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One Total Maximum Daily Load for Indicator Bacteria in Carancahua Bay

Segment 2456

Assessment Unit 2456_02

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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"Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Carancahua Bay"
prepared by the Texas Institute for Applied Environmental Research

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Abbreviations

AU	assessment unit
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming units
DAR	drainage-area ratio
DMU	Deer Management Unit
DSLP	days since last precipitation
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FDC	flow duration curve
FG	future growth
ft^3	cubic feet
GIS	geographic information system
I&I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
MGD	million gallons per day
mi^2	square miles
mL	milliliter
MOS	margin of safety
MSGP	multi-sector general permit
MS4	municipal separate storm sewer system
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODEQ	Oregon Department of Environmental Quality
OSSF	on-site sewage facility
ppt	parts per thousand
SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWQM	surface water quality monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research

TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TSSWCB	Texas State Soil and Water Conservation Board
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
UA	urbanized area
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WQBEL	water quality-based effluent limit
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility
WUG	Water User Group

One TMDL for Indicator Bacteria in Carancahua Bay

Executive Summary

This document describes a total maximum daily load (TMDL) for Carancahua Bay where concentrations of indicator bacteria exceed the criteria used to evaluate attainment of the primary contact recreation use. This TMDL takes a watershed approach to address the indicator bacteria impairment. The Texas Commission on Environmental Quality (TCEQ) first identified the impairment to Carancahua Bay in the *2006 Texas Water Quality Inventory and 303(d) List* (TCEQ, 2007) and then in each subsequent edition through the latest EPA approved edition, now known as the *2018 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (Texas Integrated Report) (TCEQ, 2019a).

Only one facility [City of La Ward Wastewater Treatment Facility (WWTF)] treats domestic wastewater and is authorized to discharge into the impaired watershed. Regulated stormwater coverage comprises a very small amount (0.16 percent) of the Carancahua Bay assessment unit (AU) 2456_02 watershed. There are no Phase I or Phase II municipal separate storm sewer systems (MS4s) or industrial permittees authorized to discharge stormwater. The area included within past and active construction permits in the watershed was used to estimate the area under stormwater regulation.

Escherichia coli (*E. coli*) are widely used as indicator bacteria to assess attainment of the contact recreation use in freshwater bodies, while Enterococci are used as the indicator bacteria in saltwater. Enterococci are the relevant indicator for the Carancahua Bay segment, because it is saltwater. The criteria for assessing attainment of the contact recreation use are expressed as the number (or "counts") of Enterococci, typically given as colony forming units (cfu). The primary contact recreation use is not supported when the geometric mean exceeds 35 cfu per 100 milliliters (mL) or when the single sample criterion of 130 cfu per 100 mL is exceeded 20% of the time as described in TCEQ's Guidance for Assessing and Reporting Surface Water Quality in Texas as amended.

Only one recently monitored TCEQ surface water quality monitoring (SWQM) station (13388) had sufficient Enterococci data for assessment of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2015). A geometric mean of 123.82 cfu/100 mL for Enterococci was calculated (for a seven-year period from December 1, 2005, through November 30, 2012),

which exceeded the geometric mean criterion of 35 cfu/100 mL and resulted in non-support of the primary contact recreation use. The impaired status was carried forward to the 2016 Texas Integrated Report due to the lack of available Enterococci samples for re-assessment.

A modified load duration curve (LDC) analysis [Oregon Department of Environmental Quality (ODEQ), 2006] adapted to the Carancahua Bay AU 2456_02 was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources of bacteria. The wasteload allocation (WLA) for WWTFs was established as the full permitted discharge flow rate multiplied by the instream geometric criterion. Future growth (FG) of existing or new domestic point sources was determined using population projections.

For the Carancahua Bay AU 2456_02 watershed, unregulated nonpoint sources such as wildlife (avian and non-avian), feral animals, agricultural animals, agricultural activities, land application fields, urban runoff not covered by a permit, failing on-site sewage facilities (OSSFs), and domestic pets are the most likely sources of bacteria loadings during high flow conditions. The sources of bacteria loadings occurring under lower flow conditions and in the absence of overland flow contributions (i.e., without stormwater contribution) are expected to emanate from direct deposition sources such as wildlife (avian and non-avian), feral animals, and livestock.

The TMDL calculations in this report will guide determination of the assimilative capacity of the water body under changing conditions, including FG. Future wastewater discharge facilities will be evaluated on a case-by-case basis.

Compliance with this TMDL is based on keeping the indicator bacteria concentrations in the selected waters below the geometric mean criterion of 35 cfu/100 mL.

Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a TMDL for each pollutant that contributes to the impairment of a listed water body. TCEQ is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget — it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program can address impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses — such as drinking water supply, recreation, support of aquatic life, or fishing — of impaired or threatened water bodies.

This TMDL addresses the impairment of the primary contact recreation use due to exceedance of the geometric mean criterion for Enterococci in Carancahua Bay AU 2456_02. Carancahua Bay (Segment 2456) is delineated into two AUs, with the upper portion of the bay identified as AU 2456_02 and the lower portion designated as AU 2456_01. The upper portion of the bay, AU 2456_02, is the only impaired AU within Segment 2456. This document will, therefore, consider a bacteria impairment in one AU of one segment:

- Carancahua Bay (AU 2456_02)

The Carancahua Bay AU 2456_02 watershed drains 204,242 acres [319 square miles (mi^2)] and includes portions of Calhoun, Jackson, Wharton, and Matagorda counties.

This TMDL takes a watershed approach to address the bacteria impairment. While TMDL allocations were developed only for the impaired AU identified in this report, the entire project watershed (Figure 1) and all regulated dischargers that discharge within it are included within the scope of this TMDL.

Section 303(d) of the Clean Water Act and the implementing regulations of the United States Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations (CFR), Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

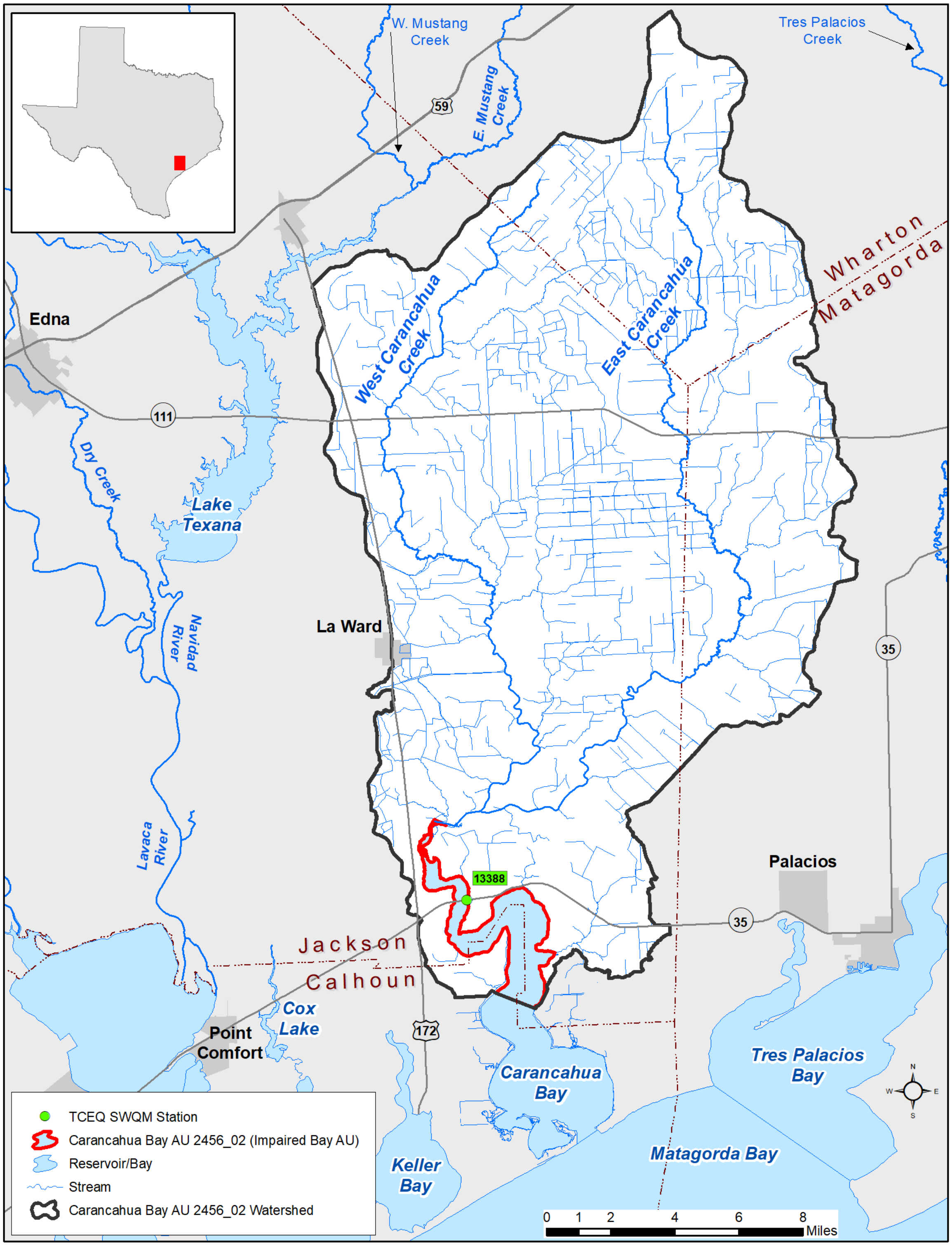

Figure 1. Overview map showing Carancahua Bay AU 2456_02 watershed and TCEQ SWQM monitoring station.

The TCEQ must consider certain elements in developing a TMDL. They are described in the following sections of this report:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Margin of Safety
- Pollutant Load Allocation
- Seasonal Variation
- Public Participation
- Implementation and Reasonable Assurance

Upon adoption of the TMDL report by the TCEQ and subsequent EPA approval, this TMDL will become an update to the state's Water Quality Management Plan (WQMP).

Problem Definition

The TCEQ first identified the bacteria impairment within Carancahua Bay AU 2456_02 in the *2006 Texas Water Quality Inventory and 303(d) List* (TCEQ, 2007) and then in each subsequent edition through the latest EPA approved edition, now known as the 2018 Texas Integrated Report (TCEQ, 2019a).

This document will, therefore, consider the bacteria impairment in one AU of one segment: Carancahua Bay (AU 2456_02).

Ambient Indicator Bacteria Concentration

Routine monitoring in AU 2456_02 with sufficient Enterococci samples for assessment (minimum of 20 samples) has occurred at only one TCEQ SWQM station (13388; Table 1 and Figure 1). Enterococci data collected at station 13388 over the seven-year period of December 1, 2005, through November 30, 2012, were used to determine support of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2015). The 2016 Texas Integrated Report carried forward the non-support status of the primary contact recreation use due to limited data collected during the assessment period (TCEQ, 2018a). The 2018 Texas Integrated Report assessment data indicate non-support of the primary contact recreation use due to exceedance of the geometric mean criterion and the single sample criterion of 130 cfu/100 mL (TCEQ, 2019a). As a result of revisions to bacteria criteria in the 2018 Texas Surface Water Quality Standards (TSWQS), recreation uses in coastal recreation waters, which includes bays designated as primary contact recreation, are assessed with both geometric mean and single sample criteria (TCEQ, 2018b).

Table 1. 2014 Integrated Report summary for the impaired AU 2456_02.

Water Body	AU	Parameter	Station	Data Date Range	Number of Samples	Geometric Mean (cfu/100 mL)
Carancahua Bay	2456_02	Enterococci	13388	Dec. 1, 2005 - Nov. 30, 2012	20	123.82

Watershed Overview

Carancahua Bay is located along the Texas Gulf Coast midway between the cities of Palacios and Port Lavaca, with portions of the bay in Calhoun and Jackson counties (Figure 1). Carancahua Bay is comprised of two AUs, with the upper portion of the bay designated as AU 2456_02 and the lower portion designated as AU 2456_01 (Figure 1). The impaired AU 2456_02 has a surface area of 4,503 acres (seven mi^2). Two unclassified creeks, West Carancahua Creek (Segment 2456A) and East Carancahua Creek (no segment number assigned), merge immediately upstream of the confluence with Carancahua Bay AU 2456_02 and provide most of the streamflow into Carancahua Bay.

Carancahua Bay AU 2456_02 drains 204,242 acres (319 mi^2) with portions of the watershed in Calhoun (1.5 percent), Jackson (64.5 percent), Matagorda (16.7 percent), and Wharton (17.3 percent) counties.

Watershed Climate and Hydrology

The Carancahua Bay AU 2456_02 watershed is located in the southeast portion of the state of Texas along the Gulf of Mexico coastline (Figure 1) and falls within the subtropical humid climate region as classified by Larkin & Bomar (1983). This regional climate is characterized as a modified marine climate including warm summers with the occasional invasion of drier, cooler continental airflow offsetting the prevailing flow of tropical maritime air from the Gulf of Mexico (Larkin & Bomar, 1983).

