). This is to be expected – as stated above, Trinity Bay is a weakly saline system at around 10 psu during normal flows (seawater is approximate 30-35 psu) and closer to 0 psu during the rainy season. Figure E-7 Water quality stations in Trinity Bay closest to the mouth of Double Bayou shows four water quality monitoring stations with salinity data from 1996-2014; the average salinity from these four stations during this time period was 10.1 psu, with a maximum of 25.2 psu and a minimum of 0.17 psu.

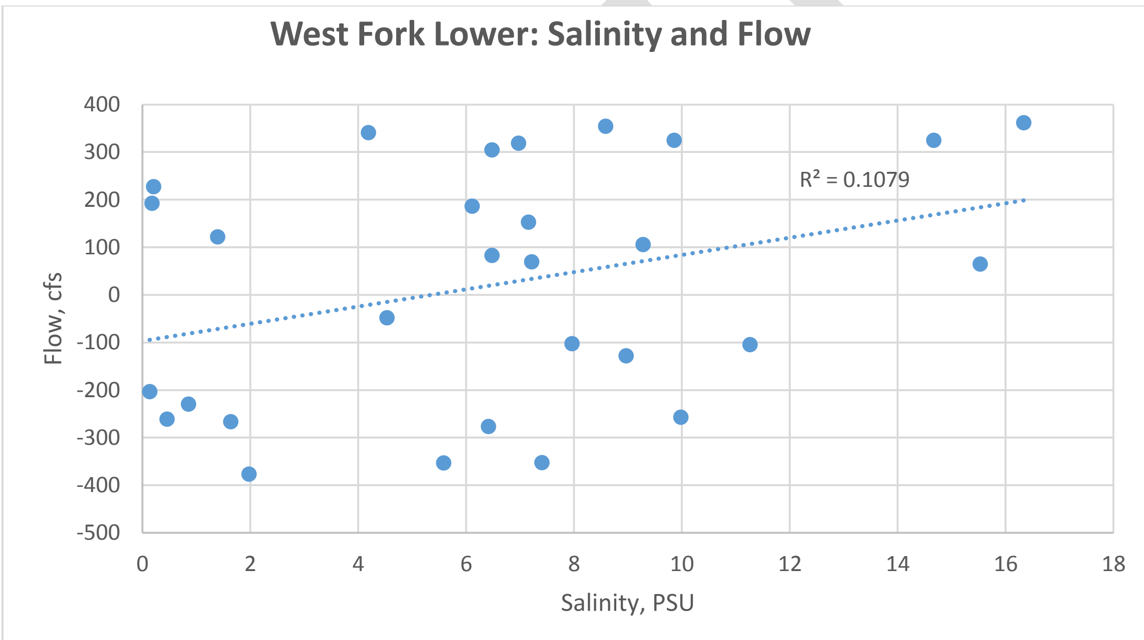


Figure E-6 West Fork Lower Salinity versus Flow

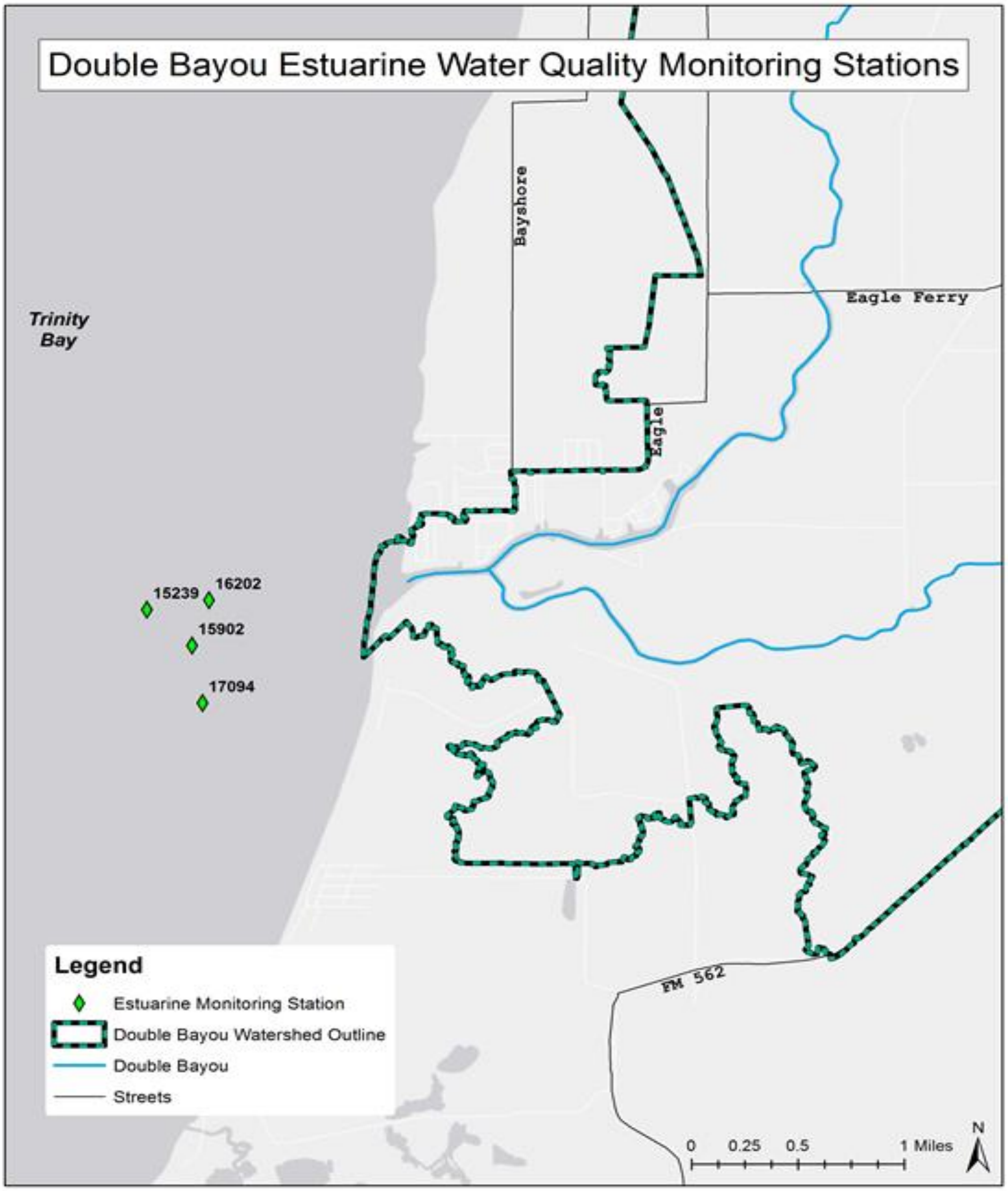


Figure E-7 Water quality stations in Trinity Bay closest to the mouth of Double Bayou

At first, an analysis of the positive flow values might appear to be beneficial to analyze pollutant loadings; however, there is very little correlation ($r^2 = 0.07$, Figure E-8 West Fork Lower Positive Flow values versus Enterococci concentration) between positive flow and bacteria concentration for West Fork Lower. This is likely due to the wind-driven nature of the system – periods of intense rainfall will often be accompanied by high winds, causing erratic flow patterns. This also could be due to the nature of the pollutant sources – direct deposition, for example. Because of the weak correlation between flow and bacteria, analysis based on flow regimes would be difficult. However, it is important to note that there is a strong connection between bacteria results for targeted rain events compared to non-rain event samples. The rainfall event samples targeting Enterococci had a percent exceedance of 100% (Enterococci single sample criterion 89 cfu/100 mL) and the Enterococci geomean of rain event samples was 2,550 cfu/100 mL (note that this is a small sample size, n = 7, under the preferred 20 minimum). It is the correlation between targeted rain events and flow that is relatively weak – some rain events had negative flow or weak flow, due to the reasons discussed above. But the magnitude of difference for Enterococci samples on targeted rain event days does suggest non-point sources as potential contributors.

