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Two Total Maximum Daily Loads for Indicator Bacteria at Corpus Christi Bay Beaches, Cole Park and Ropes Park

Segment 2481CB

Assessment Units 2481CB_03 and 2481CB_04

Water Quality Planning Division, Office of Water
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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"Technical Support Document: Two Total Maximum Daily Loads for Indicator Bacteria in Corpus Christi Bay at Cole and Ropes Parks, Corpus Christi, Texas Segment 2481CB, Assessment Units 2481CB_03 and 2481CB_04" by the Center for Coastal Studies, Texas A&M University-Corpus Christi.

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Abbreviations

ASCE	American Society of Civil Engineers
AU	assessment unit
BAV	Beach Action Value
BEACH Act	Beaches Environmental Assessment and Coastal Health Act
BMP	best management practice
C	runoff coefficient
CCIA	Corpus Christi International Airport
CCN	Certificate of Convenience and Necessity
CCS	Center for Coastal Studies
CFR	Code of Federal Regulations
cfu	colony forming unit
DWL	dry weather loading
EC	event concentration
EMC	event mean concentration
EPA	United States Environmental Protection Agency
FG	future growth
GIS	geographic information system
I/I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
MCM	minimum control measure
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
NAS-CC	Naval Air Station-Corpus Christi
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
RMSE	root mean square error

SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWQM	surface water quality monitoring
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TGLO	Texas General Land Office
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
USCB	United States Census Bureau
WLA	wasteload allocation
WLA_{SW}	wasteload allocation – stormwater
WLA_{WWTF}	wasteload allocation – wastewater treatment facilities
WQBEL	water quality-based effluent limits
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

Two TMDLs for Indicator Bacteria at Corpus Christi Bay Beaches, Cole Park and Ropes Park

Executive Summary

This document describes total maximum daily loads (TMDLs) for Corpus Christi Bay recreational beaches at Cole Park and Ropes Park in Nueces County. Bacteria concentrations exceed the target concentration used by the Texas General Land Office (TGLO) to issue beach advisories, as part of the Texas Beach Watch Program, as per the federal Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act). The Texas Commission on Environmental Quality (TCEQ) uses beach advisories issued by TGLO to identify impairments included in the Texas Integrated Report of Surface Water Quality. TCEQ first identified the impairments to Corpus Christi Bay recreational beaches at Cole Park and Ropes Park in the *2010 Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d)*, referred to subsequently in this report as the Texas Integrated Report (TCEQ, 2011). The impaired assessment units (AUs) and TGLO Beach ID numbers for Corpus Christi Bay (Recreational Beaches) Segment 2481CB addressed in this TMDL document are:

- Cole Park 2481CB_03 (Beach ID TX259473)
- Ropes Park 2481CB_04 (Beach ID TX821303)

These two beaches were listed as impaired for being under an advisory more than 25% of the days sampled. TGLO issues a beach advisory when bacteria levels in the water exceed 104 colony forming units (cfu) per 100 milliliters (mL) of the indicator bacteria (Enterococci). The target of 104 cfu/100 mL of Enterococci has been accepted by the United States Environmental Protection Agency (EPA) as a Beach Action Value (BAV) to issue beach advisories under the Texas Beach Watch Program as per the BEACH Act.

TCEQ initiated the TMDL process to improve water quality and ensure the contact recreation use for these beaches will be met. The major proportion of bacteria pollutant loading to the TMDL watershed comes from stormwater runoff. The TMDL watershed is divided into twelve subwatersheds, which contribute rainfall runoff to Corpus Christi Bay through outfalls at, and adjacent to, the impaired AUs. There are no wastewater treatment facility (WWTF) discharges within the TMDL watershed and all sanitary sewer conveyances are carried to a WWTF that discharges outside of the watershed.

Analysis of the data shows that single sample bacteria concentrations often exceeded the BAV of 104 cfu/100 mL of indicator bacteria causing TGLO to

issue advisories for both beaches. TCEQ includes this information in the Texas Integrated Report to protect human health by identifying beaches with persistent advisories. Assessment consists of identifying the percentage of days each beach has an advisory. Since the assessment results indicated both beaches were under an advisory for more than 25% of the days sampled, the recreation use was identified as impaired for the Cole Park and Ropes Park beaches.

