Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Carancahua Bay

Segment 2456

Assessment Unit 2456_02

Carancahua Bay (Assessment Unit 2456_02; East side of Bay looking towards the West) near the intersection of CR 478 and CR 480

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Segment 2456

Assessment Unit 2456_02

Prepared for
Total Maximum Daily Load Program
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Abbreviations and Acronyms

AES	AgriLife Extension Service
AU	assessment unit
CCN	certificate of convenience and necessity
cfs	cubic feet per second
DAR	drainage area ratio
DMR	discharge monitoring report
DMU	Deer Management Unit
ECHO	Enforcement & Compliance History Online
E. coli	*Escherichia coli*
FDC	flow duration curve
FG	future growth
I&I	inflow and infiltration
ICIS	Integrated Compliance Information System
I-Plan	Implementation Plan
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
mi^2	miles squared or square miles
mL	milliliter
MOS	margin of safety
MPN	most probable number
MSGP	multi-sector general permit
MS4	municipal separate storm sewer system
NASS	National Agricultural Statistics Service
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
SSURGO	Soil Survey Geographic
SWQMIS	Surface Water Quality Monitoring Information System
TAMU	Texas A&M University
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	total maximum daily load
TNRIS	Texas Natural Resources Information System
TPDES	Texas Pollutant Discharge Elimination System

TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	wasteload allocation
WWTF	wastewater treatment facility
WUG	Water User Group

SECTION 1
INTRODUCTION

1.1 Background

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 total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (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. In addition to the TMDL an implementation plan (I-Plan) is developed, which is a description of the regulatory and voluntary management measures necessary to improve water quality and restore full use of the water body.

The TCEQ's TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, 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.

The TCEQ first identified the bacteria impairment within Carancahua Bay Assessment Unit (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 edition, now known as the 2014 *Texas Water Quality Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303 (d)* (TCEQ, 2015). 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 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 bacteria impairments in 1 water body (segment), consisting of 1 AU: Carancahua Bay (AU 2456_02).

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific users. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards and publishes the *Texas Water Quality Integrated Report* list biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2010) are rules that:

- designate the uses, or purposes, for which the state's water bodies should be suitable;
- establish numerical and narrative goals for water quality throughout the state; and
- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the Texas Surface Water Quality Standards to water bodies are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

Fecal indicator bacteria are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Both *E. coli* (*Escherichia coli*) and Enterococcus spp. are present in the intestinal tracts of humans and other warm blooded animal. The presence of these bacteria in water indicates that associated pathogens from the wastes that may be reaching water bodies as a result of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). *E. coli* is widely used as an indicator in freshwater, while Enterococci are more often used as an indicator in saltwater. Enterococci are the relevant indicator for Carancahua Bay AU 2456_02.

On June 30, 2010 the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2010) and on June 29, 2011 the United States Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria. For saltwater, recreational use consists of three categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for Enterococci of 35 most probable number (MPN) per 100 mL and a single sample criterion of 104 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for Enterococci of 175 per 100 mL;
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for Enterococci of 350 per 100 mL.

The impaired AU Carancahua Bay 2456_02 is approved for primary contact recreation, and since it is considered a saltwater water body, the associated Enterococci geometric mean criterion of 35 MPN per 100 mL and single sample criterion of 104 MPN per 100 mL are applied.

1.3 Report Purpose and Organization

The TMDL project for the watershed of Carancahua Bay AU 2456_02 was initiated through a contract between the TCEQ and the Texas Water Resources Institute (TWRI), with the Texas Institute for Applied Environmental Research (TIAER) as a subaward recipient to TWRI. The activities of this project to be performed by TIAER were to (1) acquire existing (historical) data and information necessary to support assessment activities; (2) perform the appropriate activities necessary to allocate Enterococci loadings; and (3) assist the TCEQ and TWRI in preparing the TMDL.

Using historical bacteria and flow data, this portion of the project aims to: (1) review the characteristics of the watershed and explore the potential sources of Enterococci bacteria for the impaired segment; (2) develop an appropriate tool for development of a bacteria TMDL for the impaired segment; and (3) submit the draft and final technical support document for the impaired segment. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the Carancahua Bay AU 2456_02 watershed. This report contains:

- information on historical data,
- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to presence of indicator bacteria (Enterococci),
- development of load duration curves (LDCs), and
- application of the LDC approach for the pollutant load allocation process.

SECTION 2
WATERSHED OVERVIEW AND DATA REVIEW

2.1 Description of Study Area

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 a tertiary embayment covering a surface area of 12,361 acres (19.3 square miles (mi^2)) and adjoins the northern portion of Matagorda Bay. It is comprised of two AUs with the upper portion of the bay designated as AU 2456_02 and the lower portion designated as 2456_01 (Figure 1). The impaired AU 2456_02 has a surface area of 4,503 acres (7.0 mi^2). Two unclassified creeks, West Carancahua Creek (Segment 2456A) and East Carancahua Creek, merge immediately upstream of the confluence with Carancahua Bay AU 2456_02 and provide the majority of 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 of the watershed), Jackson (64.5 percent of the watershed), Matagorda (16.7 percent of the watershed), and Wharton (17.3 percent of the watershed) counties.

The 2014 Texas Integrated Report (TCEQ, 2015) provides the following Segment and AU description for the water body considered in this document:

- Segment 2456 (AU 2456_02): Upper half of bay.

For the purposes of this study, only the watershed of the impaired AU 2456_02 is considered in this overview section and will be the focus of the TMDL (Figure 1).

2.2 Watershed Climate and Hydrology

The Carancahua Bay AU 2456_02 watershed is located in the eastern 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, 1983). For the period from 1981 to 2010, average annual precipitation over the Carancahua Bay AU 2456_02 watershed was 44.7 inches (Figure 2; Prism, 2012).

As depicted in Figure 3, for the most recent 15 year period from 2002 – 2016 at the nearest NOAA weather station (Palacios Municipal Airport - USW00012935) located approximately 8 miles east of AU 2456_02 (Figure 2), average high temperatures generally peak in August (92.1°F) with average monthly lows ranging from 76.9°F (June) to 78.2°F (August) during the summer months (NOAA, 2017). During the winter, the average low temperature generally bottoms out at 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.

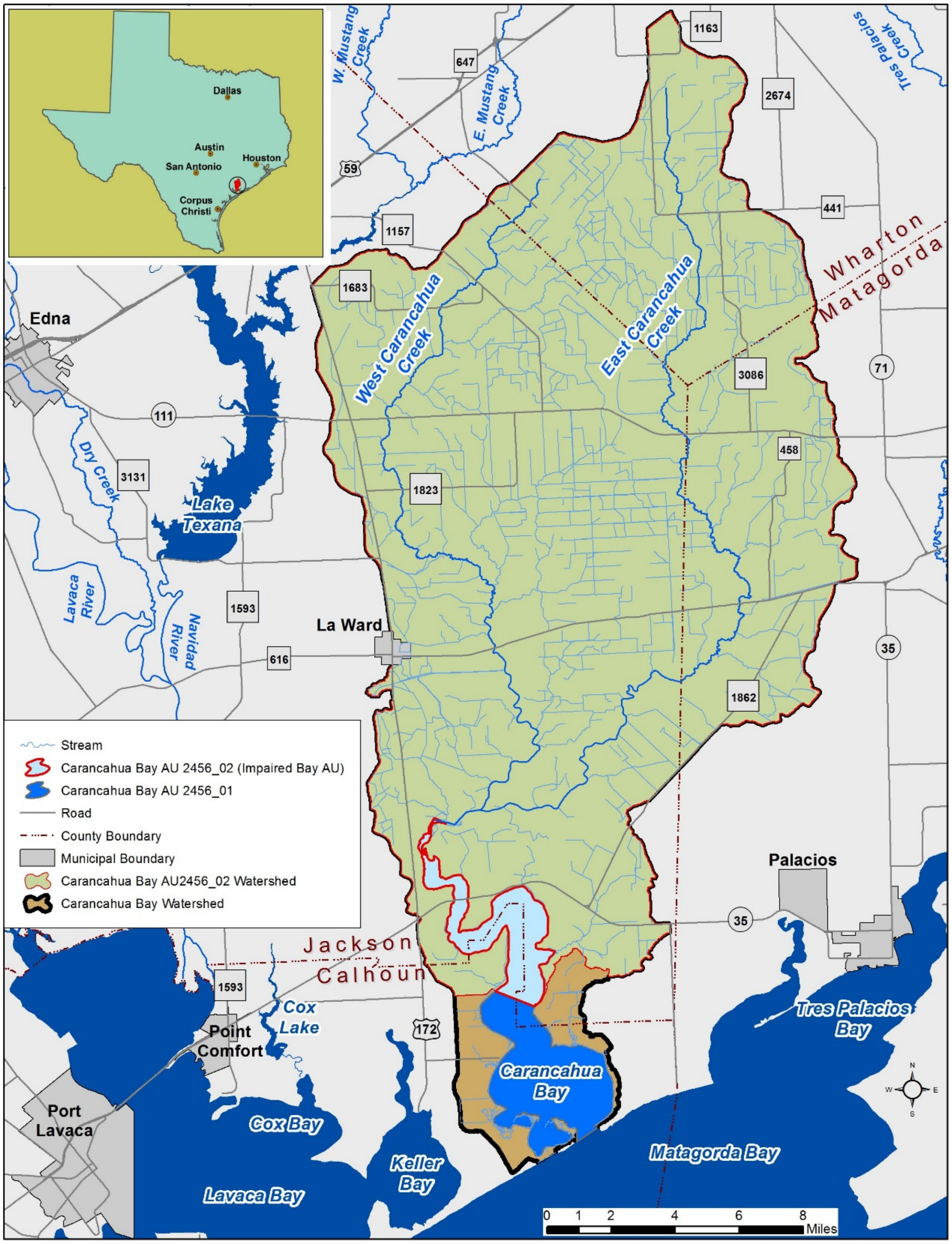

Figure 1. Overview map showing the Carancahua Bay AUs and watershed.

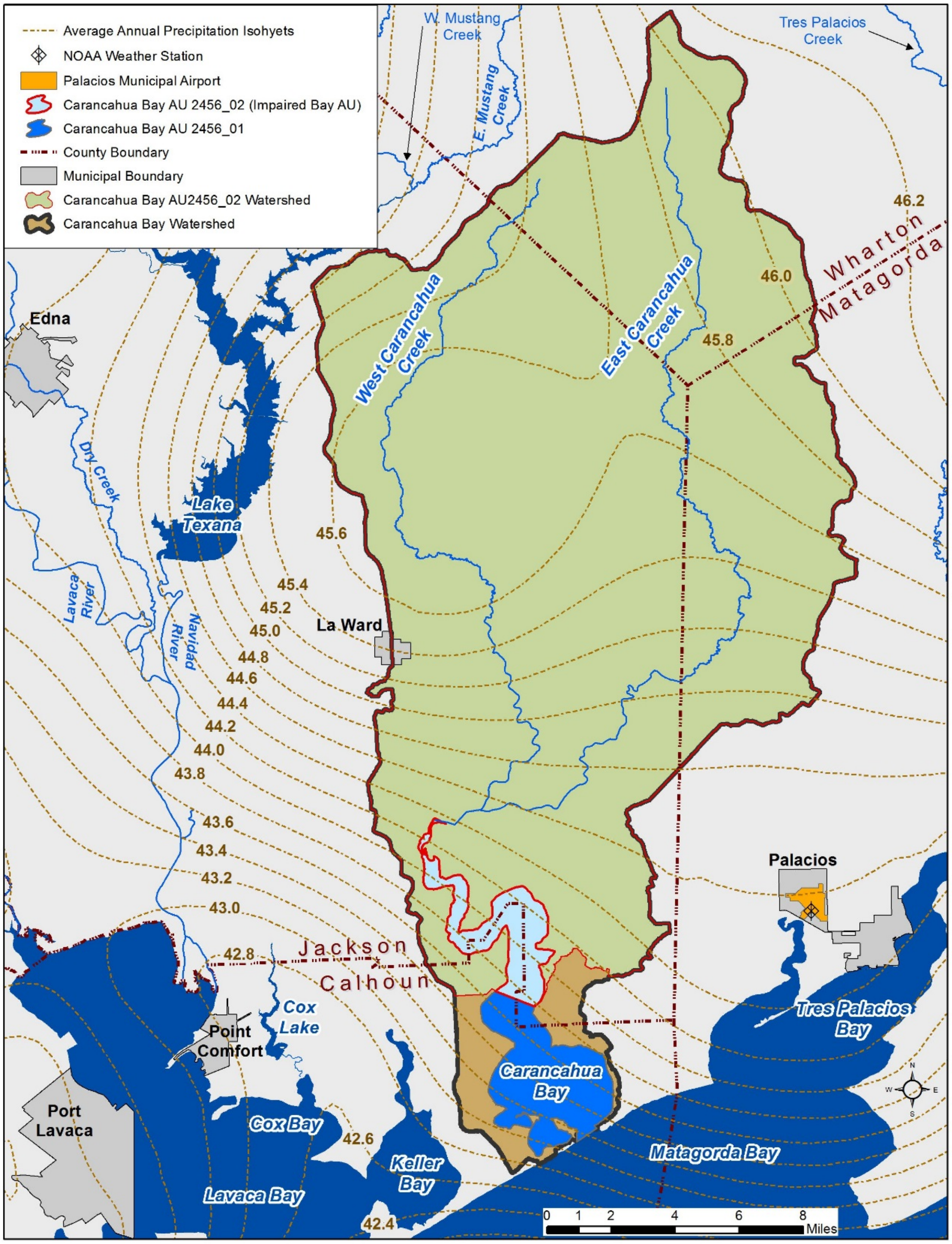

Figure 2. **Annual average precipitation isohyets (in inches) in the Carancahua Bay watershed (1981-2010). Municipalities within the watershed including Palacios Municipal Airport and NOAA weather station (USW00012935).**

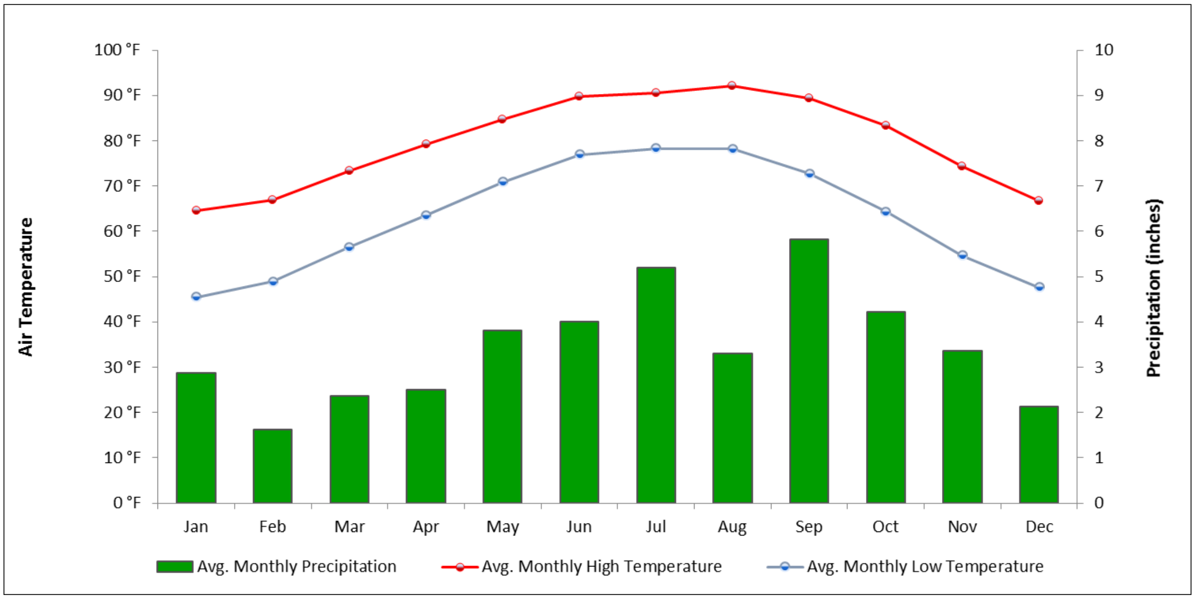

Figure 3. Average minimum and maximum air temperatures and average precipitation by month from 1981-2010 for the Palacios Municipal Airport.

