Watershed Characterization Report for Indicator Bacteria in the Cotton Bayou Watershed

Cotton Bayou

Segment: 0801C

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November 2020

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Prepared For:

Total Maximum Daily Load Program

Texas Commission on Environmental Quality

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List of Acronyms and Abbreviations

AU	assessment unit
AVMA	American Veterinary Medical Association
cfs	cubic feet per second
cfu	colony forming unit
CWA	Clean Water Act
DMR	discharge monitoring report
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
H-GAC	Houston-Galveston Area Council
IR	Texas Integrated Report of Surface Water Quality
mL	milliliter
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
MUD	Municipal Utility District
NHD+	National Hydrography Dataset Plus
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	onsite sewage facility
SSO	sanitary sewer overflow
SWQMIS	Surface Water Quality Monitoring Information System
SWQS	surface water quality standards
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WPP	Watershed Protection Plan
WWTF	wastewater treatment facility

Section 1: Introduction

1.1 Background

The Cotton Bayou Watershed is located near the northern border of Galveston Bay and is bisected by Interstate Highway 10 in Chambers County, Texas (Figure 1). Cotton Bayou (Segment 0801C, with one assessment unit (AU) 0801C_01) and its principal tributary Hackberry Gully are the main water bodies in the 16.2-square-mile watershed area. The associated stream network is largely modified. Land in the majority of the watershed is cultivated, grassland, and woody; however, development is increasing near Mont Belvieu and other areas experiencing the effects of urban sprawl. This pressure, as well as compounding stresses associated with cultivation and natural pollution, has impacted the water quality in the watershed and will continue to pose challenges as development increases in this region.

To better understand the factors influencing water quality in the Cotton Bayou Watershed, the Houston-Galveston Area Council (H-GAC), in coordination with the Texas Commission on Environmental Quality (TCEQ), prepared a Watershed Characterization Report. The objective of the report is to assess trends in historical observations of water quality, determine potential drivers of impairment (especially where fecal indicator bacteria are concerned), and provide information to aid in future management strategies targeted at improving water quality.

In addition to the aforementioned project goals, the benefits of this assessment include enhanced public involvement through stakeholder meetings and outreach materials designed to effectively communicate the role of the community in watershed management. The preparation of this report will also provide critical foundational information if a total maximum daily load (TMDL) study and implementation plan are pursued in the future. Further, this document will serve as a resource for stakeholders and managers alike should the community pursue development of a Watershed Protection Plan (WPP).

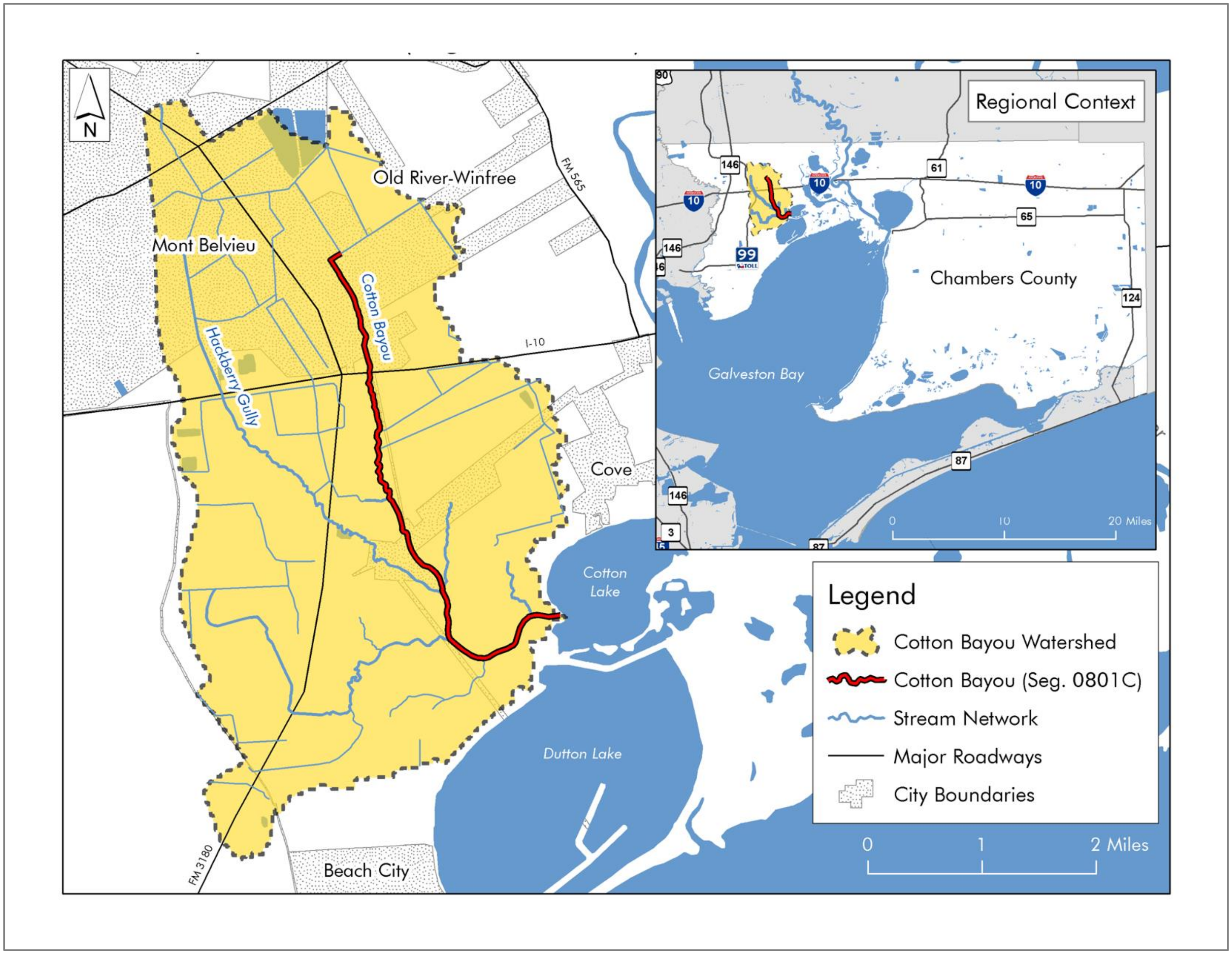

Figure 1. Cotton Bayou Watershed

1.2 Water Quality Standards

The United States Environmental Protection Agency (EPA) works to protect human health and the environment by enforcing regulations such as those listed in Section 303(d) of the Clean Water Act (CWA), which charge states to identify waters that do not meet water quality standards. Surface water quality standard (SWQS) criteria vary according to the designated uses of different waterways. In Texas, these designations and standards are determined by TCEQ, codified in Title 30, Chapter 307 of the Texas Administrative Code (TAC), and are meant to:

- Define suitable uses for the state's water bodies,
- Determine water quality goals for the state by establishing numerical and narrative criteria, and
- Establish implementation methods for TCEQ regulatory programs to use as a basis to attain those goals.

Specifically, Texas SWQS are designed to protect the quality of water supplied by the state's streams, lakes, rivers, and bays, as well as protecting public health and aquatic life. TCEQ determines whether or not these uses are supported in individual waterways by measuring levels of pollutants and conditions pertaining to water quality (e.g., dissolved oxygen levels, temperature, pH, dissolved minerals, toxic substances, and bacteria) against criteria defined in the SWQS.

To monitor the water quality in state water bodies, TCEQ conducts regular assessments of water samples from individual waterways. The results of these assessments are summarized every two years in the Texas Integrated Report of Surface Water Quality (IR). Water bodies determined to be in exceedance of SWQS designated use criteria for pollutants or conditions relevant to water quality are listed in the IR 303(d) list of impaired water bodies. Cotton Bayou (Segment 0801C) was first identified as impaired in the 2010 IR for recreation use and aquatic life use due to high levels of bacteria and low levels of dissolved oxygen, respectively. A summary of impairments and concerns identified in the 2020 IR, the most recent TCEQ- and EPA-approved edition at the time of this report, are shown in Table 1. This Watershed Characterization Report will investigate the potential sources of fecal waste contributing to elevated bacteria levels in Cotton Bayou to support the development of strategies to reduce the impairment enough to support recreation use.

Table 1. 2020 IR Summary of Impairments and Concerns for Cotton Bayou

Impairments								
Assessment Unit	**Parameter**	**Use**	**Period of Record**	**# of Samples**	**Criteria**	**Assessed/ Exceedance Value**	**Impairment Status**	**Impaired Since**
0801C_01	Dissolved Oxygen Grab Minimum	Aquatic Life	12/1/2011 to 11/30/2018	49	3 mg/L	1.55 mg/L	5c	2006
	Bacteria Geomean (Enterococcus)	Recreation	12/1/2011 to 11/30/2018	43	35 cfu/100 mL	137.41 cfu/100 mL	5c	2010
Concerns								
Assessment Unit	**Parameter**	**Use**	**Period of Record**	**# of Samples**	**Criteria**	**Assessed/ Exceedance Value**	**Concern Level**	**--**
0801C_01	Dissolved Oxygen Grab Screening Level	Aquatic Life	12/1/2011 to 11/30/2018	49	4 mg/L	2.47 mg/L	CS	
	Chlorophyll-a Screening Level	General Use	12/1/2011 to 11/30/2018	50	21 µg/L	49.52 µg/L	CS	
	Nitrate Screening Level	General Use	12/1/2011 to 11/30/2018	51	1.10 mg/L	6.67 mg/L	CS	
	Total Phosphorous Screening Level	General Use	12/1/2011 to 11/30/2018	44	0.66 mg/L	1.58 mg/L	CS	

1.3 Contact Recreation and Bacteria

Fecal waste can be introduced into the environment through a variety of vectors and poses a threat to water quality due to its association with pathogens and other health risks. The presence of fecal waste in water can be traced by testing water samples for bacteria commonly found in the intestines of warm-blooded animals. Such organisms are known as indicator bacteria due to their association with pathogens. Water bodies are designated as impaired for recreational use when indicator bacteria levels exceed the SWQS criteria.

Contact recreation impairment indicated by elevated levels of bacteria is the most common impairment in Texas, particularly in the greater Houston area and surrounding region. In Texas, freshwater streams are monitored for the presence of the indicator bacteria *Escherichia coli* (*E. coli*), whereas tidal streams, such as Cotton Bayou, are monitored for Enterococci. Concentrations of Enterococci and other indicator bacteria are often expressed as colony forming units (cfu) in every 100 milliliters (mL) of water. Allowable indicator bacteria concentrations in water bodies designated for recreation use vary based on categories of recreation use as set forth in Title 30, Chapter 307 TAC. Recreational use in tidal systems may be described as primary where the risk of ingestion of water is significant (e.g., swimming, diving, etc.) or secondary where ingestion of water is less likely, but the risk of incidental contact is high (e.g., fishing, boating, etc.). The allowable primary contact recreation use 1 criteria for Enterococci concentrations in tidal streams are 35 cfu/100 mL for the geometric mean (or geomean) of samples collected over a known period and 130 cfu/100 mL in any single sample.

1.4 Total Maximum Daily Load Program

For every impaired water body identified, states must prepare a TMDL for the pollutants driving the impairment to satisfy the requirements of the CWA. TMDLs act as "budgets" and are the result of analyses to determine the maximum allowable pollutant level that can be sustained by a water body without negatively impacting its ability to support designated uses including recreation, aquatic life, fish consumption, and water supply. A TMDL is typically expressed as units of mass over a set period, also known as a load. Once the load value is established, an implementation plan may be pursued in order to identify management actions that can be taken to reduce bacteria loads and meet the SWQS.

In the state of Texas, TCEQ assumes responsibility for executing the development of TMDLs through the TMDL Program. TCEQ often works with regional partners to develop TMDLs. In the greater Houston area, H-GAC supports TCEQ with TMDL projects and resulting implementation plans for impaired or threatened water bodies in the 13-county region.

1.5 Characterization Report Purpose and Organization

To determine the drivers behind the contact recreation impairment in Cotton Bayou (Segment 0801C), this report will investigate factors throughout the watershed that are known to contribute to elevated bacteria levels. Characteristics such as geography, hydrology, land cover, and infrastructure, as well as assessments of human, wildlife, and livestock populations, will be described in order to provide a more complete understanding of contaminant sources and the degrees to which these sources are affecting water quality in the Cotton Bayou Watershed. These data have been compiled from environmental agencies, monitoring programs, and local stakeholder input. This report will be foundational to the future development of a TMDL and implementation plan for bacteria in Cotton Bayou. Further, local stakeholder involvement throughout the characterization process could yield valuable insight regarding water quality concerns in the Cotton Bayou Watershed and foster important relationships for the continued stewardship of water quality at the local level.

The report will adhere to the following format:

- Section 1: Introduction
- Section 2: Watershed Description
- Section 3: Review of Historical Data
- Section 4: Potential Sources of Contamination
- Section 5: Findings and Recommendations

Section 2: Watershed Description

2.1 Description of the Cotton Bayou System

Segment Description

Cotton Bayou (Segment 0801C) is designated as an unclassified stream segment, which qualifies it as a tributary to a primary, classified segment—in this case Segment 0801, Trinity River Tidal. The watershed area for Cotton Bayou is near the terminal end of the Trinity River Basin and within the boundaries of Chambers County (Figure 2). Much of the stream network in the Cotton Bayou Watershed consists of modified channels; however, Cotton Bayou itself, as well as its principal tributary, Hackberry Gully, are more natural waterways. The Cotton Bayou Watershed drains into Cotton Lake, where the terminal end of Cotton Bayou forms a confluence with the lake. In turn, Cotton Lake receives tidal exchange that ultimately influences Cotton Bayou.