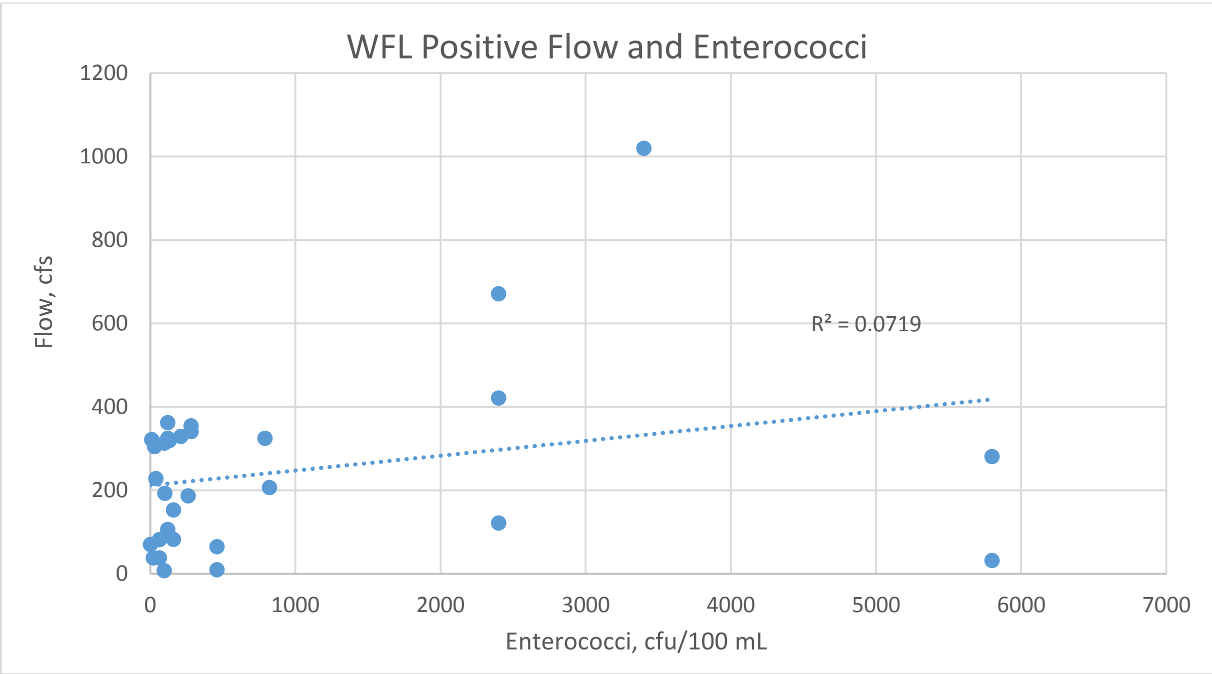


Figure E-8 West Fork Lower Positive Flow values versus Enterococci concentration

It was determined that development of a loading capacity analysis of event loads based on the volumetric flow measurements would be beneficial for understanding pollutant loadings and the needed load reductions. In this sense, the following approach was used (Daniel Turner and Mike Wiltsey 2006) to calculate daily load:

$$Daily\ Load\ (\frac{cfu}{day}) = V_t(\frac{m^3}{day}) * \ \mathrm{C}(\frac{cfu}{100\ mL}) * 1{,}000{,}000\ (\frac{mL}{m^3})$$

Where:

V_t = Daily total volume (m^3/day), which is defined as $V_b + V_s$

V_b = Volume of bayou water (m^3/day)

V_s = Volume of bay water (m^3/day)

C = Concentration of Enterococci (cfu/100 mL)

V_b and V_s were calculated using the quantitative flow measurements. For every day a bacteria sample was taken, flow results were analyzed– 12 hours before and 12 hours after the sample measurement. Instantaneous flow measurements were recorded every 15 minutes. Assuming that during these 15 minutes flow is fairly regular and similar to the flow measurement recorded, each flow measurement was converted to volume. (15 minutes x 60 seconds = 900 seconds; flow rates were recorded in cfs, or cubic feet per second, each rate was multiplied by 900 seconds resulting in cubic feet). The next step was to combine the discrete volume measurements into a day's worth of volume. Integrating the flow (combining all the 15 minute discrete measurements of water) gives the volume of water for that day. Positive flow measurements were used to calculate V_b and negative flow measurements were used to calculate V_s. The two were then summed to represent the total volume of water that moved through the bayou that day. The integration is represented below as the integral of flow (f) with respect to t (time):

$$V_x = \int_{t=0}^{t_f} f(t)\Delta t$$

Where:

$V_x = V_b$ or V_s, depending on positive or negative designation of flow

f(t) = flow at time t, expressed in cubic feet per second

Δt = change in time t; as stated our time steps were 15 minutes (every 900 seconds)

t_f = final time measurement

This integration was performed for every 24-hour time period a bacteria sample was taken with the result of a final V_b or V_s for every 24-hour time period. Note that the gauge had time gaps on some days due to short term error (gauge being out of water, bumped by wildlife, etc). Any sampling date that had more than 10% gap measurements was not considered for this analysis. This left a total sample size of 46.