2.3 Watershed Population and Population Projections

As depicted in Figure 4, the Carancahua Bay AU 2456_02 watershed lies within portions of Calhoun, Jackson, Wharton, and Matagorda counties and one municipal boundary (La Ward) lies partially within the watershed. According to the 2010 United States Census Bureau (USCB) data, population data reveal there are an estimated 1,888 people within the watershed revealing an average population density of approximately 6 people/square mile (USCB, 2017). Of those, an estimated 104 people (6 percent) are located within the city of La Ward, indicating that the watershed population is mostly rural. Figure 4 provides a depiction of the population density per acre of the Carancahua Bay AU 2456_02 watershed.

Population projections from 2010 - 2050 were developed by the Texas Water Development Board (TWDB) and indicate a population increase of 14.5 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 that portion of the Carancahua Bay AU 2456_02 watershed that lies within Calhoun County, but that area only contributes 23 additional people by 2050. The La Ward population within the study area is projected to increase by 10 people by 2050. The Jackson County-Other population within the watershed maintains the largest projected per capita increase with 124 people by 2050. Table 1 provides a summary of the 2010 – 2050 population projections.

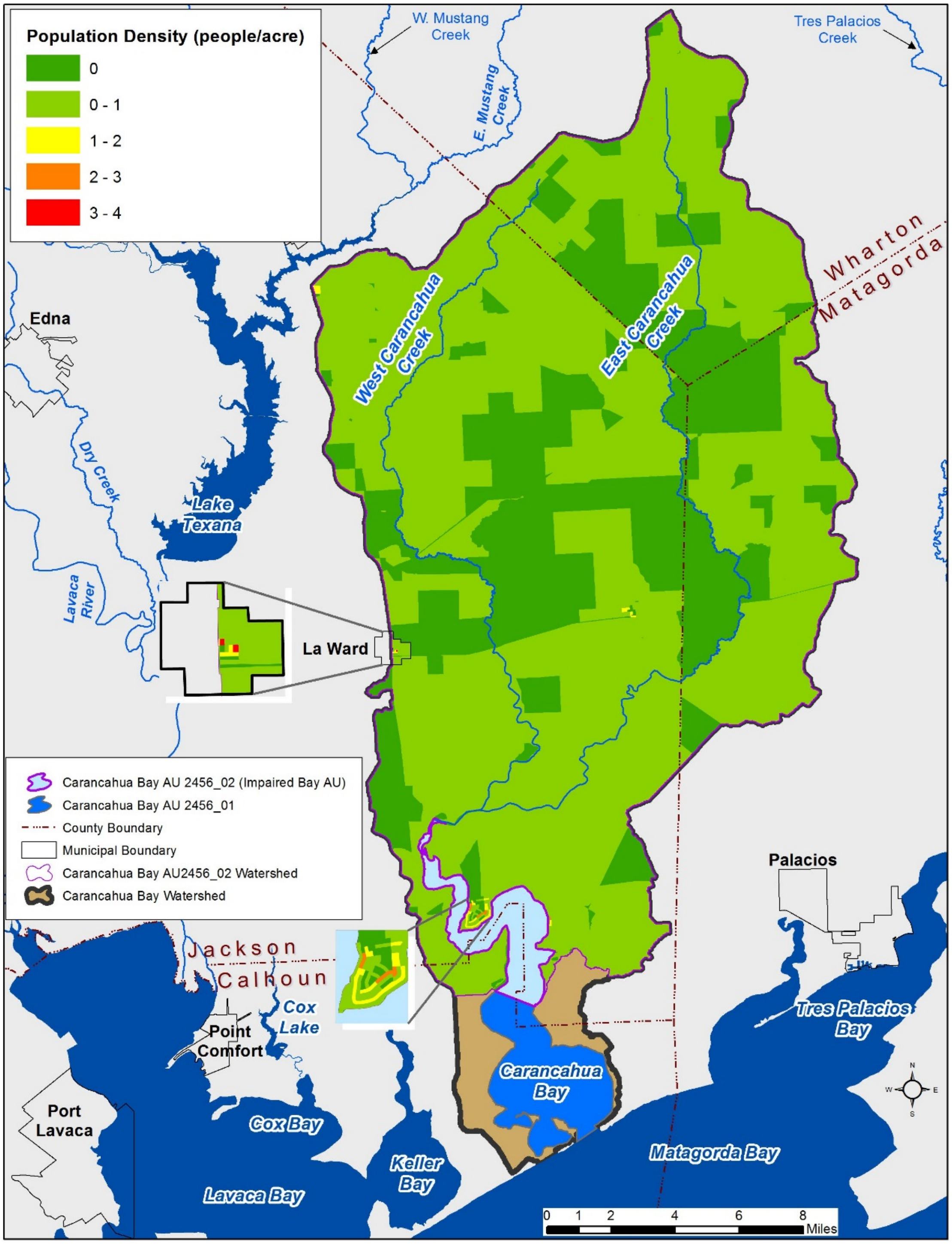

Figure 4. Population density for the Carancahua Bay AU 2456_02 watershed based on the 2010 U.S. Census Blocks.

Table 1. 2010 population with 2020 – 2050 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%**

2.4 Review of Carancahua Bay AU 2456_02 Watershed Routine Monitoring Data

2.4.1 Data Acquisition

Ambient *E. coli* and Enterococci data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on January 11, 2017 (TCEQ, 2017a). The data represented all the historical routine ambient bacteria and other water quality data collected in the project area, and included bacteria data collected in the Carancahua Bay AU 2456 watershed for the entire period of record. General assessment criteria methodologies established by TCEQ were used in data evaluations.

2.4.2 Analysis of Bacteria Data

Recent environmental indicator bacteria monitoring in AU 2456_02 with sufficient Enterococci samples for assessment (minimum of 10 samples) has occurred at only one TCEQ monitoring station (13388; Table 2 and Figure 5). Enterococci data collected at station 13388 over the seven-year period of December 1, 2005 through November 30, 2012 were used in assessing attainment of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2015). The 2014 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the geometric mean criteria of 35 MPN/100 mL for Enterococci.

Table 2. 2014 Integrated Report Summary for the impaired AU 2456_02. The geometric mean criterion for primary contact recreation use is 35 MPN/100 mL for Enterococci.

Water Body	AU	Parameter	Station	Data Date Range	No. of Samples	Geometric Mean (MPN/100 mL)
Carancahua Bay	2456_02	Enterococci	13388	Dec. 1, 2005 - Nov. 30, 2012	20	123.82

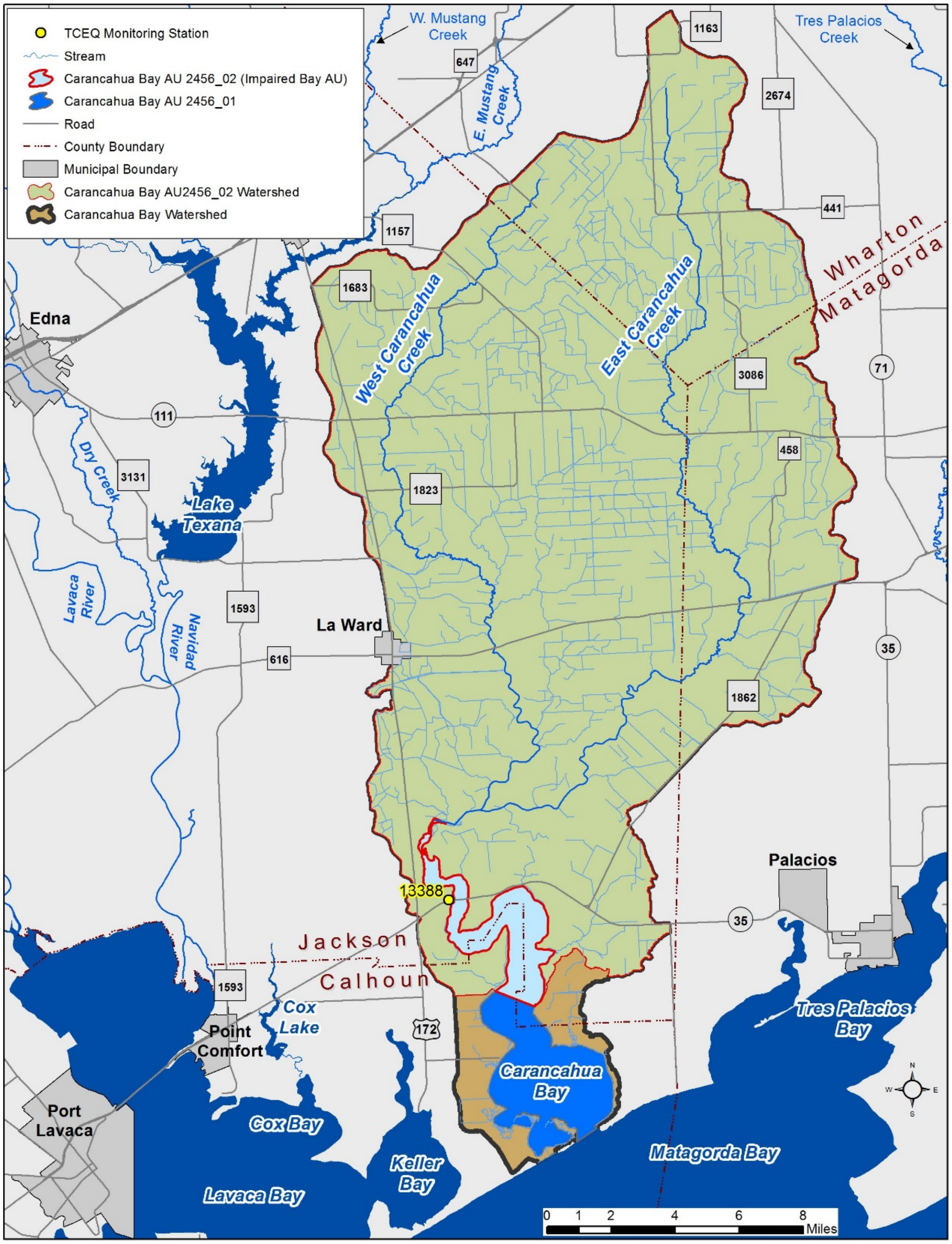

Figure 5. **Carancahua Bay AU 2456_02 watershed showing TCEQ surface water quality monitoring (SWQM) station.**

2.5 Water Rights Review

Surface water rights in Texas are administered and overseen by the TCEQ. A search of the TCEQ active water rights database files (TCEQ, 2017b) revealed that, within the Carancahua Bay AU 2456_02 watershed, there are an estimated 5 surface water rights owners (Table 3; Figure 6). As noted in Table 3, diverted water uses are exclusively for irrigation with an authorized diversion of 12,135 acre-feet annually.

A review of the water use data file containing historical, self-reported diversions indicate that 4 of the 5 water users diverted an average of approximately 677 acre-feet annually (with the remainder reporting zero diversions) from 1990 – 1999 (TCEQ, 2017c). For the more recent reporting period (2000 – 2014), only 2 of the 5 water users reported diversions occurring from 2000 – 2003 with an estimated 166 acre-feet diverted annually. Historical trends indicate a decline in water use and diversions upstream of Carancahua Bay AU 2456_02 and because of the absence of any recently reported diversions upstream of the AU from water rights owners, it is assumed that water diversions will have an insignificant impact on stream hydrology and pollutant load allocations.

Table 3. Permitted annual diversion amounts for water rights permittees in Carancahua Bay AU 2456_02 watershed.

Permit No.	Use	Diversion Location (Watershed)	Authorized Diversion Amount (acre-feet/year)
3827	Irrigation	West Carancahua Creek	100
3884	Irrigation	West Carancahua Creek	9,000
3972	Irrigation	East Carancahua Creek	1,500
4790	Irrigation	East Carancahua Creek	1,500
5487	Irrigation	West Carancahua Creek	35
Watershed Total			12,135

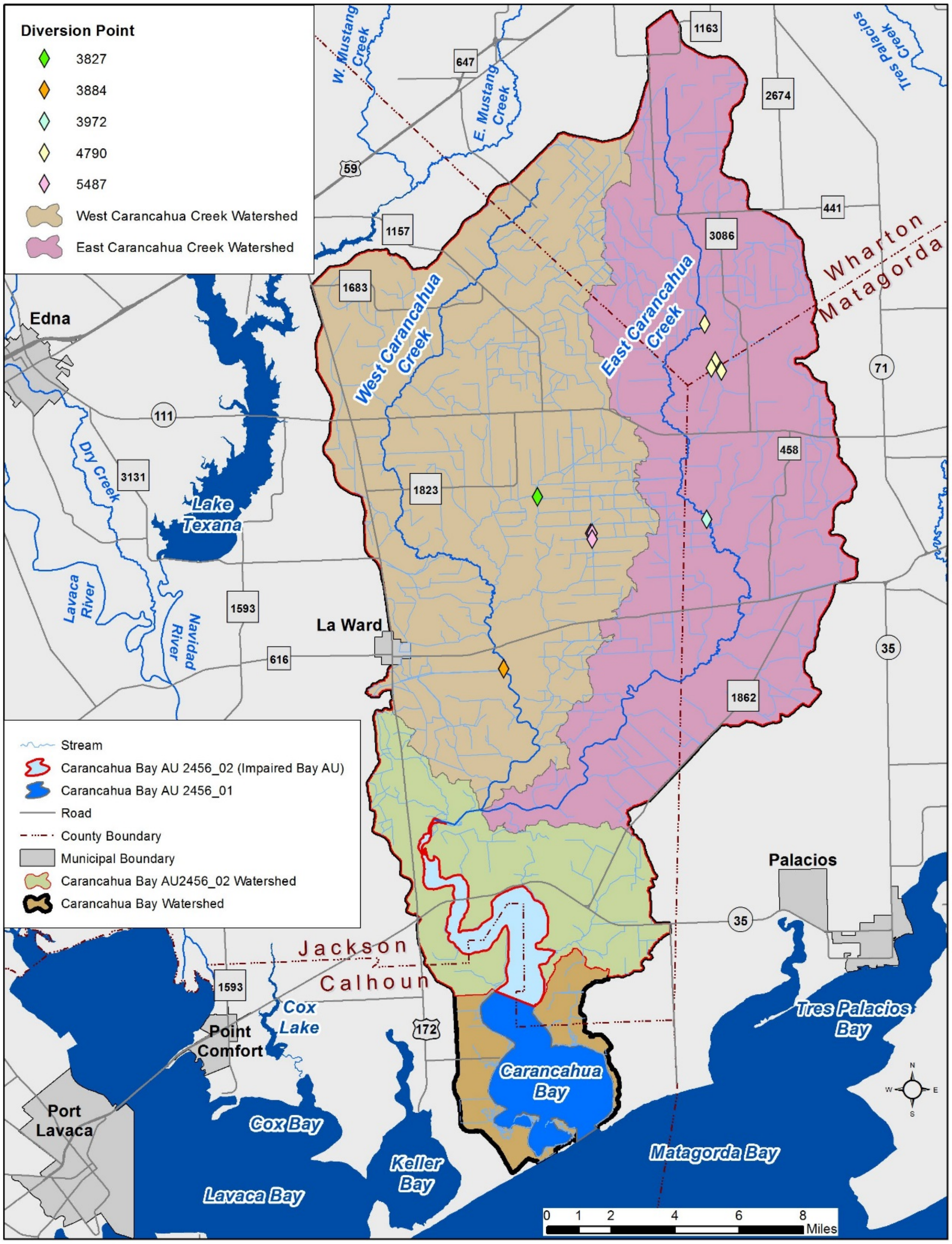

Figure 6. **Diversion locations with associated ID numbers for active surface water rights holders within the Carancahua Bay watershed.**

2.6 Land Use

The land use/land cover data for the Carancahua Bay AU 2456_02 watershed was obtained from the United States Geological Survey 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 to 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 5 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 5 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 5 meters tall, and greater than 20 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 5 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 grammanoid 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 4. As depicted in Figure 7, the dominant land uses are Cultivated Crops (46 percent) and Pasture/Hay (30 percent) comprising 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 4. Land use / land cover within the Carancahua Bay AU 2456_02 watershed.