As depicted in Figure 2, for the most recent 15-year period from 2002–2016 at the nearest National Oceanic and Atmospheric Administration (NOAA) weather station (Palacios Municipal Airport - USW00012935) located approximately eight miles east of AU 2456_02, average high temperatures generally peak in August (92.1˚F) (NOAA, 2017). During the winter, the average low temperature is 45.5˚F in January. Additionally, September (5.8 inches) is indicated to be the wettest month with February (1.6 inches) observed to be the driest month.

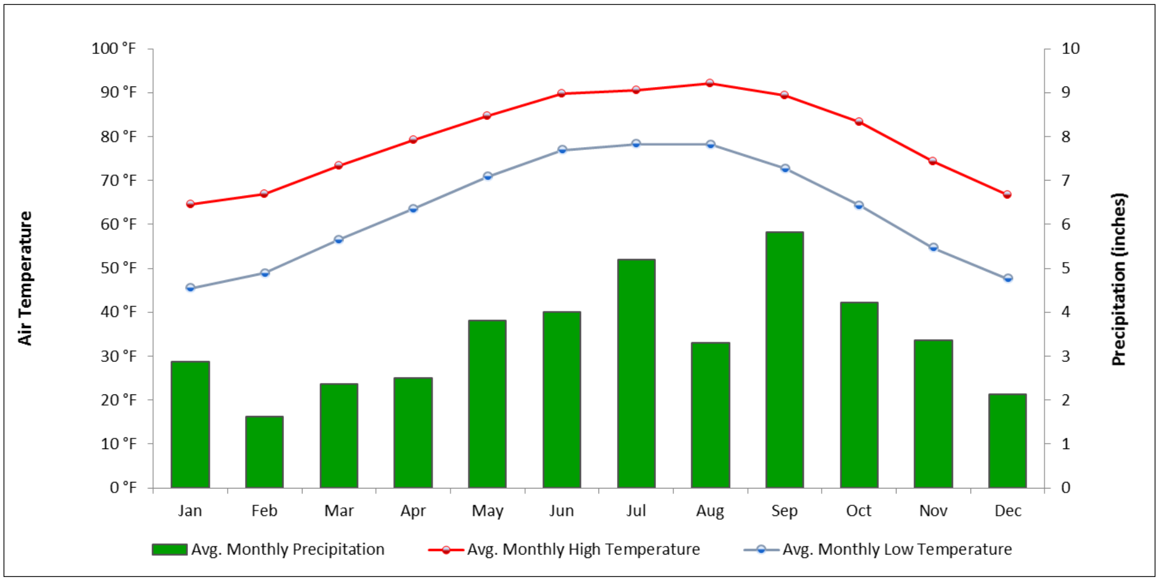

Figure 2. Average minimum and maximum air temperatures and average precipitation by month from 2002-2016 for the Palacios Municipal Airport.

Watershed Population and Population Projections

As depicted in Figure 3, the Carancahua Bay AU 2456_02 watershed lies within portions of Calhoun, Jackson, Wharton, and Matagorda counties. One municipal boundary (La Ward) lies partially within the watershed. According to data utilized from the 2010 United States Census Bureau (USCB), there are an estimated 1,883 people within the watershed, revealing an average population density of approximately six people/mi^2 (USCB, 2017). Of those, an estimated 104 people (5.5 percent) are located within the City of La Ward, indicating that the watershed population is mostly rural. Figure 3 provides a depiction of the population density per acre of the Carancahua Bay AU 2456_02 watershed.

Watershed population (USCB, 2017) and population projections from the Texas Water Development Board (TWDB) were obtained by Texas Institute for Applied Environmental Research (TIAER) to complete the population projection exercise. The steps of the population projection exercise are provided in Appendix B. The exercise indicates a population increase of 14.6 percent in the Carancahua Bay AU 2456_02 watershed by 2050 based on Water User Groups (WUGs) (TWDB, 2015). The 2010-2050 WUG population projection increases range from 10.2 percent to 52.2 percent. The largest population percent increase over the 40-year span is anticipated to occur in the portion of the Carancahua Bay AU 2456_02 watershed that lies within Calhoun County, but that area only contributes 24 additional people by 2050. The City of La Ward population within the study area is projected to increase by 11 people by 2050. The Jackson County-Other population within the watershed maintains the largest projected per capita increase, with 123 people by 2050. Table 2 provides a summary of the 2010-2050 population projections. Populations in Table 2 were estimated by TIAER by multiplying the estimated 2010 USCB populations by the percent increases projected by TWDB.

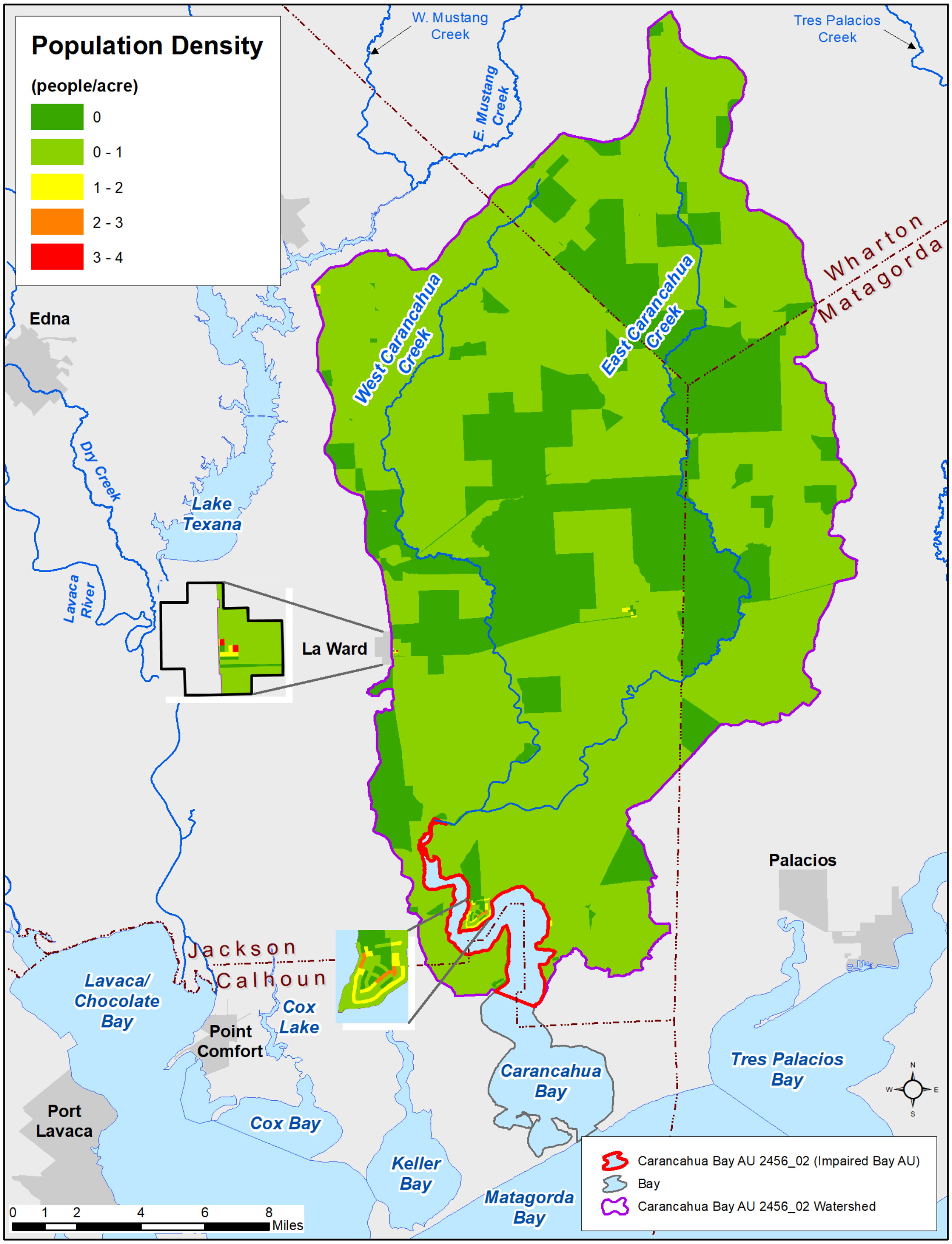

Figure 3. Population density for the Carancahua Bay AU 2456_02 watershed based on the 2010 U.S. Census Blocks.

Table 2. 2010 population with population projections for the Carancahua Bay AU 2456_02 watershed.

Location or WUG	2010 U.S. Census Population	2020 Population Projection	2030 Population Projection	2040 Population Projection	2050 Population Projection	Projected Population Increase (2010 - 2050)	Percent Increase (2010 - 2050)
Calhoun County-Other	46	52	58	64	70	24	52.2
City of La Ward	104	108	112	114	115	11	10.6
Jackson County-Other	1,209	1,254	1,298	1,317	1,332	123	10.2
Matagorda County-Other	314	335	353	364	373	59	18.8
Wharton County-Other	210	225	242	255	267	57	27.1
Watershed Total	**1,883**	**1,974**	**2,063**	**2,114**	**2,157**	**274**	**14.6**

Water Rights Review

Surface water rights in Texas are administered and overseen by the TCEQ. A search of the TCEQ GIS files by river basin (TCEQ, 2017a) revealed that within the Carancahua Bay AU 2456_02 watershed, there are five surface water rights owners.

A review of the water use data file containing historical, self-reported diversions indicates that four of the five water users diverted an average of approximately 548 acre-feet annually (with the remainder reporting zero diversions) from 1990 to 1999 (TCEQ, 2017b; TCEQ, 2019b). For the more recent reporting period (2000-2014), only two of the five water users reported diversions occurring after 2000 with an average of 127 acre-feet diverted annually. Historical trends indicate a decline in water use and diversions upstream of Carancahua Bay AU 2456_02, therefore, it is assumed that water diversions will have an insignificant impact on stream hydrology. Additionally, water rights authorizations allow withdrawals of water, as opposed to discharges, and do not need to be assigned loadings in a TMDL.

Land Use

The land use/land cover data for the Carancahua Bay AU 2456_02 watershed was obtained from the United States Geological Survey (USGS) 2011 National Land Cover Database (NLCD) (USGS, 2014).

The land use/land cover is represented by the following categories and definitions (USGS, 2014):

- **Open Water** – All areas of open water, generally with less than 25 percent cover of vegetation or soil.
- **Developed, Open Space** – Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- **Developed, Low Intensity** – Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
- **Developed, Medium Intensity** – Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
- **Developed, High Intensity** – Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80-100 percent of the total cover.
- **Barren Land (Rock/Sand/Clay)** – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.
- **Deciduous Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
- **Evergreen Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
- **Mixed Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
- **Shrub/Scrub** – Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

- **Grassland/Herbaceous** – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- **Pasture/Hay** – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
- **Cultivated Crops** – Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
- **Woody Wetlands** – Areas where forest or shrub land vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- **Emergent Herbaceous Wetlands** – Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

A summary of the land use/land cover data is provided in Table 3. As depicted in Table 3 and Figure 4, the dominant land uses are Cultivated Crops (approximately 46 percent) and Pasture/Hay (approximately 30 percent), comprising approximately 76 percent of the land use/land cover. To summarize, the land use coverage indicates a mostly rural, agricultural watershed with very little urbanization.

Table 3. Land use/land cover within the Carancahua Bay AU 2456_02 watershed.