The only AU in Cotton Bayou is 0801C_01, which is described in the 2020 IR[1] as the stream area between a point approximately one mile north of Interstate Highway 10 and the confluence with Cotton Lake, which is approximately 7 miles downstream.

[1] 2020 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d) https://www.tceq.texas.gov/waterquality/assessment/20twqi.

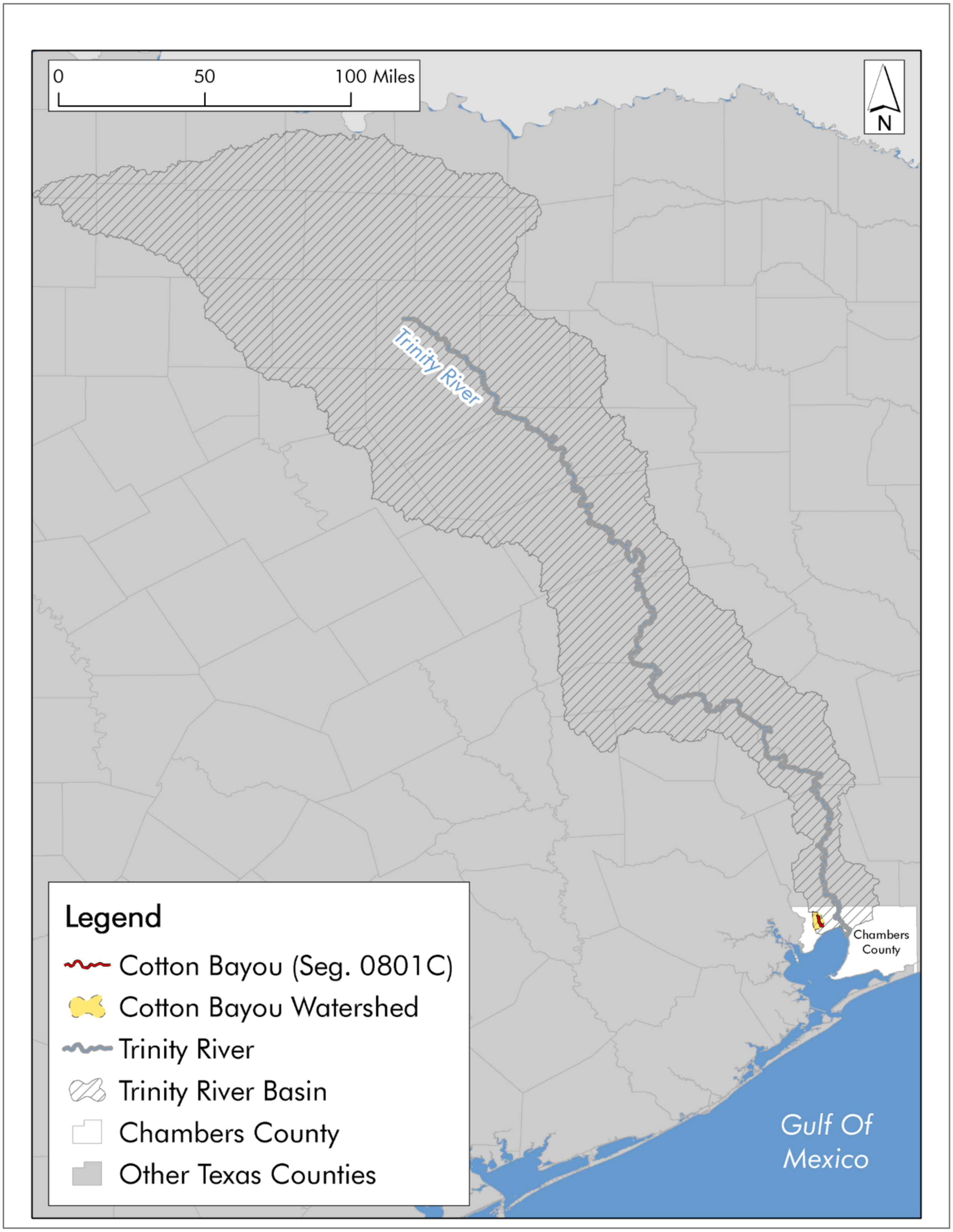

Figure 2. Cotton Bayou and the Trinity River Basin

Stream Network

Cotton Bayou is sourced by approximately 40 additional miles of stream network including tributaries, canals, and impoundments (Figure 3). The principal tributary to Cotton Bayou is Hackberry Gully, which runs parallel to the main stem on the west side of the watershed. Another (unnamed) tributary enters Cotton Bayou to the south of its confluence with Hackberry Gully. Cedar Point Lateral, a canal that runs parallel to the northern border of the watershed, intersects Hackberry Gully near its origin. Outside the watershed boundary, Cotton Lake is a major lake that both receives flows from the Cotton Bayou network and facilitates tidal exchange with waters from Galveston Bay. Many of the smaller, modified canals that form the remainder of the Cotton Bayou stream network appear to be conditional flow vectors.

Primary Tributary

Hackberry Gully – Hackberry Gully is the only named major tributary connected to Cotton Bayou. The gully is approximately 5 miles long and starts in the City of Mont Belvieu. Hackberry Gully forms a confluence with Cotton Bayou to the south of Cove's city limits and drains the watershed area to the north and west of Cotton Bayou.

Drainage Area/Watershed Delineation

Approximately 16.2 square miles of watershed area are drained by Cotton Bayou and its associated stream network. To determine the initial boundary limits of the watershed, the United States Geological Survey (USGS) National Hydrography Dataset Plus (NHD+) was referenced, because of its granular approach to delineating watershed boundaries at the catchment level (Figure 4). The NHD+ watershed boundary was then adjusted throughout the assessment, depending on stakeholder feedback, field observations, and higher-resolution geospatial and aerial data, to better represent the drainage area.

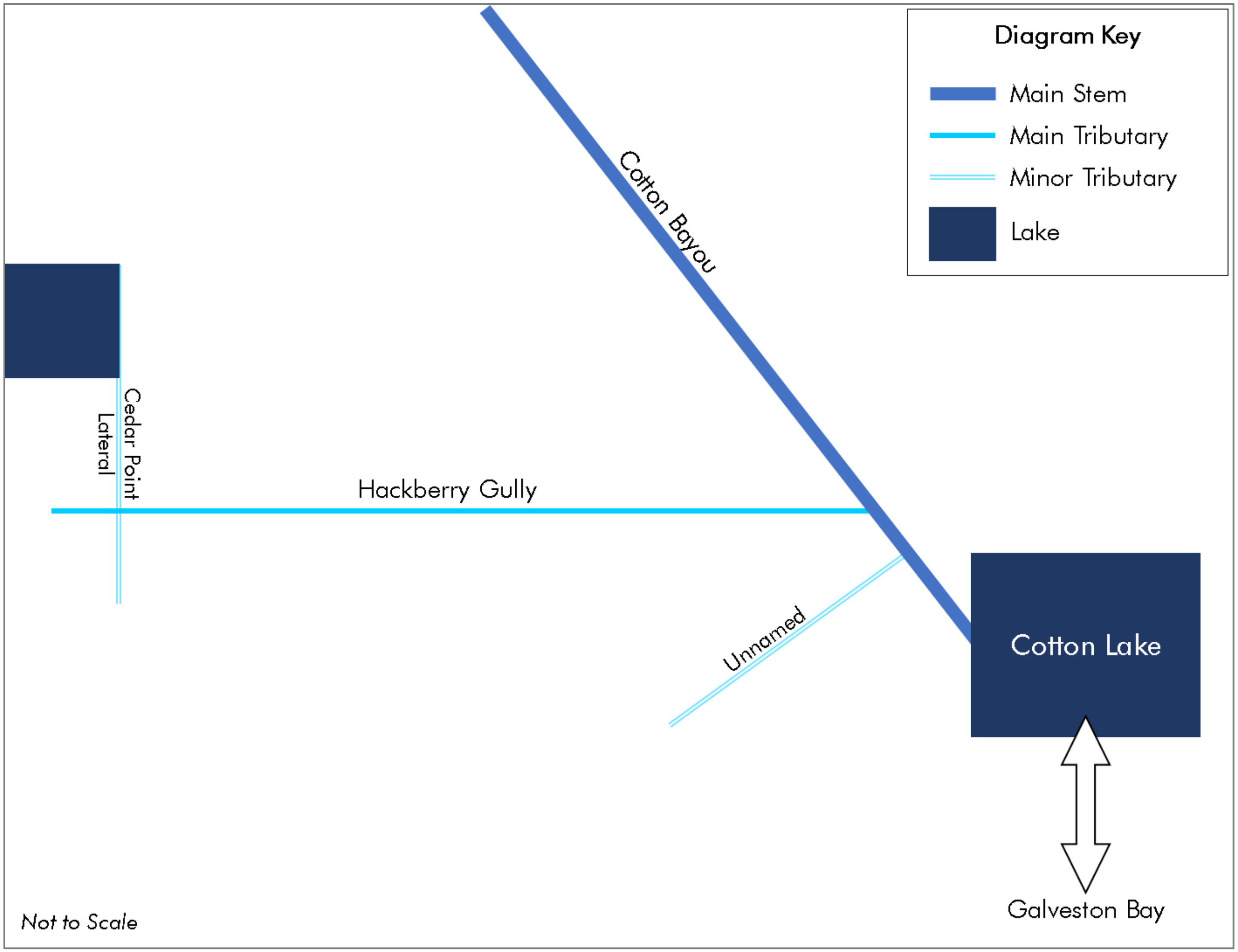

Figure 3. Stream Network Diagram for Cotton Bayou

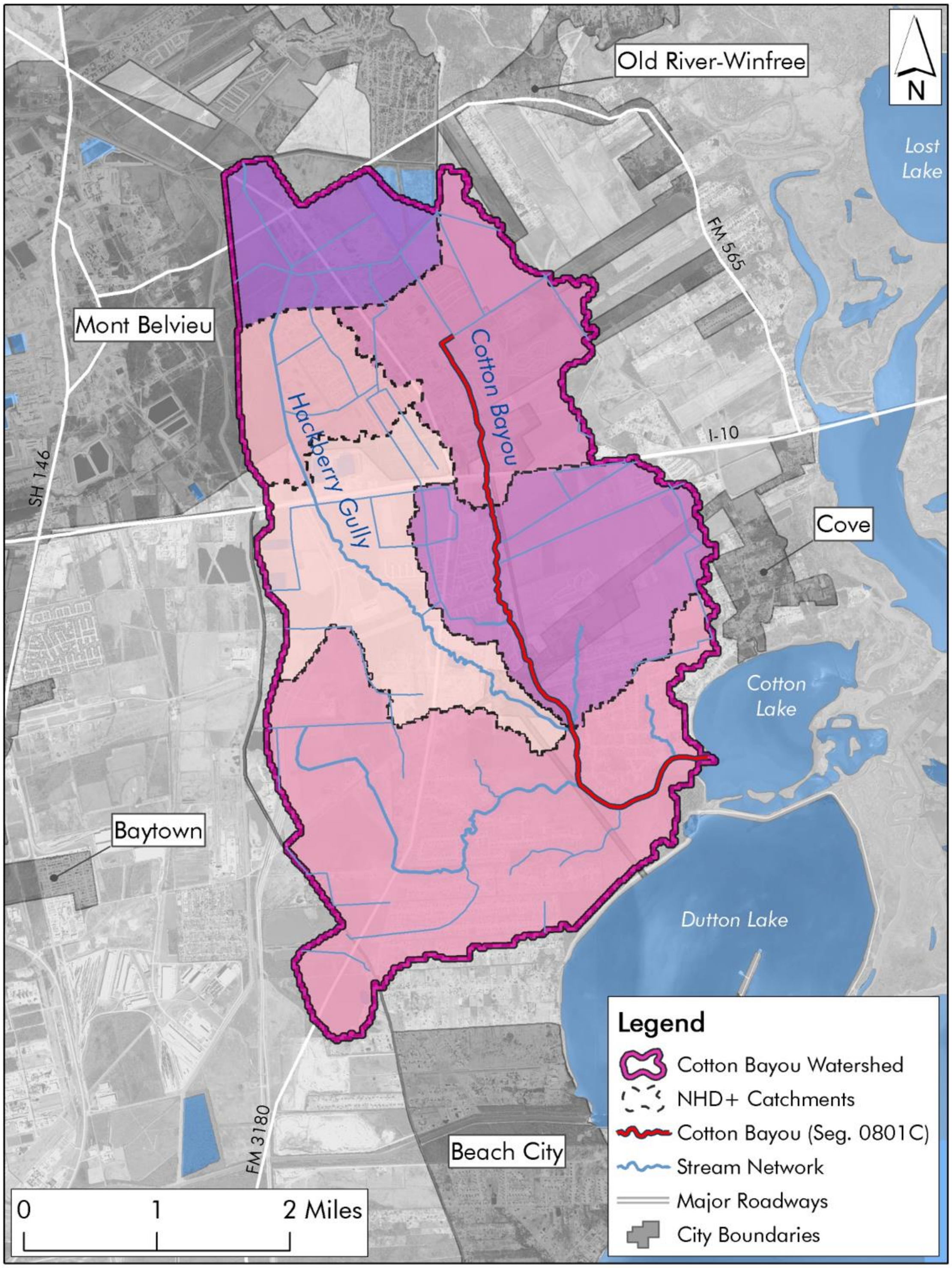

Figure 4. Cotton Bayou Watershed Delineation

2.2 Watershed Climate and Environmental Characteristics

Precipitation and Temperature

Near the Cotton Bayou Watershed, the National Oceanic and Atmospheric Administration (NOAA) operates a weather station in the City of Baytown. From this station (GHCND:USC00410586), daily, monthly, and annual averages for weather parameters including temperature and precipitation have been assessed for the period from 1981 through 2010. From this dataset, the estimate for total annual precipitation in the region is 59.9 inches. Mean monthly precipitation ranged from a minimum of 3.5 inches in April to a maximum of 7.4 inches in June (Figure 5). The driest months typically occurred in late winter or early spring, while the wettest periods occurred in June, as well as the fall months.