2011 NLCD Classification	Area (acres)	Percent of Total [a]
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	99.99%

[a] Due to rounding the column does not add to exactly 100.00%

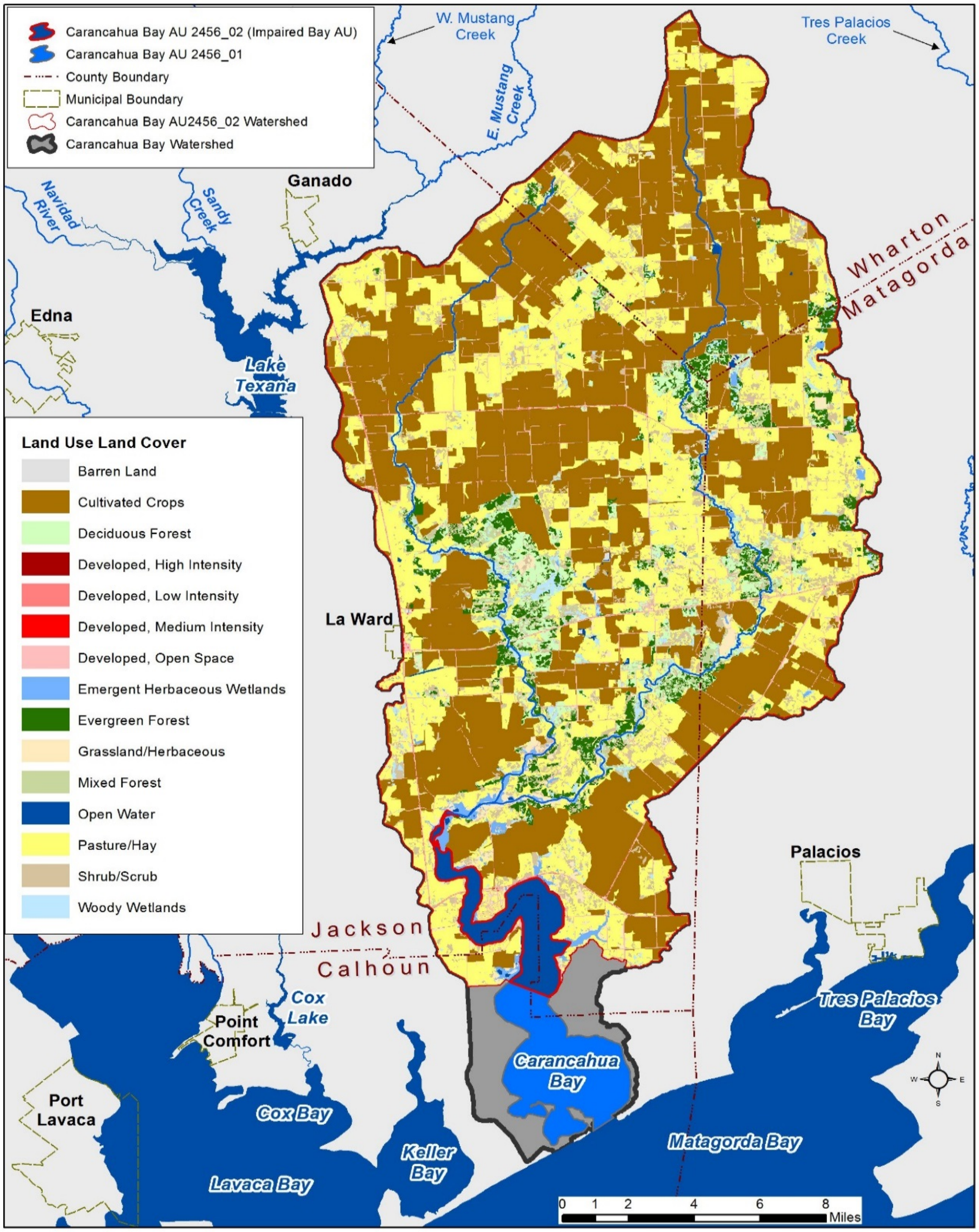

Figure 7. 2011 NLCD land use/ land cover within the Carancahua Bay watershed.

2.7 Soils

Soils within the Carancahua Bay watershed categorized by septic tank absorption fields, including dominant conditions are shown in Figure 8. These data were obtained through the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) 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 dominate soil condition within a septic drainage field can be used to identify soils that may prove problematic regarding septic system installation/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 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.*
- *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 8, approximately 97 percent of the soils are rated Very Limited within the Carancahua Bay AU 2456_02 watershed based on the dominate soil condition for septic drainage field installation and operation.

2.8 Potential Sources of Fecal Indicator Bacteria

Potential sources of indicator bacteria pollution can be divided into two primary categories: *regulated* and *unregulated*. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual wasteload allocations or WLAs (see report Section 4.7.3, Wasteload Allocation), the regulated and unregulated sources in this section are presented to give a general account of the potential sources of bacteria in the watershed.

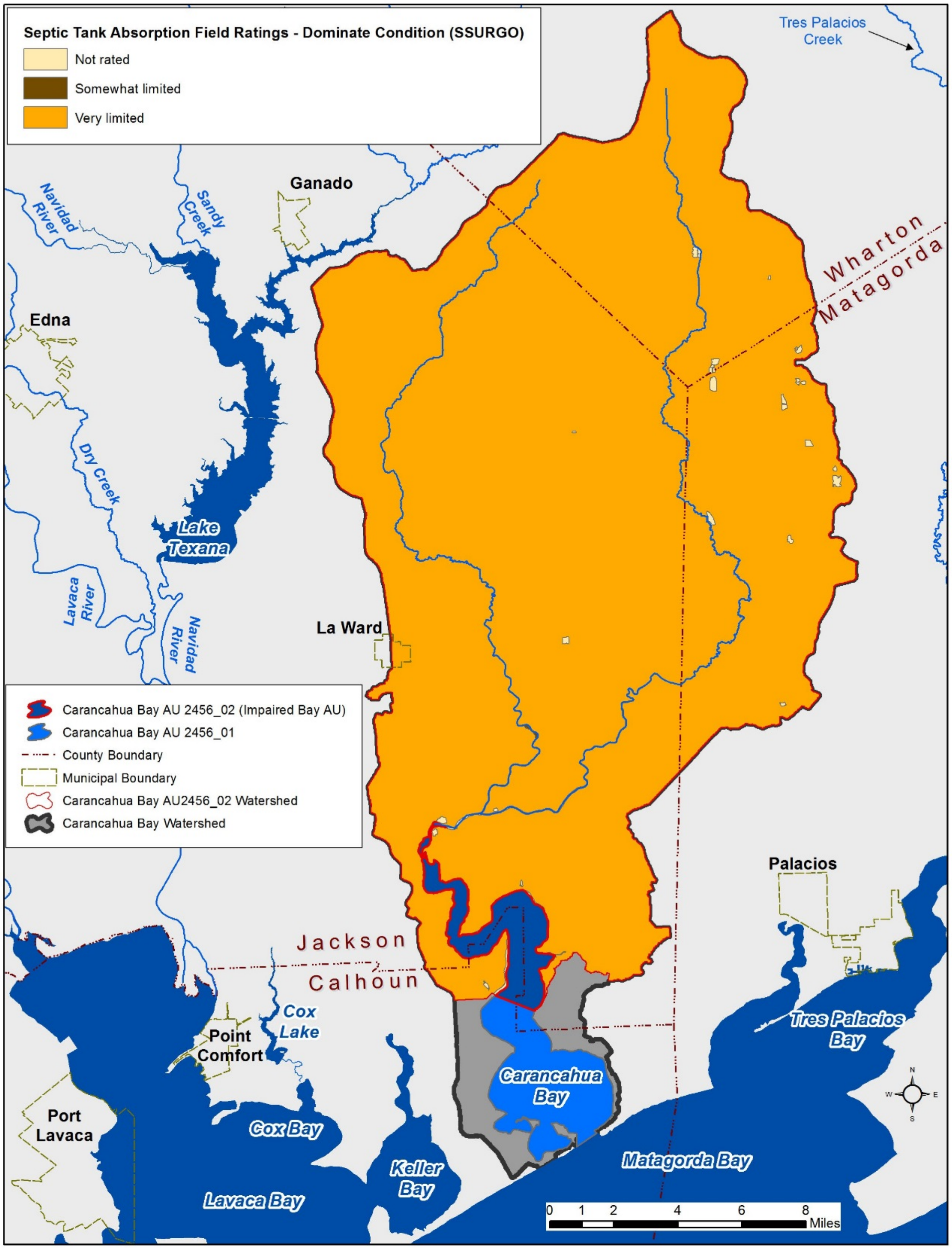

Figure 8. Septic tank absorption field limitation ratings for soils within the Carancahua Bay AU 2456_02 watershed.

2.8.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. WWTF outfalls and stormwater discharges from construction permits represent the permitted sources in the Carancahua Bay AU 2456_02 watershed.

2.8.1.1 Domestic and Industrial Wastewater Treatment Facilities

As of February 24, 2017, there is only one facility with a TPDES/ NPDES permit operating within the impaired watershed (Figure 9, Table 5). The La Ward WWTF treats domestic wastewater and discharges into an unnamed tributary, then to West Carancahua Creek and eventually into Carancahua Bay AU 2456_02. Discharge units are reported in million gallons per day (MGD).

2.8.1.2 TPDES General Wastewater Permits

In addition to the individual wastewater discharge permit listed in Table 5, discharges of processed wastewater from certain types of facilities are required to be covered by one of several TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production facilities
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides
- TXG920000 – concentrated animal feeding operations
- WQG20000 – livestock manure compost operations (irrigation only)

A review of active general permit coverage (TCEQ, 2017d) in the Carancahua Bay AU 2456_02 watershed as of March 30, 2017 revealed one pesticide permittee was covered by the general permit. Pesticide management areas do not have bacteria reporting or limits in their permit. These facilities were assumed to contain inconsequential amounts of indicator bacteria in their effluent; therefore, it was unnecessary to allocate bacteria load to these facilities. No other active general wastewater permit facilities or operations were found.

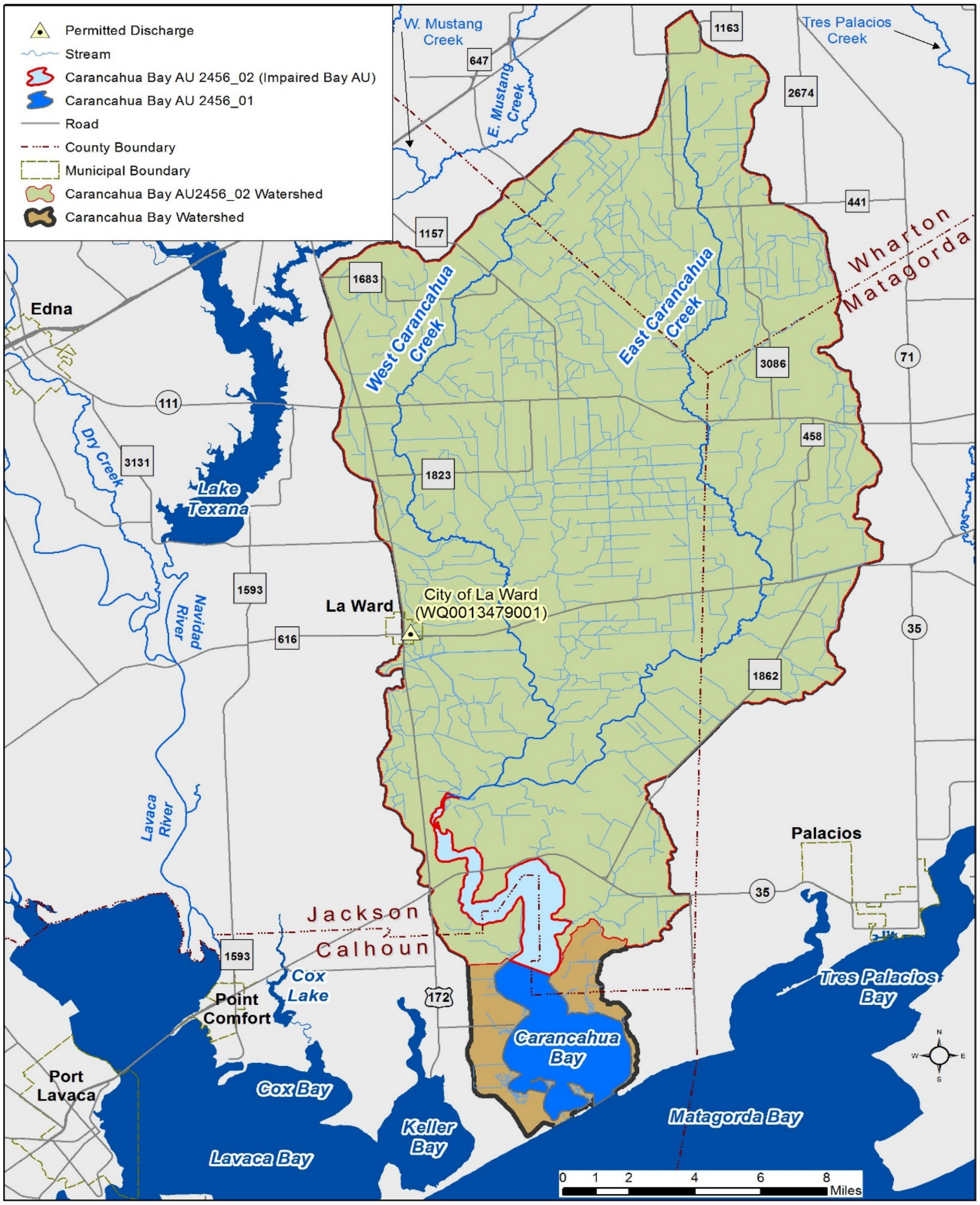

Figure 9. **Carancahua Bay AU 2456_02 watershed showing WWTF.**

Table 5. Permitted wastewater treatment facility in the Carancahua Bay AU 2456_02 watershed.