Once daily load had been calculated for each sample date, a regulatory load was calculated in the same manner, using the maximum allowable Enterococci standard of 35 cfu/100 mL for the

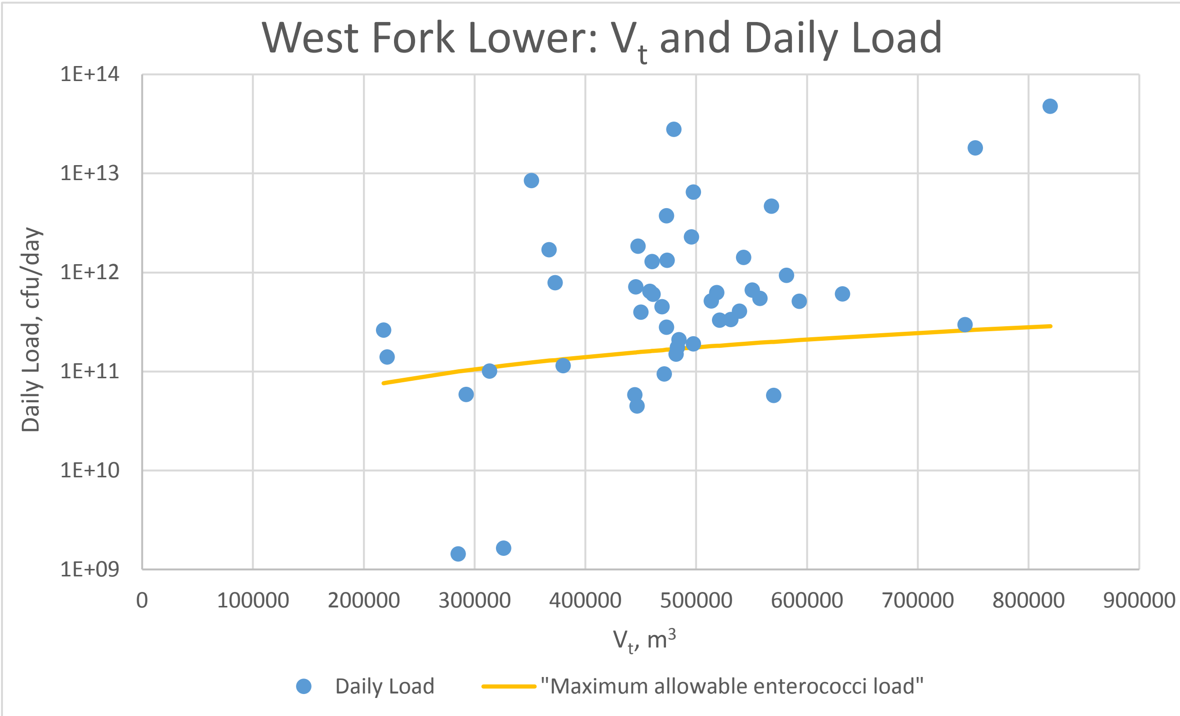


Figure E-9 West Fork Lower calculated Daily Load

C = concentration of Enterococci factor in the equation. This yields the graph line shown in Figure E-9 West Fork Lower calculated Daily Load.

The stakeholders decided on a 5% MOS for the West Fork Lower percent reduction goal. Figure E-9 West Fork Lower calculated Daily Load show the 5% MOS factored into the maximum allowable Enterococci load. The frequency distribution of samples in percent exceedance categories are shown in Table E-1 West Fork Lower percent exceedances and reduction with 5% MOS.

Percent Exceedance Category	Number of % exceedances in each category	Percent Reduction
75-100%	17	91%
40-74%	15	61%
Under 0 (meeting criteria) - 39%	14	-987%