A numerical model was created to simulate watershed processes and predict bacteria loading to the beaches from runoff. The model was evaluated based on its ability to produce values similar in magnitude and recurrence frequency to the measured data collected by the TGLO Beach Watch Program from 2006 through 2013. TMDL compliance is based on limiting the incidence of indicator bacteria concentrations exceeding the BAV of 104 cfu/100 mL, and the resultant beach advisories issued, to less than 25% of the days sampled. The TMDL calculations in this report will guide determination of the assimilative capacity of each AU under changing conditions.

Introduction

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

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

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

The two TMDLs described in this document address the impairments to contact recreation due to elevated Enterococci concentrations in Corpus Christi Bay recreational beaches at Cole Park and Ropes Park. The TMDLs take a watershed approach to addressing bacterial impairments. While TMDL allocations were only developed for the impaired AUs identified in this report, the entire TMDL watershed (Figure 1) is included within the scope of the TMDLs.

Figure 1. Map of the TMDL watershed

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

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

- Problem Definition
- Endpoint Identification

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

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

Problem Definition

TCEQ assessed TGLO information as part of the Integrated Report to protect human health by identifying beaches with persistent advisories. Beginning with the 2010 Texas Integrated Report, TCEQ considered recreational beach advisories to assess attainment of the recreation use at Cole Park and Ropes Park beaches. Assessment consisted of calculating the percentage of sampled days each beach had an advisory. An advisory is issued when indicator bacteria levels exceed the BAV of 104 cfu/100 mL. Beaches that are under an advisory for more than 25% of the days sampled do not support the recreation use.

Nine recreational beaches were identified for Corpus Christi Bay, two of which were found to not meet the recreation use: Cole Park (2481CB_03) and Ropes Park (2481CB_04). The impaired AUs were first listed in the 2010 Texas Integrated Report and have been listed in all subsequent reports, including the most recent EPA-approved 2018 Integrated Report (TCEQ, 2019a).

Ambient Indicator Bacteria Concentrations

Bacteria monitoring data have been primarily collected by TGLO and the Center for Coastal Studies (CCS). Data collected by the TGLO Beach Watch Program, at seven stations with the NUE prefix (Figure 2), are used by TGLO to issue advisories. The number of advisories issued per sampled days is used by TCEQ to assess the contact recreation use in the Texas Integrated Report. Advisory data from the EPA approved 2018 Integrated Report are provided in Table 1.

Additional special study data were collected at 26 TCEQ surface water quality monitoring (SWQM) stations within, or near, the impaired AUs (Figure 2) by CCS at Texas A&M University. These data were collected to provide support for TCEQ's development of TMDLs for Enterococci bacteria impairments at the Corpus Christi Bay beaches (Nicolau and Hill, 2011; Nicolau and Hill, 2013). For this study, data collection occurred from May 2011 through August 2011 and February 2012 through July 2012.