AU	Facility	TPDES Permit No.	NPDES Permit No.	Receiving Waters	Discharge Type	Permitted Discharge (MGD)	Recent Discharge (MGD)
2546A_01	City of La Ward	WQ0013479001	TX0105104	unnamed tributary; then to West Carancahua Creek; thence to Carancahua Bay	Domestic Wastewater	0.024 (daily avg)	0.008[a]

[a] Average measured data from June 2012 through March 2017 from Discharge Monitoring Report data (USEPA, 2017)

2.8.1.3 TPDES-Regulated Stormwater

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

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

Phase 1 MS4 permits are associated with large urban areas and as such, no permits of this nature occur for the Carancahua Bay AU 2456_02 watershed. Discharges of stormwater from a Phase II MS4 area, industrial facility, construction site, or other facility involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 – stormwater Phase II MS4 general permit for urbanized areas
- TXR050000 – stormwater multi-sector general permit (MSGP) for industrial facilities
- TXR150000 – stormwater from construction activities disturbing more than one acre
- TXG110000 – concrete production facilities
- TXG340000 – petroleum bulk stations and terminals

Three of these permits (MS4, MSGP, and construction) pertain solely to stormwater discharges. The other two – concrete production facilities and petroleum bulk stations and terminals – also authorize the discharge of process wastewater as discussed above under TPDES General Wastewater Permits.

A central registry query of active stormwater general permits coverage (TCEQ, 2017d) in the Carancahua Bay AU 2456_02 watershed, as of March 30, 2017, found two active construction activities covering 320 acres. There are currently no Phase II MS4s, MSGP, concrete production facilities, or petroleum bulk stations and terminals facilities in the impaired watershed. Based on the active stormwater general permits, regulated stormwater comprises 0.16 percent of the area within the Carancahua Bay AU 2456_02 watershed.

2.8.1.3 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, based on the one facility, revealed that no SSOs have been reported for the most recent reporting period 2012 - 2016 (TCEQ, 2017e). It is possible that SSOs are being under-reported in the Carancahua Bay AU 2456_02 watershed as some data would have been anticipated over the period covered in the dataset.

2.8.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated stormwater can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term “illicit discharge” is defined in TPDES General Permit No. TXR040000 for Phase II Municipal Separate Storm Sewer Systems 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 (NEIWPCC, 2003) includes:

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (e.g., used motor oil) 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 municipal 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.

2.8.1.5 Review of Compliance Information on Permitted Sources

A review of the USEPA Enforcement & Compliance History Online (ECHO) database (USEPA, 2017) conducted May 4, 2017, revealed non-compliance issues (effluent violations) regarding bacteria for the only WWTF located in the Carancahua Bay watershed (Table 6). The La Ward WWTF has a current *E. coli* compliance status of “No Violation”. None of the bacteria effluent violations were reported as “Significant Non-compliance” effluent violations.

2.8.2 Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint and can emanate from wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing on-site sewage facilities (OSSFs), and domestic pets.

Table 6. Bacteria monitoring requirements and compliance status for WWTFs in the Carancahua Bay AU2456_02 watershed.

Data available through the USEPA ECHO database (USEPA, 2017), assessed through the Discharge Monitoring Report Pollutant Loading Tool. "% Monthly Exceedances" were calculated based on monthly (2012 – 2013) and quarterly (2014 – present) reported records for bacteria.

TPDES Permit No.	NPDES Permit No.	Facility	Held By	Receiving Waters	Bacteria Monitoring Requirement	Min. Self-Monitoring Requirement Frequency	Daily Average (Geometric Mean Limitation)	Single Grab (or Daily Max Limitation)	% Reported Exceedances Daily Average	% Reported Exceedances Single Grab
WQ0013479001	TX0105104	La Ward WWTF	City of La Ward	unnamed tributary; thence to West Carancahua Creek; thence to Carancahua Bay	Domestic Wastewater	0.024 (daily avg)	126	399	0%[a]	10.71%[a]

[a] 28 monthly/quarterly records (2012 – 2016)

2.8.2.1 Wildlife and Unmanaged Animal Contributions

Fecal indicator bacteria, such as Enterococci and *E. coli*, are common inhabitants of the intestines of all warm blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to 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 rare, 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 the Texas A&M (TAMU) AgriLife Extension Service (AES) estimated a range of feral hog densities within Texas to be 1.33 to 2.45 hogs/square mile (TAMU AES, 2012). The average hog density of 1.89 hogs/square mile was multiplied by the hog-habitat area in the Carancahua Bay watershed (301 square miles). Habitat deemed suitable for hogs followed as closely as possible to the land use selections of the study and include from the 2011 NLCD: hay/pasture, cultivated crops, shrub/scrub, grassland/herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, and emergent herbaceous wetlands. Using this methodology, there are an estimated 569 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 (TPWD) (TPWD, 2017). The Carancahua Bay 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 7,843 deer within the Carancahua Bay AU 2456_02 watershed.

2.8.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the Carancahua Bay 2456_02 watershed was estimated from county level data obtained from the 2012 Census of Agriculture (USDA NASS, 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 farmers' use of manure as fertilizer, can contribute fecal indicator bacteria to nearby water bodies. The livestock numbers in Table 7 are provided to demonstrate that livestock are a potential source of bacteria in the impaired watershed. These numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Table 7. Estimated distributed domesticated animal populations within the Carancahua Bay AU 2456_02 watershed, based on proportional area.

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

2.8.2.3 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) and 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 and operated, 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 was 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 (CCN) sewer area or a city boundary were excluded from analyses. The total estimate is shown in Table 8 and the OSSF density is shown in Figure 10.

Table 8. OSSF estimate for the Carancahua Bay AU 2456_02 watershed.

Watershed	Estimated OSSFs
Carancahua Bay AU 2456_02	992

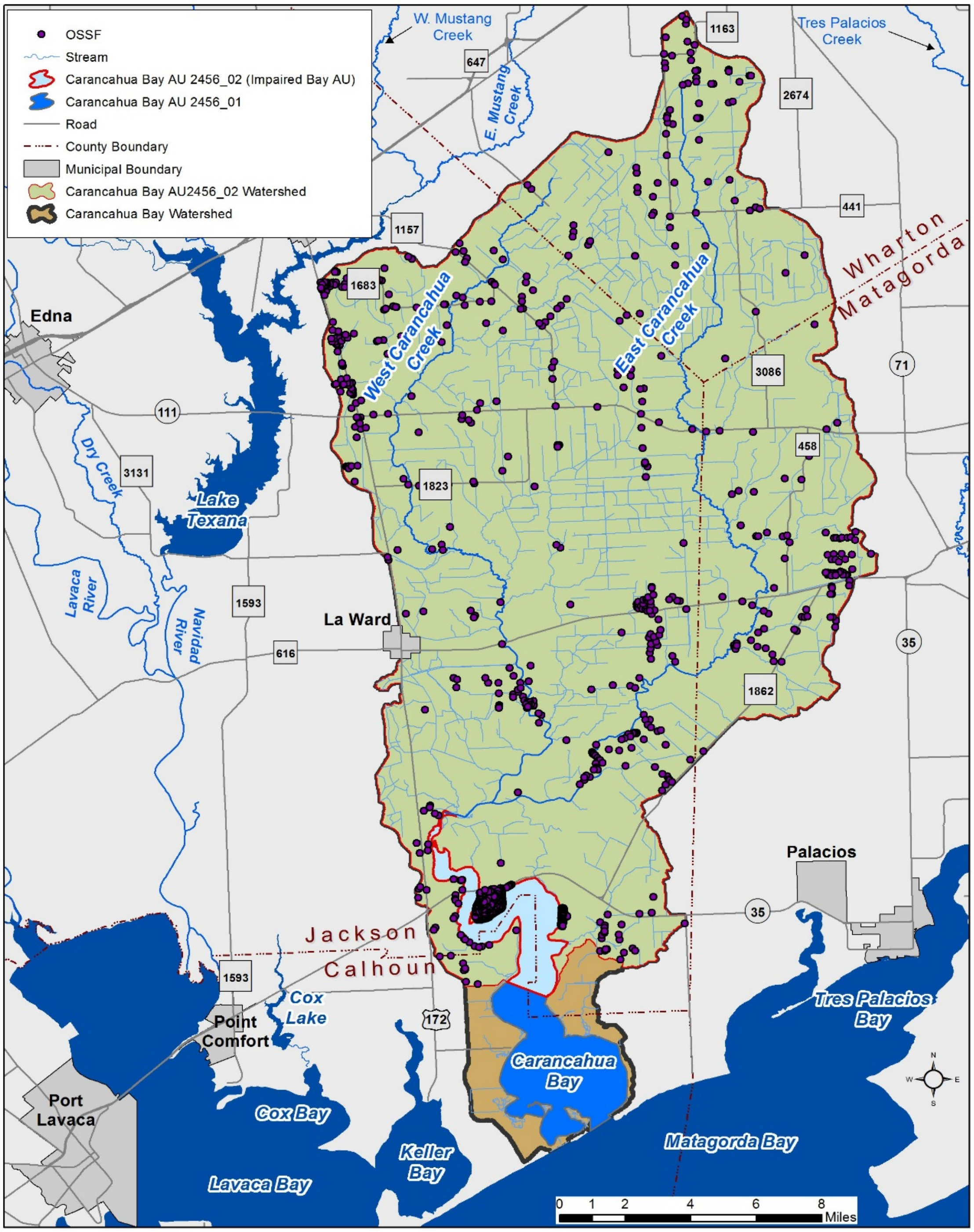

Figure 10. OSSF densities within the Carancahua Bay AU 2456_02 watershed.

2.8.2.4 Domestic Pets

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 9 summarizes the estimated number of dogs and cats for the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (AVMA, 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the watershed is unknown.

Table 9. Estimated Households and Pet Populations for the Carancahua Bay AU 2456_02 watershed.

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

2.8.2.5 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 indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their replication is less well-understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates for the TMDL watershed.

SECTION 3
DEVELOPMENT OF BACTERIA TOOLS

An essential component of a TMDL is to establish a linkage, or relationship, between pollutant sources and the water quality. It is possible through this linkage to determine the capacity of the water body to assimilate bacteria loadings while still supporting its designated use. This section describes development of the tools used to provide this linkage and to provide the data for computing the pollutant load allocations of the project water bodies.

3.1 Model Selection

The TMDL allocation process for bacteria involves assigning bacteria, e.g., Enterococci, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for the Carancahua Bay AU 2456_02 watershed considered availability of data and other information necessary for supportable application of the selected tool and guidance in the Texas bacteria task force report (TWRI, 2007). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models and an empirical approach referred to as the load duration curve (LDC).

Mechanistic computer models provide analytical abstractions of a real or prototype system. Mechanistic models, also referred to as process models, are based on theoretical principles that provide a representation of governing physical processes that determine the response of certain variables, such as stream flows and bacterial concentrations, to precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides an understanding of the important biological, chemical, and physical processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). An adaptation of the LDC method to tidal waters has been successfully developed and applied by the State of Oregon (ODEQ, 2006). In addition to estimating stream loads, the load duration curve method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations, often associated with bacteria TMDLs, which constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the load duration curve method within their three-tiered approach to TMDL development (TWRI, 2007). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion, and can give indications of broad sources of the bacteria, i.e., point source and nonpoint source.

3.1.1 Situational Limitations of Mechanistic Modeling

The present surface water bacteria standards do not restrict under what conditions the primary contact recreation criteria should meet; therefore, the allocation process must consider all hydrologic conditions ranging from low flows to high flows. Additionally, the water body for TMDL development is tidally influenced, which adds yet another level of complexity to the processes that needs to be considered. The TMDL allocation tool, therefore, must be capable of characterizing tidal influences, streamflow, and bacteria loads at desired locations under the wide variety of environmental conditions experienced in the TMDL watershed. If a mechanistic modeling tool is applied, it must be capable of simulating response of bacterial loadings to streamflow and tidal conditions during base flow as well as during times of response to rainfall runoff and those intermediate conditions between well-defined base flow and strong rainfall-runoff response. The type of mechanistic tool with capabilities to simulate all these complexities is often referred to as a combined watershed loading and hydrologic/water quality model. These models simulate the hydrologic response of the watershed's land uses and land covers to rainfall, route runoff water through the conveyance channels of the watershed, add in point source contributions, and may include other hydrologic processes such as interaction of surface waters with shallow ground water.

While admittedly the streamflow and tidal processes requiring simulation are complex, these processes are generally better understood and more readily simulated than the bacterial processes. Nonetheless, mechanistic bacteria modeling has progressed significantly over the last several decades beginning in the late 1960s to early 1970s, as increasing computer resources made such endeavors possible. Regrettably for the application of mechanistic bacteria models, while the numerical equations to represent many pertinent processes exist and are incorporated in readily available models, these processes are appreciably more watershed-specific than hydrologic processes. As one simple example, failing on-site treatment systems, such as septic systems, rarely make measurable differences to streamflow, but can dramatically impact fecal bacteria concentrations present in the same streamflow. In the vast majority of circumstances, and the Carancahua Bay AU 2456_02 watershed is no exception, only very limited watershed-specific information is available to define many of the physical and biological processes that affect bacteria concentrations and loadings. Consequentially, the operator of the mechanistic model must specify, in many circumstances, numerous input parameters governing bacteria processes for which actual numeric values may not be known within a reasonable range of certainty.

3.1.2 Carancahua Bay Data Resources

Streamflow, water diversion, salinity, and Enterococci data availability were used to provide guidance in the allocation tool selection process. (Salinity data provided a measure of the degree of mixing of seawater and freshwater in the tidal segment.) As already mentioned, the information and data necessary to allow adequate definition of many of the physical and biological processes influencing in-stream bacteria concentrations for mechanistic model application are largely unavailable for the Carancahua Bay AU 2456_02 watershed, and these limitations became an important consideration in the allocation tool selection process.

Hydrologic data in the form of daily streamflow records were unavailable for the TMDL watershed. However, streamflow records were available for two adjacent watersheds (Tres Palacios and East Mustang Creek) of similar demographic characteristics, e.g., urbanized area and agricultural influences (Table 10; Figure 11). Streamflow records that were collected and made readily available by the United States Geological Survey (USGS) for USGS streamflow gauge 08162600 (USGS, 2017; Figure 11), located within the Tres Palacios watershed, were considered to be representative of the TMDL watershed streamflow at high flow conditions based on preliminary analysis. Likewise, streamflow records at USGS streamflow gauge 08164504 (USGS, 2017; Figure 11), 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.

Table 10. Basic information on the USGS streamflow gauges utilized for streamflow development within Carancahua Bay AU 2456_02.