2011 NLCD Classification	Area (acres)	Percent of Total
Open Water	4,972	2.43
Developed, Open Space	6,065	2.97
Developed, Low Intensity	520	0.25
Developed, Medium Intensity	33	0.02
Developed, High Intensity	2	0.00
Barren Land	687	0.34
Deciduous Forest	7,409	3.63
Evergreen Forest	7,437	3.64
Mixed Forest	2,335	1.14
Shrub/Scrub	11,907	5.83
Grassland/Herbaceous	3,461	1.69
Pasture/Hay	60,879	29.81
Cultivated Crops	93,450	45.75
Woody Wetlands	3,037	1.49
Emergent Herbaceous Wetlands	2,048	1.00
Total	**204,242**	**100**

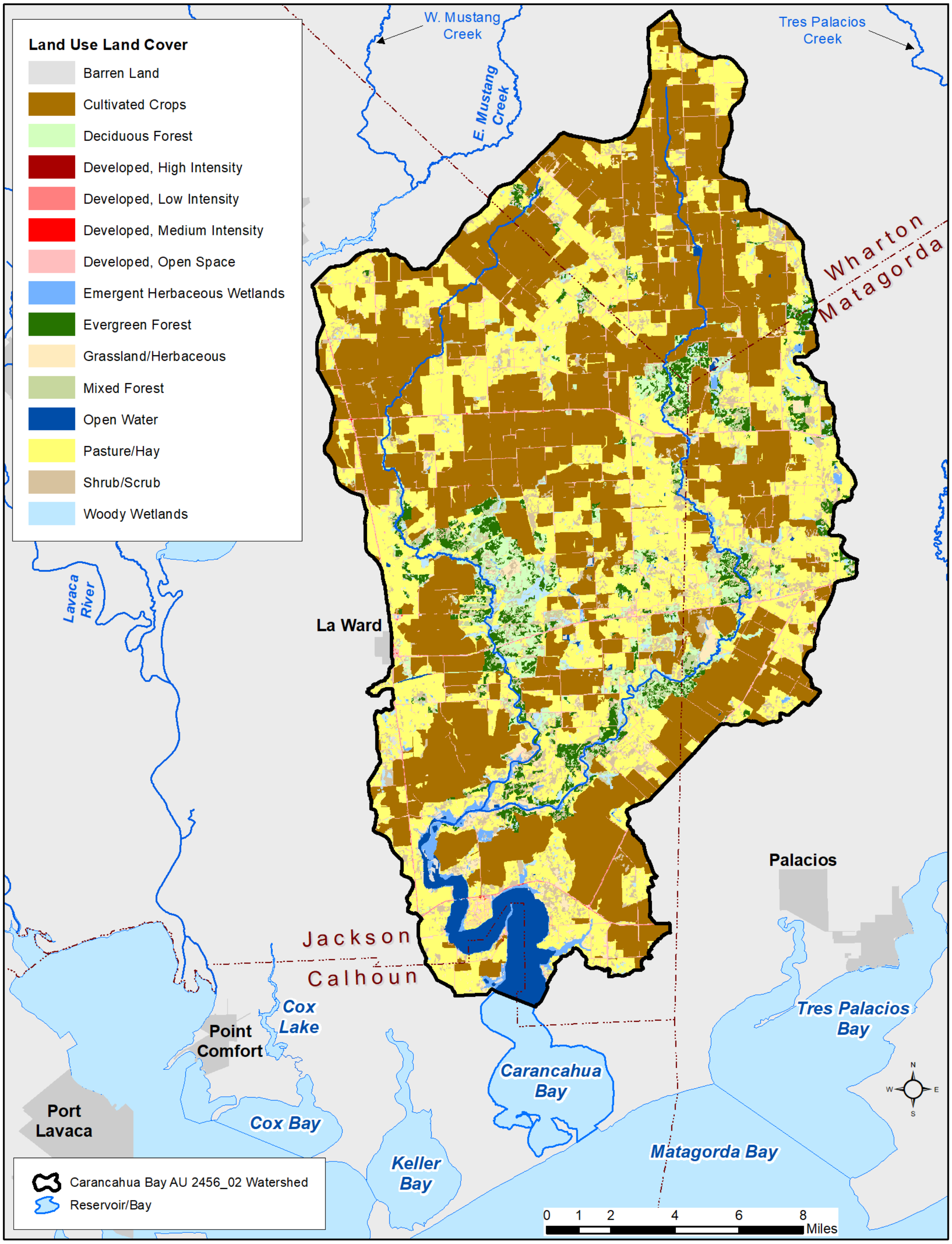

Figure 4. 2011 NLCD land use/land cover within the Carancahua Bay AU 2456_02 watershed.

Soils

Soils within the Carancahua Bay AU 2456_02 watershed are categorized by septic tank absorption field ratings, including dominant conditions. These data were obtained through the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (USDA NRCS, 2015).

Soil properties and features such as saturated hydraulic conductivity, flooding, depth to bedrock, depth to cemented pan, ponding, rocks, fractured bedrock, subsidence, and excessive slope can affect septic tank effluent absorption, construction and maintenance, and public health (USDA NRCS, 2015). The dominant soil condition within a septic drainage field can be used to identify soils that may prove problematic regarding septic system installation or performance, and potentially lead to system failures such as effluent surfacing or downslope seepage.

Soils are rated based on the limiting factors (or conditions) affecting proper effluent drainage and filtering capacity. Soil conditions for septic tank drainage fields are expressed by the following rating terms and definitions (USDA NRCS, 2015):

- **Not Limited** – Indicates that the soil has features that are very favorable for the specific use. Good performance and very low maintenance can be expected.
- **Somewhat Limited** – Indicates that the soil has one or more features that are moderately favorable for the specified use. The limitations can be overcome or minimized with special planning, design, or installation procedures. Fair performance and moderate maintenance can be expected.
- **Very limited** – Indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.
- **Not Rated** – Indicates insufficient data exists for soil limitation interpretation.

As indicated in Figure 5, approximately 97 percent of the soils are rated "very limited" within the Carancahua Bay AU 2456_02 watershed based on the dominant soil condition for septic drainage field installation and operation.

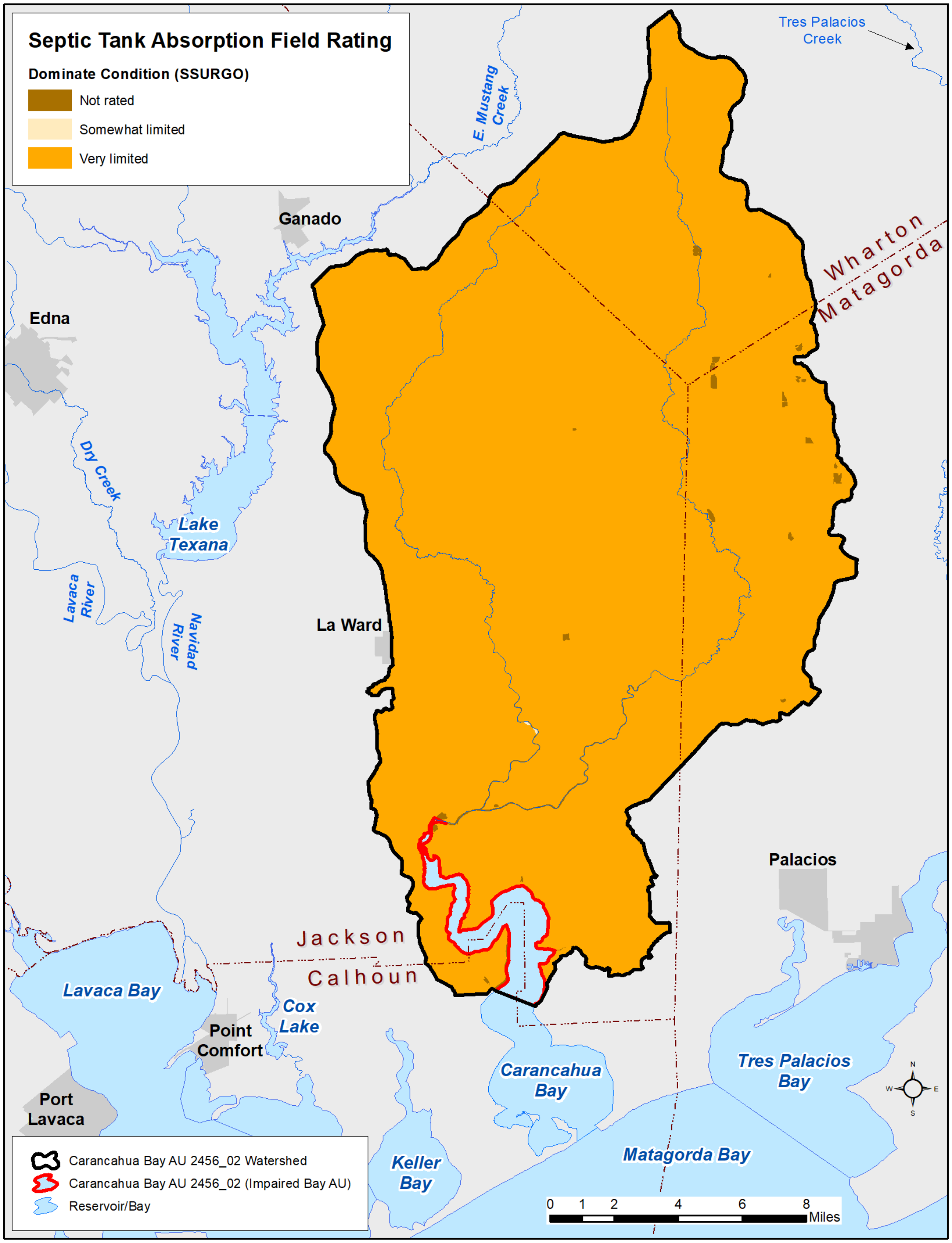

Figure 5. Septic tank absorption field limitation ratings for soils within the Carancahua Bay AU 2456_02 watershed.

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for the TMDL in this report is to maintain concentrations of Enterococci below the geometric mean criterion of 35 cfu/100 mL, which is the criterion in the 2018 TSWQS (TCEQ, 2018b) for primary contact recreation in saltwater. The geometric mean endpoint for the TMDL of 35 cfu/100 mL is expected to also result in compliance with the single sample criterion of 130 cfu/100 mL (TCEQ, 2018b).

Source Analysis

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) or the National Pollutant Discharge Elimination System (NPDES). WWTFs and stormwater discharges from industries, construction, and MS4s are considered point sources of pollution.

Unregulated sources are typically nonpoint source in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual WLAs (see the "Wasteload Allocation" section), the regulated and unregulated sources in this section are presented to give a general account of the different sources of bacteria expected in the watershed. These are not meant to be used for allocating bacteria loads or interpreted as precise inventories and loadings.

Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed include a WWTF outfall and stormwater discharges from construction activities.

Domestic and Industrial Wastewater Treatment Facilities

As of February 24, 2017, there is only one facility with a TPDES permit operating within the impaired watershed (Figure 6, Table 4). The City of La Ward WWTF treats domestic wastewater and eventually discharges into Carancahua Bay AU 2456_02. Discharge units are reported in million gallons per day (MGD). There are no permitted industrial facilities located within the TMDL watershed.

TPDES Water Quality General Permits

In addition to the individual wastewater discharge permit listed in Table 4, certain types of activities are required to be covered by one of several TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- 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
- WQG20000 – livestock manure compost operations (irrigation only)

Table 4. Permitted WWTF in the Carancahua Bay AU 2456_02 watershed.

AU	Permittee (Facility Name)	TPDES Permit Number (NPDES Permit Number)	Final Receiving Water	Discharge Type	Permitted Discharge (MGD)	Recent Discharge (MGD)
2456_02	City of La Ward (La Ward WWTF)	WQ0013479001 (TX0105104)	Carancahua Bay	Domestic Wastewater	0.024 (daily avg)	0.008*

* Average measured data from June 2012 through March 2017 from Discharge Monitoring Report data (EPA, 2017)

A review of active general permit coverage (TCEQ, 2017c) in the Carancahua Bay AU 2456_02 watershed as of March 30, 2017, revealed one permittee was covered by the general permit TXG870000 (pesticides), and is not expected to contribute to bacteria loadings. No other active general wastewater permit facilities or operations were found.

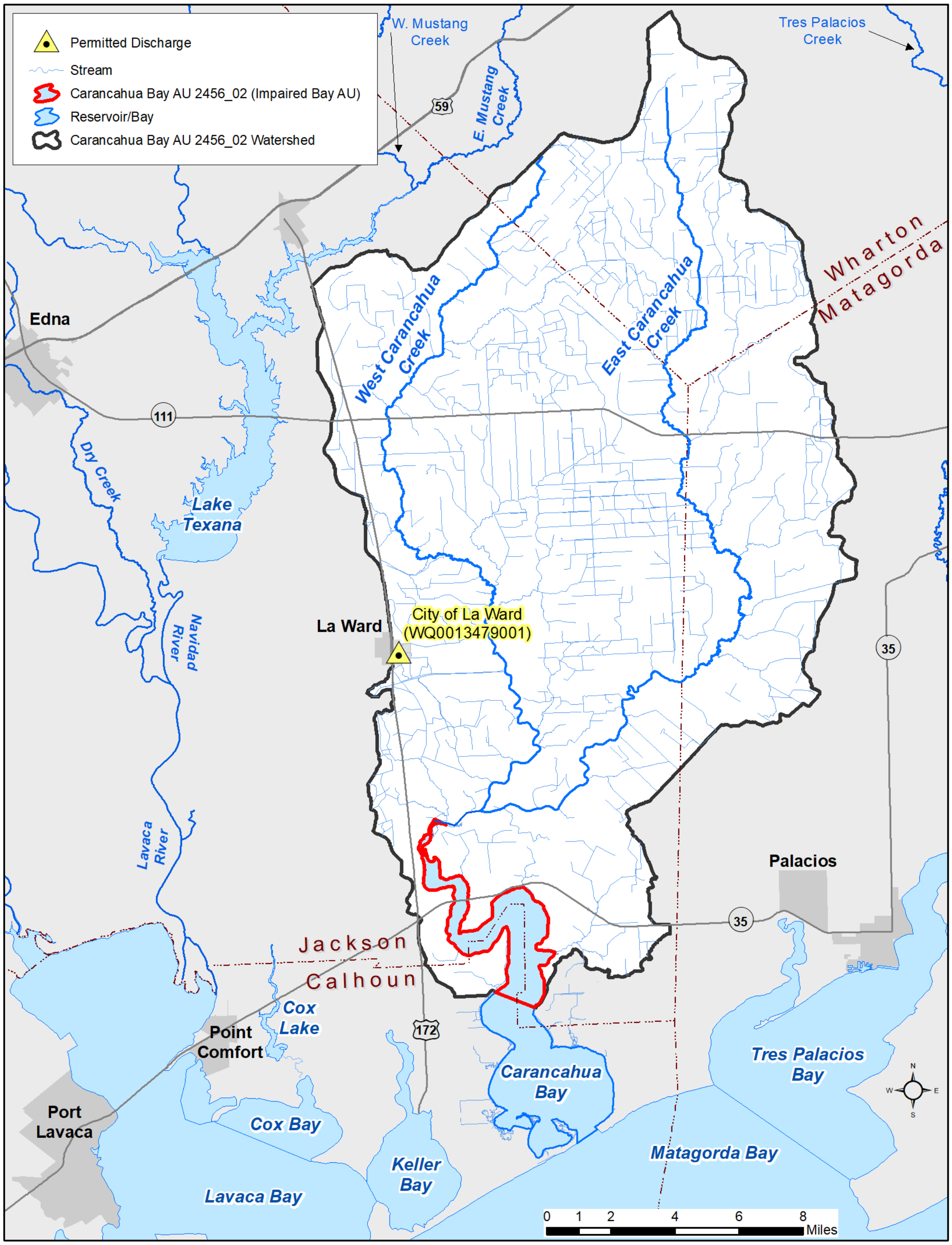

Figure 6. Carancahua Bay AU 2456_02 watershed showing a permitted WWTF (TPDES No. WQ0013479001).

Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. Inflow and infiltration (I&I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

The TCEQ Region 14 Office maintains a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. A search of the database revealed that no SSOs have been reported from January 2012 through December 2016 (TCEQ, 2017d).

TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES-regulated discharge permit and stormwater originating from areas not under a TPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1) Stormwater subject to regulation, which is any stormwater originating from TPDES-regulated municipal MS4 entities, stormwater discharges associated with industrial activities, and construction activities; or
2) Stormwater runoff not subject to regulation.

The TPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, whereas the Phase II general permit regulates smaller communities within a USCB defined urbanized area (UA). The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the MS4. The permits require that the SWMPs specify the best management practices (BMPs) to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include:

- Public education, outreach, and involvement;
- Illicit discharge detection and elimination;
- Construction site stormwater runoff control;
- Post-construction stormwater management in new development and redevelopment;
- Pollution prevention and good housekeeping for municipal operations; and
- Industrial stormwater sources.

Phase I MS4 individual permits have similar MCMs organized differently and are further required to perform water quality monitoring.

Phase I MS4 permits are associated with large urban areas. No permits of this nature occur for the Carancahua Bay AU 2456_02 watershed. Discharges of stormwater from areas involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 - Phase II MS4 general permit for small MS4s located in UAs
- TXR050000 - multi-sector general permit (MSGP) for industrial facilities
- TXR150000 - construction general permit from construction activities disturbing one acre or more

Phase II MS4 permits are associated with areas located within USCB UAs. The Carancahua Bay AU 2456_02 watershed is not located in a UA and therefore not subject to Phase II MS4 permitting requirements. In the absence of areas regulated by Phase I and Phase II MS4 areas, a review of other stormwater permits is conducted. The area of the watershed with regulated stormwater is estimated by determining coverage by individual industrial stormwater WWTFs, multi-sector, and construction permits.

A Central Registry query of active stormwater general permits coverage (TCEQ, 2017c) in the Carancahua Bay AU 2456_02 watershed, as of March 30, 2017, found 11 construction activities authorized in the watershed from April 2003 through March 2017. Due to the ephemeral nature of construction activities, a long-term average area was determined for the watershed. The average area of the construction authorizations was 160 acres. There was an average of two authorizations in a calendar year. This yielded an estimated construction permit area covering 320 acres. There were no MSGP permits in the impaired watershed. Based on the estimated general construction permits, regulated stormwater comprises 0.16 percent of the area within the Carancahua Bay AU 2456_02 watershed.

Illicit Discharges

Pollutant loads can enter streams from MS4 outfalls that carry authorized sources as well as illicit discharges under both dry- and wet-weather conditions.

The term "illicit discharge" is defined in TPDES General Permit Number TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (New England Interstate Water Pollution Control Commission, 2003) include:

Direct Illicit Discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer,
- materials that have been dumped illegally into a storm drain catch basin,
- a shop floor drain that is connected to the storm sewer, and
- a cross-connection between the sanitary sewer and storm sewer systems.

Indirect Illicit Discharges:

- an old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line, and
- a failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit, wildlife, various agricultural activities, agricultural animals, land application fields, failing OSSFs, unmanaged and feral animals, and domestic pets.

Unregulated Agricultural Activities and Domesticated Animals

The number of livestock that are found within the Carancahua Bay AU 2456_02 watershed was estimated from county-level data obtained from the 2012 Census of Agriculture (USDA National Agricultural Statistics Service, 2014). The county-level data were refined to better reflect actual numbers within the impaired AU watershed. The refinement was performed by determining the total area of each county as well as the subject watershed that was designated as either "Herbaceous/Grassland" or "Hay/Pasture" in the 2011 NLCD. A ratio was then developed by dividing the selected land use area of the watershed area within a county by the total area of the county. This ratio was then applied to the county-level data.

Activities such as livestock grazing close to water bodies and the use of manure as fertilizer can contribute bacteria loading to nearby water bodies. The livestock numbers in Table 5 are provided to demonstrate that livestock are a potential source of bacteria in the impaired watershed. The county-level estimated livestock populations were reviewed by Texas State Soil and Water Conservation Board (TSSWCB) staff. These livestock numbers, however, were not used to develop an allocation.

Table 5. Estimated livestock populations within the Carancahua Bay AU 2456_02 watershed.

Watershed	Cattle and Calves	Hogs and Pigs	Sheep and Lambs	Goats	Horses and Ponies	Mules, Burros, and Donkeys	Poultry
Carancahua Bay AU 2456_02	14,060	8	45	224	339	49	264

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 6 summarizes the estimated number of dogs and cats in the Carancahua Bay AU 2456_02 watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (American Veterinary Medical Association, 2012). The actual contribution and significance of bacteria loads from pets reaching the water bodies of the watershed is unknown.

Table 6. Estimated households and pet populations for the Carancahua Bay AU 2456_02 watershed.

Watershed	Estimated Households	Estimated Dog Population	Estimated Cat Population
Carancahua Bay AU 2456_02	784	458	500

Wildlife and Unmanaged Animals

Fecal indicator bacteria, such as Enterococci and *E. coli*, inhabit the intestines of all warm-blooded animals, including wildlife such as mammals and birds. To develop bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to the riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff.

Unfortunately, quantitative estimates of wildlife are inexact, and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire. This holds true especially when considering potential wildlife bacteria contributors such as birds. While it is noted that Carancahua Bay lies within the Central Flyway for migrating birds in North America (Shackelford et al., 2005) and migratory locations that provide rest areas and food sources (e.g., row crop fields) exist within the watershed, no data are available for avian population densities for the Carancahua Bay AU 2456_02 watershed. However, population estimates for feral hogs and deer are readily available for the impaired watershed.

For feral hogs, a study conducted by Wagner and Moench (2009) estimated feral hog densities in the nearby Copano Bay watershed to be one hog per 33.3 acres. The average hog density of one hog/33.3 acres was multiplied by the hog-habitat area (all NLCD land cover types except open water and developed land) in the Carancahua Bay AU 2456_02 watershed (192,650 acres). Using this methodology, there are an estimated 5,785 feral hogs in the Carancahua Bay AU 2456_02 watershed.

For deer, density estimates categorized by Deer Management Unit (DMU) were provided by the Texas Parks and Wildlife Department (2017). The Carancahua Bay AU 2456_02 watershed lies entirely within the DMU 10 area, for which the average deer density over the period 2006-2016 was calculated to be 38.4 deer/1,000 acres. Applying this value to the area of the entire watershed returns an estimated 7,652 deer within the Carancahua Bay AU 2456_02 watershed.

On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) or 2) aerobic systems that have an aerated holding tank and often an above-ground sprinkler system for distributing the liquid. In simplest terms, household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system which may consist of buried perforated pipes or an above ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. When they are properly designed, operated, and maintained, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01 percent of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weiskel et al., 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. Carancahua Bay is located within the east-central Texas area, which has a reported failure rate of about 12 percent, providing insights into expected failure rates for the area.

OSSF data were obtained via a geographic information system (GIS) layer from the Texas Water Resources Institute (TWRI, 2017). Estimates of the number of OSSFs in the Carancahua Bay AU 2456_02 watershed were based on 911 data with aerial imagery verification of inhabitable structures (TWRI, 2014). Additionally, 911 locations that were inside of either a Certificate of Convenience and Necessity sewer area or a city boundary were excluded from analyses. The total estimate is shown in Table 7 and the OSSF estimated locations are shown in Figure 7.

Table 7. OSSF estimate for the Carancahua Bay AU 2456_02 watershed.

Watershed	Estimated OSSFs
Carancahua Bay AU 2456_02	992

Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms can survive and replicate from improperly treated effluent during their transport in pipe networks and in organic rich materials such as compost and sludge. While the die-off of bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their replication is less understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates for the Carancahua Bay AU 2456_02 watershed.

Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. This relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources and direct fecal material deposition into the water body. During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources and direct deposition is typically diluted and would therefore be a smaller part of the overall concentrations.

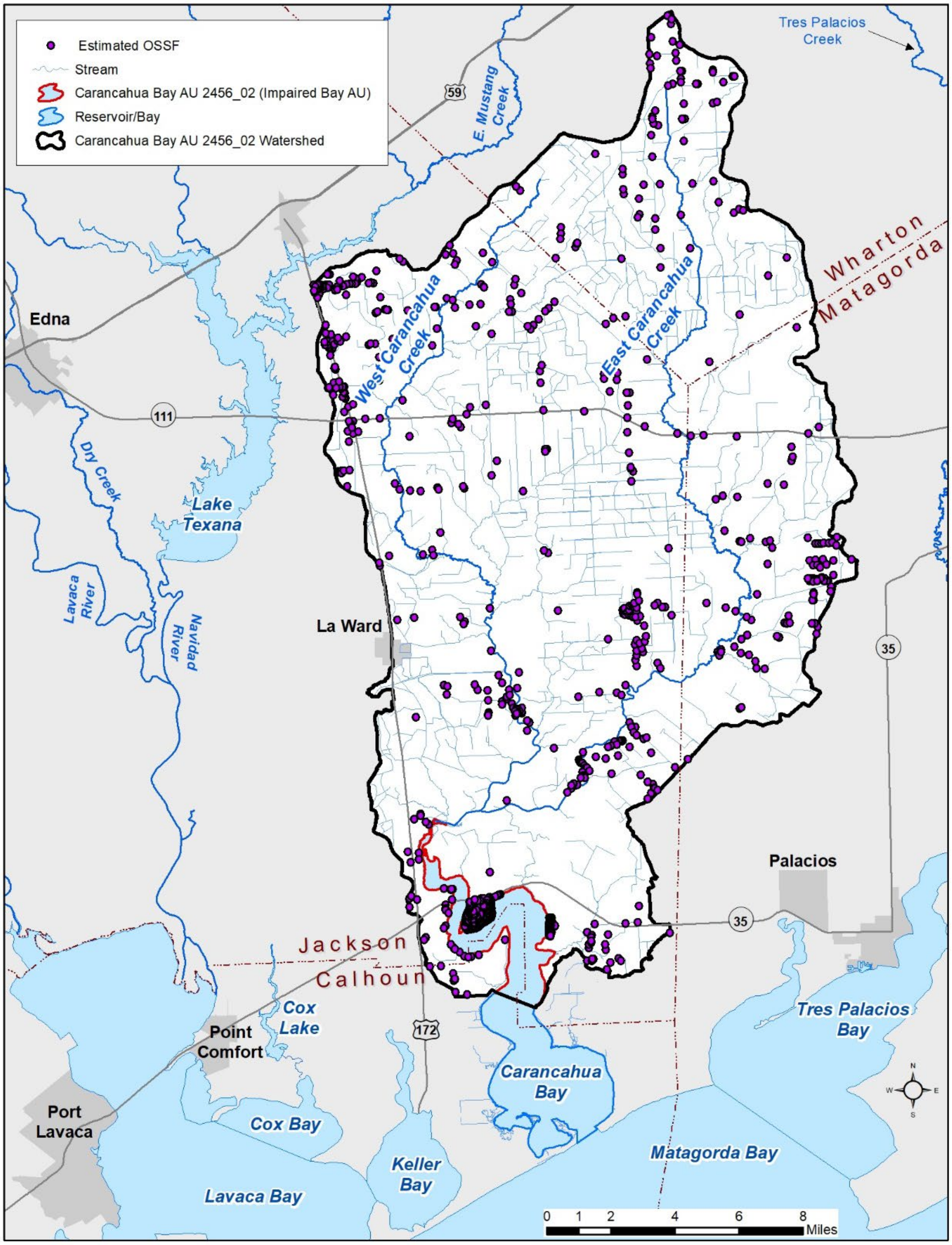

Figure 7. Estimated OSSF locations within the Carancahua Bay AU 2456_02 watershed.