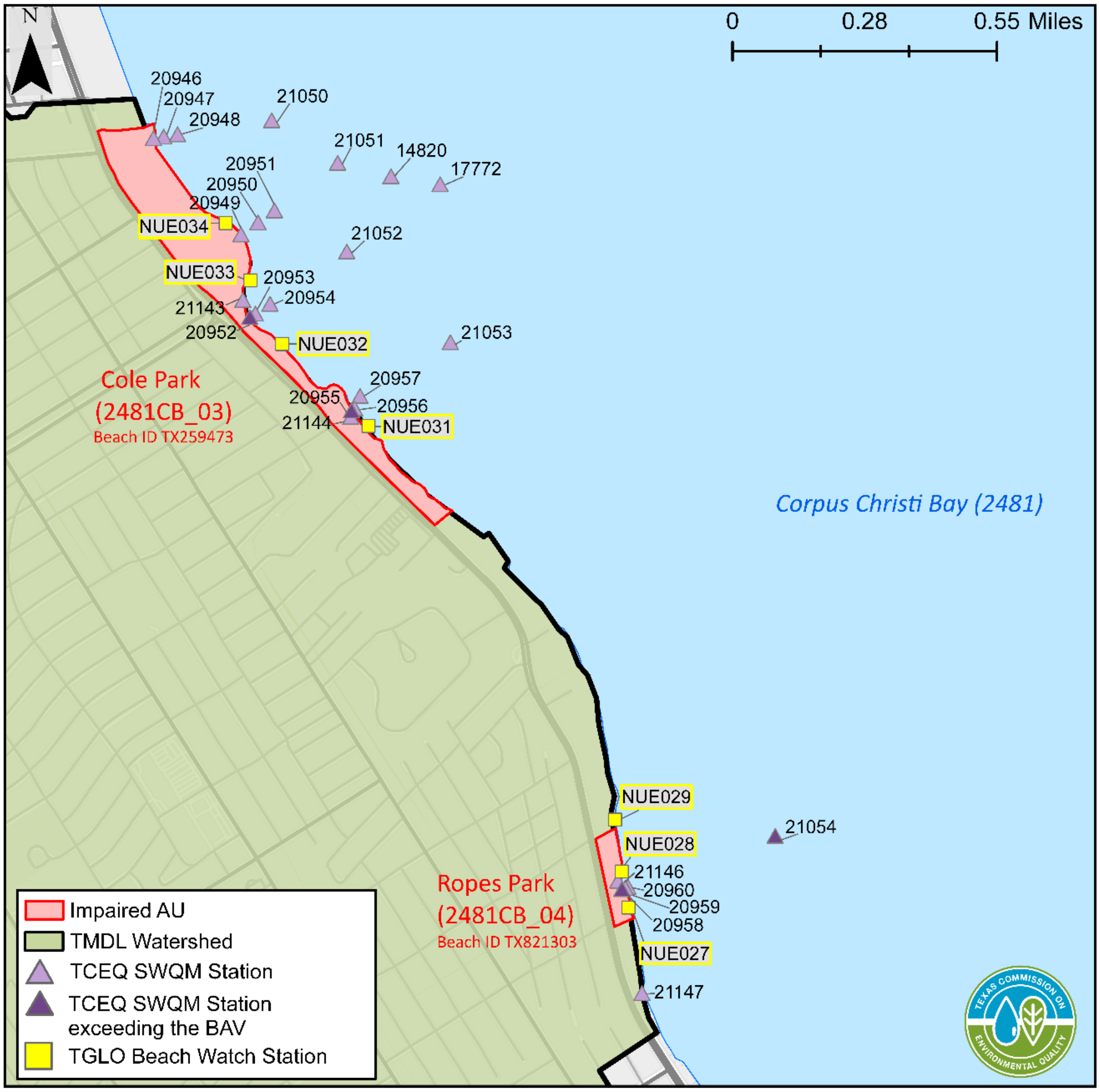

Figure 2. TGLO Beach Watch stations (7) and TCEQ SWQM stations (26)

Historical ambient water quality data, where 25% of the measured values exceed the BAV of 104 cfu/100 mL for Enterococci, are summarized in Table 2. At Cole Park (2481CB_03), TGLO measurements of bacteria concentrations indicate that three of the four TGLO stations exceed the BAV, while CCS data indicate exceedances at two SWQM stations. All stations exceeding the BAV at Cole Park are less than 15 feet from the shoreline.

At Ropes Park (2481CB_04), all three TGLO stations and two SWQM stations exceed the BAV. All stations exceeding the BAV at Ropes Park are less than 15 feet from the shoreline, except SWQM Station 21054, which is approximately 1,800 feet offshore.

Table 1. 2018 Texas Integrated Report summary for the impaired AUs

Data date range: 12/01/2009 - 11/30/2016

Description	AU	TGLO Beach Watch Monitoring Station IDs	Method	Parameter	Number Assessed	Number Exceeded	Percentage Exceeded
Cole Park (Beach ID TX259473)	2481CB_03	NUE034 NUE033 NUE032 NUE031	Texas Beach Watch Program Advisories	Enterococci	857	372	43.41
Ropes Park (Beach ID TX821303)	2481CB_04	NUE029 NUE028 NUE027	Texas Beach Watch Program Advisories	Enterococci	626	286	45.69

Table 2. Historical water quality data exceeding the BAV (Enterococci)