Gauge No.	Site Description	Drainage Area (acres)	Daily Streamflow Record (beginning and end date)
08162600	Tres Palacios Creek near Midfield, TX	92,800	June 1970 - present
08164504	East Mustang Creek near Louise ,TX	34,496	October 1996 - present

Self-reported data in the form of monthly discharge reports (DMRs) were available from January 2000 to December 2016 and necessary for streamflow development in the adjacent Tres Palacios Creek watershed (El Campo WWTF). DMR data were downloaded as available from two EPA compliance databases – ECHO and the Integrated Compliance Information System (ICIS).

Enterococci data were available through the TCEQ SWQMIS for the period of October 2001 – August 2016 for station 13388 in Carancahua Bay AU 2456_02 (Table 11), which was the only station in Carancahua Bay with more than 10 Enterococci data. During the period of October 2001 – August 2016, 87 surface measurements of salinity were also made at station 13388.

Table 11. Summary of historical bacteria and salinity data sets for station 13388.

Assessment Unit	Station	Station Location	Indicator Bacteria	No. of Bacteria Samples	Geometric Mean (MPN/100mL)	No. of Salinity Samples	Data Date Range
2456_02	13388	Carancahua Bay at SH 35	Enterococci	43	129	87[a]	October 2001 - August 2016

[a] Ten samples between January 2010 – August 2016 were actually specific conductance measurements and computed to a salinity equivalent value using a site-specific regression developed relating salinity to specific conductance

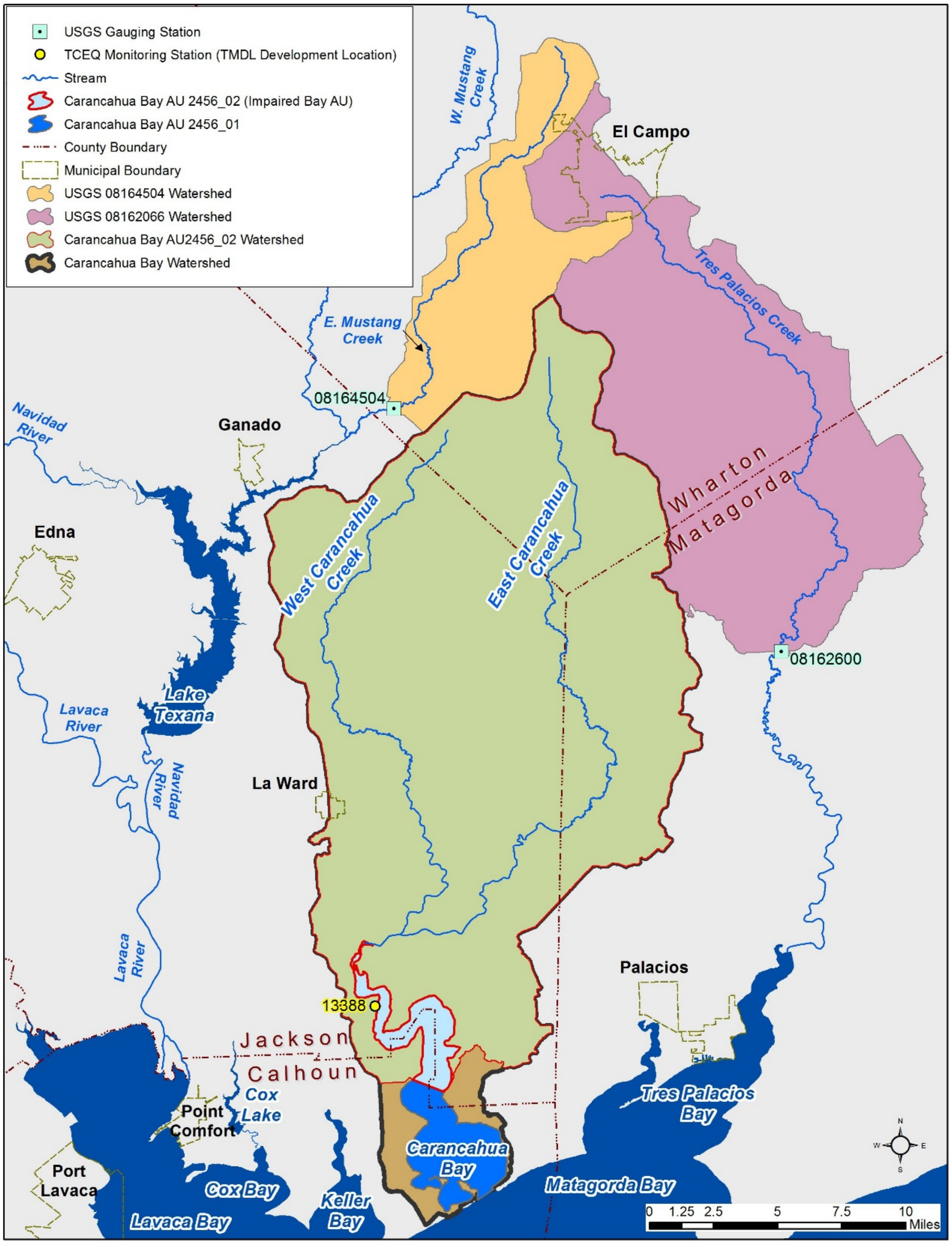

Figure 11. USGS gauging stations used in streamflow development along with the TMDL development location (station 13388) within the Carancahua Bay AU 2456_02 watershed.

In addition to streamflow data and water quality data, water diversion is an additional important data resource with respect to streamflow development. As previously stated in Section 2.5, Water rights diversion data were available and diversions were identified for Carancahua Bay AU 2456_02.

3.1.3 Allocation Tool Selection

The decision was made to use the LDC method with modifications to include tidal influences as opposed to a mechanistic watershed loading and hydrologic/water quality model, based on the following factors: good availability of historical daily streamflow records in adjacent watersheds, discharge information for relevant municipal WWTFs, Enterococci and salinity data, and water rights diversion data, as well as deficiencies in data to describe bacterial landscape and in-stream processes. A modification of the LDC method (modified LDC method) developed by State of Oregon Department of Environmental Quality for bacteria TMDLs of tidal streams of the Umpqua River Basin (ODEQ, 2006) was adapted to the Carancahua Bay AU 2456_02.

The modified LDC method is based on the assumption that the combining of river water with seawater increases the loading capacity in the tidal river because seawater typically contains lower concentrations of indicator bacteria, such as Enterococci, than river water. 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 and, as will be shown later in this section, has freshwater conditions under the high inflow conditions of freshwater considered for bacteria pollutant load allocation development in Texas.

3.2 Methodology for Flow Duration & Load Duration Curve Development

LDCs display the maximum allowable load over the complete range of flow conditions by a curved line, using the calculation of flow multiplied by the water quality criterion. Through LDCs, a TMDL can be expressed as a continuous function of flow as expressed through the curved line or as a discrete value derived from a specific flow condition.

To develop the FDCs and LDCs for Carancahua Bay AU 2456_02, the previously discussed data resources were used in the following series of sequential steps.

Step 1: Determine the hydrologic period of record to be used in developing the FDCs and LDCs.
Step 2: Determine desired TCEQ SWQM monitoring station location(s) for developing FDCs and LDCs.
Step 3: Develop naturalized freshwater flows for each desired location.
Step 4: Develop regression of salinity to streamflow at each desired location.
Step 5: Develop daily flow records at each desired location using naturalized flows from Step 3, full permitted WWTF discharges, actual water rights diversions, and daily tidal volumes.
Step 6: Develop FDC at each desired location and divide into discrete flow regimes.

Step 7: Develop the allowable bacteria LDC at each desired location based on the relevant criteria and the data from the FDC.

Step 8: Superpose historical bacteria data on each allowable bacteria LDC.

Additional information explaining the LDC method may be found in Cleland (2003) and NDEP (2003). Information on the modified LDC method is found in ODEQ (2006).

3.2.1 Step 1: Determine Hydrologic Period

Optimally, the period of record to develop an FDC should include as much data as possible in order to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the Enterococci data were collected.

As previously discussed in Section 3.1.2, no daily hydrologic records were available for the Carancahua Bay AU 2456_02 watershed. However, daily hydrologic (streamflow) records were available for two USGS gauges located in adjacent Tres Palacios Creek and East Mustang Creek watersheds (Table 10; Figure 11). Both gauges have more than a 20-year streamflow record, which is more than adequate to capture a reasonable variation in meteorological patterns of high and low rainfall periods.

A 15-year period was selected to develop the FDC to remain consistent with other TMDL development efforts along the central Texas coast using the modified LDC method (*i.e*., the adopted and approved Mission and Aransas Rivers TMDL (TCEQ, 2016a) and the Tres Palacios Creek TMDL that was still being developed at the time of this report (Painter et al., 2015). The end date of the period selected was based on ending in the year with the most recent complete record of streamflow data, which resulted in a period beginning January 1, 2002 and ending December 31, 2016. 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 and current conditions in the watershed.

3.2.2 Step 2: Determine Desired Location

Station 13388 was selected as the location for application of the modified LDC method (Figure 11). It was the only station within Carancahua Bay AU 2456_02 to have both sufficient and recent Enterococci data (Table 11). The selected 15-year period of January 1, 2002 through December 31, 2016 includes the dates of all the Enterococci data at station 13388 except one sample collected in October 2001.

Of note, only one other location, station 13389, in AU 2456_02 had Enterococci data (only 3 samples in 2001) but fell well short of the 24 sample minimum recommended for LDC development (TWRI, 2007). Other TCEQ monitoring stations within AU 2456_02 had bacteria data that were limited to fecal coliform.

3.2.3 Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station location were determined, the next step was to develop the 15-year daily record of "naturalized" flow for Station 13388. As used herein, naturalized flow is referring to the flow without the withdrawals from water rights and the additions of permitted discharges, i.e., the flows that would occur in response to precipitation, evapotranspiration, near-surface geology, soils, land covers of the watershed, and other factors. The naturalized daily streamflow records were developed from extant USGS records (Table 10).

Due to the absence of flow records within the impaired watershed, the method to develop the necessary streamflow record for the FDC/LDC location (Station 13388) involved a drainage-area ratio (DAR) approach using combined streamflow records from USGS streamflow gauges located in adjacent watersheds (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 station 13388 (185,208 acres) by the drainage area above the USGS gauge (Table 12).

Table 12. Drainage area ratios for locations within the Caranchua Bay AU 2456_02 watershed.

Waterbody	Station No.	Location Description	Location Drainage Area (acres)	DAR
Tres Palacios Creek	USGS 08162600	Tres Palacios Creek near Midfield, TX	92,800	1.996
East Mustang Creek	USGS 08164504	East Mustang Creek near Midfield, TX	34,496	5.369

Preliminary analyses to develop the salinity to streamflow regression for Step 4 indicated that the measured salinities at station 13388 were more strongly correlated with the Tres Palacios Creek streamflows than the East Mustang Creek streamflows. The assumption made from the stronger correlation using Tres Palacios streamflow is that the hydrologic record for the Tres Palacios Creek USGS gauge provides a better representation of the timing of elevated streamflows in the Carancahua Bay watershed than the hydrologic record for the East Mustang Creek USGS gauge. However, the hydrology under dry, low flow conditions of the Carancahua Bay watershed is appreciably different from the dry, low flow conditions in Tres Palacios Creek. Tres Palacios Creek has a relatively high and persistent baseflow component signifying groundwater contributions. In contrast West and East Carancahua Creeks appear to experience very low flows and perhaps even no flow conditions during dry periods based on field observations and limited instantaneous flow measurements on West Carancahua Creek. The low flow hydrology of East Mustang Creek, with no flow indicated to occur more than 20 percent of the time in the streamflow record, was considered to be more similar to the streamflows of the Carancahua Bay watershed than the Tres Palacios Creek low flow hydrology.

Based on the above observations regarding similarities in timing of elevated streamflows in the Carancahua Bay watershed to elevated streamflows in Tres Palacios Creek and the similarities of the magnitude of low flows in the Carancahua Bay watershed to low flows in East Mustang

Creek, the DAR approach was applied to the streamflow records of the USGS gauges for both Tres Palacios Creek and East Mustang Creek.

In order to properly apply the DAR, the “naturalized” flow at each USGS gauging station must be obtained. The “naturalized” flow is the gauged flow without water rights diversions or permitted discharges. First, WWTF flows in the form of estimated daily DMR reported discharge for all WWTFs upstream of the USGS gauge location were subtracted from the streamflow record of the gauge, resulting in an adjusted streamflow record with point source discharge influences removed. For USGS gauge 08162600, the only upstream WWTF included the City of El Campo. East Mustang Creek has two WWTFs (Wharton County WCID No.1 and Prasek’s Hillje Smokehouse), located upstream of USGS gauge 08164504 and are not considered to impact the streamflow based on the discharge points’ upstream distances from the gauging station and the small size of their discharges (0.15 and 0.012 MGD, respectively). Therefore, no WWTF flow adjustment for East Mustang Creek USGS gauge 08164504 was required.

Next, water rights diversions in the form of estimated daily reported diversions for all water rights holders upstream of the Tres Palacios USGS gauge were added back into the adjusted streamflow record, resulting in an adjusted streamflow record with upstream water diversions removed. For the USGS streamflow gauge 08164504, six water rights holders were identified along the mainstem of East Mustang Creek with no reported diversions from 2001 – 2014. Therefore, no adjustment to the daily reported streamflow for USGS streamflow gauge 08164504 occurred with respect to water diversion.

At this point, the “naturalized” flow at each USGS gauge (08162600 and 08164504) has been calculated. The next step was to multiply the DAR for each USGS gauge (Table 12) by the naturalized streamflow records giving an estimated daily freshwater flow record at station 13388 for each USGS gauging station. The estimated flow record based on Tres Palacios Creek provided the better estimate of the time of occurrence of elevated streamflow events, while the estimated streamflow record based on East Mustang Creek provided the better estimate of the magnitude of flow under moderate and low flow conditions.

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 station 13388 would have been computed as the means of the DAR-developed daily streamflows from Tres Palacios Creek and East Mustang Creeks. A refinement to that multiple reference gauge approach was made wherein a weighting factor was developed that was based on the exceedance frequency for the daily streamflows developed from Tres Palacios Creek gauged record. The Tres Palacios Creek gauged record was used as the basis because the initial analyses of salinity response to freshwater at station 13388 indicated that this record better reflected the timing of hydrologic variations than the East Mustang Creek record. The streamflow record for each day of the selected 15-year period was created used the following:

$$Q_{13388,\, i} = (1\text{-}F_i) * \bar{Q}_{TPC,\, i} + F * \bar{Q}_{EMC,\, i} \qquad \text{(Eq. 1)}$$

Where

$Q_{13388,\, i}$ = daily streamflow on day i at station 13388 on Carancahua Bay

$\bar{Q}_{TPC,\, i}$ = DAR streamflow on day i using Tres Palacios Creek USGS gauge record

$\bar{Q}_{EMC,\, i}$ = DAR developed streamflow on day i using East Mustang Creek USGS gauge record

i = individual days from January 1, 2002 through December 31, 2016

F_i = Factor on day i with a value between 0 and 1 based on the exceedance frequency of $\bar{Q}_{TPC,\, I}$

The value of F_i was calculated from a logistics function defined as:

$$F_i = L/(1+e^{-k(X_i - X_0)}) \qquad \text{(Eq. 2)}$$

Where

X_i = is the exceedance frequency of $\bar{Q}_{TPC,\, I}$ on day i represented as a fraction

X_0 = the x-value of the Sigmoid's midpoint for which a value of 0.5 was used

L = the curve's maximum value for which a value of 1.0 was used

K = the steepness of the curve for which a value of -10.0 was used.