Table E-1 West Fork Lower percent exceedances and reduction with 5% MOS

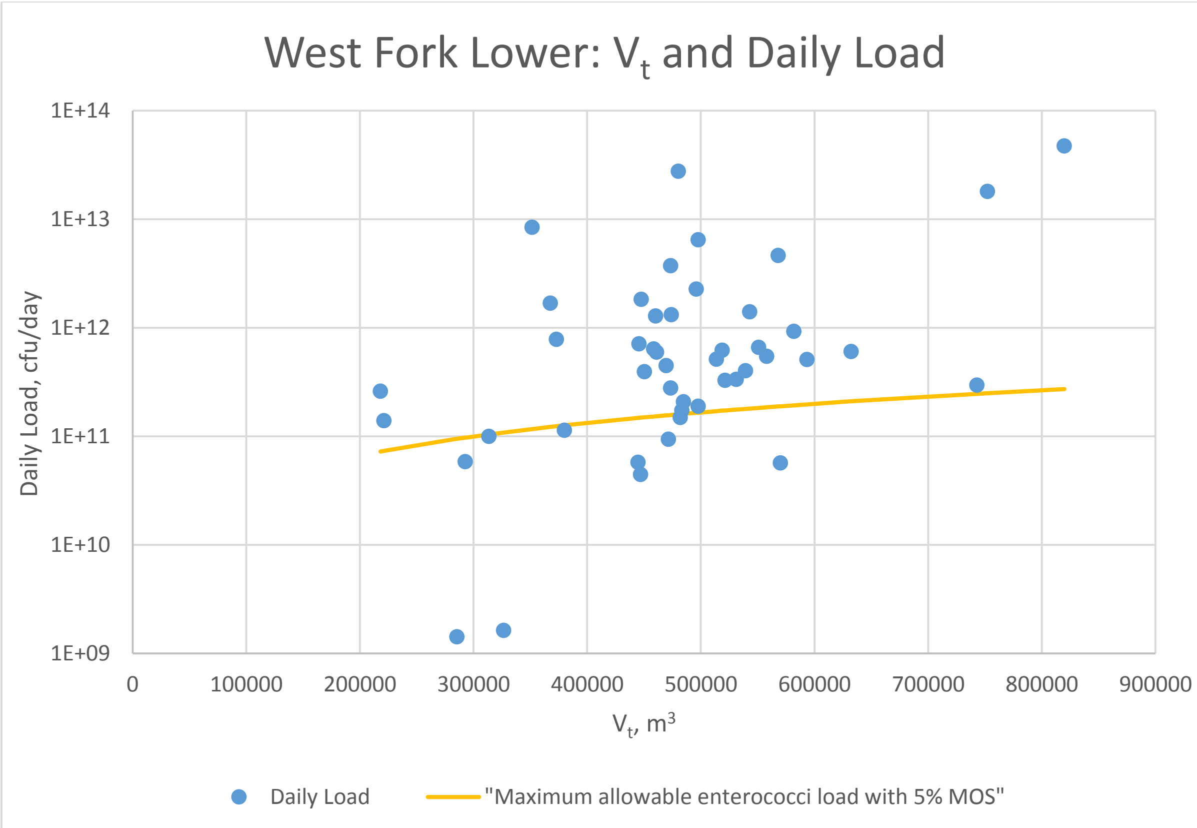


Figure E-10 West Fork Lower Daily Load by Volume with 5% MOS

F) Appendix F: Management Practice Efficiencies

Literature review and load reduction tables amended from Geronimo Creek Watershed Protection Plan and are provided to aid management measure selection and placement.

Agricultural Management Measures

Sediment /Solids	N	P	Fecal Coliform*	Length of Strip	Unit	Citation
97.60%	95.30%	93.60%	-	18.3m	Load(kg/ha)	Lim et al. 1998
91.90%	90.10%	83.80%	-	18.3m	Conc.(mg/L)	
77.30%	86.90%	92.60%	-	21m	Load(kg/ha)	Chaubey et al. 1994
92.10%	94.60%	96.90%	86.80%	21m	Conc.(mg/L)	
95.00%	80.00%	80.00%	-	9.1m	Load(kg/ha)	Dillaha et al. 1988
99%	-	-	74%	9m	Load(kg/ha)	Coyne et al. 1995
79%	84%	83%	69%		Conc.(cfu/mL)	Young et al. 1980
-	-	-	95%	1.37m	Conc.(cfu/mL)	Larsen et al. 1994
-	-	-	FC-54% EC-13%	-	-	Rifai (2006),Goel, et al.
-	-	-	FC-30-100% EC-58-99%	-	-	Peterson et al. 2011

* Concentration reductions are for fecal coliform unless otherwise labeled.

Table F-1 Load reductions for filter strips

Sediment/Solids	N	P	Fecal Coliform*	Width	Citation
79.00%	84.00%	83.00%	69%	27m	Young et al. 1980
84.00%	73.00%	79.00%	-1	9.1m	Lee et al. 1999
66.00%	0.00%	27.00%	-	4.6m	Magette et al. 1999
70.00%	50.00%	26.00%	-	4.3 & 5.3m	Parsons et al. 1991
99.00%	-	-	-	5-61m	Dosskey et al. 2002
67%	-	-	-	5-61m	Dosskey et al. 2002
59%	-	-	-	5-61m	Dosskey et al. 2002
41%	-	-	-	5-61m	Dosskey et al. 2002
-	-	-	95%	1.37m	Larsen et al. 1994

* Concentration reductions in cfu/mL.