Data date range: CCS 2011-2012, TGLO 2003-2013

Beach	AU	Collected by	Station	% of Samples >104 cfu or MPN/100 mL
Cole Park	2481CB_03	CCS	20952	31.4
Cole Park	2481CB_03	CCS	20955	30.1
Cole Park	2481CB_03	TGLO	NUE033	31.8
Cole Park	2481CB_03	TGLO	NUE032	31.8
Cole Park	2481CB_03	TGLO	NUE031	33.8
Ropes Park	2481CB_04	CCS	20958	25.2
Ropes Park	2481CB_04	CCS	21054	28.6
Ropes Park	2481CB_04	TGLO	NUE029	33.3
Ropes Park	2481CB_04	TGLO	NUE028	34.6
Ropes Park	2481CB_04	TGLO	NUE027	35.8

It should be noted that most probable number (MPN) is a method used to estimate the concentration of viable microorganisms (counts or cfu) in a water sample by means of replicate liquid broth growth in ten-fold dilutions. The model used for the TMDL calculations in this document reported results in counts. The data used for analysis from TGLO were reported in cfu, and the

Beach Watch data were reported in MPN. For practical purposes, the units MPN, counts, and cfu are used interchangeably in this document.

Watershed Overview

The impaired AUs, recreational beaches at Cole Park and Ropes Park, are within Nueces County, in the City of Corpus Christi. The TMDL watershed consists of 12 subwatersheds, which range in size from 7 to 2,041 acres, totaling 4,412 acres (Table 3).

Cole Park is primarily influenced by subwatershed 220, with minimal impact from smaller neighboring subwatersheds (101, 102, and 105) (Figure 3). Ropes Park is primarily influenced by subwatershed 103, with minimal drainage from two smaller watersheds (104 and 170). The remaining five subwatersheds (106, 180, 190, 200, and 230) drain areas of land immediately adjacent to the AUs directly into Corpus Christi Bay (Figure 3). The two largest subwatersheds comprise 90% of the contributing area.

Table 3. Subwatershed drainage to each AU

AU	Subwatershed	Area (acres)
Cole Park 2481CB_03 (Beach ID TX259473)	220	2,040.5
	101	8.4
	102	11.3
	105	22.5
Sub Total		**2,082.7**
Ropes Park 2481CB_04 (Beach ID TX821303)	103	1,931.6
	104	7.2
	170	29.2
Sub Total		**1,968.0**
Subwatersheds adjacent to AUs	106	11.4
	180	104.0
	190	31.6
	200	122.5
	230	92.0
Sub Total		**361.5**
Total		**4,412.2**

Given that 90% of the bacteria load contributing to the impairments in AU 2481CB_03 and 2481CB_04 emanate from subwatersheds 220 and 103, the TMDLs presented in this document concentrate on meeting the single sample criterion established under the BEACH Act at the outfalls associated with these subwatersheds.