Bacteria load contributions from permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of lower concentrations in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Modified Load Duration Curve Analysis

A modified LDC method was used to examine the relationship between instream water quality and the broad sources of bacteria loads, which are the basis of the TMDL allocations. The strength of this TMDL is the use of the modified LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of the basic LDC method to characterize pollutant sources including the modifications to include tidal influences. In addition, many other states are using this basic method to develop TMDLs, though the modified LDC method is more limited in its application.

Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a one-to-one relationship between instream loadings and loadings originating from point sources and the landscape as regulated and unregulated sources. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (LA). The allocation of pollutant loads was based on apportioning the loadings based on flows assigned to WWTFs, a fractional proportioning of the remaining flow based on the area of the watershed under stormwater regulation and assigning the remaining portion to unregulated stormwater.

The modified LDC method allows for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003), with adjustments to include tidal influences (ODEQ, 2006). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater), and provides a means to allocate allowable loadings.

The modified LDC method is based on the assumption that by combining freshwater with seawater, the loading capacity in the tidal river increases because seawater typically contains lower concentrations of bacteria, such as Enterococci, than freshwater. More details on the modified LDC method are provided in Appendix A. The rationale for extending application of the modified LDC method beyond tidal streams to Carancahua Bay is discussed in the last portion of Appendix A. In summary, Carancahua Bay AU 2456_02, being the upstream end of a tertiary bay, exhibits geomorphological characteristics similar to the bayward end of a tidal stream. As will be shown later in this section, with additional details in Appendix A, the upper bay experiences essentially freshwater conditions and little or no tidal exchange of seawater occurs under the high inflows considered for bacteria pollutant LA development in Carancahua Bay AU 2456_02.

The weaknesses of this method includes the limited information it provides regarding the magnitude or specific origin of the various sources. Only limited information is gathered regarding point and nonpoint sources in the watershed. The general difficulty in analyzing and characterizing Enterococci in the environment is also a weakness of this method.

Data requirements for the modified LDC method are minimal, consisting of continuous daily streamflow records and both historical bacteria and salinity data. A 15-year period of record from January 1, 2002, through December 31, 2016, was selected for LDC development, and this period included all available Enterococci data at the time of the study. A 15-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent conditions in the watershed.

SWQM station 13388 was selected as the location for application of the modified LDC method (Figure 1) as it was the only station within Carancahua Bay AU 2456_02 to have both sufficient and recent Enterococci data. Forty-three Enterococci samples and 87 salinity measurements were obtained from the Surface Water Quality Monitoring Information System (SWQMIS) (TCEQ, 2017e) for the period mentioned above.

Hydrologic data in the form of daily streamflow records were unavailable for the Carancahua Bay AU 2456_02 watershed. However, streamflow records were available for two adjacent watersheds (Tres Palacios and East Mustang Creek) of similar land cover characteristics, e.g., limited UA and significant agricultural influences. Streamflow records that were collected and made readily available by the USGS for streamflow gauge 08162600 (USGS, 2017), located within the Tres Palacios watershed, were considered to be representative of the Carancahua Bay AU 2456_02 watershed streamflow at high flow conditions. Likewise, streamflow records at USGS streamflow gauge 08164504 (USGS, 2017), located in the East Mustang Creek watershed, were determined to be more representative of moderate and baseflow conditions in the impaired watershed. Thus, streamflow records from both USGS streamflow gauges, 08162600 and

08164504, were utilized in streamflow development in the Carancahua Bay AU 2456_02 watershed.

Due to the absence of flow records within the impaired watershed, the method to develop the necessary streamflow record for the flow duration curve (FDC)/LDC location (SWQM station 13388) involved a drainage-area ratio (DAR) approach using combined streamflow records from USGS streamflow gauges located in Tres Palacios and East Mustang Creek. With this basic approach, each selected USGS gauge's daily streamflow record within the 15-year period was multiplied by a factor to estimate the flow at the desired SWQM station location. The factor was determined by dividing the drainage area above SWQM station 13388 (185,208 acres) by the drainage area above the USGS gauge (92,800 acres for Tres Palacios and 34,496 acres for East Mustang Creek).

Prior to application of the DAR, the USGS gauge record was corrected by removing (subtracting) the upstream WWTF discharge based on Discharge Monitoring Report information. After multiplication of the corrected streamflow record by the DAR, a final adjustment occurred for the purposes of pollutant load computations. The hydrologic records were adjusted to reflect full permitted flows from the upstream WWTF and FG flows that account for the probability that additional flows from WWTF discharges may occur as a result of population increases.

To take advantage of the separate strengths of the two streamflow estimates, a modification of the DAR method for multiple USGS gauge locations was developed. Strictly following the computations in Asquith et al. (2006) for application of the DAR approach using multiple reference gauge records, the daily flow record for SWQM station 13388 would have been computed as the means of the DAR-developed daily streamflows from Tres Palacios Creek and East Mustang Creek. A refinement to that multiple reference gauge approach was made, wherein weighting factors were developed that were based on the exceedance frequency for the daily streamflows developed from the Tres Palacios Creek gauged record. The Tres Palacios Creek gauged record was used as the basis for determining the weighting factors, because the analyses of salinity response to freshwater at SWQM station 13388 indicated that this record better reflected the timing of hydrologic variations impacting observed salinity concentrations than the East Mustang Creek record.

Another part of the development of the modified LDC method is to determine a relationship of daily streamflow and measured salinities. The resulting regression is used to determine the daily volume of saltwater present for each daily freshwater flow in the 15-year period of record.

Information on the modified LDC method is provided in Appendix A and additional details are provided in the document titled *Technical Support*

Document for Total Maximum Daily Load for Indicator Bacteria in Carancahua Bay (Adams and Hauck, 2017).

The FDC was generated by:

1) Ordering the daily streamflow data from highest to lowest values and assigning a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);

2) Computing the percent of days each flow was exceeded by dividing each rank by the total number of data points plus one; and

3) Plotting the corresponding flow data against exceedance percentages.

Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100 percent occur during low flow or drought conditions while values approaching zero percent occur during periods of high flow or flood conditions.

The bacteria LDC was developed by multiplying each streamflow value along the FDC by the Enterococci criterion (35 cfu/100 mL) and by the conversion factor to convert to loading in colonies per day. This effectively displays the LDC as the TMDL curve of maximum allowable loading:

TMDL (cfu/day) = criterion * flow, cubic feet per second (cfs) * conversion factor

Where:

Criterion = 35 cfu/100 mL (Enterococci)

Conversion factor (to cfu/day) = 283.168 mL/cubic feet (ft^3) * 86,400 seconds/day (sec/day)

The resulting curve plots each bacteria load value (y-axis) against its exceedance value (x-axis). Exceedance values along the x-axis represent the percent of days that the bacteria load was at or above the allowable load on the y-axis.

For the LDC at TCEQ SWQM station 13388, historical bacteria data obtained from the TCEQ SWQMIS database were superimposed on the allowable bacteria LDC. Each historical Enterococci measurement was associated with the streamflow on the day of measurement and converted to a bacteria load. The associated streamflow for each bacteria loading was compared to the FDC data to determine its value for “percent days flow exceeded,” which becomes the “percent of days load exceeded” value for purposes of plotting the Enterococci loading. Each load was then plotted on the LDC at its percent exceedance. This process was repeated for each Enterococci measurement. Points above the LDC represent exceedances of the bacteria criterion and its associated allowable loadings.

As a further refinement, the historical Enterococci points on the LDC were symbolized according to whether the sampling event was considered to be a wet or non-wet weather event based on antecedent rainfall. A sample was determined to be influenced by a wet weather event based on the "days since last precipitation" (DSLP) as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform data users of the general climatic conditions. A wet weather event was defined as a sample collected with DSLP of five days or less.

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of the FDC and LDC. For this TMDL, the five flow regimes that are provided in Cleland (2003) were used. These five intervals along the x-axis of the FDCs and LDCs are (1) 0-10 percent (high flows); (2) 10-40 percent (moist conditions); (3) 40-60 percent (mid-range flows); (4) 60-90 percent (dry conditions); and (5) 90-100 percent (low flows). Additional information explaining the LDC method may be found in Cleland (2003) and Nevada Division of Environmental Protection (2003) and for the modified LDC method in ODEQ (2006) and Adams and Hauck (2017).

The median loading of the high flow regime (0-10 percent exceedance) is used for the TMDL calculations, because it represents a reasonable yet high value for the allowable pollutant LA.

An important observation is that under the high flow regime used for the TMDL calculations, there was no seawater volume computed as being present at the location where the LDC was developed. Saltwater was effectively pushed out of the water body by the freshwater inflows present under the high flow regime. With an absence of seawater at these high flows, the modified LDC results are effectively simplified to those of the LDC method without any adjustments to accommodate tidal influences.

Load Duration Curve Results

To develop the TMDL allocation, an LDC was constructed using data obtained from SWQM station 13388. Geometric mean loadings for the data points within each flow regime have also been distinguished in Figure 8 to aid interpretation. The LDC provides a means of identifying the streamflow conditions under which exceedances in Enterococci concentrations have occurred. The LDC depicts the allowable loadings at the station under the geometric mean criterion (35 cfu/100 mL) and shows that existing loadings often exceed the criterion. In addition, the LDC also presents the allowable loading at the station under the single sample criterion (130 cfu/100 mL).

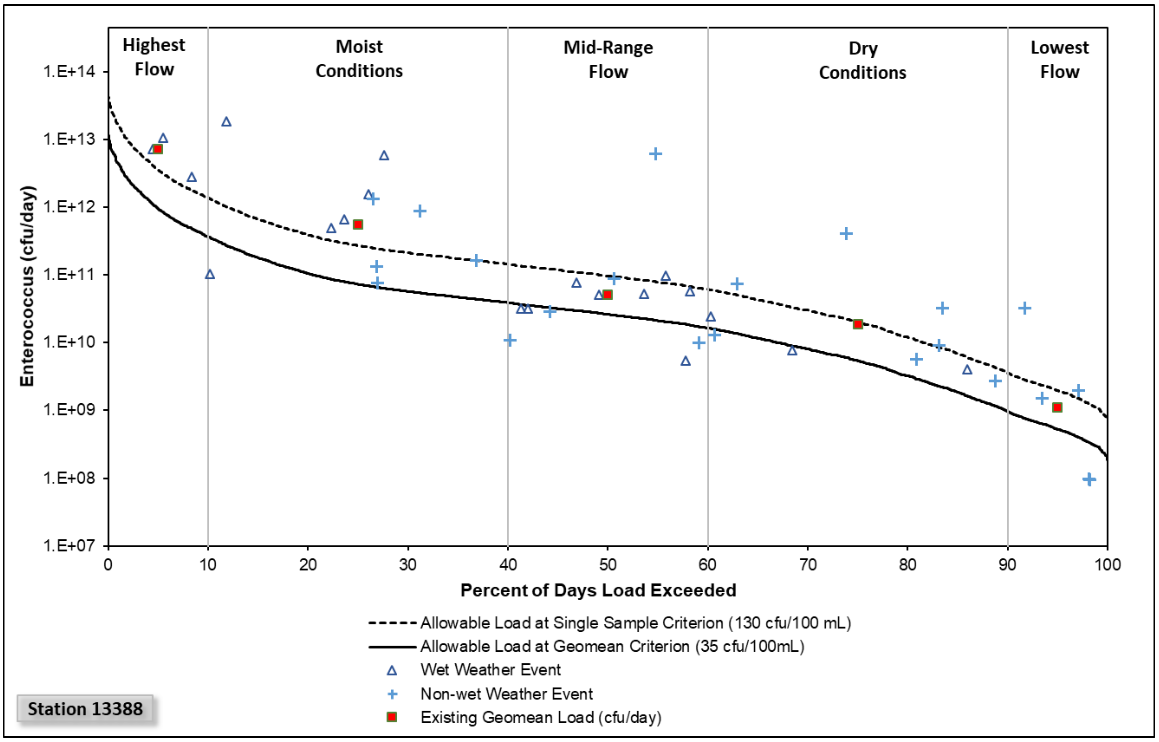

Figure 8. **Load duration curve at SWQM station 13388 on Carancahua Bay AU 2456_02 for the period of January 1, 2002, through December 31, 2016.**

Based on the LDC for SWQM station 13388 with historical Enterococci data added to the graph (Figure 8), the following broad linkage statements can be made for the Carancahua Bay AU 2456_02 watershed. The historical Enterococci data indicate that elevated bacteria loadings occur under all flow conditions but become most elevated under the highest flows and fall below the single sample criterion most frequently under the mid-range and lower flows. Regulated stormwater comprises only a relatively small portion of the Carancahua Bay AU 2456_02 watershed (0.16 percent) and must be considered only a minor contributor. It is therefore likely that unregulated stormwater comprises the majority of high flow related loadings. The elevated Enterococci loadings under the lower flow conditions cannot be reasonably attributed exclusively to WWTF discharges because the outfall of the City of La Ward WWTF is located some distance from SWQM station 13388, and recently the facility has a good compliance record. Therefore, other sources of bacteria loadings under lower flows and in the absence of overland flow contributions (i.e., without stormwater contribution) are most likely contributing bacteria directly to the water, as could occur through direct deposition of fecal material from such sources as wildlife (avian and non-avian), feral hogs, and livestock. The actual contribution of bacteria loadings attributable to these direct sources of fecal material deposition cannot be determined using LDCs.

Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated into the TMDL using two methods:

1) Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
2) Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning an MOS.

The TMDL covered by this report incorporates an explicit MOS of five percent of the total TMDL allocation.

Pollutant Load Allocation

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding water quality standards. The pollutant LAs for the selected scenarios were calculated using the following equation:

$$TMDL = WLA + LA + FG + MOS$$

Where:

WLA = wasteload allocation, the amount of pollutant allowed by regulated dischargers

LA = load allocation, the amount of pollutant allowed by unregulated sources

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

As stated in 40 CFR 130.2(i), a TMDL can be expressed in terms of mass per time, toxicity, or other appropriate measures.

The TMDL components for the Carancahua Bay AU 2456_02 watershed covered in this report are derived using the median flow within the high flow regime (or five percent flow) of the LDC developed for SWQM station 13388. The following sections will present an explanation of the TMDL component, followed by the results of the calculation for that component.

AU-Level TMDL Computations

The bacteria TMDL for Carancahua Bay AU 2456_02 was developed as a pollutant LA based on information from the LDC for station 13388 (Figure 8). As discussed in more detail in Appendix A, bacteria LDCs using modifications to include tidal influences were developed by multiplying each flow value along the FDCs by the Enterococci criterion (35 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the “Allowable Load” displayed in the modified LDC at five percent exceedance (the median value of the high flow regime) is the TMDL:

TMDL (cfu/day) = criterion * flow (cfs) * conversion factor

Where:

Criterion = 35 cfu/100 mL (Enterococci)

Conversion factor (to cfu/day) = 283.168 100 mL/ft^3 * 86,400 sec/day

At five percent load duration exceedance, the TMDL values are provided in Table 8.

Table 8. Summary of allowable loading calculations for the Carancahua Bay AU 2456_02 watershed.

Indicator Bacteria	5% Exceedance Flow (cfs)	5% Exceedance Load (Billion cfu/day)	TMDL (Billion cfu/day)
Enterococci	1,106.373	947.387	947.387

Margin of Safety

The MOS is only applied to the allowable loading for a watershed. Therefore, the MOS is expressed mathematically as the following:

MOS = 0.05 * TMDL

Where:

MOS = margin of safety load

TMDL = total maximum daily load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 9).

Table 9. MOS calculations for the Carancahua Bay AU 2456_02 watershed.

Indicator Bacteria	TMDL (Billion cfu/day)	MOS (Billion cfu/day)
Enterococci	947.387	47.369

Wasteload Allocation

The WLA consists of two parts — the wasteload that is allocated to TPDES-regulated WWTFs (WLA_{WWTF}) and the wasteload that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW}$$

Wastewater Treatment Facilities

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. The saltwater Enterococci criterion (35 cfu/100 mL) is used as the WWTF target. The WLA_{WWTF} term is also calculated for the freshwater *E. coli* primary contact recreation geometric mean criterion of 126 cfu/100 mL, since WWTF bacteria permit limits are often expressed in terms of *E. coli*. This is expressed in the following equation:

$$WLA_{WWTF} = \text{criterion} * \text{flow} * \text{conversion factor}$$

Where:

Criterion = 35 cfu/100 mL for Enterococci; 126 cfu/100 mL for *E. coli*

Flow = full permitted flow (MGD)

Conversion factor (to cfu/day) = 1.54723 cfs/MGD *283.168 100 mL/ft^3 * 86,400 sec/day

Thus, the daily allowable loading of Enterococci and *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of the only WWTF in the watershed. Table 10 presents the WLA for the City of La Ward WWTF (Figure 6 and Table 4) located within the Carancahua Bay AU 2456_02 watershed. Since the pollutant LA is developed in terms of Enterococci as the indicator bacteria, it is the Enterococci loadings from Table 10 that will be used in subsequent computations.

Table 10. Wasteload allocations for TPDES-permitted facilities in Carancahua Bay AU 2456_02.

AU	TPDES Permit Number	NPDES Permit Number	Facility	Full Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (Billion cfu/day)	Enterococci WLA_{WWTF} (Billion cfu/day)
2456_02	WQ0013479001	TX0105104	City of La Ward WWTF	0.024	0.114	0.032

Regulated Stormwater

Stormwater discharges from MS4s, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA was used in the development of this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

The percentage of land area included in the Carancahua Bay AU 2456_02 watershed that is under the jurisdiction of stormwater permits was used to estimate the amount of the overall runoff load to be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint source runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

Thus, WLA_{SW} is the sum of loads from regulated stormwater sources and is calculated as follows:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$$

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the area of the watershed under regulated stormwater permits. As described in the "TPDES-Regulated Stormwater" section, a search for all categories of stormwater general permits was performed. The search results are displayed in Table 11.

No MS4 Phase I or Phase II permits are held in the Carancahua Bay AU 2456_02 watershed. For the construction permits, the long-term acreages associated with permits were estimated. The watershed acreage was calculated by determining the average area of the permitted areas and multiplying by the average number of authorizations in a calendar year. No MSGPs were located within the Carancahua Bay AU 2456_02 watershed.

In order to calculate WLA_{SW}, the FG term must be known. The calculation for the FG term is presented in a later section, but the results will be included here for continuity. Table 12 provides the information needed to compute WLA_{SW}.

Table 11. Regulated stormwater FDA_{SWP} basis for the Carancahua Bay AU 2456_02 watershed.

MS4 General Permit (acres)	Construction General Permit (acres)	Multi-Sector General Permit (acres)	Concrete Production Facilities (acres)	Petroleum Bulk Stations (acres)	Total Area of Permits (acres)	Watershed Area (acres)	FDA_{SWP}
0	320	0	0	0	320	204,242	0.16%

In UAs currently regulated by an MS4 permit, development and/or re-development of land in UAs must implement the control measures/programs outlined in an approved SWMP. Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in the TPDES permit and the SWMP.

An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality.

Table 12. Regulated stormwater calculations for the Carancahua Bay AU 2456_02 watershed.

Indicator Bacteria	TMDL	WLA_{WWTF}	FG	MOS	FDA_{SWP}	WLA_{SW}
Enterococci	947.387	0.032	0.032	47.369	0.16%	1.440

Load units expressed as billion cfu/day

Once the WLA_{SW} and WLA_{WWTF} terms are known, the WLA term can be calculated as the sum of the two parts, as shown in Table 13.

Table 13. Wasteload allocation calculations for the Carancahua Bay AU 2456_02 watershed.

WLA_{WWTF}	WLA_{SW}	WLA
0.032	1.440	1.472

Load units expressed as billion cfu/day

Implementation of Wasteload Allocations

The TMDL in this document will result in protection of existing beneficial uses and conform to Texas' antidegradation policy. The three-tiered antidegradation policy in the TSWQS prohibits an increase in loading that would cause or contribute to degradation of an existing use. The antidegradation policy applies to point source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality.

The TCEQ intends to implement the individual WLAs through the permitting process as monitoring requirements and/or effluent limitations as required by Title 30 Texas Administrative Code (TAC) Chapter 319, which became effective November 26, 2009. The WWTF discharging to the TMDL watershed will be assigned an effluent limit based on the TMDL. Monitoring requirements are based on permitted flow rates and are listed in 30 TAC Section 319.9.

The permit requirements will be implemented during the routine permit renewal process. However, there may be a more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, the individual WLAs, as well as the WLAs for stormwater, are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of an update to the state's WQMP. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The executive director or commission may establish interim effluent limits and/or monitoring-only requirements during a permit amendment or permit renewal. These interim limits will allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet the TCEQ and EPA approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits will not contain interim effluent limits because compliance schedules are not allowed for a new permit.

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the WLAs. For TPDES-regulated municipal, construction stormwater discharges, and industrial stormwater discharges, water quality-based effluent limits (WQBELs) that implement the WLA for stormwater may be expressed as BMPs or other similar requirements, rather than as numeric effluent limits.

The November 26, 2014, memorandum from EPA relating to establishing WLAs for stormwater sources states:

> "Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality concerns, permits would be modified in subsequent terms to include "more specific conditions or limitations [which] may include an integrated suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric WQBELs, action levels, etc."

Using this iterative adaptive BMP approach to the maximum extent practicable is appropriate to address the stormwater component of this TMDL.

Updates to Wasteload Allocation

This TMDL is, by definition, the total of the sum of the WLA, the sum of the LA, and the MOS. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the TMDL document; instead, changes will be made through updates to the state's WQMP. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Allocation

The LA is the sum of loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$$

Where:

LA = allowable load from unregulated sources

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 14.

Table 14. Load allocation calculations for the Carancahua Bay AU 2456_02 watershed.

Indicator Bacteria	TMDL	WLA_{WWTF}	WLA_{SW}	FG	MOS	LA
Enterococci	947.387	0.032	1.440	0.032	47.369	898.514

Load units expressed as billion cfu/day

Allowance for Future Growth

The FG component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of streams increases as the amount of flow increases.

The allowance for FG will result in protection of existing beneficial uses and conform to Texas' antidegradation policy.

While the allowance for FG is often computed for a bacteria TMDL using information from existing WWTF permits, it is not intended to restrict any future assignments of the allocation solely to expansions at these facilities. Rather, the FG allocation is purposed for both any new facilities that may occur and expansions of existing facilities.

The above definition of FG is relevant for the Carancahua Bay AU 2456_02 watershed, since application of the projected population growth (10.6 percent; Table 2) over the period of 2010 to 2050 for the City of La Ward yields an additional flow of only 0.0025 MGD. The distinct possibility exists, however, for additional community development along the bay front of Carancahua Bay AU 2456_02 (see inset showing bay area on the population density map of Figure 3 and OSSF locations on Figure 7), which could necessitate a future WWTF that almost certainly would be greater than 0.0025 MGD in size. To accommodate the possibility of such an occurrence along the bay front or anywhere else in the watershed, FG flow of 0.024 MGD was assigned, which is equivalent to the City of La Ward WWTF. Table 15 provides information necessary for the FG computations for the Carancahua Bay AU 2456_02 watershed, which is the same equation used for computing the WLA_{WWTF} term.

Table 15. Future growth calculations for the Carancahua Bay AU 2456_02 watershed.

FG Flow (MGD)	FG (Enterococci Billion cfu/day)
0.024	0.032

Compliance with this TMDL is based on keeping the bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. FG of existing or new point sources is not limited by this TMDL as long as the sources do not cause bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Consequently, increases in flow allow for increased loadings. The LDC and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including FG.

Summary of TMDL Calculations

Table 16 summarizes the TMDL calculations for the impaired Carancahua Bay AU 2456_02. The TMDL was calculated based on the median flow in the 0-10 percentile range (five percent exceedance, high flow regime) for flow exceedance from the LDC developed for SWQM station 13388. Allocations are based on the current geometric mean criterion for Enterococci of 35 cfu/100 mL for each component of the TMDL.

The final TMDL allocations (Table 17) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 16. TMDL allocation summary for the Carancahua Bay AU 2456_02 watershed.

AU	Segment Name	TMDL	WLA_{WWTF}	WLA_{SW}	LA	FG	MOS
2456_02	Carancahua Bay	947.387	0.032	1.440	898.514	0.032	47.369

Load units expressed as billion cfu/day

Table 17. Final TMDL allocations for the Carancahua Bay AU 2456_02 watershed.

AU	TMDL	WLA_{WWTF}[a]	WLA_{SW}	LA	MOS
2456_02	947.387	0.064	1.440	898.514	47.369

Load units expressed as billion cfu/day

[a]WLA_{WWTF} includes the FG component

Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations [40 CFR 130.7(c)(1)] require that TMDLs account for seasonal variation in watershed conditions and pollutant loading.

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing Enterococci concentrations obtained from routine monitoring collected in the warmer months (May-September) against those collected during the cooler months (November-March). The months of April and October were considered transitional between the warm and cool seasons and were excluded from the seasonal analysis. Differences in Enterococci concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test on the natural-log transformed dataset.

This analysis of Enterococci data indicated that there was no significant difference ($\alpha=0.05$, $p=0.6565$) in indicator bacteria between cool and warm weather seasons for Carancahua Bay AU 2456_02.

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

The TCEQ and the TWRI are jointly providing coordination of public participation for development of both the TMDL and implementation plan (I-Plan). A series of public meetings have been held since 2017 to keep the public aware of the TMDL and to engage public participation in the development of the I-Plan.