Table F-2 Load reductions for riparian buffers

Sediment/Solids	N	P	Unit	Citation
57%	55%	50%	Load(kg/ha)	Arabi 2005
45%	35%	30%	Load(kg/ha)	Arabi 2005
50%	45%	25%	Load(kg/ha)	Arabi et al. 2006
48%	45%	24%	Load(kg/ha)	Arabi et al. 2006
81%	32%	-	Load(kg/ha)	Tate et al. 2000

Table F-3 Load reductions for field borders

Sediment/Solids	N	P	Fecal Coliform	Unit	Citation
97.00%	-	-	-	Load(kg/ha)	Fiener & Auerswald 2003
77.00%	-	-	-	Load(kg/ha)	Fiener & Auerswald 2003
95.00%	-	-	-	Load(t/ha)	Chow et al. 1999
-	-	-	95.00%	Conc.(cfu/mL)	Larsen et al. 1994
-	-	-	16%	Conc.(cfu/mL)	Dickey and Vanderholm, 1981

Table F-4 Load reductions for grassed waterways

Sediment/Solids	N	P	Unit	Citation
97.20%	93.90%	91.30%	Load(kg/ha)	Lee et al. 2003
76.00%	-	-	Mass(g/event)	Schoonover et al. 2005
61.30%	-	-	Conc.(mg/L)	Schoonover et al. 2005
90.00%	-	-	Conc.(mg/L)	Peterjohn & Correll 1984
-	89.00%	80.00%	Load(kg/ha)	Peterjohn & Correll 1984

Table F-5 Load reductions for forest buffers

Sediment/ Solids	N	P	Bacteria	Reduction in Time Spent in Stream	Reduction in Time Spent Near Stream	Reduction in Time Spent Drinking From Stream	Unit	Citation
96%	55.60%	98%	-	-	-	92%	Load (kg/ha)[1]	Sheffield et al. 1997
90%	54%	81%	FC-51%	-	-	92%	Conc. (mg/L)[2]	Sheffield et al. 1997
-	-	-	-	85%	53%	73.50%	-	Clawson 1993
-	-	-	-	-	75%	-	-	Godwin & Miner et al. 1996
-	-	-	-	90%	-	-	-	Miner et al. 1992
77%*	-	-	EC-85% FC-51-94%	-	-	-	-	Peterson et al. 2011

* Estimated reduction in stream bank erosion.
[1] Load Reductions based on measurements taken only from the watershed outlet.
[2] Concentration reduction based on measurements averaged from all 5 sample sites in the studied watershed.

Table F-6 Load reductions for alternative water facilities

Nutrient Management

N*	NO3-N**	P*	Management Practice	Citation
-	47.00%	-	Variable Rate Application	Delgado & Bausch 2005
-	59.00%	-	Nitrification Inhibitor	Di & Cameron 2002
-	-	12-41%	Variable Rate Application	Wittry & Mallarino 2004

* Reductions in nutrient applied to crop and continuing to maintain yield.
** Reduction in residual soil NO3-N and NO3-N leaching potential.

Table F-7 Load reductions for nutrient management

Sediment/Solids	N	P	Bacteria	Citation
71.00%	-	-	-	USEPA 2009 STEPL BMP Efficiency Rates
90.00%	-	-	-	Grace 2000
99.00%	-	-	-	Robichaud et al. 2006
89.00%	-	-	-	Robichaud et al. 2006

Table F-8 Load reduction for conservation cover

Sediments/ Solids	N	P	Bacteria*	Citation
18-25%	18-25%	18-25%	EC-46% FC-44%-52%	Peterson et al. 2011
-300.00%	35%[1]*	78%[2]*		

* Concentration reductions.
[1] Nitrate nitrogen.
[2] Particulate phosphorus.

Table F-9 Load reductions for stream crossings

Sediments/ Solids	N	Bacteria	Citation
-	-	EC – 85%*	Peterson et al. 2011

* When combined with an off-stream water source.

Table F-10 Load reductions for alternative shade structures

Agricultural Management Practices References

Arabi, M. 2005. A modeling framework for evaluation of watershed management practices for sediment and nutrient control, Thesis for PhD. Purdue University.