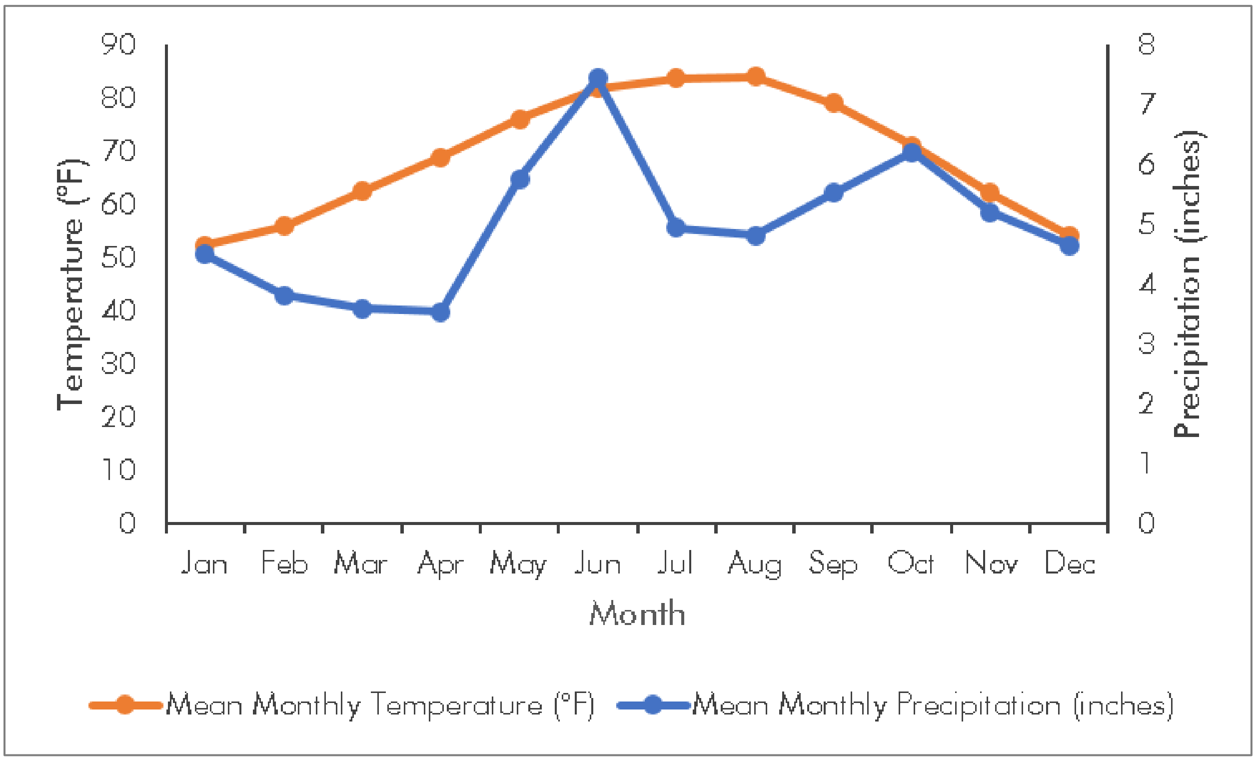

Figure 5. Mean Monthly Temperature and Precipitation, NOAA Station GHCND:USC00410586 (1981 through 2010)

Precipitation numbers in the Cotton Bayou Watershed and the greater Houston area are increasingly impacted by severe storm events associated with flooding events in the late spring and hurricane season. For example, the calculations of the aforementioned means do not include data from more recent years, where one-time observation rainfall maximums such as the measurements listed in Table 2 occurred at the same weather station.

Table 2. Observations of Precipitation ≥4.0 Inches Near the Cotton Bayou Watershed (2015 through 2019)

Date	Observed Precipitation (inches)	Associated Storm Event
5/26/2015	6.4	"Memorial Day Flood"
10/25/2015	7.2	Hurricane Patricia
4/18/2016	4.0	"Tax Day Flood"
8/27/2017	16.6	Hurricane Harvey
8/28/2017	12.7	Hurricane Harvey
8/29/2017	11.9	Hurricane Harvey
9/20/2019	4.1	Tropical Storm Imelda

Temperatures in the Cotton Bayou Watershed are consistent with subtropical coastal areas. At NOAA Station GHCND:USC00410586 (Baytown, TX), the annual mean temperature was estimated to be 69.2°F from an average of mean monthly values recorded from 1981 through 2010. Winters are generally mild, and January is typically the coolest month of the year, with an average temperature of 52.3°F. August tends to be the warmest summer month, with an average temperature of 83.9°F (Figure 5).

Elevation

The area of the Cotton Bayou Watershed is relatively flat. A slight slope is formed by a transect moving southeast between its highest and lowest points, which are separated by approximately 17 meters (56 feet) of elevation (Figure 6). This topography is typical of the region; therefore, flows in the Cotton Bayou Watershed are less likely to be driven by natural elevation change than channelization and other modifications to the stream network.

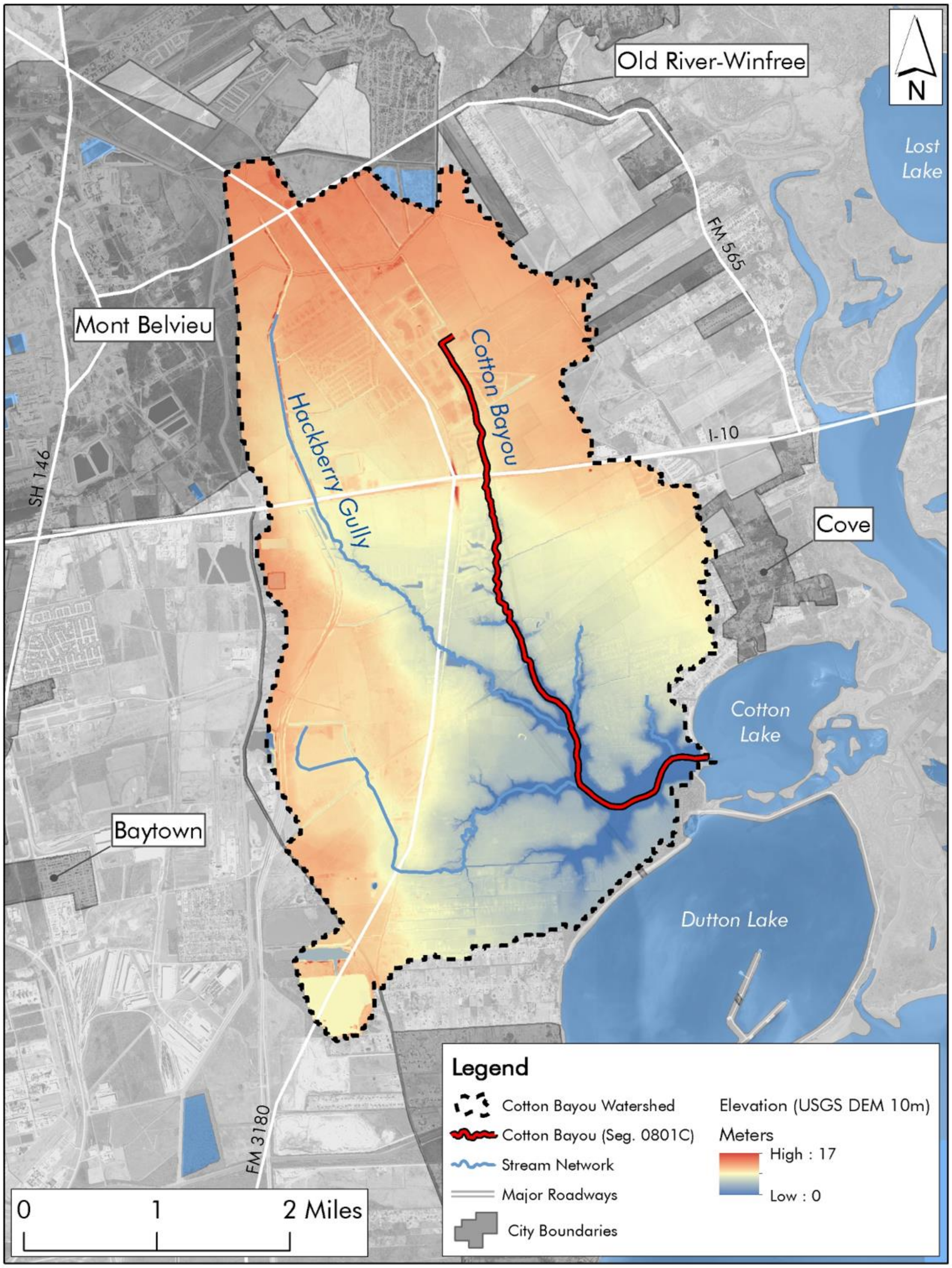

Figure 6. Elevation Change in the Cotton Bayou Watershed

Water Usage

There are no adjudicated water rights within the boundary of the Cotton Bayou Watershed. North of the watershed, the City of Houston owns rights to a diversion point on Old River for industrial use, irrigation, and municipal use. South of the Cotton Bayou Watershed, NRG Texas Power, LLC holds the right to impound and use the waters of Dutton Lake for industrial use and power generation.

Soils

Based on data from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), soils in the Cotton Bay Watershed range from fine to fine-silty (Figure 7). The soil types are clayey and loamy and transition from acidic-neutral in the northern reaches to neutral-alkaline and saline with increasing proximity to Galveston Bay[2].

Ecoregions

Ecoregions are classifications of land that describe areas of similar biotic, abiotic, terrestrial, and aquatic ecosystem components. EPA has categorized ecoregions of the United States at multiple levels of resolution, with Level I being the most coarse and Level IV being the most detailed. At the highest resolution available for the continental United States (Level III), most land bordering the Texas coast is classified as the Western Gulf Coastal Plain ecoregion. This region is characterized by grassland, wooded land, and minimal variations in topography. As such, it is widely used as pasture and cropland.

For the conterminous 48 states, Level IV ecoregion resolutions are available. The majority of the Cotton Bayou Watershed falls within the Northern Humid Gulf Coast Prairie ecoregion, though a very small fraction of the watershed overlaps the Texas-Louisiana Coastal Marshes (Figure 8). As with the Level III classification, these ecoregions are known for flat topography covered primarily with grassland and wooded areas, especially in riparian areas. Other distinguishing features of this ecoregion relate to its diverse hydrology, which includes rivers, bayous, lakes, marshes, and estuaries. These ecoregions support a variety of wildlife, including an especially diverse array of bird species. Invasive species in this region include feral hogs and invasive plants such as Chinese tallow, alligator weed, and others.

[2] From the USDA NRCS assessment of soils in Chambers County https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/texas/TX071/gsm.pdf