Applying these two equations results in weighting the daily flow from the two estimated records such that at high flows based on the Tres Palacios Creek gauged record, a higher weighting is given to the Tres Palacios Creek based streamflow record, and, conversely, at low flows, a much higher weighting is given to the streamflow record based on the East Mustang Creek gauge. For example, at a high flow exceeded 5 percent of the time (X_i = 0.05), the value of F_i is 0.011, resulting in the computation of the flow for station 13388 in Eq. 1 using 0.989 times the flow based on Tres Palacios Creek and 0.011 times the flow based on East Mustang Creek. At a flow exceeded 95 percent of the time, the weighting factor for each of the two flow records would be exactly reversed.

Now that the naturalized flow record is estimated for station 13388, the final consideration is to see if there are any adjustments required to account for flows from the La Ward WWTF reaching station 13388. Because the average discharge from the La Ward WWTF is only 0.008 MGD or 0.012 cubic feet per second (cfs) and the discharge is located several miles upstream of station 13388, any contributions of the La Ward WWTF discharge were considered insignificant and most likely during dry period no contribution from the discharge arrives at station 13388. Note that the smallest non-zero flow measured at a USGS streamflow gauge is 0.01 cfs, which is close to the average discharge from the La Ward WWTF. Therefore the estimated naturalized streamflow records was not adjusted for WWTF flows to develop an estimated actual streamflow record, i.e., the naturalized and actual streamflow records were considered to be identical.

3.2.4 Step 4: Salinity to streamflow regression for station 13388

Due to the need to consider future growth and full permitted discharges in the pollutant load allocation process in Section 4, two distinct streamflow records are required for Station 13388 in order to develop the modified LDC. The streamflow record representing an estimate of the actual daily flow computed for station 13388 for the selected hydrologic period of January 1, 2002 through December 31, 2016 is required in this step to develop the salinity to streamflow regression required for the modified LDC method. The second streamflow record is required to determine the pollutant load allocation and will be discussed in Step 5.

As part of the development of the modified LDC method, it was necessary to develop a relationship between estimated actual daily streamflow and measured salinity for station 13388. The resulting regression was instrumental in determining the daily volume of saltwater present for each daily freshwater flow in the 15-year period of record. A salinity to streamflow regression was developed for station 13388. The resultant equation was used to calculate the volume of seawater that would flow through the station cross-section over the period of a day (Figure 12). It is noteworthy that above a streamflow of 314 cfs, tidal influences become minimal and measured salinities are at the background levels of the freshwater inflows.

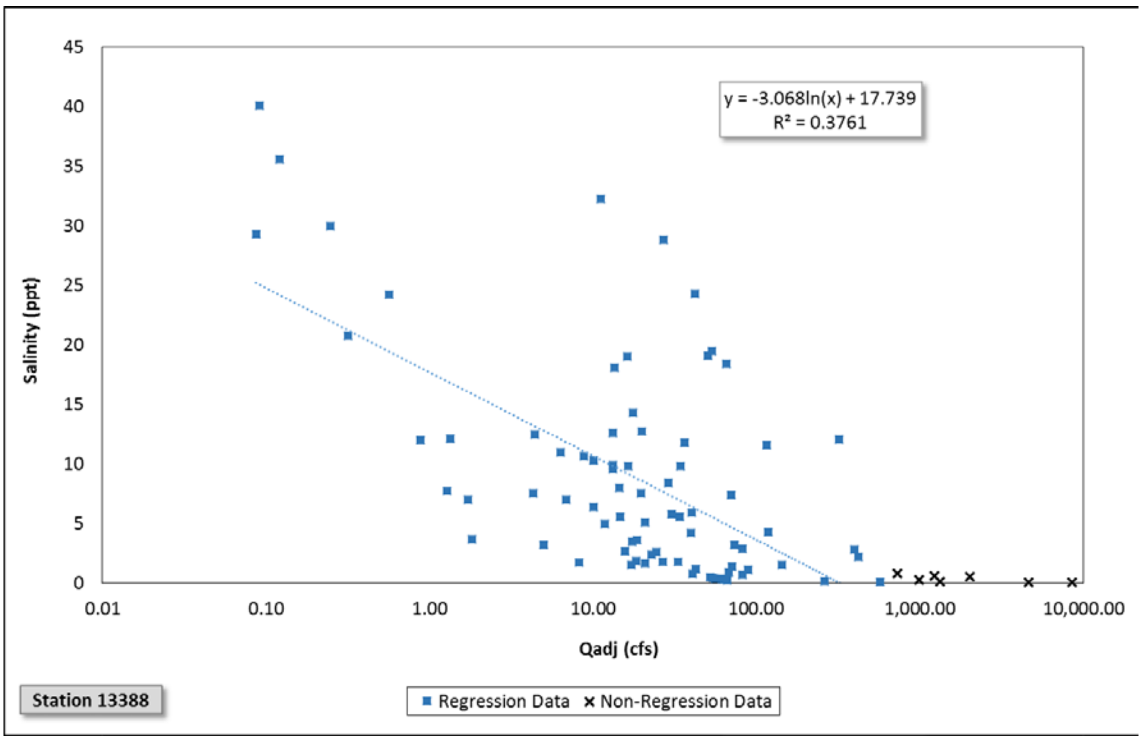

Figure 12. **Salinity to Streamflow regression for Station 13388.**

3.2.5 Step 5: Development of streamflow records for Station 13388

As previously mentioned, the daily streamflow record for Station 13388 contains an additional flow component necessary for determining the daily tidal volume of flow. Within this step, this daily tidal volume component is discussed.

The regression equations from Step 4 were used in Step 5 to provide information to allow computation of a total daily flow volume including freshwater and seawater. The process requires manipulation of the following mass balance equation for salinity at a tidally influenced station:

$$(V_r + V_s) * S_t = V_r * S_r + V_s * S_s \quad \text{(Eq. 3)}$$

Where

V_r = volume of daily freshwater (river) flow

V_s = volume of daily seawater flow

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

S_r = background salinity of upstream river water (ppt); assumed = 0 ppt

S_s = salinity of seawater (assumed to be 35 ppt)

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:

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

$$\text{for } S_t > \text{ than background salinity, otherwise } V_s = 0 \quad \text{(Eq. 4)}$$

Where S_t was computed for each day of the 15-year streamflow record using the regression equation of Step 4 and the estimated actual daily streamflow (V_r), also from Step 4, as input to the equation. The calculation of S_t allowed V_s to be computed from Eq. 4.

The modified daily flow volume (V_t) that includes the daily freshwater flow (V_r) and the daily volume of seawater flow (V_s) is computed as:

$$V_t = V_r + V_s \quad \text{(Eq. 5)}$$

For Station 13388, the adjusted streamflow records underwent the final modification of adding in upstream permitted discharges (full permitted discharge) and upstream future growth discharge for each WWTF to which a wasteload allocation will be assigned in the TMDL and the upstream actual water rights diversions. This included the addition of 0.037 cfs to each naturalized daily streamflow record to account for the La Ward WWTF influence to the actual estimated streamflow at station 13388 using the full permitted discharge flow from Table 5 (0.024 MGD). To account for future growth, a flow large enough to allow for expansion of WWTF discharges but of reasonable magnitude with respect to the demographics of the region is necessary for pollutant load allocation. Considering the demography of and future growth projections for the TMDL watershed (Table 1), 0.037 cfs (0.024 MGD) was determined to be an appropriate flow to accommodate a reasonable expansion of growth within the watershed, and the flow was added to each naturalized daily streamflow record. Future growth allocation is further discussed in Section 4.7.4.

3.2.6 Step 6 Development of flow duration curves (FDCs)

In this step, the FDCs were developed for Station 13388. In order to generate an FDC, the following actions were undertaken:

1) Order the daily streamflow data from highest to lowest values and assign a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);
2) Compute the percent of days each flow was exceeded by dividing each rank by the total number of data point plus 1; and
3) Plot 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 0 percent occur during periods of high flow or flood conditions. This graphical procedure provides information on basic hydrological characteristics in the stream based upon flows observed within specific reaches.

The amount of estimated seawater is presented in the intermediate FDC using the flows from Step 4 (Figure 13). As expected from the modified daily flow volume equation, the amount of seawater present increases as both the freshwater flow decreases and the percent of days the flow is exceeded increases. Note that the x-axis direction of increase on the seawater plot is reversed from that on the FDC.

The final FDC for station 13388 was created as previously described, and is shown in Figure 14.

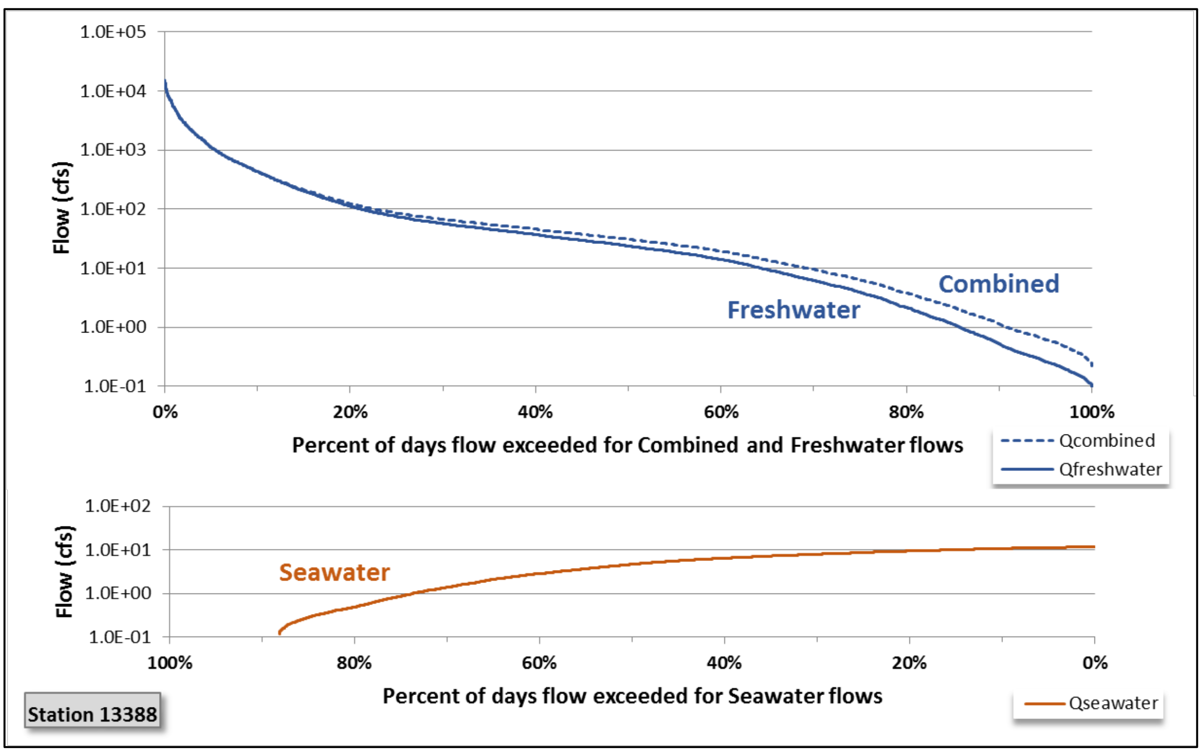

Figure 13. Flow duration curves for station 13388 showing the freshwater and seawater components, prior to final streamflow record modification.

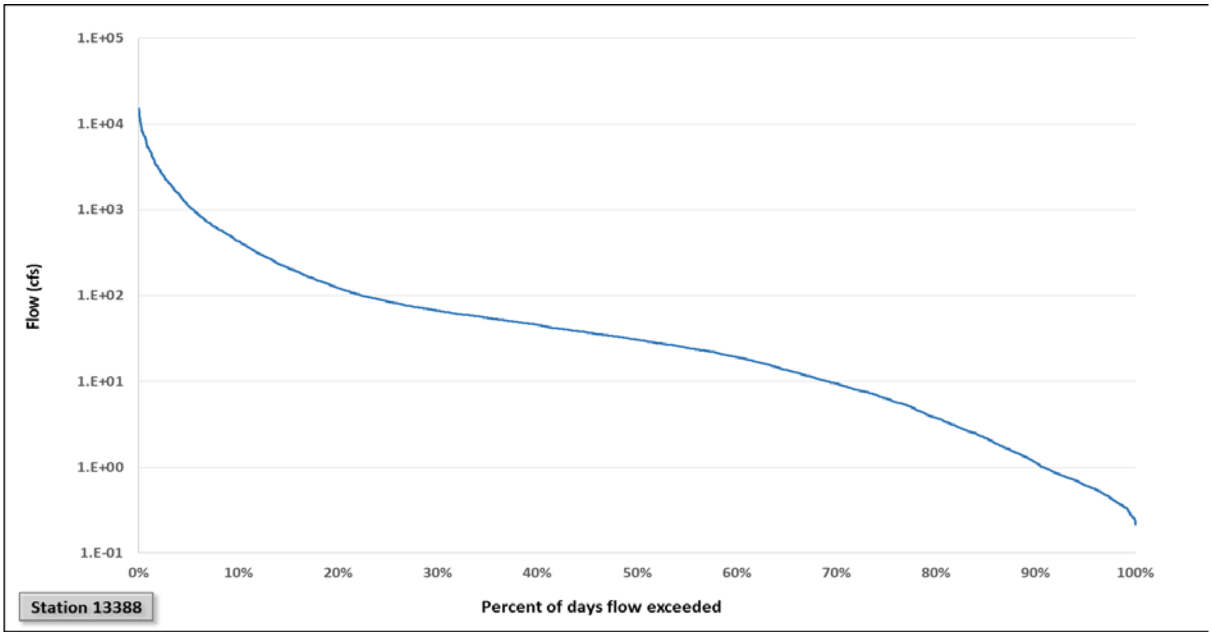

Figure 14. Flow duration curve for station 13388.

3.2.7 Step 7: Development of LDCs

In Step 7 the modified FDC for station 13388 was combined with the pertinent numeric water quality criterion established to protect the contact recreation use. The pertinent criterion for station 13388 is the geometric mean concentration of Enterococci not to exceed 35 MPN per 100 mL. The LDC was developed by multiplying the daily streamflow values (in cfs) from Step 6 by the appropriate bacteria criterion and by the conversion factor (2.44657×10^7) to express the loadings as MPN per day. Based on whether or not daily tidal volumes were included in the computed streamflow record, a modified LDC was created for Carancahua Bay AU 2456_02 (station 13388).

The shape of the LDC is identical to that of the FDC, because the data in the FDC has been multiplied by the same conversion factor. The label on the y-axis simply changes from Flow (cfs) to Enterococcus (MPN/ day), and the label on the x-axis changes from "percent of days flow exceeded" to "percent of days load exceeded."

A useful refinement of the LDC method is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (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).

3.2.8 Step 8: Superpose historical bacteria data

In this step, historical bacteria measurements (Enterococci) were aligned with the streamflow on the day of measurement. The historical bacteria measurements were then multiplied by the streamflow value and the conversion factor, as performed in Step 7, to calculate a loading associated with each measured bacteria concentration.