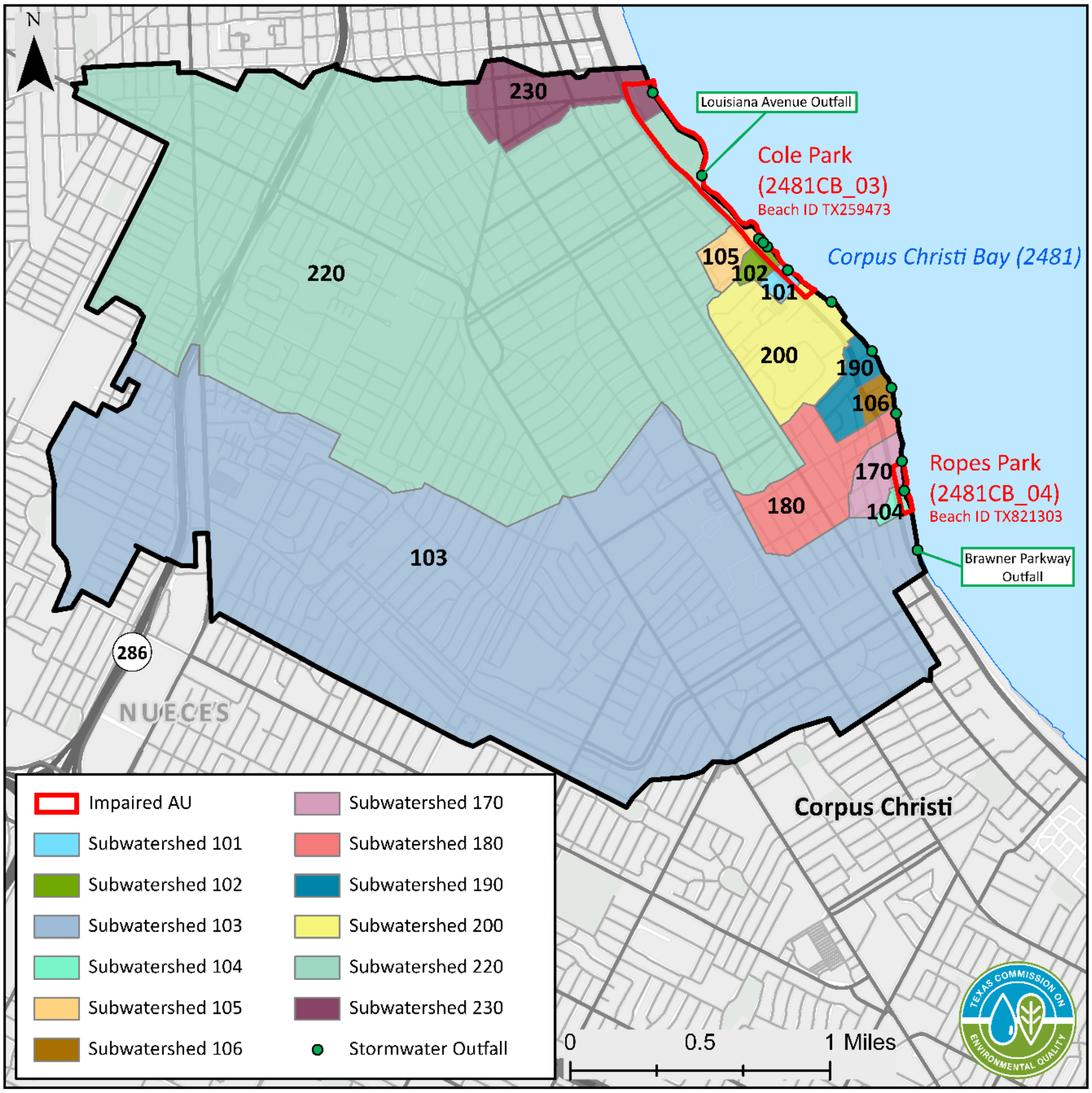

Figure 3. TMDL watershed divided into 12 subwatersheds

Climate

Corpus Christi is located between a humid subtropical region to the northeast and a semiarid region to the west and southwest of the city. Summers are hot and humid with average high temperatures of 93˚F peaking in August; however, temperatures exceeding 100˚F can occur in June, July, and August. Moderate winters, where the average high in January is 57˚F and the low is 47˚F, occasionally produce a freeze following the passage of strong northerly high-pressure fronts (Jones, 1975) (Figure 5).

The dominant wind direction in the TMDL watershed is from the southeast. Due to the curved nature of the shoreline (see Figure 1 inset map) each AU is affected differently, with a mostly longshore forcing at Cole Park, and a slightly onshore but mostly longshore forcing at Ropes Park. Without another forcing, such as tides and currents, this would tend to drive water along the coastline in a northwesterly direction or, looking out from shore, it would tend to move water from right to left (Figure 4).

Southeasterly prevailing winds serve as a primary source of atmospheric moisture. Hurricane season runs from June to November (peak months are August and September), with tropical storms and hurricanes occasionally yielding substantial amounts of rainfall during late summer and early fall (Armstrong, 1987).

There are two rain gauges near the TMDL watershed that are part of the National Weather Service's meteorological network. One meteorological station is at Naval Air Station-Corpus Christi (NAS-CC - ID 12926), approximately 8 miles southeast of the middle of the watershed. The other station is at the Corpus Christi International Airport (CCIA - ID 412015), approximately 7 miles west of the middle of the watershed. Monthly precipitation averages at both sites showed rainy periods occurring in May-July, September, and October (Figure 5).

Precipitation events in the TMDL watershed are generally intense and of short duration. Analysis of nine years (2005-2013) of Next Generation Radar, or NEXRAD, hourly precipitation data, showed 96% of the precipitation occurred over 2.5% of this time period.

Land Use

The TMDL watershed is in a heavily urbanized land use area. Table 4 and Figure 6 summarize land use and the corresponding percentages of each land use category present in the TMDL watershed. The land use data were supplied by the City of Corpus Christi's geographic information system (GIS) services, maintained by the city's Department of Development Services (City of Corpus Christi, 2019a). The designations, or abbreviations, for each land use category are defined in Table 4. Land use based on property descriptions utilizes the Classifications Database, created by the City of Corpus Christi in April 2003 (City of Corpus Christi, 2014).