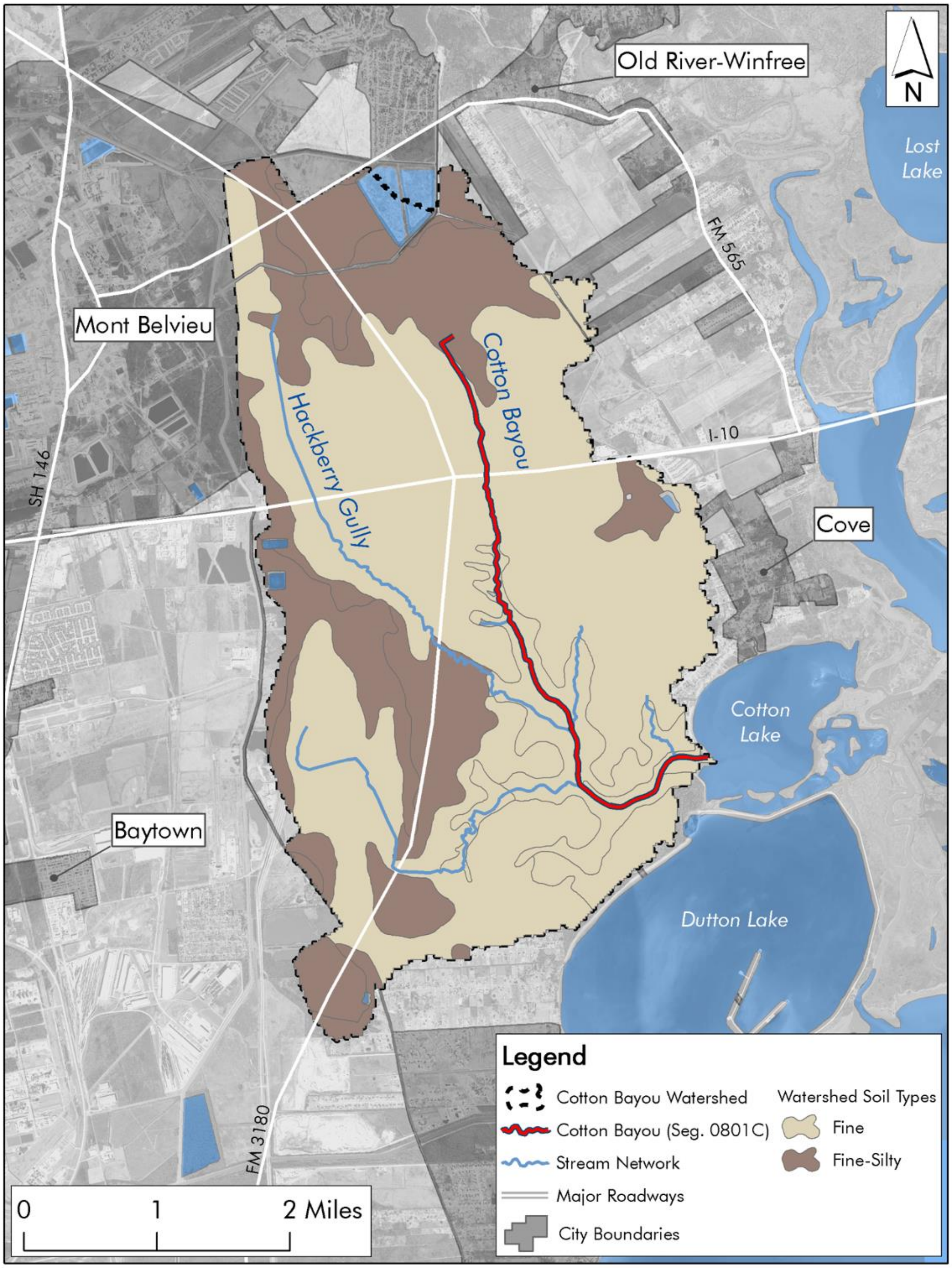

Figure 7. Soils in the Cotton Bayou Watershed

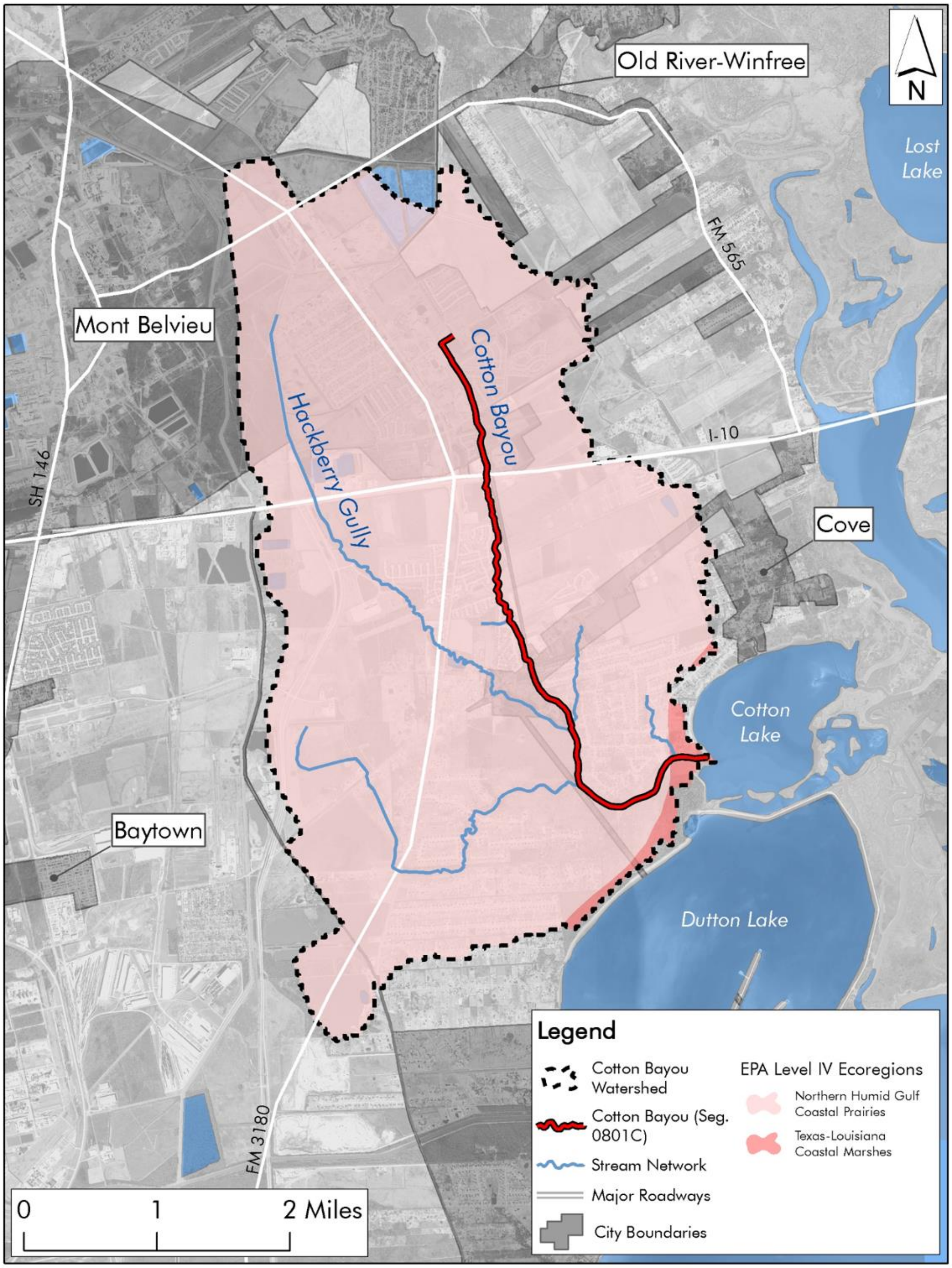

Figure 8. Cotton Bayou Watershed, Level IV Ecoregions

Local Political Geography

The Cotton Bayou Watershed falls completely within the boundaries of Chambers County. The watershed area is also wholly under the service area of the Coastal Water Authority, as well as falling within the boundaries of the Trinity River Authority. Portions of the cities of Mont Belvieu and Cove lie within the watershed boundaries, as well as nominal sections of Baytown, Beach City, and Old River-Winfree (Figure 9). Two Municipal Utility Districts (MUDs)—Chambers County MUDs 2 and 3—are contained within the watershed boundary, and Chambers County Improvement Districts 2 and 3 overlap with the Cotton Bayou Watershed.

2.3 Watershed Population and Population Projections

As of 2018, the population of the Cotton Bayou Watershed area was approximately 3,301, based on the ratio of watershed area to census tract areas 48071710100 and 48071710200 in Chambers County, Texas assuming equal distribution. This calculation was further used to estimate households in the Cotton Bayou Watershed at 1,182. According to projections from the H-GAC Regional Growth Forecast, the population of the Cotton Bayou Watershed could increase to approximately 8,830, representing 3,368 households, by the year 2045. Overall, this would represent a 167% increase in population, or a net gain of 5,529 residents between 2018 and 2045.

Table 3. Population Change in the Cotton Bayou Watershed

	2018	2020	2025	2030	2035	2040	2045
Population	3,301	3,826	4,341	4,743	4,905	6,290	8,830
Change, Year to Year	-	525	515	402	162	1,385	2,541
Percentage Change, Year to Year	-	16%	13%	9%	3%	28%	40%

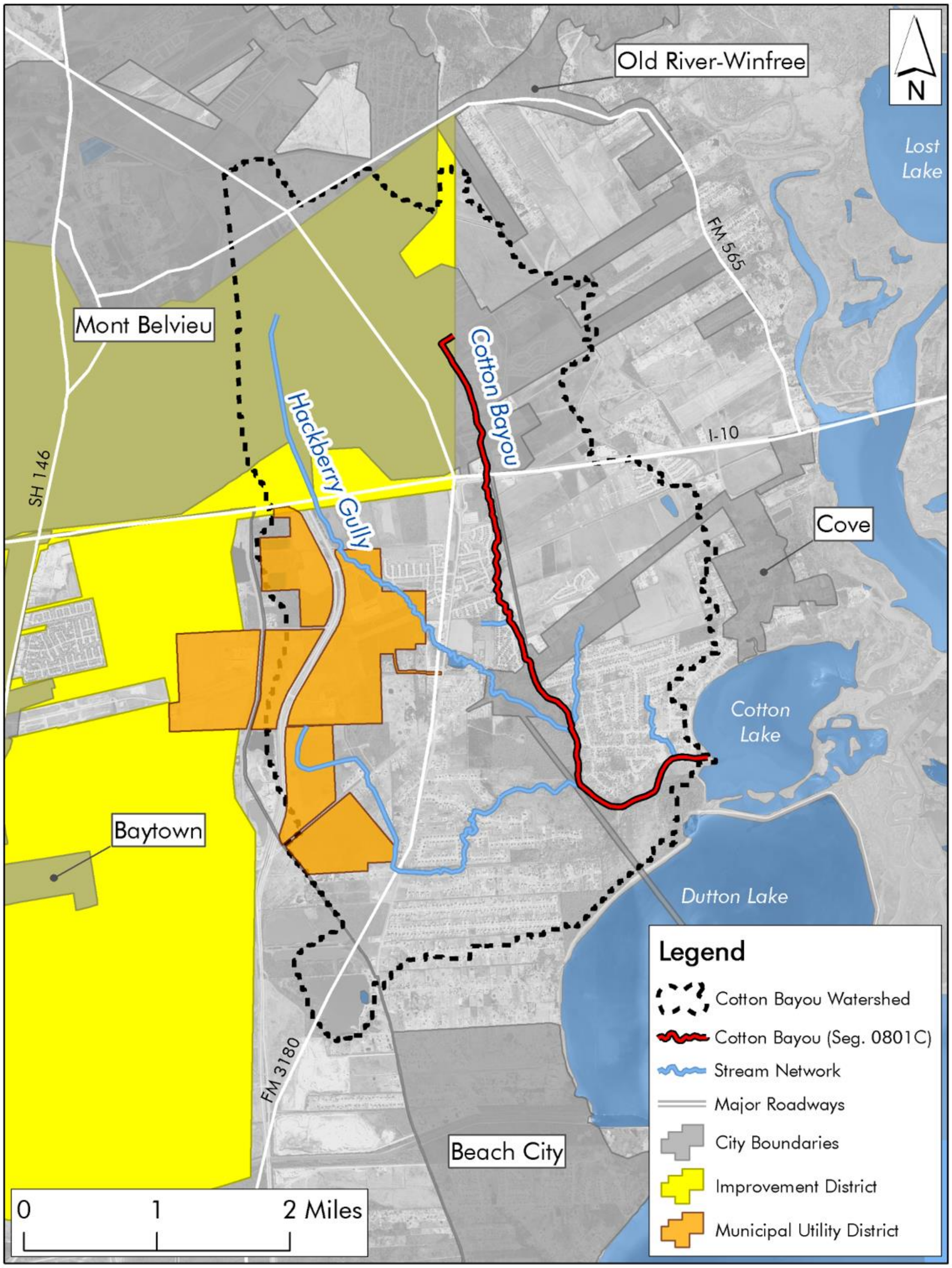

Figure 9. Political Geography of the Cotton Bayou Watershed

2.4 Land Cover

As with many urban centers nationwide, areas surrounding the City of Houston have experienced an increase in development associated with urban sprawl, especially along transportation corridors. Due to its proximity to Houston and the Interstate Highway 10 corridor, the Cotton Bayou Watershed has shown evidence of this trend and is expected to continue to expand development in the coming years.

In 2018, H-GAC used LANDSAT imagery to categorize the Houston-Galveston region into 10 classes of land cover. In Figure 10, this assessment is shown specifically for the Cotton Bayou Watershed area. Table 4 below summarizes the results of this assessment by showing how much area, by percentage and acreage, each of the ten land cover categories contributes to the total area of the watershed. Just over half (55.4%) of the watershed area is considered “natural” or otherwise undeveloped (open water, barren land, forests and shrubland, pasture and grassland, and wetlands). Of the developed area, low intensity developments, including residential structures, make up the largest land cover contribution (23.8%). However, according to the growing population projections referenced in Table 3, developed areas are predicted to expand and shift the balance of land cover types in the coming decades.