The points were then plotted on the LDC, and 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 reported “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 of the general climatic and hydrologic conditions. A “wet weather event” influenced bacteria sample was defined as occurring on any collection data with DSLP ≤ 5 days. Points above a curve represent exceedances of the bacteria criteria and associated allowable loadings. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low baseflow in the stream. Geometric mean loadings for the data points within each flow regime were calculated and displayed on each figure to aid in interpretation.

For station 13388, the wet weather data points occurred, as expected, predominately under the higher flow regimes and consistently exceeded the geometric mean criterion (Figure 15). Wet weather data points in the dry flow regime typically represent bacteria data collected after a small rainfall runoff event when conditions leading up to the event were dry.

The LDC developed for station 13388 provided in Figure 15 was used to develop the pollutant load allocation for Caranachua Bay AU 2456_02. The LDC indicates measured Enterococci loadings exceeded the allowable loadings for the geometric mean criterion (35 MPN/100mL) within all flow regimes. Additionally, measured Enterococci loadings often exceeded the allowable loadings for the single sample criterion (104 MPN/mL) in all flow regimes. Enterococci loading exceedances were generally not restricted to wet weather events but also occurred during conditions not influenced by rainfall runoff. Further, there is not a distinct pattern that measured Enterococci exceedances are more likely under wet-weather event conditions as compared to non wet-weather conditions.

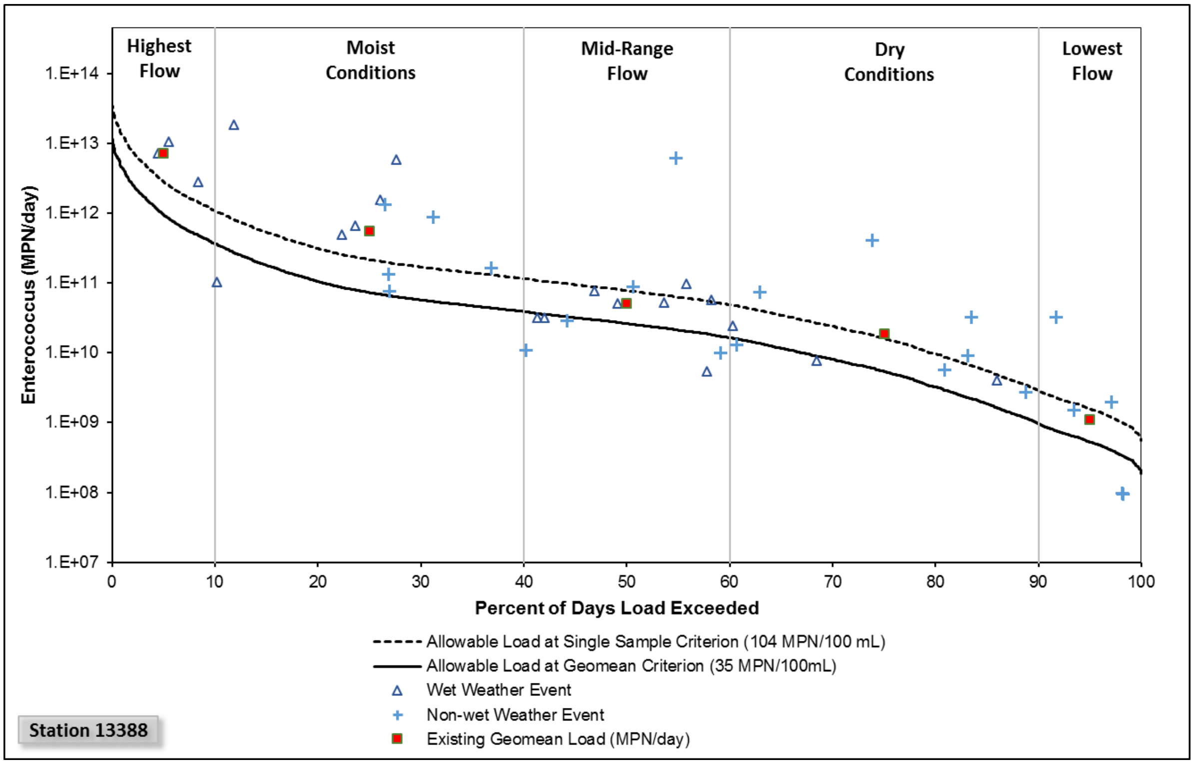

Figure 15. **Load duration curve at Station 13388 on Carancahua Bay AU 2456_02 for the period of January 1, 2002 through December 31, 2016.**

SECTION 4
TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocation for the TMDL watershed. The tool used for developing the TMDL allocation for station 13388 was the modified LDC method, which accounts for tidal influences, as previously described in Section 3 — Bacteria Tool Development. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

The modified LDC method provided a flow-based approach to determine necessary reductions in bacteria loadings and allowable loadings within the TMDL watershed. As developed previously in this report, the modified LDC method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the primary contact recreation use.

For the purposes of this TMDL study, the TMDL watershed is considered to be the entire Carancahua Bay AU 2456_02 as shown in the overview map (Figure 1) The LDC and TMDL were both computed for station 13388. Station 13388 was selected as the location for TMDL development because it is the only station in the impaired waterbody (AU 2456_02) with sufficient Enterococci measurements.

4.1. 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. Carancahua Bay AU 2456_02 has a use of primary contact recreation, which is measured against a numeric criterion for the indicator bacteria Enterococci due to the fact that it is tidally influenced. Indicator bacteria are not generally pathogenic and are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. The Enterococci criterion to protect contact recreation in saltwater systems consists of a geometric mean concentration not to exceed 35 MPN/100 mL (TCEQ, 2010).

The endpoint for this TMDL is to maintain concentrations of Enterococci below the geometric mean criterion of 35 MPN/100 mL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standard (TCEQ, 2010) for primary contact recreation in saline water bodies.

4.2 Seasonality

Seasonal variations or seasonality occur(s) 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.

4.3 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. The 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.

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 indicator 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 indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Load duration curves were used to examine the relationship between instream water quality and the source of indicator bacteria loads. 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 (Section 4.7). 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.

4.4 Modified Load Duration Curve Analysis

A modified LDC method was used to examine the relationship between instream water quality and the broad sources of indicator 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. Modified 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 modified LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The USEPA 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. As discussed in more detail in Section 4.7 (Pollutant Load Allocation), the TMDL loads were based on the median flow within the high flow regime (or 5 percent flow), where exceedances of the primary contact recreation criteria are most pronounced. Under the high flow regime, there was no seawater volume computed as being present at station 13388. With an absence of seawater at these high flows, the modified LDC results effectively simplified to those of the unmodified LDC method without adjustments to accommodate tidal influences (see Figure 13).

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.

Based on the LDC for station 13388 to be used in the pollutant load allocation process with historical Enterococci data added to the graphs (Figure 15) and Section 2.8 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. The historical Enterococci data indicate that elevated bacteria loadings occur under all flow conditions, but become most elevated under the highest flows and only fall below the single sample criterion under the mid-range and lowest 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. Most likely non-regulated 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 due to the outfall of the La Ward WWTF being located at some distance from station 13388 and the facility having a good compliance record (Table 6). 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.

4.5 Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (USEPA, 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 by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for Enterococci of 33.3 MPN/100 mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6 Load Reduction Analysis

While the TMDL for the Carancahua Bay AU 2456_02 watershed was developed using an LDC and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each of the five flow regimes was determined using the historical bacteria data for station 13388, the selected station for which the LDC was developed. For flow regime, the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean Enterococci concentration and the 35 MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration for station 13388 (Table 13).

Table 13. Percent reduction calculations for Enterococci by flow regime for station 13388.

AU	High Flows (0-10%)		Moist Conditions (10-40%)		Mid-Range Flow (40-60%)		Dry Conditions (60-90%)		Low Flows (90-100%)	
	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction
2456_02	268	86.9%	269	87.0%	68	48.5%	122	71.3%	73	52.1%

4.7 Pollutant Load Allocation

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

TMDL = WLA + LA + FG + MOS (Eq. 6)

Where:

TMDL = total maximum daily load

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

LA = load allocation, the amount of pollutant allowed by non-regulated or non-permitted sources

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For Enterococci, TMDLs are expressed as MPN/day, and represent the maximum one-day load the water body can assimilate while still attaining the standards for surface water quality.

The TMDL component for the impaired AU covered in this report is derived using the median flow within the high flow regime (or 5 percent flow) of the LDC developed for the SWQM station 13388. For the remainder of this report, each section will present an explanation of the TMDL component first, followed by the results of the calculation for that component.

4.7.1 AU-Level TMDL Computations

The bacteria TMDL for Carancahua Bay AU 2456_02 was developed as a pollutant load allocation based on information from the LDC for station 13388 (Figure 15). As discussed in more detail in Section 3, bacteria LDCs using modifications to include tidal influences were developed by multiplying each flow value along the flow duration curves by the Enterococci criterion (35 MPN/100 mL) and by the conversion factor used to represent maximum loading in MPN/day. Effectively, the “Allowable Load” displayed in the modified LDC at 5 percent exceedance (the median value of the high-flow regime) is the TMDL:

TMDL (MPN/day) = Criterion * Flow (cfs) * Conversion factor (Eq. 7)

Where:

Criterion = 35 MPN/100 mL (Enterococci)

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

At 5 percent load duration exceedance, the TMDL values are provided in Table 14.

Table 14. Summary of allowable loading calculations for the impaired AU 2456_02 within Carancahua Bay (station 13388).

Indicator Bacteria	5% Exceedance Flow (cfs)	5% Exceedance Load (MPN/day)	TMDL (Billion MPN/day)
Enterococci	1,106.373	9.47387E+11	947.387

4.7.2 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 (Eq. 8)

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 15).

Table 15. MOS calculations for station 13388 within the Carancahua Bay AU 2456_02 watershed.

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

4.7.3 Wasteload Allocation

The wasteload allocation (WLA) consists of two parts – the waste load that is allocated to TPDES-regulated wastewater treatment facilities (WLA_{WWTF}) and the waste load that is allocated to regulated stormwater dischargers (WLA_{SW}).

$WLA = WLA_{WWTF} + WLA_{SW}$ (Eq. 9)

TPDES-permitted WWTFs are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion and also reduced to account for the required MOS. The saltwater Enterococci criterion (35 MPN/100mL) is used as the WWTF target. The WLA_{WWTF} term is also calculated for the freshwater *E. coli* primary contract recreation geometric mean criterion of126 MPN/100 mL, since WWTF bacteria permit limits are often expressed in terms of *E. coli*. This is expressed in the following equation:

WLA_{WWTF} = Criterion * Flow * Conversion Factor * (1 – F_{MOS}) (Eq. 10)

Where:

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

Flow = full permitted flow (MGD)

Conversion Factor (to MPN/day) = 1.54723 cfs/MGD *283.168 100 mL/ft3 * 86,400 s/d

F_{MOS} = fraction of loading assigned to margin of safety (5 percent or 0.05)

Thus, the daily allowable loading of Enterococci and *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of each WWTF using Eq. 10 and summed for the watershed. Table 16 presents the wasteload allocations for the only WWTF (La Ward WWTF; Figure 9 and Table 5) located within the TMDL watershed. Since the pollutant load allocation is developed in terms of Enterococci as the indicator bacteria, it is the Enterococci loadings from Table 16 that will be used in subsequent computations.

Table 16. Wasteload allocations for TPDES-permitted facilities in Carancahua Bay AU 2456_02 watershed.

AU	TPDES Permit No.	NPDES Permit No.	Facility	Full Permitted Flow (MGD)[a]	*E. coli* WLA_{WWTF} (Billion MPN/day)	Enterococci WLA_{WWTF} (Billion MPN/day)
2456A_01	WQ0013479001	TX0105104	La Ward WWTF	0.024	0.109	0.030

[a] Permitted Flow from Table 5; load computed using Eq. 10

Stormwater discharges from MS4, industrial, and construction areas are also considered permitted or regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas 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 the land area included in the Carancahua Bay AU 2456_02 watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should 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 runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \qquad \text{(Eq. 11)}$$

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 permitted 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 Section 2.8.1.3, a search for all categories of stormwater general permits was performed. The search results are displayed in Table 17.

No MS4 phase I or phase II permits are held in the Carancahua Bay AU 2456_02 watershed. For the construction permits, the acreages associated with active permits were tallied. These acreages were calculated by importing the location information associated with the authorizations into GIS, and measuring the estimated disturbed area based on the most recently available aerial imagery. No multi-sector, concrete production facilities or petroleum bulk stations general permits were located within the TMDL watershed.

Table 17. 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 order to calculate WLA_{SW} (Equation 11), the future growth (FG) term must be known. The calculation for the FG term is presented in the next section, but the results will be included here for continuity. Table 18 provides the information needed to compute WLA_{SW}.

Table 18. Regulated stormwater calculations for the Carancahua Bay AU 2456_02 watershed.

Load units expressed as billion MPN/day

Indicator Bacteria	TMDL[a]	WLA_{WWTF}[b]	FG[c]	MOS[d]	FDA_{SWP}[e]	WLA_{SW}[f]
Enterococci	947.387	0.030	0.030	47.369	0.16%	1.440

[a] TMDL from Table 14
[b] WLA_{WWTF} from Table 16
[c] FG from Table 19
[d] MOS from Table 15
[e] FDA_{SWP} from Table 17
[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Eq. 11)

4.7.4 Future Growth

The FG component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

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

While the FG allowance is often computed for bacteria TMDLs 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 future growth allocation is purposed for any new facilities that may occur and expansions of existing facilities.

This above definition of FG is relevant for the Carancahua Bay watershed, as application of the projected population growth (10.2 percent; Table 1) over the period of 2010 to 2050 for the City of La Ward yields an additional flow of only 0.002 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 4 and OSSF locations on Figure 10), which could necessitate a future WWTF that almost certainly would be greater than 0.002 MGD in size. To accommodate the possibility of such an occurrence along the bay front or anywhere else in the watershed, a FG flow of 0.024 MGD was assigned, which is equivalent to the La Ward WWTF. Table 19 provides information necessary for the FG computations for the AU 2456_02 watershed using Eq. 10, which is the same equation used for computing the WLA_{WWTF} term.

Table 19. Future growth calculations for the Carancahua Bay AU 2456_02 watershed.

Future Growth Flow (MGD)	FG (Enterococci Billion MPN/day)[a]
0.024	0.030

[a] FG = Criterion * Flow * Conversion Factor * (1 – FMOS))

4.7.5 Load Allocation

The load allocation (LA) is the loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \qquad \text{(Eq. 12)}$$

Where:

LA = allowable loads from unregulated sources within the AU

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 permitted facilities

MOS = margin of safety load

The calculation results are shown in Table 20.

Table 20. Load allocation calculations for the Carancahua Bay AU 2456_02 watershed.

Load units expressed as billion MPN/day

Indicator Bacteria	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	FG[d]	MOS[e]	LA[f]
Enterococci	947.387	0.030	1.440	0.030	47.369	898.518

[a] TMDL from Table 14
[b] WLA_{WWTF} from Table 16
[c] WLA_{SW} from Table 18
[d] FG from Table 19
[e] MOS from Table 15
[f] LA = TMDL – WLA_{WWTF} - WLA_{SW} - FG – MOS (Eq. 12)

4.8 Summary of TMDL Calculations

Table 21 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 (5 percent exceedance, high flow regime) for flow exceedance from the LDC developed for the station 13388. Allocations are based on the current geometric mean criterion for Enterococci of 35 MPN/100 mL for each component of the TMDL.