The first public meeting to discuss watershed-based plans was held in Lolita on August 17, 2017, and stakeholder meetings have continued every couple of months through 2018. Stakeholders provided input on the documents associated with both the TMDL and the I-Plan. Notices of meetings were posted on the project webpages for both TWRI and TCEQ and on the TCEQ's TMDL program's online calendar. At least two weeks prior to scheduled meetings, the TWRI issued media releases through Texas A&M AgriLife and local AgriLife Extension Offices, and formally invited stakeholders to attend. To ensure that absent or new stakeholders could get information about past meetings and pertinent material, the TWRI project webpage provides meeting summaries, presentations, and documents produced for review.

Implementation and Reasonable Assurance

The issuance of TPDES permits consistent with TMDLs provides reasonable assurance that WLAs in this TMDL report will be achieved. Per federal requirements, each TMDL is included in an update to the Texas WQMP as a plan element.

The WQMP coordinates and directs the state's efforts to manage water quality and maintain or restore designated uses throughout Texas. The WQMP is continually updated with new, more specifically focused plan elements, as identified in federal regulations [40 CFR 130.6(c)]. Commission adoption of a TMDL is the state's certification of the associated WQMP update.

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, the TCEQ certifies additional elements to the WQMP after the I-Plan is approved by the commission. Based on the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits.

Currently, there are no Phase II MS4 permit authorizations or Phase I MS4 individual permits held in the Carancahua Bay AU 2456_02 watershed. However, future population growth within the UAs located in the watershed may require some entities to obtain authorizations under the Phase II MS4 general permit. For MS4 entities, where numeric effluent limitations are infeasible, the permits require that the MS4 develop and implement BMPs under each MCM, which are a substitute for effluent limitations, as allowed by federal rules. How a regulated MS4 meets each MCM is not prescribed in detail in the MS4 permits but is included in the permittee's SWMP. During the permit renewal process, TCEQ revises its MS4 permits as needed to require the implementation of other specific revisions in accordance with an approved TMDL and I-Plan.

Strategies for achieving pollutant loads in TMDLs from both point and nonpoint sources are reasonably assured by the state's use of an I-Plan. The TCEQ is committed to supporting implementation of all TMDLs adopted by the commission.

I-Plans for Texas TMDLs use an adaptive management approach that allows for refinement or addition of methods to achieve environmental goals. This adaptive approach reasonably assures that the necessary regulatory and voluntary activities to achieve pollutant reductions will be implemented. Periodic, repeated evaluations of the effectiveness of implementation methods ascertain whether progress is occurring and may show that the original distribution of loading among sources should be modified to increase efficiency. I-plans will be adapted as necessary to reflect needs identified in evaluations of progress.

Key Elements of an Implementation Plan

An I-Plan includes a detailed description and schedule of the regulatory and voluntary management measures to implement the WLAs and LAs of particular TMDLs within a reasonable time. I-Plans also identify the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress.

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to an impairment.

The TCEQ works with stakeholders and interested governmental agencies to develop and support I-Plans and track their progress. Work on I-Plans typically begins during development of TMDLs. Because this TMDL addresses agricultural sources of pollution, the TCEQ worked in close partnership with TSSWCB staff when developing the I-Plan. The TSSWCB is the lead agency in Texas responsible for planning, implementing, and managing programs and practices for preventing and abating agricultural and silvicultural nonpoint sources of water pollution. The cooperation required to develop an I-Plan will become a cornerstone for the shared responsibility necessary to carry it out.

Ultimately, the I-Plan will identify the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the I-Plan that is approved may not approximate the predicted loadings identified category-by-category in the TMDL and its underlying assessment. The I-Plan is adaptive for this very reason; it allows for continuous update and improvement.

In most cases, it is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction is required by the TMDL, there is high uncertainty with the TMDL analysis, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

References

Adams, Todd, and L. Hauck. 2017. Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Carancahua Bay. PR 1703. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas.

Asquith, W., M. Roussel, and J. Vrabel. 2006. Statewide Analysis of the Drainage-Area Ratio Method for 34 Streamflow Percentile Ranges in Texas. U.S. Geological Survey Scientific Investigations Report 2006-5286. Retrieved July 20, 2017. <https://pubs.usgs.gov/sir/2006/5286/>

American Veterinary Medical Association. 2012. U.S. Pet Ownership & Demographics Sourcebook (2012 Edition). Retrieved April 17, 2017, from <https://www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx>

Cleland, B. 2003. TMDL Development From the “Bottom Up” - Part III: Duration Curves and Wet-Weather Assessments. Retrieved May 16, 2015, from <https://www.researchgate.net/publication/228822472_TMDL_Development_from_the_Bottom_Up-_PART_III_Durations_Curves_and_Wet-Weather_Assessments>

EPA. 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. Retrieved June 22, 2017. <https://tinyurl.com/y2ynbhnc>

EPA. 2017. Enforcement & Compliance History Online. Retrieved May 4, 2017. <https://echo.epa.gov/>

Larkin, T. J., & Bomar, G. W. 1983. Climatic Atlas of Texas. Retrieved May 4, 2017, from Texas Water Development Board: <https://www.twdb.texas.gov/publications/reports/limited_printing/doc/LP192.pdf>

Nevada Division of Environmental Protection. 2003. Load Duration Curve Methodology for Assessment and TMDL Development. Retrieved June 27, 2017, from <https://ndep.nv.gov/uploads/water-tmdl-docs/LOADCURV.PDF>

New England Interstate Water Pollution Control Commission. 2003. Illicit Discharge Detection and Elimination Manual. Retrieved May 3, 2017, from <https://www.neiwpcc.org/neiwpcc_docs/iddmanual.pdf>

NOAA, National Centers for Environmental Information. 2017. Monthly Summaries for Palacios Airport. Retrieved May 4, 2017, from <https://www.ncdc.noaa.gov/cdo-web/>

ODEQ. 2006. Chapter 2 - Umpqua Basin TMDL. Retrieved June 6, 2017, from <https://www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Umpqua-Basin.aspx>

Reed, Stowe, and Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Retrieved May 3, 2017. <https://www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/StudyToDetermine.pdf>

Shackelford, C. E., E. R. Rozenburg, W. C. Hunter and M. W. Lockwood. 2005. Migration and the Migratory Birds of Texas: Who They Are and Where They Are Going. Texas Parks and Wildlife PWD BK W7000-511 (11/05). Booklet, 34pp. Retrieved May 3, 2017. <https://tpwd.texas.gov/publications/pwdpubs/media/pwd_bk_w7000_0511.pdf>.

TCEQ. 2007. 2006 Texas Water Quality Inventory and 303(d) List. Retrieved April 24, 2017. <https://www.tceq.texas.gov/waterquality/assessment/06twqi/twqi06.html>

TCEQ. 2015. 2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). Retrieved April 12, 2019. <https://www.tceq.texas.gov/waterquality/assessment/14twqi/14txir>

TCEQ. 2016. Seven Total Maximum Daily Loads for Indicator Bacteria in Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek Watersheds. Retrieved July 21, 2017. <https://www.tceq.texas.gov/assets/public/waterquality/tmdl/82sanjacinto/82B-EWFSJ-tmdl-adopted.pdf>

TCEQ, 2017a. GIS files by river basin. Retrieved April 20, 2017. <https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html/#wrapinput>

TCEQ. 2017b. Water Use Data files (.xls) for 1990-1999 and 2000-2014. Retrieved April 20, 2017. <https://www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud/>

TCEQ. 2017c. Central Registry Query. Retrieved March 30, 2017. <https://www15.tceq.texas.gov/crpub/index.cfm?fuseaction=home.welcome>

TCEQ. 2017d. SSO data request - Carancahua Bay Watershed; TCEQ Region 14 Office. Personal Communication received April 26, 2017.

TCEQ. 2017e. Surface Water Quality Monitoring Information System, 09/24/1973-09/16/2016 (Updated daily) rawDataCombined_Seg2456&Seg2456A.xlsx. Compiled by TCEQ Data Management & Analysis Team. Austin, Texas. Data Request ID 306.

TCEQ. 2018a. 2016 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). Retrieved Sept 10, 2019. <https://www.tceq.texas.gov/waterquality/assessment/16twqi/16txir>

TCEQ. 2018b. 2018 Texas Surface Water Quality Standards. Final 2018 TAC Chapter 307 Rule. Retrieved June 11, 2019. <https://texreg.sos.state.tx.us/public/readtac$ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=307&rl=Y>

TCEQ. 2019a. 2018 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). Retrieved Sept 27, 2019. <https://www.tceq.texas.gov/waterquality/assessment/18twqi/18txir>

TCEQ. 2019b. TCEQ Water Rights Permitting and Availability Section; Personal Communication received on July 3, 2019.

Texas Parks and Wildlife Department. 2017. White-tailed deer and feral hog density data request - Pleasanton, Texas. Personal communication received June 6, 2017.

TWDB. 2015. 2016 Approved Regional Water Plans (Regions K, L, and P). November - December 2015. Retrieved on April 20, 2017. <https://www.twdb.texas.gov/waterplanning/rwp/plans/2016/index.asp#region->

TWRI. 2014. Basin Approach to Address Bacterial Impairments in Basins 15, 16, and 17. TR-462. Retrieved May 3, 2017. <https://tinyurl.com/y3eykf9r>

TWRI. 2017. OSSF GIS file request. Personal communication received April 25, 2017.

USCB. 2017. 2010 Census Block Shapefiles for Calhoun, Jackson, Matagorda, and Wharton counties. Retrieved March 31, 2017. <www.census.gov/cgi-bin/geo/shapefiles/index.php>; Tabular data from: 2010 Census Block Households and Families. <https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>

USDA National Agricultural Statistics Service. 2014. 2012 Census Volume 1, Chapter2: State Level Data. Retrieved April 17, 2017. <https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/>

USDA NRCS. 2015. Soil Survey Geographic database (SSURGO). Retrieved April 11, 2017. <https://catalog.data.gov/dataset/soil-survey-geographic-ssurgo-database-for-various-soil-survey-areas-in-the-united-states->

USGS. 2014. National Land Cover Database 2011 Land Cover (2011 Edition, amended 2014). Retrieved February 28, 2017. <https://www.usgs.gov/core-science-systems/ngp/tnm-delivery/>

USGS. 2017. USGS Surface-Water Data for Nation. Search for Surface Water Stations. Retrieved January 2017. <https://waterdata.usgs.gov/nwis/sw>

Wagner, K. L. and Moench, E. 2009. Education Program for Improved Water Quality in Copano Bay. Task Two Report. College Station, TX: Texas Water Resources Institute. TR-347. Available online at <https://tinyurl.com/y665oe5t>

Weiskel, P., Howes, B., & Heufelder, G. 1996. Coliform Contamination of Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology, 30, 1872-1881. Retrieved May 3, 2017. <https://pubs.acs.org/doi/pdf/10.1021/es950466v>

Appendix A.
Modified Load Duration Curve

Traditionally, the LDC method has been restricted in TMDL development to freshwater, non-tidally influenced streams and rivers. The reason for excluding application of LDCs in TMDL development for tidally influenced stream and river systems is the presence of seawater in these river systems, i.e., an additional flow that has a loading. An assumption behind the LDC method is that the loadings of bacteria are derived exclusively from the sources of the streamflows. These sources and their associated loadings may be varied, but it is inherently assumed that they may be computationally determined based on the streamflow at the selected exceedance frequency on the LDC used for the LA. But in a tidal system there is other water (i.e., seawater) that is a source with an associated loading that must be considered.

If the LDC method is to be adapted to tidally influenced streams and rivers, some means of addressing the additional water and loadings from the seawater that mixes with freshwater in tidal rivers is needed. Oregon's Umpqua Basin Bacteria TMDL provides a modification of the LDC method that accounts for the seawater component (ODEQ, 2006).

Theoretical Development of Modified Load Duration Curve Approach

The approach taken in ODEQ (2006) is based on determining the volume of seawater that must be mixed with the volume of freshwater going down the river to arrive at the "observed" salinity using a simple mass balance approach as provided in the following:

$$(V_r + V_s)*S_t = V_r*S_r + V_s*S_s \qquad \text{(A-1)}$$

Where:

V_r = volume daily river flow (m^3) = Q (cfs)*86,400 (sec/day); where Q = river flow (cfs)

V_s = volume of seawater

S_t = salinity in river (parts per thousand or ppt)

S_r = background salinity of river water (ppt); assumed to be close to 0 ppt

S_s = salinity of seawater (35 ppt)

As noted in the computation of V_r, the volumes are actually time-associated using a day as the temporal measure, thus providing the proper association for the daily pollutant load computation. Through algebraic manipulation, this mass balance equation can be solved for the daily volume of seawater required to be mixed with freshwater (again, freshwater having an assumed salinity = 0), giving the equation found in the ODEQ (2006) technical information:

$$V_s = V_r / (S_s/S_t - 1);$$

for S_t > than background salinity; otherwise $V_s = 0$ (A-2)

For the Umpqua Basin tidal streams (e.g., Figure A-1), as well as the present application to the Carancahua Bay AU 2456_02 (Figure 8 in this report), regressions were developed of S_t to Q using measured salinity data (S_t) with freshwater flows (Q). These regressions all had some streamflow above which $S_t = 0$. The daily Q and regression-developed S_t were then used to compute V_s. As S_t approaches 0.0, V_s likewise approaches a value of 0.0 in Equation A-2, meaning the only flow present is the river flow (Q or V_r).