Table 4. Land Cover by Category

Land Cover Category	% of Total Land Cover	Acres
Open Water	1.8	219
Developed – High Intensity	2.1	249
Developed – Medium Intensity	3.1	366
Developed – Low Intensity	23.8	2,816
Developed – Open Space	6.7	790
Barren Land	1.4	160
Forests and Shrubland	11.3	1,340
Pasture and Grassland	25.1	2,959
Cropland	8.9	1,049
Wetlands	15.8	1,864
TOTAL	**100.0**	**11,812**

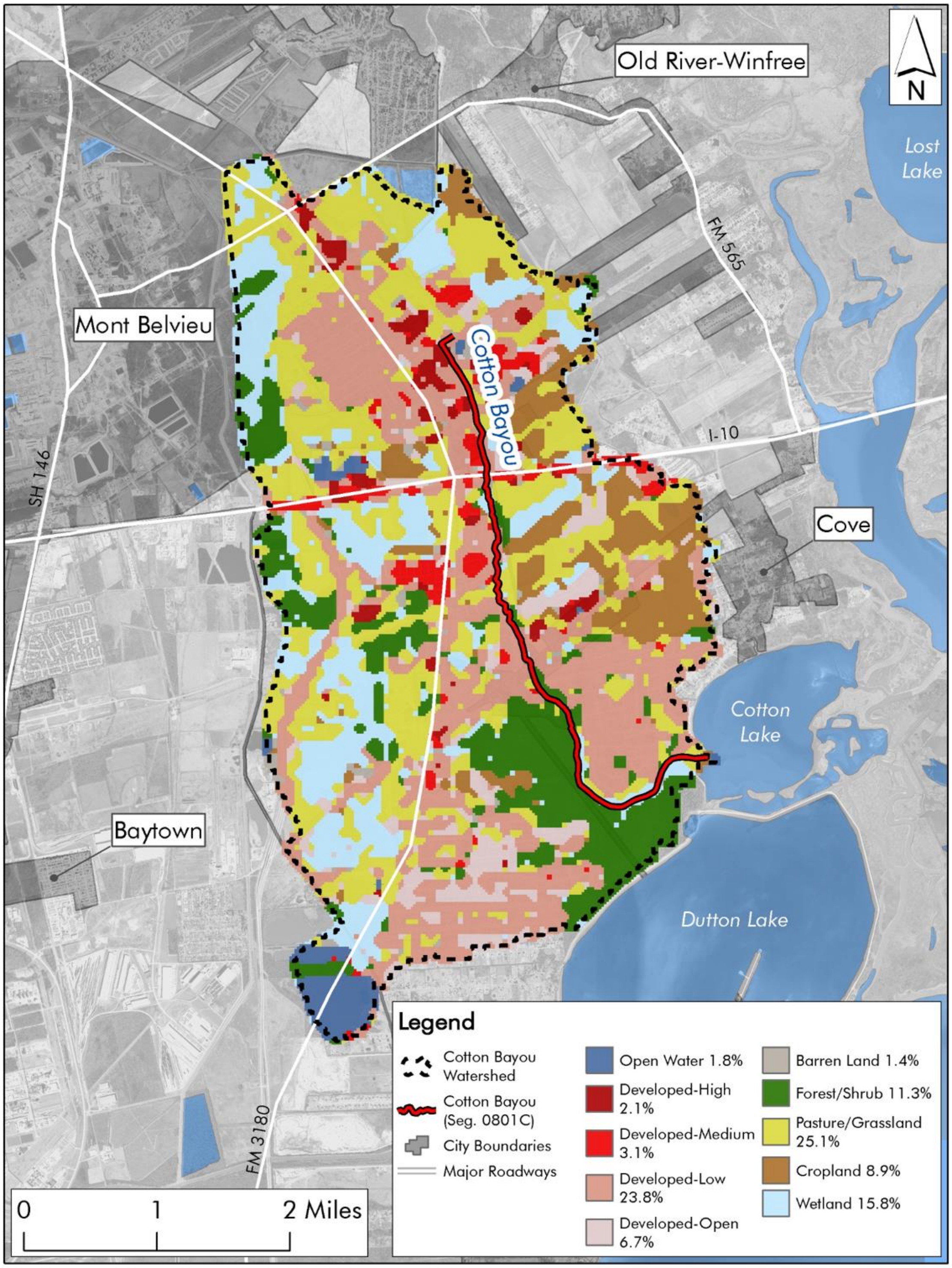

Figure 10. Land Cover in the Cotton Bayou Watershed

Section 3: Review of Historical Data

3.1 Historical Data Sources Overview

In order to better understand the variables driving the contact recreation impairment in Cotton Bayou, it is necessary to review historical water quality data that has been collected in the area. This information is collected from a variety of sources and includes discharge monitoring reports (DMRs) from wastewater treatment facilities (WWTFs), sanitary sewer overflow (SSO) reports from wastewater collection systems, and environmental monitoring data found in the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database. By considering this, in conjunction with potential sources of pollution identified in the watershed and feedback from local stakeholders, a more comprehensive analysis of the relationship between pollutant loads and stream flows can be achieved.

3.2 Wastewater Treatment Facility Discharge Monitoring Reports

Data Acquisition

Three facilities discharge into the stream network of the Cotton Bayou Watershed (Table 5). DMR data collected between 2012 through 2019 from these facilities have been used to characterize the long-term trends in discharge water quality. However, only one of these facilities (the discharge permitted by Tiki Leasing Company, LTD. on Cotton Bayou just north of the confluence with Hackberry Gully) assessed Enterococci concentrations.

Table 5. WWTFs in the Cotton Bayou Watershed

Facility/ Permittee Name	Permit Number	TPDES ID	Fecal Indicator Bacteria	Flow Limit (MGD)	Average Flow (MGD)	Number of Outfalls
Tiki Leasing Company, Ltd.	TX0085961	WQ0011109001	Enterococci	0.32	0.01	1
Aqua Texas, Inc.	TX0066656	WQ0011449001	*E. coli*	0.60	0.19	2
City of Mont Belvieu	TX0053317	WQ0014807001	*E. coli*	1.50	0.87	1

DMR Data Review – Bacteria

As mentioned previously, the only permitted discharge monitored for Enterococci levels in the Cotton Bayou Watershed is that of the Tiki Leasing Company, LTD. According to quarterly DMRs reported from 2012 through 2019, none of the 29 samples collected exceeded the 35 cfu/100 mL Enterococci geomean criterion at this outfall. The other two permittees discharging into Cotton Bayou—the City of Mont Belvieu and Aqua Texas, Inc.—monitored for the freshwater fecal indicator bacteria *E. coli*, which is measured against a geomean criterion of 126 cfu/100 mL. From 2012 to 2019, the 188 samples reported by Aqua Texas, Inc. were found to be in exceedance of the *E. coli* geomean criterion 8% of the time. The WWTF operated by the City of Mont Belvieu had far more incidents of exceedance, with 55% of their 97 samples found to have bacteria levels greater than the *E. coli* geomean criterion.

DMR Data Review – Other Parameters

Similar to the analysis of ambient water quality, many other water quality parameters are reported in DMRs along with bacteria data. In Table 6, the results of ammonia nitrogen, total suspended solids, dissolved oxygen (grab), and carbonaceous biochemical oxygen demand (5-day) analyses reported from 2012 through 2019 in the Cotton Bayou Watershed are summarized. For all parameters, permitted facilities in the watershed were in compliance with water quality criteria greater than 95% of the time. Only the Aqua Texas, Inc. facility exceeded the criterion for ammonia nitrogen 7.4% of the time.

Table 6. Other Parameters Reported in DMRs

Facility/ Permittee Name	**Permit Number**	**DMR Exceedances of Criteria/Screening Levels by Parameter (*number and percent of total samples*)**			
		Ammonia Nitrogen	Total Suspended Solids	Dissolved Oxygen (grab, minimum)	Carbonaceous Biological Oxygen Demand (5-Day)
Tiki Leasing Company, Ltd.	TX0085961	0 (0%)	0 (0%)	1 (1.5%)	0 (0%)
Aqua Texas, Inc.	TX0066656	15 (7.4%)	0 (0%)	0 (0%)	1 (0.5%)
City of Mont Belvieu	TX0053317	4 (2.0%)	3 (1.5%)	0 (0%)	0 (0%)

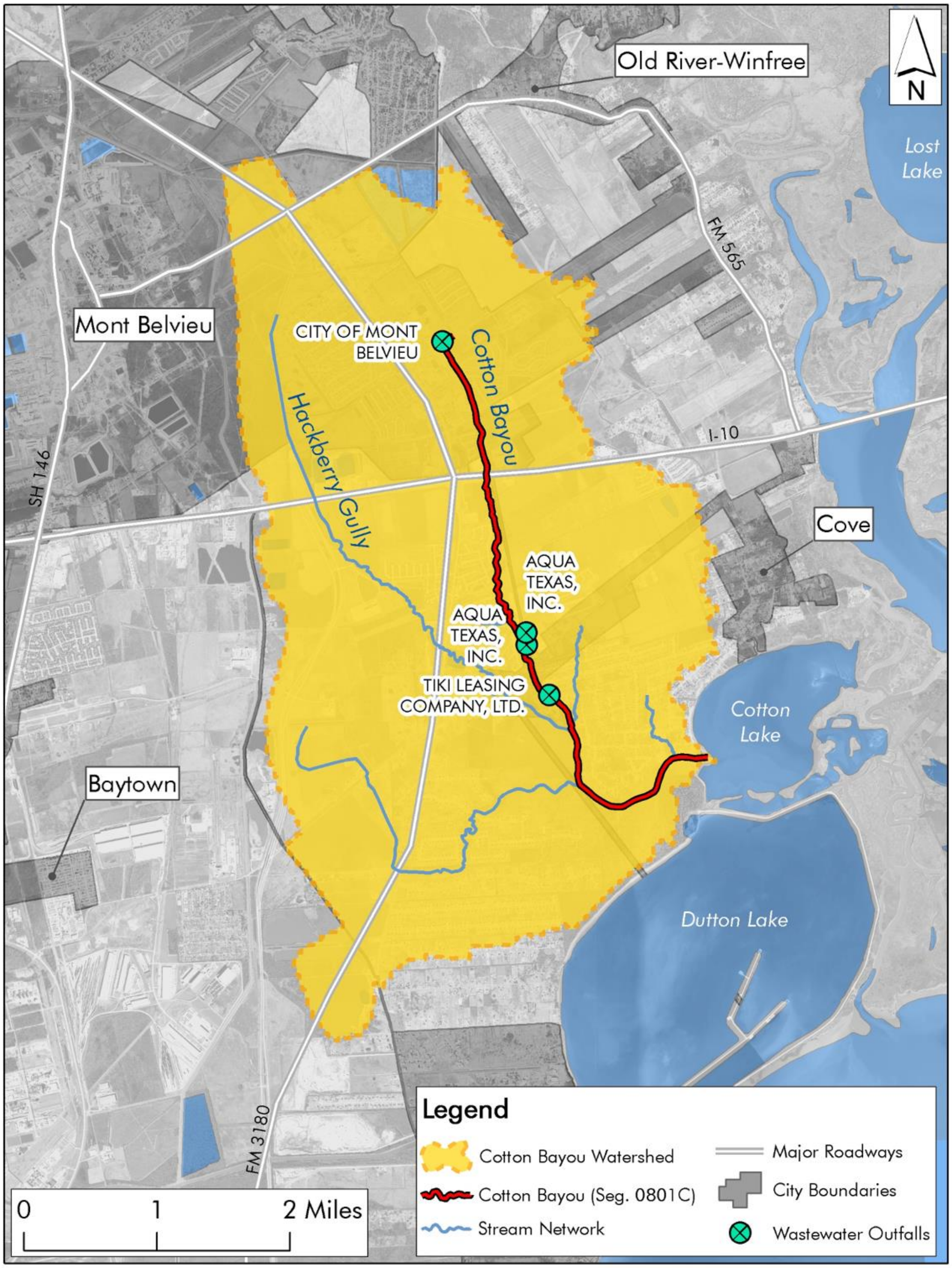

Figure 11. Wastewater Outfalls in the Cotton Bayou Watershed

3.3 Sanitary Sewer Overflow Reports

Data Acquisition

Data from 2012 through 2019 were also assessed for any reports of overflows, leaks, or otherwise unpermitted discharges, which might indicate acute sources of untreated fecal waste in the Cotton Bayou Watershed. Communications with the Region 12 TCEQ office revealed that none of the permitted facilities in the watershed area reported SSOs during this timeframe.

3.4 Ambient Monitoring Data

On Cotton Bayou, surface water quality monitoring stations 18696 and 18697 are being actively monitored. Additional monitoring stations on Cotton Bayou and its tributary, Hackberry Gully have been sampled (Figure 12) but are no longer active. In this report, data from the two active sites will be evaluated for trends in bacteria, total phosphorous, nitrogen (as nitrite + nitrate), and dissolved oxygen collected from grab samples. Analysis of actively monitored sites with long-term data records ensures good representation of current conditions, and context for how conditions have changed over time (Table 7).

Table 7. Years of Available Monitoring Data by Station

Parameter	Years of Available Data (2005 through 2019)	
	Station 18696	Station 18697
Enterococci	14	14
Total Phosphorous	14	14
Nitrite + Nitrate	14	14
Dissolved Oxygen (grab)	14	14

Analysis of Enterococci Data

Cotton Bayou, Segment 0801C, has been considered impaired for bacteria levels since 2010. The EPA-approved 2020 IR notes the Enterococci geomean for this segment from 12/1/2011 through 11/30/2018 as 137.41 cfu/100 mL. Because the SWQMIS dataset assessed in this report covers a longer period of study, the geomeans calculated for the span of the dataset (Table 8) differ from the IR, but continue to exceed the SWQS criterion. The results of quarterly Enterococci measurements for stations 18696 and 18697 are shown in Figure 13 and are marked by a highly variable range of values.

Table 8. Enterococci Results by Monitoring Station, 2005 through 2019

Station	Number of Enterococci Samples	Maximum Value (cfu/100 mL)	Geomean	% Samples in Exceedance
18696	42	24,000	247.5	90.5
18697	47	24,192	105.9	63.8

One limitation of the SWQMIS dataset is the narrow spatial scope of the sample sites. Though the lower half of Segment 0801C is well represented by data from stations 18696 and 18697, no data is available for Cotton Bayou north of Interstate Highway 10. However, due to the frequency of measurements of Enterococci well in excess of the SWQS criterion at both sites throughout the period of record, it can be inferred that water quality impairments persist throughout the watershed.