Table 21. TMDL allocation summary for the Carancahua Bay AU 2456_02 watershed.

Load units expressed as billion MPN/day

AU	Waterbody	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA[e]	FG[f]
2456_02	Carancahua Bay	947.387	47.369	0.030	1.440	898.518	0.030

[a] TMDL from Table14
[b] MOS from Table 15
[c] WLA_{WWTF} from Table 16
[d] WLA_{SW} from Table 18
[e] LA from Table 20
[f] Future Growth from Table 19

The final TMDL allocations (Table 22) needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF}.

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix B provides guidance for recalculating the allocations in Table 22. Figure B-1 was developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for Enterococci. The equations provided, along with Figure B-1 and Table B-1, allow calculation of a new TMDL and pollutant load allocation based on any potential new water quality criterion for Enterococci.

Table 22. Final TMDL allocations for the impaired Carancahua Bay AU 2456_02 watershed.

Load units expressed as billion MPN/day

AU	TMDL	WLA_{WWTF}[a]	WLA_{SW}	LA	MOS
2456_02	947.387	0.060	1.440	898.518	47.369

[a] WLA_{WWTF} includes the FG component

References

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. <pubs.usgs.gov/sir/2006/5286/>

AVMA (American Veterinary Medical Association). (2012). *U.S. Pet Ownership & Demographics Sourcebook (2012 Edition). Retrieved April 17, 2*017, from <www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx >

Cleland, B. (200*3). TMDL Development From the "Bottom Up" - Part III: Duration Curves and Wet-Weather Assessments. R*etrieved May 16, 2015, from <www.researchgate.net/publication/228822472_TMDL_Development_from_the_Bottom_Up-_PART_III_Durations_Curves_and_Wet-Weather_Assessments>

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

NDEP (Nevada Division of Environmental Protection). 2003. Load Duration Curve Methodology for Assessment and TMDL Developmen*t.* Retrieved June 27, 2017, from <truckeeriverinfo.org/resource/538>

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

NOAA (National Oceanic and Atmospheric Administration - National Centers for Environmental Information). 2017. Monthly Summaries for Palacios Airport. Retrieved May 4, 2017, from <www.ncdc.noaa.gov/cdo-web/>

ODEQ (Oregon Department of Environmental Quality). 2006. *Chapter 2 - Umpqua Basin TMDL.* Retrieved June 6, 2017, from <www.oregon.gov/deq/wq/tmdls/Pages/TMDLs-Umpqua-Basin.aspx>

Painter, S., A. McFarland, and L. Hauck. 2015. Techncial Support Document for Total Maximum Daily Load for Indicator Bacteria in Tres Palacios Creek Tidal. Retreived July 19, 2017. <www.tceq.texas.gov/assets/public/waterquality/tmdl/108trespalacios/108-TresP_TSD_FINAL_5Apr16.pdf>

PRISM Climate Group at Oregon State University. 2012. PRISM Products Matrix. Retrieved April 3, 2017, from PRISM Climate Group: <www.prism.oregonstate.edu/normals/>

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. <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. <tpwd.texas.gov/publications/pwdpubs/media/pwd_bk_w7000_0511.pdf>

TAMU AES (Texas A&M University AgriLife Extension Service). 2012. *Feral Hog Population Growth, Density and Harvest in Texas (SP-472 August 2012).* Retrieved June 16, 2017, from <feralhogs.tamu.edu/files/2010/04/FeralHogPopulationGrwothDensityandHervestinTexasedited.pdf>

TCEQ (Texas Commission on Environmental Quality). 2006. Preserving & Improving Water Quality – The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. Retrieved April 24, 2017. <www.tceq.texas.gov/publications/gi/gi-351.html>

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

TCEQ (Texas Commission on Environmental Quality). 2010. 2010 Texas Surface Water Quality Standards. Final 2010 Chapter 307 Rule Amendment. Retrieved, April 25, 2017. <www.tceq.texas.gov/waterquality/standards/2010standards.html>

TCEQ (Texas Commission on Environmental Quality). 2015. 2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d). Retrieved April 12, 2017. <www.tceq.texas.gov/waterquality/assessment/14twqi/14txir>

TCEQ (Texas Commission on Environmental Quality). 2016a. Two Total Maximum Daily Loads for Indicator Bacteria in the Tidal Segments of the Mission and Aransas Rivers. Retreived July 19, 2017. <www.tceq.texas.gov/assets/public/waterquality/tmdl/76copano/76A-MissionAransasTMDL-adopted.pdf>

TCEQ (Texas Commission on Environmental Quality). 2016b. 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. Retreived July 21, 2017. <www.tceq.texas.gov/assets/public/waterquality/tmdl/82sanjacinto/82B-EWFSJ-tmdl-adopted.pdff>

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

TCEQ (Texas Commission on Environmental Quality) 2017b. Active Water Rights data file (.xls) retrieved April 20, 2017. <www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud/>

TCEQ (Texas Commission on Environmental Quality) 2017c. Water Use Data files (.xls) for 1990-1999 and 2000-2014. retrieved April 20, 2017. <www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud/>

TCEQ (Texas Commission on Environmental Quality) 2017d. Central Registry Query. Retrieved March 30, 2017. <www15.tceq.texas.gov/crpub/index.cfm?fuseaction=home.welcome>

TCEQ (Texas Commission on Environmental Quality) 2017e. SSO data request - Carancahua Bay Watershed; TCEQ Region 14 Office. *Personal Communication received April 26, 2017.*

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

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

TWRI (Texas Water Resources Institute). 2007. Bacteria Total Maximum Daily Load Task Force Final Report (TR-341 2009). Retrieved June 6, 2017. <twri.tamu.edu/reports/2009/tr341.pdf>

TWRI (Texas Water Resources Institute). 2014. Basin Approach to Address Bacterial Impairments in Basins 15, 16, and 17. TR-462. Retreived May 3, 2017. <twri.tamu.edu/media/468420/tr-462.pdf>

TWRI (Texas Water Resources Institute). 2017. OSSF GIS file request. Personal communication received April 25, 2017. <twri.tamu.edu/media/468420/tr-462.pdf>

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

USDA NASS (United States Department of Agriculture National Agricultural Statistics Service). 2014. 2012 Census Volume 1, Chapter2: State Level Data. Retrieved April 17, 2017. <www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/>

USDA NRCS (United States Department of Agriculture Natural Resources Conservation Service). *2015. Soil Survey Geographic (SSURGO) database. Retrieved April 11, 2017. <datagateway.nrcs.usda.gov/>*

USEPA (United States Environmental Protection Agency). 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. Retrieved June 22, 2017. <nepis.epa.gov/Exe/ZyNET.exe?ZyActionL=Register&User=anonymous&Password=anonymous&Client=EPA&Init=1>

USEPA (United State Environmental Protection Agency). 2017. Enforcement & Compliance History Online (ECHO). Retrieved May 4, 2017. <echo.epa.gov/>

USGS (United States Geological Survey). 2014. National Land Cover Database 2011 Land Cover (2011 Edition, amended 2014). Retrieved February 28, 2017. <viewer.nationalmap.gov/launch/>

USGS (United States Geological Survey). 2017. USGS Surface-Wata Data for Nation. Search for Surface Water Stations. Retrieved January, 2017. <waterdata.usgs.gov/nwis/sw>

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. <pubs.acs.org/doi/pdf/10.1021/es950466v>

Appendix A. Modified Load Duration Curve

Background

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 load allocation. 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 12 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).

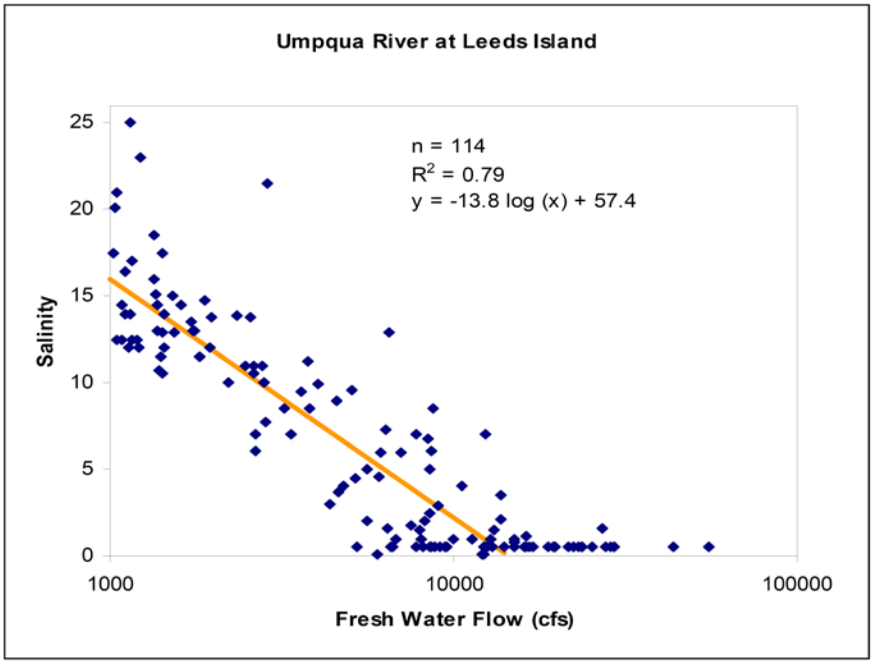

Figure A-1. Example salinity to flow regression from Umpqua Basin Tidal streams (ODEQ, 2006).

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):

$$V_t = V_r + V_s \tag{A-3}$$

Resulting in

$$\text{TMDL (MPN/day)} = \text{Criterion} * V_t * \text{Conversion factor} \tag{A-4}$$

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 extremely relevant to discuss the response of measured salinities at assessment stations to streamflow and the streamflows above which salinities approach background levels (again, assumed to be 0.0) within the context of the FDC for AU 2456_02. These FDCs 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 load allocation. 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 regression analysis as needed to result in an absence of seawater.

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., <u>no modification occurring to that portion of the LDC</u>. Therefore regarding the pollutant load allocation 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, in hindsight, is that for this tidal waterbody, the same Pollutant Load Allocation results would 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 upper western arm of Lake Houston using the standard LDC method to develop the pollutant load allocation (TCEQ, 2016b). 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.

Regarding tidal systems, under the informal constraint imposed by TCEQ on the application of the modified LDC method to tidal streams, if the same condition of freshwater (*i.e.,* background salinities) under high flows can be demonstrated to exist at the relevant location in the bay, then by logical extension there are some bays or portions of some bays where the modified LDC method is applicable for defining a maximum allowable daily load. Such bays or bay portions would be expected to be analogous to the river-reservoir transition zone of the above mentioned Lake Houston TMDL.

Further supporting the potential applicability of the modified LDC method to Carancahua Bay at station 13388, is the geomorphology of the bay as depicted aptly in Figure 4 in the 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 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 to 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 load allocation 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 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 load allocation for AU 2456_02.

Appendix B. Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

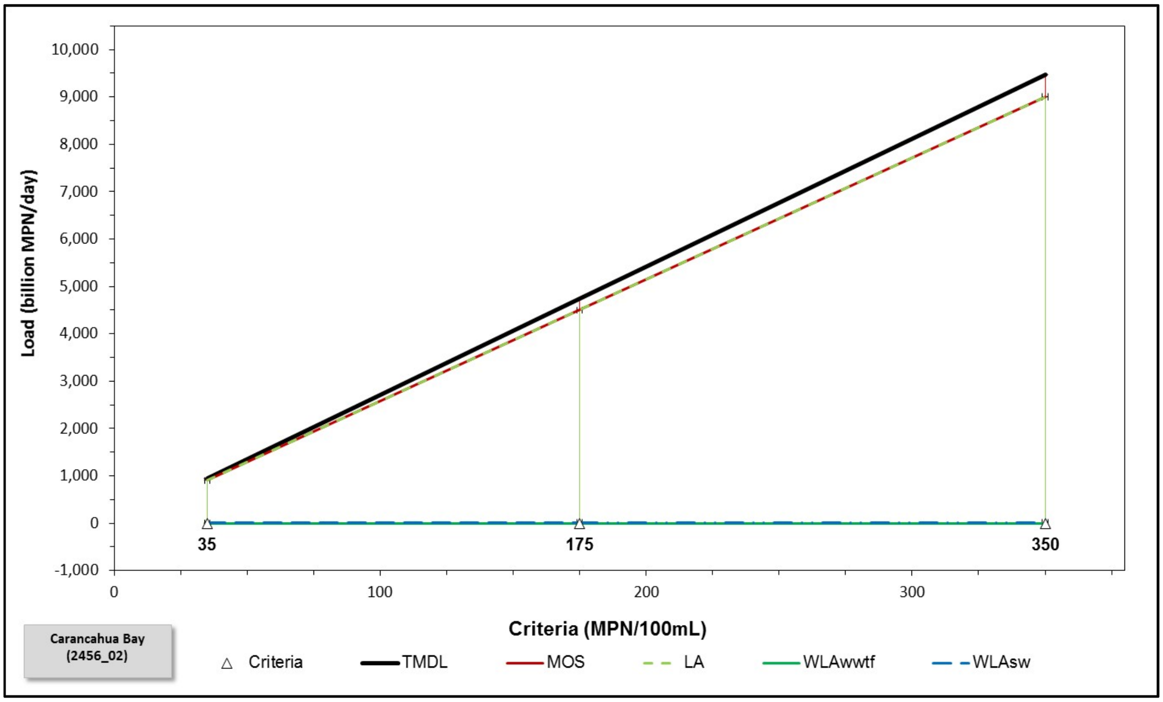

Figure B-1. Allocation loads for Carancahua Bay (2456_02) as a function of water quality criteria.

Equations for calculating new TMDL and allocations (billion MPN/day)

TMDL	= 27.0682063 * Std
MOS	= 1.3534126 * Std
LA	= 25.6736508 * Std - 0.060
WLA_{WWTF}	= 0.060
WLA_{SW}	= 0.0411429 * Std

Where:

Std =	Revised Contact Recreation Standard
MOS =	Margin of Safety
LA =	Total load allocation (non-permitted source contributions)
WLA_{WWTF} =	Wasteload allocation (permitted WWTF load + future growth) [Note: WWTF load held at Primary Contact (35 MPN/ 100 mL) criterion]
WLA_{SW} =	Wasteload allocation (permitted stormwater)

Table B-1 provides a summary of the computed load allocations at (1) the primary contact recreation criterion (35 MPN/100 mL), (2) secondary contract recreation 1 criterion (175 MPN/100 mL) and (3) the secondary contact recreation 2 criterion (350 MPN/100 mL).

Table B-1. Summary of TMDL allocations for the Carancahua Bay AU 2456_02 watershed at selected water quality criterion for various contact recreation categories.

Load units expressed as billion MPN/day

Criterion (MPN/100 mL)	TMDL	MOS	LA	WLA_{WWTF}[a]	WLA_{SW}
35	947.387	47.369	898.518	0.060	1.440
175	4,736.936	236.847	4,492.829	0.060	7.200
350	9,473.872	473.694	8,985.718	0.060	14.400

[a] WLA_{WWTF} includes the FG component