Arabi, M., R.S. Govindaraju, H.M. Mohamed and Engel, B.A. 2006. Role of Watershed Subdivision on Modeling the Effectiveness of Best Management Practices With SWAT. Journal of the American Water Resources Association; Vol 42(2) pp 513.

Chaubey, L., D.R. Edwards, T.C. Daniel and P.A. Moore. 1994. Nichols D.J., Effectiveness of Vegetative Filter Strips in Retaining Surface-Applied Swine Manure Constituents. Transactions of the ASAE. 37(3): pp 837-843.

Chow, T.L., H.W. Rees and J.L. Daigle. 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: A field evaluation. Journal of Soil and Water Conservation. Vol. 54, 3. pp 577.

Clawson, J.E. 1993. The use of off-stream water developments and various water gap configurations to modify the behavior of grazing cattle. M.S. Thesis, Oregon State University, Department of Rangeland Resources, Corvallis, OR.

Coyne, M.S., R.A. Gilfillen, R.W. Rhodes and R.L. Blevins. 1995. Soil and fecal coliform trapping by grass filter strips during simulated rain. Journal of Soil and Water Conservation 50(4)405-408.

Delgado, J.A. and W.C. Bausch. 2005. Potential use of precision conservation techniques to reduce nitrate leaching in irrigated crops. Journal of Soil and Water Conservation. Vol. 60(6) pp 379.

Di, H.J. and K.C. Cameron. 2002. The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. Journal of Soil Use and Management. Vol. 18, pp 395-403.

Dickey, E.C. and D.H. Vanderholm. 1981. Vegetative Filter Treatment of Livestock Feedlot Runoff. Journal of Environmental Quality 10(3):279-284.

Dillaha, T.A., D.L. Sherrard, S. Mostachimi and V.O. Shanholtz. 1988. Evaluation of Vegetative Filter Strips as a BMP for Feed Lots. Journal of Water Pollution Control Federation. Vol. 60, No. 7, July 1988, 1231-1238.

Dosskey, M.G., M.J. Helmers, T.G. Eisenhauer, T.G. Franti and K.D. Hoagland. 2002. Assessment of concentrated flow though riparian buffers. Journal of Soil and Water Conservation. Vol. 57(6) pp 336.

Fiener, P. and K. Auerswald. 2003. Effectiveness of Grassed Waterways in Reducing Runoff and Sediment Delivery from Agricultural Watersheds. Journal of Environmental Quality. Vol. 32(3): 927.

Godwin, D.C. and J.R. Miner. 1996. The potential of off-stream livestock watering to reduce water quality impacts. Bioresource Technology 58:285-290.

Goel, P.K., R.P. Rudra, B. Gharbaghi, S. Das and N. Gupta. 2004. Pollutants Removal by Vegetative Filter Strips Planted with Different Grasses. ASAE/CSAI Annual International Meeting. Ottowa, Ontaria, Canada.

Grace, J.M. III. 2000. Forest road sideslopes and soil conservation techniques. Journal of Soil and Water Conservation. Vol 55(1) pp 96.

Hartley, M.J., G.C. Atkinson, K.H. Bimler, T.K. James and A.I. Popay. 1978. Control of barley grass by grazing management. Proceedings of New Zealand Weed Pest Control Society Conference. 31: pp 198-202.

Helgeson, E.A. 1942. Control of leafy spurge by sheep. North Dakota Agricultural Experiment Station, Bimonthly Bull. Vol. 4(5) pp 10-12.

Johnston, A. and R.W. Peake. 1960. Effect of Selective Grazing by Sheep on the Control of Leafy Spurge. Journal of Range Management, Vol 13(4) pp 192-195.

Larsen, R.E., R.J. Miner, J.C. Buckhouse and J.A. Moore. 1994. Water Quality Benefits of Having Cattle Manure Deposited Away From Streams. Biosource Technology Vol. 48 pp 113-118.

Lee, K-H., T.M. Isenhart, R.C. Schultz and S.K. Michelson. 1999. Nutrient and Sediment Removal by Switchgrass and Cool-Season Grass Filter Strips in Central Iowa, USA. Journal of Agroforestry Systems. Vol. 44(2-3) pp 121-132.

Lim, T.T., D.R. Edwards, S.R. Workman, B.T. Larson and L. Dunn. 1998. Vegetated Filter Strip Removal of Cattle Manure Constituents in Runoff. Transactions of the ASABE. Vol 41(5) pp 1375-1381.