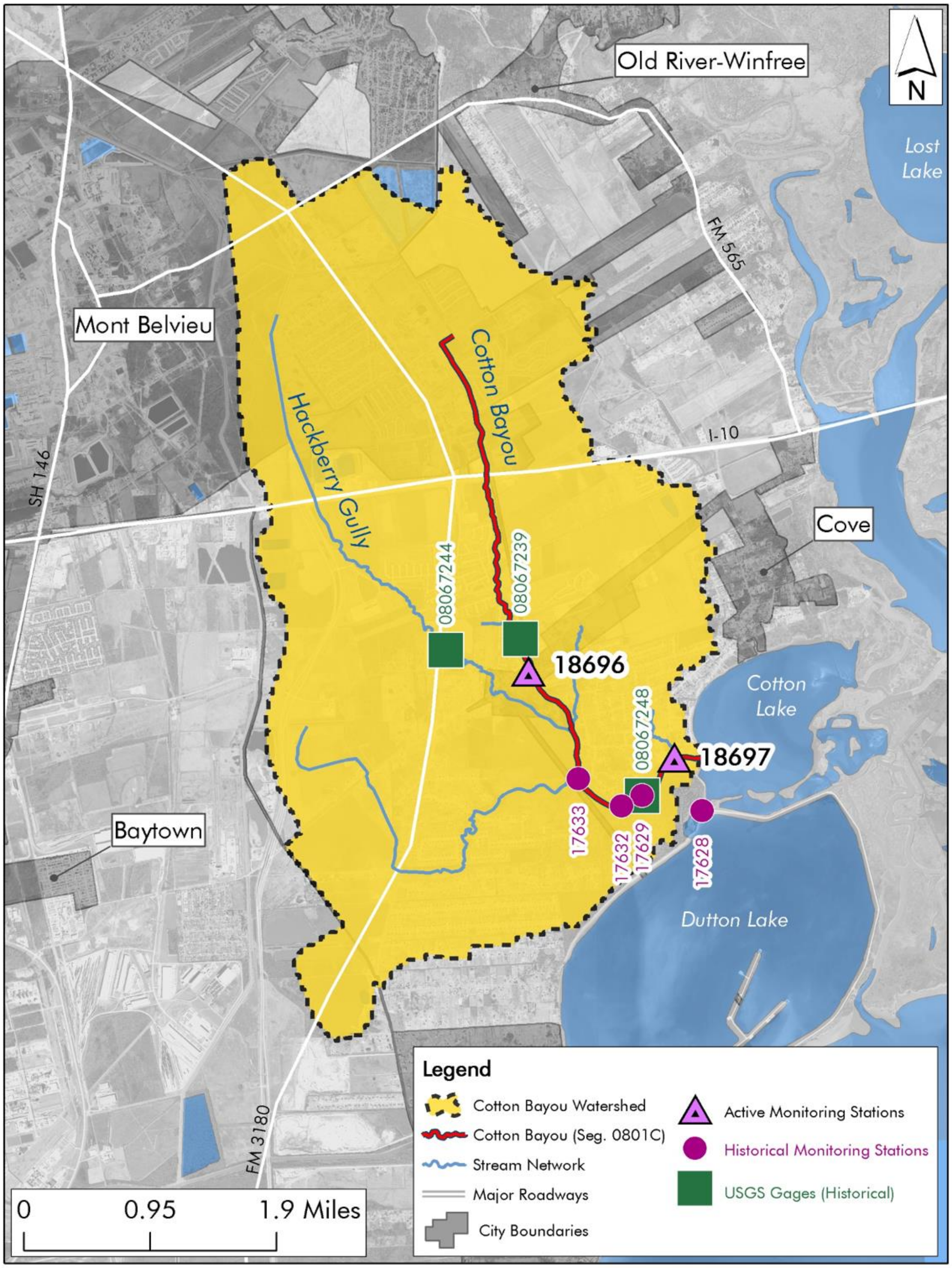

Figure 12. Monitoring Stations in the Cotton Bayou Watershed

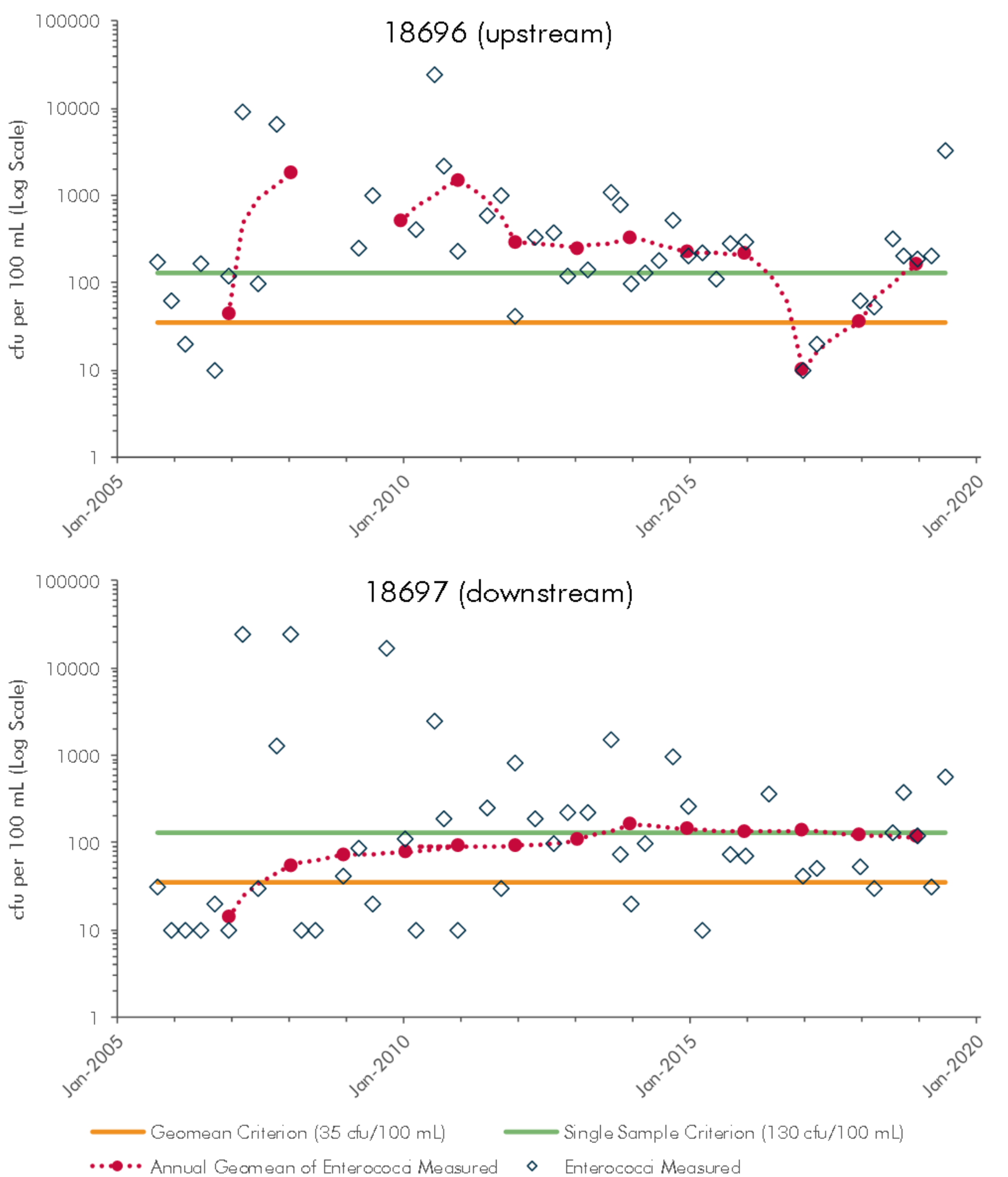

Figure 13. Enterococci Results by Station

Analysis of Other Parameters

While this characterization focuses on Enterococci as indicators of fecal waste, other parameters were evaluated to provide a more detailed understanding of the factors influencing water quality in the Cotton Bayou Watershed. In Table 9, measurements for nitrogen (as nitrite + nitrate), total phosphorous, and dissolved oxygen in exceedance of criteria or screening levels at stations 18696 and 18697 are summarized.

Table 9. Other Water Quality Parameter Analyses

Station	Exceedances of Criteria/Screening Levels by Parameter (*number and percent of total samples*)			
	Nitrogen	Total Phosphorous	Dissolved Oxygen (grab, minimum)	Dissolved Oxygen (grab, screening level)
18696	42 (84.0%)	34 (75.6%)	6 (11.5%)	8 (15.4%)
18697	10 (19.2%)	3 (6.5%)	5 (8.6%)	12 (20.7%)

These data indicate that nitrogen and phosphorous loadings are more extreme at station 18696 (mid-bayou), whereas criteria exceedances for these parameters occur less frequently at station 18697 (confluence with Cotton Lake). Measured values for dissolved oxygen for each station violated criteria and screening levels with comparative frequency. In fact, the 2020 IR notes that aquatic life use in Cotton Bayou is either a concern at the screening level or not supported due to depressed dissolved oxygen levels since 2006.

3.5 Evaluating Flow and Enterococci Loading

Origins of fecal waste indicated by Enterococci in waterways may be informed by the stream flow conditions measured in cubic feet per second (cfs) observed at the time of sample collection. This information is also helpful in determining the strategies that will be most effective in reducing contamination. For example, if fecal bacteria levels are highest in periods of high flows, such as during a flooding event, stormwater flows and other non-point sources are likely to be the major contributors to impairment. If fecal bacteria levels are highest when flows are limited, point sources or sources known to steadily contribute contaminants into waterways are indicated as the greater concern.

To capture how fecal bacteria levels relate to changes in varying flow conditions, as well as comparing observed bacteria measurements against SWQS, load duration curves may be used. Load duration curves compare flow duration curves representing the frequency of different flow magnitudes throughout a known period and standard curves representing the maximum allowable load at the SWQS criterion with observed and modeled bacteria and flow data. By measuring the difference between observed loads and loads deemed acceptable by SWQS, the amount of load reduction needed to bring water quality into compliance can be determined.

Data Acquisition

To calculate load duration curves for the Cotton Bayou Watershed, stream flow data from USGS and Enterococci data from SWQMIS were used. USGS gage data is ideal to produce flow duration curves due to the long-term, continuous measurements recorded by the gages. As discussed in Section 3, SWQMIS data for Enterococci levels have been collected regularly in the Cotton Bayou Watershed at stations 18696 and 18697 since 2005. Historically, USGS gages 08067244 and 08067248 corresponded to stations 18696 and 18697, respectively, but have not actively produced flow measurements since 2007. Contextually, this data is important for quantifying what flows have been observed at these stations in the past and how they compare to current flows measured on USGS gages on nearby stream segments. These comparisons led to the selection of USGS gage 08067525 on Goose Creek in Baytown, Texas, as a proxy for modeling stream flow comparable to that of Cotton Bayou. Modeled flow data was further adjusted using a ratio of drainage area upstream of the Goose Creek USGS gage to drainage area upstream of each Cotton Bayou station to be more reflective of the conditions unique to the Cotton Bayou Watershed. These methods are based on the more stringent data requirements of other formal watershed-based planning efforts and are therefore sufficient for the conceptual nature of this analysis.

Load Duration Curves for Cotton Bayou

Each load duration curve developed for this report represents the five streamflow categories shown in Table 10.

Table 10. Stream Flow Categories for Load Duration Curve Analyses

Flow Condition	Percentage of Study Period Days Flow Condition Observed
High Flows	< 10
Moist Conditions	< 40
Mid-Range Flows	< 60
Dry Conditions	< 90
Low (Minimum) Flows	90-100

Based on the percentage of days during the study period, flows of a known magnitude are observed, and a flow duration curve is developed and plotted. To this plot, curves resulting from the multiplication of the criteria for Enterococci (geomean of 35 cfu/100 mL and single-sample of 130 cfu/100 mL) by the values of the flow duration curve are added to represent the maximum allowable contaminant loads during each flow condition. Finally, individual observed Enterococci levels collected during the study period and a curve modeled from these observations (load regression curve) are plotted. For areas where the load regression curve exceeds the maximum allowable contaminant load curve, reductions are needed.

At the upstream station (18696), the load duration curve modeled from observed data exceeds the curve representing the geomean maximum in all flow conditions (Figure 14). This indicates that both point and non-point sources are influencing the bacteria impairment at this site and that reductions are needed for all flow conditions.

At the downstream station (18697), the load duration curve modeled from observed data exceeds the curve representing the geomean maximum in all flow conditions except low flow conditions (Figure 15). This indicates that non-point sources are a stronger driver of bacteria impairment at this site. While reduction strategies targeting improvement of non-point source pollutants will benefit this site more directly, improvements to both point and non-point source loading will positively affect the watershed.

Based on these results, potential reduction targets for Enterococci loads at each flow condition are detailed in Table 11.