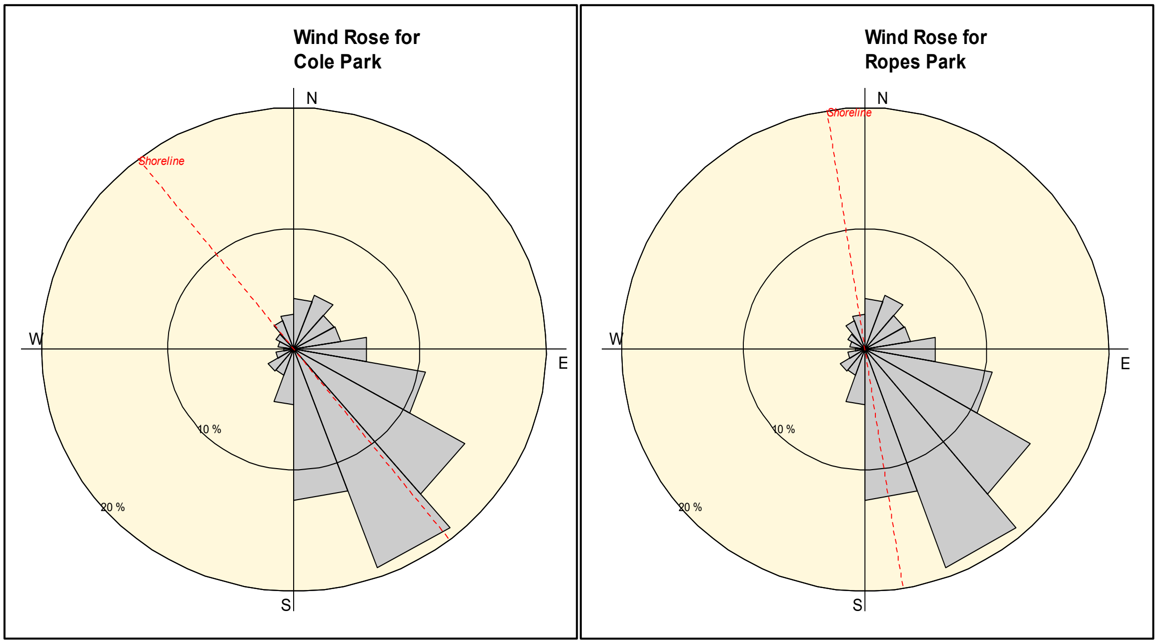

Figure 4. Dominant wind direction in the TMDL watershed

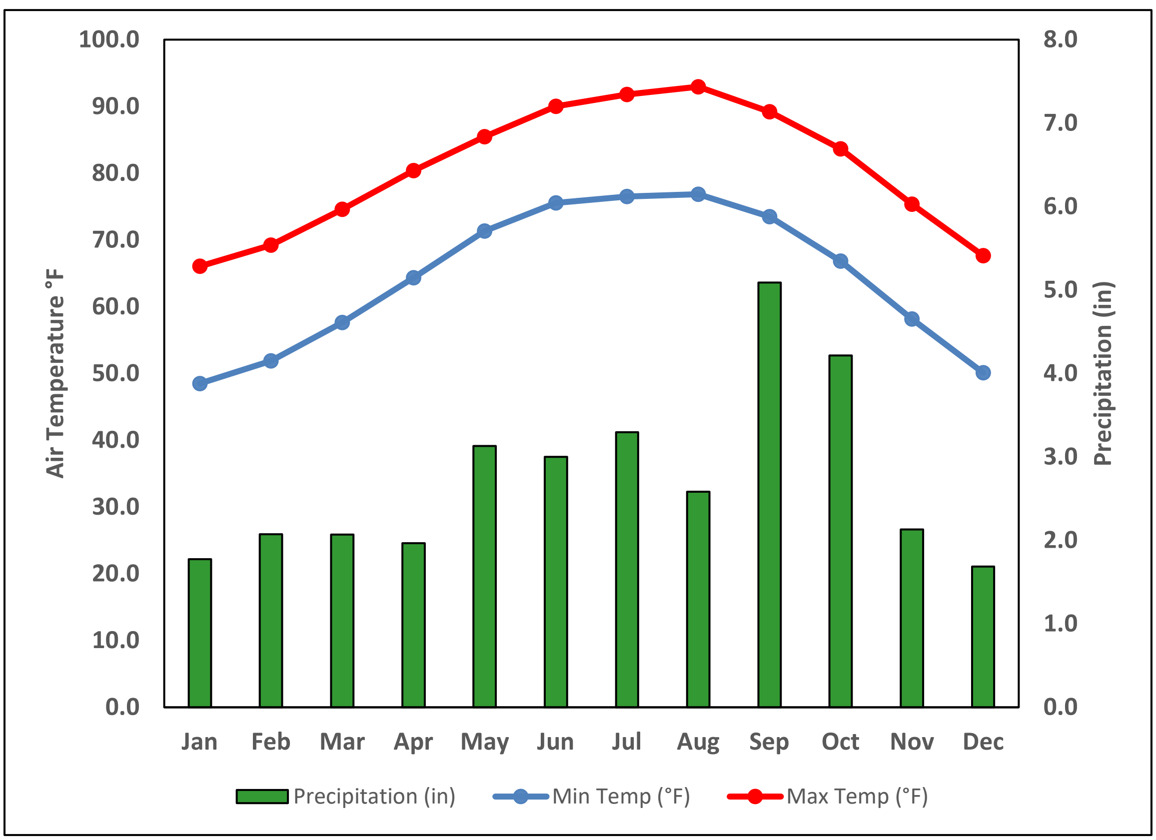

Figure 5. Average monthly precipitation and minimum and maximum temperature by month from 1981-2018 at National Weather Service Stations NAS-CC (12926) and CCIA (412015)

The largest single land use in the TMDL watershed is Low Density Residential, which accounts for 46.9% of the total watershed. Transportation (roads and highways) makes up the second largest (24.7%) land use category in the watershed.

Table 4. Land use summary within the TMDL watershed

Land Use Description	Designation	Acres	Percentage
Commercial	COM	245.3	5.6
Ditch/Culvert	DC	2.8	0.1
Estate Residential	ER	61.2	1.4
High Density Residential	HDR	4.0	0.1
Low Density Residential	LDR	2,068.1	46.9
Light Industry	LI	14.5	0.3
Middle Density Residential	MDR	271.6	6.2
Parks	PARK	148.0	3.4
Professional Offices	PO	68.6	1.5
Public/Semi Public	PSP	341.7	7.7
Vacant	VAC	90.0	2.0
Water	WATER	6.0	0.1
Transportation	TRANS	1,090.4	24.7
Total		**4,412.2**	**100.0**

Soils

The predominant soil type for Nueces County is the Victoria Series. It can be characterized as a rich clayey loam with some sandy areas. The Victoria Series has strong shrink/swell characteristics. During lengthy dry periods, the soil will present large, wide cracks. During wet periods, the soil is able to absorb large quantities of water (NRCS, 2005). However, 94.4% of the TMDL watershed is overlain by built-up urban cover, which strongly influences the runoff characteristics, leaving just 4.7% of the Victoria Clay exposed. The remaining 0.9% is a mixture of deep, poorly draining coastal soils (NRCS, 2019).