Lym, R.G., K.K. Sedivec and D.R. Kirby. 1997. Leafy spurge control with angora goats and herbicides. Journal of Range Management. Vol 50(2) pp 123-128.

Magette, W.L., R.B. Brinsfield, R.E. Palmer and J.D. Wood. 1989. Nutrient and Sediment Removal by vegetated filter strips. Trans ASAE 32: pp 663–667.

Miner, J. R., J. C. Buckhouse and J.A. Moore. 1992. Will a Water Trough Reduce the Amount of Time Hay-Fed Livestock Spend in the Stream (and therefore improve water quality). Rangelands 14(1):35-38.

Olson, B.E. and J.R. Lacey. 1994. Sheep: A Method for Controlling Rangeland Weeds. Sheep Research Journal: Special Issue.

Parsons, J.E., R.D. Daniels, J.W. Gilliam and T.A. Dillaha. 1991. The effect of vegetation filter strips on sediment and nutrient removal from agricultural runoff. In: Proceedings, Environmentally Sound Agriculture Conference, April, Orlando, FL.

Peter, J., T. William and D.L. Correll. 1984. Nutrient Dynamics in an Agricultural Watershed: Observations on the Role of a Riparian Forest. Journal of Ecology. Vol 65, No. 5, pp 1466-1475.

Peterson, J., L. Redmon and M. McFarland. 2011. Reducing Bacteria With Best Management Practices for Livestock- Waste Storage facility. http://agrilifebookstore.org. AgriLife Bookstore.

Peterson, J., L. Redmon and M. McFarland. 2011. Reducing Bacteria With Best Management Practices for Livestock-Watering Facility. http://agrilifebookstore.org. AgriLife Bookstore.

Peterson, J., L. Redmon and M. McFarland. 2011. Reducing Bacteria With Best Management Practices for Livestock- Prescribed Grazing. http://agrilifebookstore.org. AgriLife Bookstore.

Peterson, J., L. Redmon and M. McFarland. 2011. Reducing Bacteria With Best Management Practices for Livestock- Stream Crossing. http://agrilifebookstore.org. AgriLife Bookstore.

Peterson, J., L. Redmon and M. McFarland. 2011. Reducing Bacteria With Best Management Practices for Livestock-Watering Facility. http://agrilifebookstore.org. AgriLife Bookstore.

Popay, I. and R. Field. 1996. Grazing Animals as Weed Control Agents. Weed Technology, Vol 10(1) pp 217-231.

Raphs, M.H., J.E. Bowns and G.D. Manners. 1991. Utilization of larkspur by sheep. Journal of Range Management. Vol 44 pp 619-622.

Rifai, H. 2006. Study on the Effectiveness of BMPs to Control Bacteria Loads. Prepared by University of Houston for TCEQ as Final Quarterly Report No. 1.

Robichaud, P.R., T.R. Lillybridge and J.W. Wagenbrenner. 2006. Effects of postfire seeding and fertilization on hillslope erosion in north-central Washington, USA. Catena Vol. 67, pp 56-67.

Rolston, M.P., M.G. Lambert, D.A. Clark and B.P. Devantier. 1981. Control of rushes and thistles in pasture by goat and sheep grazing. Proceedings of New Zealand Weed Pest Control Conference. 34: pp 117-121.

Schoonover, J.E., W.J. Willard, J.J. Zaczek, J.C. Mangun and A.D. Carver. 2006. Agricultural Sediment Reduction by Giant Cane and Forest Riparian Buffers. Journal of Water, Air, and Soil Pollution. Vol. 169 pp 303-315.

Sheffield, R.E., S. Mostaghimi, D.H. Vaughn, E.R. Collins Jr. and V.G. Allen. 1997. Off-Stream Water Sources for Grazing Cattle as a Stream Bank Stabilization and Water Quality BMP. Transactions of the ASABE, Vol 40(3): 595-604.

Tate, K.W., G.A. Nader, D.J. Lewis, E.R. Atwill and J.M. Connor. 2000. Evaluation of Buffers to Improve the Quality of Runoff from Irrigated Pastures. Journal of Soil and Water Conservation. Vol 55(4) pp 473.

Wittry, D.J. and A.P. Mallarino. 2004. Comparison of Uniform and Variable-Rate Phosphorus Fertilization for Corn-Soybean Rotations. Agronomy Journal, Vol 96, pp 26-33.

Young, R.A., T. Huntrods and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. Journal of Environmental Quality 9:483-487.

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