Table 11. Potential Fecal Indicator Bacteria Reductions Needed by Station

Station	High Flow (%)	Moist Conditions (%)	Mid-Range Flow (%)	Dry Conditions (%)	Low Flow (%)
18696	97.5	92.2	86.5	81.1	73.9
18697	98.8	88.0	65.3	36.3	--

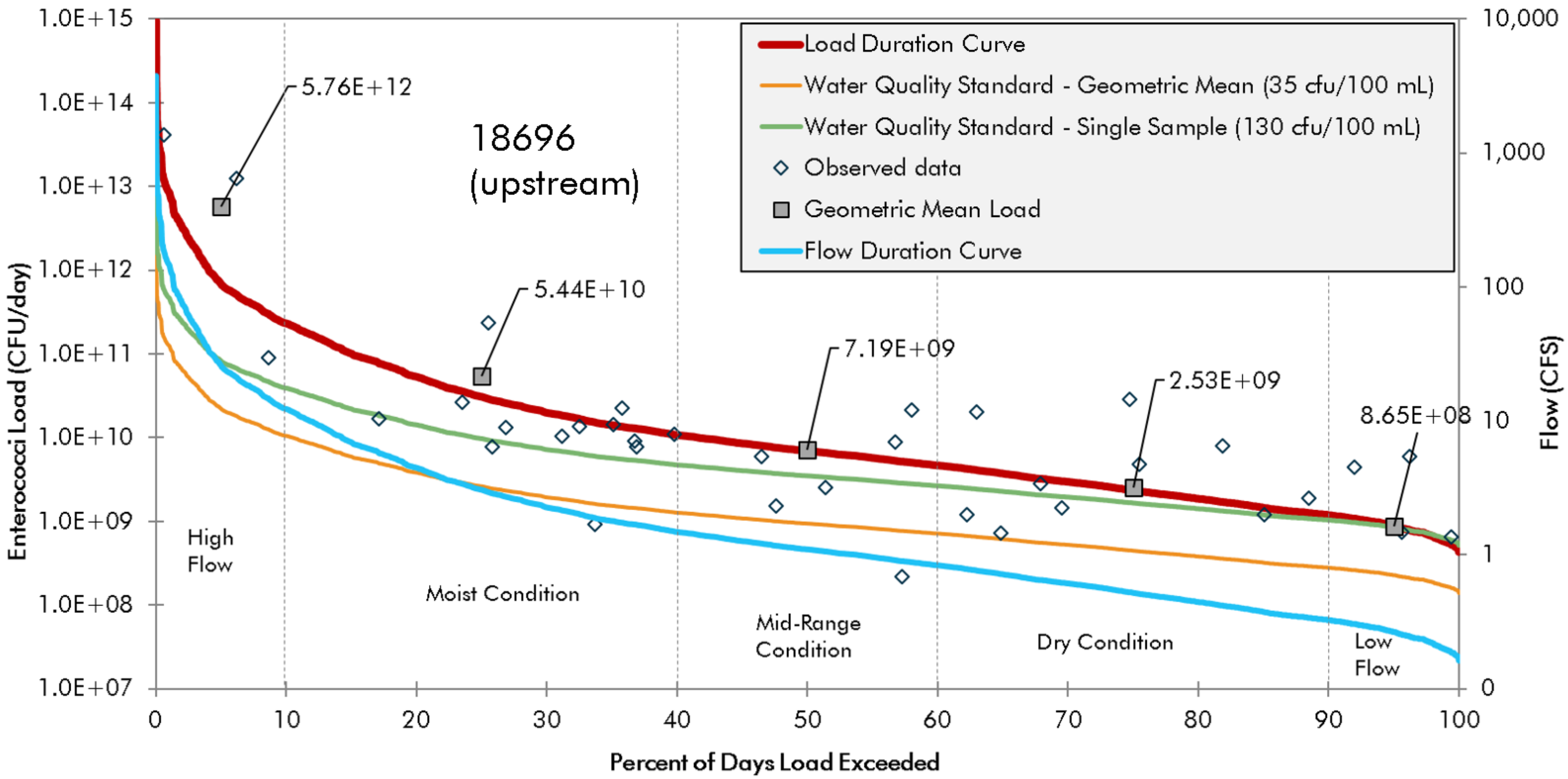

Figure 14. Load Duration Curve Analysis of Enterococci at Station 18696

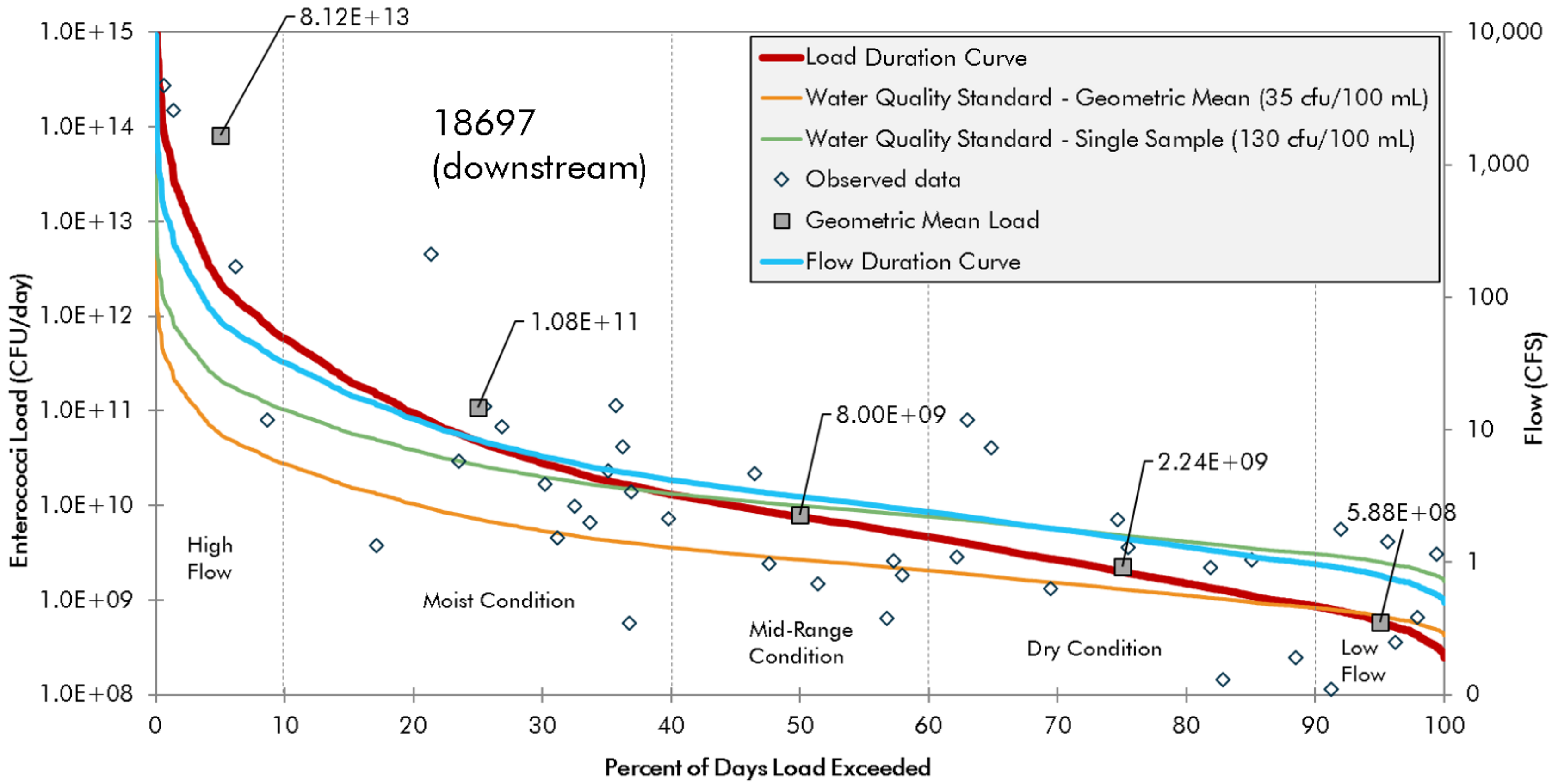

Figure 15. Load Duration Curve Analysis of Enterococci at Station 18697

Section 4: Potential Sources of Contamination

4.1 Identifying Potential Sources

While load duration curves are useful for estimating source loading under different flow conditions in a watershed and providing insight into whether high fecal bacteria levels are the result of point or non-point loading, identifying more specific sources of contamination requires further investigation. In order to understand the bacterial loading pressures affecting the Cotton Bayou Watershed, data from sources such as the USDA, Texas Parks and Wildlife Department (TPWD), DMRs, and SSO reports were used in addition to ground reconnaissance and stakeholder feedback to generate a survey of known sources of fecal waste[3]. These results are summarized in Table 12. General categories for these pressures include human, domestic animal, agricultural animal, and wildlife sources, which can be further generalized into categories of regulated and unregulated sources. These distinctions can arise from differences in contaminant delivery into waterways. For example, discharges from WWTFs are regulated, whereas direct depositions from wildlife are unregulated.

Table 12. Potential Source Survey

Potential Source	Means of Measurement
Sanitary Sewer Overflows (SSOs)	SSO reports; DMR data; land application projects
Onsite Sewage Facilities (OSSFs)	presence of OSSF database (permitted); presence of houses outside sanitary service areas (recon., aerials, feedback)
Domestic Pets	literature value[4] and household data (1.6 dogs per household)
Livestock	USDA data[5]; stakeholder feedback
Feral Hogs	literature value based on land cover from Texas A&M; stakeholder feedback
Other Wildlife	literature values from TPWD (deer); anecdotal (other wildlife)
Landfills	regulatory compliance; stakeholder feedback
Illegal Dumping	anecdotal

[3] All information in this section is based on potential sources. Any discussion of links to observed conditions is intended as conceptual in nature. No specific load models or fate and transport considerations for bacteria sources were developed. Further consideration may be part of future efforts to develop TMDL(s) or other formal watershed planning efforts.
[4] Referenced at www.avma.org/KB/Resources/Statistics/Pages/Market-Research-Statistics-US-Pet-Ownership.aspx.
[5] Referenced at https://www.nass.usda.gov/AgCensus/.

Throughout the watershed, potential sources of fecal waste contamination are fairly evenly distributed. When considering spatially unique combinations of land cover types, more variation in source profiles will be distinguished from the overall mix of sources present in the total watershed area.

The source estimations formed in this report are reflective of currently observed sources and do not account for future growth and development in the watershed. This will also limit the scope of the estimations, in that they will not account for changes in stream flow that correspond to increased development, such as increased stormwater runoff and reduced capacity for filtration of contaminants. Further, as the focus of this report is the characterization of contamination by fecal waste, source analyses for nutrients (agriculture and landscaping), sediments (erosion and development), or other impacts to aquatic habitat or species profundity (pesticide use and changes in hydrology) are not included. Strategies developed for addressing water quality challenges in a more comprehensive way will need to consider these additional and often compounding stressors moving forward.

4.2 Regulated Sources

The Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs regulate permitted wastewater and stormwater discharges from sources such as industry, construction, and multiple separate storm sewer systems (MS4s). Prevalence of these potential sources of fecal waste contamination in the Cotton Bayou Watershed are discussed in further detail below.

Domestic and Industrial Wastewater Treatment Facilities

Within the watershed area, only three permitted facilities discharge into Cotton Bayou (Table 5). Only one of these outfalls, the Tiki Leasing Company, LTD is monitored for the fecal indicator bacteria Enterococci. From 2012 through 2019, no exceedance of the geomean criterion has been observed. However, it is important to note that the other two facilities further upstream on Cotton Bayou have reported exceedance of the geomean criterion for freshwater fecal indicator bacteria. Human waste sources represent an elevated risk to public health; therefore, these contributions to the total waste load in the Cotton Bayou Watershed are of specific concern.

Sanitary Sewer Overflows

No SSOs were reported within the watershed from 2012 through 2019. While they do not represent an appreciable contribution to the waste load in the Cotton Bayou Watershed, they have been known to represent acute, periodic loading in similar study areas.

Dry Weather Discharges/Illicit Discharges

Permittees reporting on the water quality of outfalls must report dry weather and illicit discharges in addition to SSOs more commonly observed in high flow conditions. Examples of these include leaking sanitary sewers leaching into storm sewers, failing OSSFs leaking into storm sewers, connections between a municipal sanitary sewer and storm sewer, and home sanitary pipes connected directly to storm sewers. No known data were available for these sources in the Cotton Bayou Watershed.

TCEQ/TPDES Water Quality General Permits

TCEQ regulates certain types of facilities that process wastewater, some of which potentially contain fecal waste. General wastewater permit types include:

- TXG110000 – concrete production facilities,
- TXG130000 – aquaculture production facilities,
- TXG340000 – petroleum bulk stations and terminals,
- TXG670000 – hydrostatic test water discharges,
- TXG830000 – water contaminated by petroleum fuel or petroleum substances,
- TXG870000 – pesticides (application only),
- TXG920000 – concentrated animal feeding operations,
- WQG100000 – wastewater evaporation, and
- WQG200000 – livestock manure compost operations.

After reviewing the TCEQ Central Registry[6] for active permit coverage in the Cotton Bayou Watershed, two general permits were found. Both are registered to Chevron Phillips for a facility located in Mont Belvieu. These permits regulate hydrostatic test water discharges. While this facility is regulated for petrochemical pollutants, there is no bacteria criteria associated with the permits. No other active general permit facilities or operations were found.

TPDES-Regulated Stormwater

As with wastewater, stormwater can be regulated in Phase I or II urbanized areas, industrial facilities, construction sites, and other facilities. With the exception of Phase I permits, which are individual, these can be covered under the following TPDES general permits:

- TXR040000 – Phase II MS4 general permit for small MS4s located in urbanized areas,
- TXR050000 – multi-sector general permit (MSGP) for industrial facilities, and

[6] TCEQ Water Quality General Permits and Registration Search (https://www2.tceq.texas.gov/wq_dpa/index.cfm) accessed March 27, 2020

- TXR150000 – construction general permit from construction activities distributing one acre or more.

A review of the TCEQ Central Registry indicates the only active stormwater general permit is registered to the City of Mont Belvieu Phase II MS4. Of the total 15.32 square miles covered by the MS4 service area boundary, 23.92% (3.67 square miles) fall within the watershed boundary.