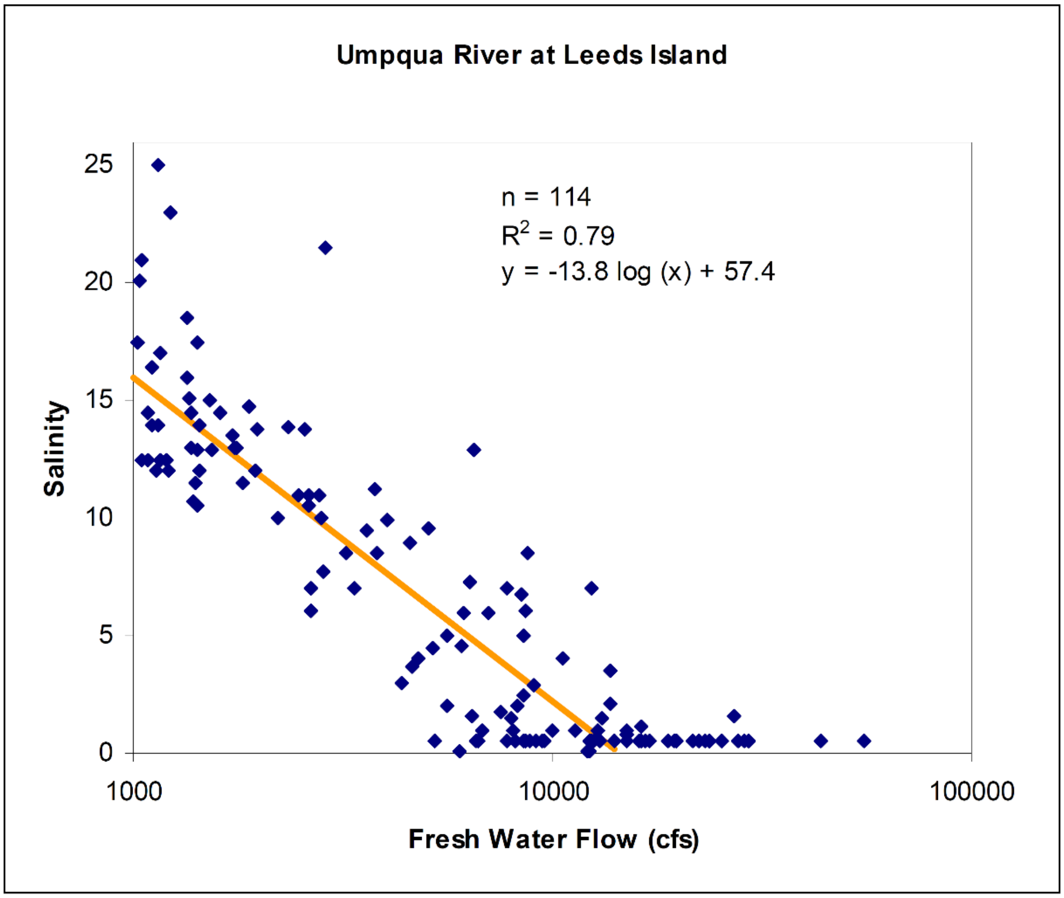

Figure A-1. Example of salinity to flow regression from Umpqua Basin Tidal streams (ODEQ, 2006).

Continuing with the theoretical development of the modified LDC for the Umpqua TMDLs, a total daily volume (V_t) is comprised of V_r computed from Q and the volume of seawater (V_s):

$$V_t = V_r + V_s \quad \text{(A-3)}$$

Resulting in:

$$\text{TMDL (cfu/day)} = \text{criterion} * V_t * \text{conversion factor} \quad \text{(A-4)}$$

The modified LDC method as captured in Equation A-4 is based on the assumption that combining of river water with seawater increases the loading capacity in the tidal river or bay because seawater typically contains lower concentrations of indicator bacteria, such as Enterococci, than river water.

Significance of Pollutant Load Allocation Based on Highest Flow Regime

It is also relevant to discuss the response of measured salinities at the assessment station to streamflow and the streamflows above which salinities approach background levels (assumed to be 0.1 ppt based on field observations at SWQM station 13388) within the context of the FDC for AU 2456_02. This FDC and the plotted flow exceedance values, where salinities approach background, should be viewed from the perspective of TCEQ's approach for bacteria TMDLs. Within the TCEQ TMDL approach with indicator bacteria, the highest flow regime is selected for developing the pollutant LA. This flow regime is defined as the range of 0-10 percent for the Carancahua Bay AU 2456_02. All the flows in the highest flow regime are greater than the amount of streamflow indicated by the salinity-to-flow regression analysis to result in an absence of seawater at SWQM station 13388 (see Figure A-2). Specifically, the FDC for SWQM station 13388 indicates that the flow of 314 cfs is the smallest flow that is predicted to result in a background salinity of 0.1 ppt, and its exceedance is 11.9 percent. The 10 percent exceedance flow is 429 cfs, and the five percent exceedance flow used in the pollutant LAs for this TMDL is 1,106 cfs.

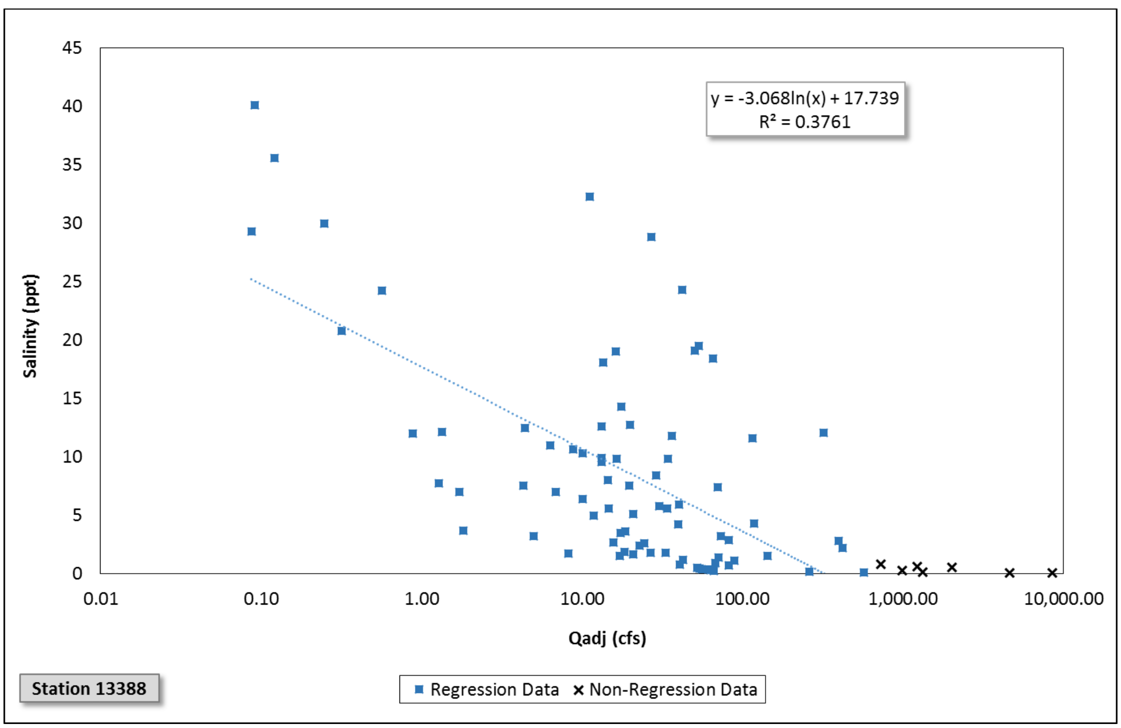

Figure A-2. Salinity to Streamflow regression for SWQM station 13388.

The significance of the above observation is related to what happens within the modified LDC method when salinities are at background. As salinity approaches background, V_s in Equation A-2 approaches a value of zero, and in fact would be defined as zero when salinities are at background levels, resulting in the modified LDC flow volume ($V_s + V_r$) defaulting to the flow of the river, i.e., no modification occurring to that portion of the LDC. Therefore, regarding the pollutant LA process for Carancahua Bay 2456_02, the modified LDC method provides identical allowable loadings in the highest flow regime to those that would be computed using the standard LDC method that does not include tidal influences. The identical results of the modified and standard LDC method for the highest flow regime is the physical reality indicated in the observed salinity data that at these elevated streamflows seawater is effectively pushed completely out of AU 2456_02. But the other implication is that for this tidal water body, the same pollutant LA results could be determined with the LDC method with or without tidal influences being considered due to development of the TMDL for the higher streamflows.

Rationale for Broadening Application of the Modified LDC Method to Carancahua Bay AU 2456_02

Similar to the limitation that the standard LDC method only be applied to freshwater streams and not to lakes and reservoirs due to the differences in dominating hydrodynamic processes, perhaps overly simply distinguished as the difference between lotic and lentic systems, the modified LDC method has been limited to date in its Texas applications to tidal streams. But transition zones from either freshwater stream to lake or tidal stream to bay provide an opportunity for broadening the application of these simple tools for developing bacteria TMDLs. For example, a TMDL has been approved and adopted for AU 1002_06 of the upper western arm of Lake Houston using the standard LDC method to develop the pollutant LA (TCEQ, 2016). This upper arm of Lake Houston is relatively shallow and stream-like in many aspects, and for this reason TCEQ staff were comfortable with extending the standard LDC method to the transition zone of a reservoir, especially since under the highest flow conditions defining the TMDL, this upper arm of the lake would be exhibiting visible downstream moving water.

As presented in the immediately preceding appendix section, freshwater conditions (i.e., background salinities) are experienced under high streamflow conditions at the location of Carancahua Bay SWQM station 13388. That is, salinities at SWQM station 13388 are responding under high freshwater inflows more like a tidal stream than as a bay, which experiences a spatial gradient of salinities. From the perspective of the high freshwater inflows used for development of bacteria TMDL allocations, Carancahua Bayou at SWQM station 13388 is behaving as a transition zone from a tidal creek to a bay analogous to the river-reservoir transition zone of the above-mentioned Lake Houston TMDL. This tidal-creek like response at SWQM station 13388 affords the opportunity for application of the modified LDC method within the context of TMDL development.

Further supporting the applicability of the modified LDC method to Carancahua Bay at SWQM station 13388 is the geomorphology of the bay as depicted in Figure 1 in this report. West Carancahua Creek Tidal transitions into Carancahua Bay effectively as a drowned river debouching into Matagorda Bay, and especially the upper portion of Carancahua Bay in the vicinity of SWQM station 13388 is relatively narrow. This suggests strong freshwater hydrologic and hydrodynamic influences during higher streamflows.

Admittedly there is a danger of overreach wherein the modified LDC method is applied, out of convenience, to water bodies for which the hydrologic assumptions of the approach are violated. A safeguard against this overreach is actually afforded by the TCEQ limitation that for TMDL development the approach must give results that default to standard LDC results for all flows within the hydrologic regime used to define the TMDL, i.e., typically the high flow regime defined by the 0-10 percentile exceedance flows. Under this flow limitation, which requires that salinities at the location of interest be at freshwater background levels, the water body is effectively behaving as a freshwater stream (i.e., exhibiting unidirectional flow in the downstream direction and producing freshwater levels of salinity) with either damped or no tidal influences. Since it is for these higher flows that the pollutant LA is developed, the fact that the water body may behave under low freshwater inflow conditions as a complex tidally influenced bay is of secondary importance to the purpose of estimating the high flow pollutant loading needed for TMDL purposes.

Based on the geomorphology of Carancahua Bay in the vicinity of SWQM station 13388 and the results of computations in the FDC and salinity regression for that station showing freshwater conditions existing under the highest flow regime, it was concluded that the modified LDC method is an acceptable means of developing a reliable indicator bacteria pollutant LA for AU 2456_02.

Appendix B.
Population Projections

TIAER took the following series of steps to complete the population projection exercise:

1. Obtained U.S. Census data at the block level
2. Developed 2010 watershed populations using the block level data for these locations: the portion of the community of La Ward and the four counties of Calhoun, Jackson, Matagorda, and Wharton within the watershed
3. For blocks not entirely within the watershed, a simple fraction of area within the watershed was proportioned
4. Obtained TWDB 2016 Regional Water Plan information to be used for population projections
5. No large cities are in the watershed, only the small community of La Ward and rural areas, which indicates there are no direct TWDB projections for La Ward and other rural areas
6. The TWDB Regional Water Plan does, however, provide projections for a category called "County – Other", which were used to determine growth rates for La Ward and other rural areas
7. "County – Other" projections for Calhoun, Jackson, Matagorda, and Wharton counties were used
8. From the Regional Water Plans, the decadal population projections are available for "County – Other", and decadal percent increases in population were calculated using those projections
9. The decadal percent population increases for each county were applied to the 2010 population for the watershed locations of La Ward and the portions of the four counties in the watershed, and these projections were summed by decade to give the decadal population projections out to 2050