4.3 Unregulated Sources

Non-point sources of fecal waste are often unregulated because they come from diffuse accumulations rather than a single discrete source. OSSFs, certain agricultural activities, land application fields, urban runoff not covered under a permit, pet waste, and wildlife waste are examples of unregulated sources.

Onsite Sewage Facilities

Rural and low-density suburban residences and stand-alone commercial and industrial businesses within a city or county's extraterritorial jurisdiction are more likely to use owner-operated OSSFs—often referred to as septic systems. These systems can also be more modern aerobic systems or other onsite treatment technologies. Some OSSFs in the watershed are operated under permit; however, some units are unregistered or not consistently reported. For the purposes of this report, all OSSFs will be treated as unregulated sources of fecal waste due to the nature of their permits, lack of reported data, and diffuse nature.

Within the Cotton Bayou Watershed, 212 permitted OSSFs have been documented (Figure 16). Unpermitted OSSF locations were estimated using H-GAC's geographic information database of potential OSSF locations in the Houston-Galveston area using known OSSF locations, county parcel data, and WWTF service boundaries. An estimated additional 143 OSSFs added to the 212 permitted systems equal a total of 355 units.

OSSFs can be an appreciable source of fecal waste when not sited or functioning properly, especially when they are in close proximity to waterways. Many factors including soil type, design, age, and maintenance can influence the likelihood of an OSSF failure. Literature values suggest that failure rates for OSSFs in Texas occur at a rate of approximately 12%[7]. By applying this estimate of failure rates to the number of OSSFs estimated in the watershed area, 43 OSSFs are projected to be failing. As with WWTFs, failing OSSFs are of specific concern to water quality due to the increased health risk posed by human fecal waste.

[7] Reed, Stowe, and Yanke, LLC. 2001. Study to determine the magnitude of, and reasons for, chronically malfunctioning onsite sewage facility systems in Texas. Texas Onsite Wastewater Treatment Council.

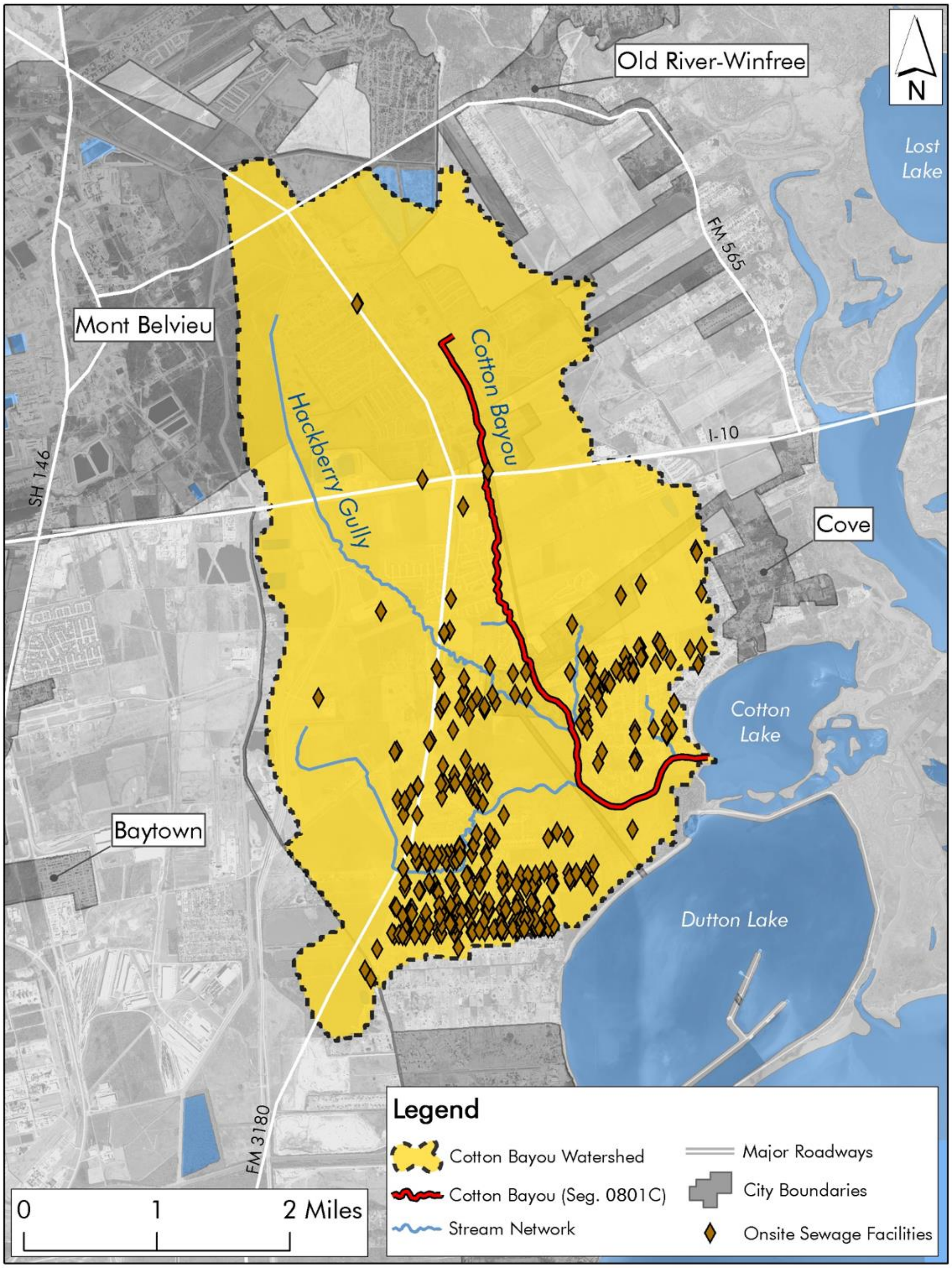

Figure 16. Permitted Onsite Sewage Facilities in the Cotton Bayou Watershed

Agriculture

Agricultural land constitutes the majority of land cover in the Cotton Bayou Watershed. Fecal waste from livestock such as cattle, pigs/hogs, sheep, goats, horses, and poultry can be introduced through direct deposition and as runoff from manure used in crop fertilization. While there are no permitted concentrated animal feeding operations in the Cotton Bayou Watershed, livestock and other agricultural pressures should be considered in estimating bacterial source loads.

In Table 13, estimates of livestock in the Cotton Bayou Watershed are shown. These estimations were calculated by applying a ratio of watershed land area compared to county land area (2.56%) to numbers from the 2017 Census of Agriculture for Chambers County performed by the USDA. This calculation assumes equal distribution of livestock and farm operations throughout Chambers County.

Table 13. Agricultural Animal Populations in the Cotton Bayou Watershed

Farms	Cattle	Pigs/Hogs	Sheep	Goats	Poultry	Horses[8]
14	608	2	12	14	33	21

While there are no reliable estimates for volumes of manure spread over agricultural land for crop production, much of the manure used in those operations is sourced from the animals represented above. Therefore, no further analysis for this concern was pursued for this report.

Domestic Pets

In urban and rural settings, pet waste can contribute to high fecal bacteria levels through direct deposition and runoff. Domestic pet waste is unregulated; therefore, load estimates rely heavily on pet ownership statistics provided by the American Veterinary Medical Association (AVMA) and feedback from local stakeholders. Due to the higher likelihood of direct deposition into the watershed area associated with dog waste, dogs are the primary concern when estimating the impact of domestic pets in a watershed. The AVMA determined that dog ownership is prevalent in 38.4% of national households. Each of the households in that subset are estimated to have an average of 1.6 dogs in residence. These assumptions were applied to 2018 census data and regional growth forecast data for 2045 and are represented in Table 14 below.

[8] Agricultural census data may not fully reflect horse populations in the watershed, as non-farm horses are not fully accounted for (*e.g.* equestrian horses, etc.).

Table 14. Dog Population Estimates in the Cotton Bayou Watershed

Statistic	2018	2045
Total Households	1,182	3,368
Dog Owning Households	454	1,293
Dogs	726	2,069

These estimates do not weigh households differently according to development and assume equivalence between urban and rural households.

Wildlife and Invasive Animals

Wildlife fecal waste can impact waterways through direct deposition and stormwater runoff. As the fecal indicator bacteria Enterococci are known to be present in the intestines of warm-blooded animals, they will be the focus in this report.

Most avian and mammalian wildlife including invasive species are difficult to estimate, as long-term monitoring data or literature values indicating historical baselines are lacking. However, the White-Tailed Deer Program of the TPWD estimates deer populations for their Resource Management Units. In the ecoregion surrounding Cotton Bayou, TPWD deer population estimates recorded from 2008 through 2019 average 1 deer for every 216.7 acres. By applying this factor to the acreage in the Cotton Bayou Watershed, the white-tailed deer population can be estimated at 68.

Feral hogs are a non-native, invasive species, which likely impact the watershed with fecal waste contamination. Like deer, factors for estimating feral hog populations based on land area are available. These factors vary depending on land cover types and range between 1.3 and 2.45 hogs per square mile. Feral hog population estimates may be weighted more heavily in riparian areas where animals are protected from the stresses associated with development and have more direct access to water resources. Considering these factors, in addition to insights from local stakeholders, feral hog populations were estimated to be 1.3 per square mile in low intensity development, 2 per square mile in developed open space, bare land, and cultivated land, 2.45 per square mile in grasslands, forests, and wetlands, and no hogs in developed areas or open water (Table 15).

Table 15. Wildlife and Invasive Species in the Cotton Bayou Watershed

Animal	Population
Deer	68
Feral Hogs	31

Section 5: Findings and Recommendations

5.1 Summary

The Cotton Bayou Watershed covers an area in western Chambers County historically covered by a majority of natural land cover types. However, this area, along with many others in the greater Houston region, is expected to experience more development as its population expands by 167% in the next 25 years. This growth will impact water dynamics in the watershed as well as water quality. As water quality in this area is currently impaired due to high levels of the fecal indicator bacteria Enterococci, it is critical to develop a framework for reducing contaminant loads in order to ensure a safer, more productive future for the inhabitants and environment of the Cotton Bayou Watershed.

5.2 Findings and Recommendations

Data Analyses

Analyses of WWTF data, ambient water quality monitoring data, and estimates of unregulated sources of bacteria loading in the Cotton Bayou Watershed indicate that Cotton Bayou is impacted by pressures from both human communities and the natural environment. While water quality concerns for a variety of parameters are prevalent in the watershed—especially in the case of high nutrient levels and low dissolved oxygen—high levels of the fecal indicator bacteria Enterococci are the primary sources of impairment in Cotton Bayou.

According to load duration curve analyses, bacteria loads in the bayou are well above the SWQS criteria at nearly all levels of flow. Bacteria reductions in excess of 65% are needed throughout the water body at mid-range, moist, and high flow conditions. This indicates that non-point source load pressures are of particular concern in this watershed and should be central to the development of future water quality improvement strategies. However, point sources should also be considered as targets for improvement, as load duration curve results indicated considerable point source influence on bacteria loads at the upstream station on the bayou in dry and low flow conditions. Ultimately, strategies for reducing bacteria loads delivered to the waterway by non-point and point sources will benefit overall water quality throughout the watershed.

Stakeholder Involvement

Reducing fecal bacteria in the waterways of the Cotton Bayou Watershed requires the development of a robust reduction plan combining knowledge gained from rigorous data analyses, as well as the input of local watershed stakeholders. In the spring of 2020, stakeholders from the watershed participated in the first of a series of meetings to review the characterization assessment and offer insight regarding how accurately the preliminary analyses and estimations reflected conditions in the watershed. At this meeting, watershed stakeholders shared insights about freshwater conditions observed in the Cotton Bayou waterway and expressed an interest in evaluating whether the segment is accurately represented by its current classification as a tidal stream. This prompted H-GAC to conduct a more robust statistical analysis of the ambient data from the two active stations referenced in this report, as well as available data recorded at historical stations. This analysis revealed a significant difference in salinity and specific conductance values recorded at stations 18696 and 18697. Salinity and specific conductance data from the downstream station (18697) indicated tidal influence, especially in periods of low flow. A closer examination of the historical stations showed salinities indicative of tidal influences as far upstream as station 17629. However, salinities recorded at the upstream station (18696) remained at or below two throughout the period of record. Further, biological data collected upstream of station 18696 indicated the presence of freshwater species. At the time of this report, TCEQ is in discussions to formally split Segment 0801C into tidal and above-tidal AUs based on this analysis. As a result of this, field operations from TCEQ Region 12 will discontinue sampling for Enterococci at station 18696 and will begin monitoring surface water for the freshwater fecal indicator bacteria *E. coli*.

It is unclear at this time how this change will affect the impairment status of Cotton Bayou. Statistical analyses of water quality parameters show that concentrations of Enterococci have been historically high and remain higher than the SWQS criteria at both the downstream and upstream active monitoring stations on the waterway. Dissolved oxygen levels monitored at stations 18696 and 18697 are also similar, but nutrients are much higher at the upstream station compared to the downstream station (Table 9).

Conclusions

Whether the impairment status of Cotton Bayou is extended to an additional freshwater AU in the future or restructured to pertain only to the tidal portion of the waterway, the associated development of a TMDL and a plan to implement water quality improvements will ultimately benefit the entire watershed area. Therefore, the findings in this report support the continuation of the TMDL development process for Cotton Bayou and its surrounding watershed. The next step in this process would be for H-GAC to develop a technical support document detailing calculations determining the TMDL thresholds for the watershed. Using this information, area stakeholders would be empowered to determine the necessary steps to achieve bacteria reductions and improve water quality in Cotton Bayou and its tributaries. The culmination of this step would result in the development of a formal implementation plan.