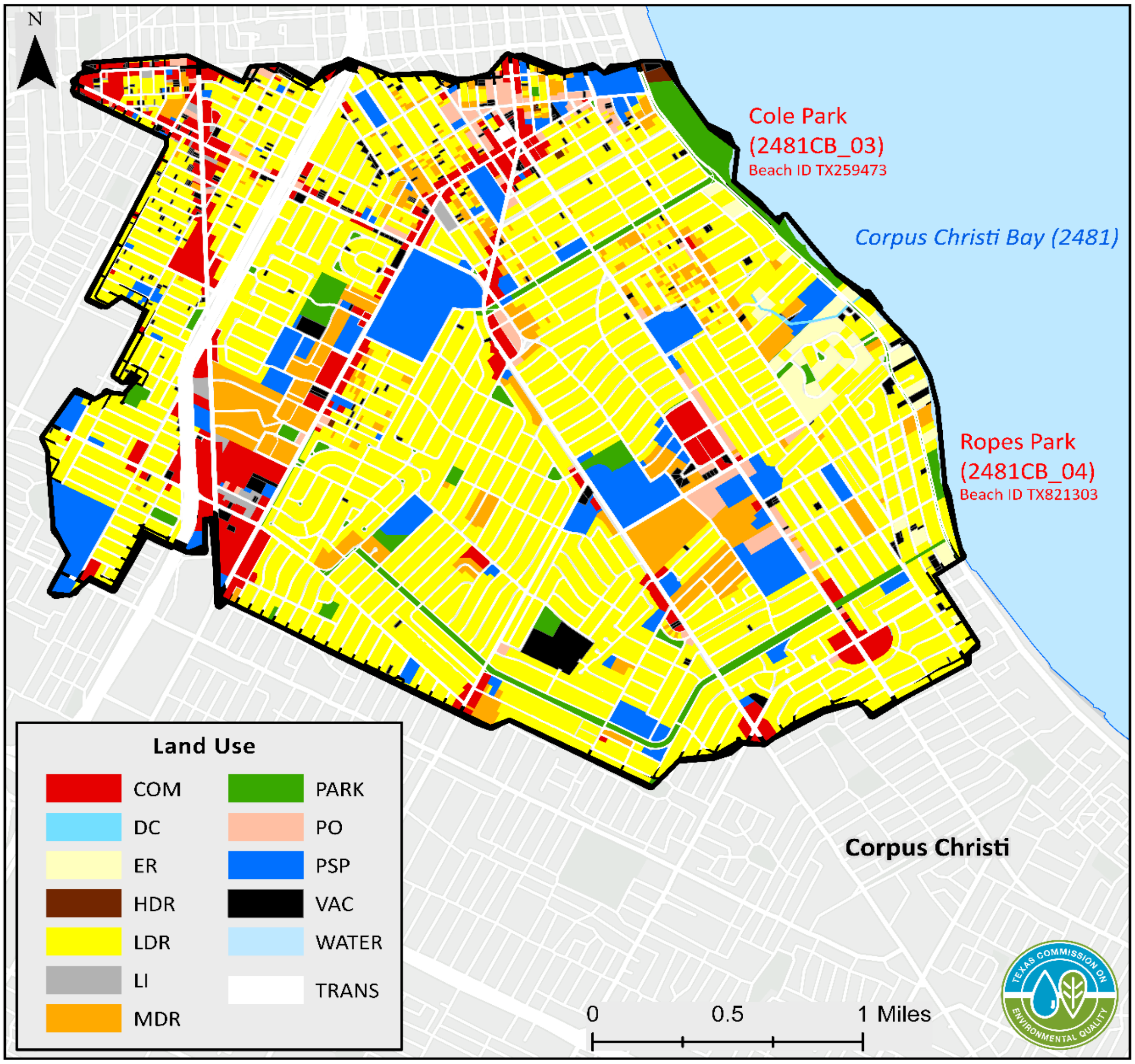

Figure 6. Land use within the TMDL watershed

Endpoint Identification

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

While the single sample bacteria criterion adopted by TCEQ for coastal recreation waters in saltwater is 130 cfu/100 mL of Enterococci, TGLO uses a BAV of 104 cfu/100 mL of Enterococci to issue beach advisories. When the BAV is exceeded, TGLO will issue a Beach Advisory until the Enterococci concentrations fall below 104 cfu/100 mL. TCEQ includes this information in the Texas Integrated Report in order to protect human health by identifying beaches with persistent advisories. TCEQ assessment consists of identifying the percentage of days each beach has an advisory. If more than 25% of the days sampled have an advisory, the beach is listed as impaired in the Texas Integrated Report. The endpoint for the TMDLs in this report is the BAV for Enterococci, 104 cfu/100 mL, to not exceed more than 25% of the days sampled.

Source Analysis

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

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

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

Regulated Sources

Regulated sources are controlled by permit under the TPDES program. The regulated sources in the TMDL watershed are stormwater from industries, construction activities, and MS4s.

Domestic and Industrial Wastewater Treatment Facilities

The TMDL watershed has been serviced by a municipal sanitary sewer system since the 1940s. All sanitary wastewater is conveyed out of the watershed and the treated effluent is not discharged within the watershed, nor in the vicinity of the impaired AUs. Based on the City of Corpus Christi's future land use GIS-viewer, maintained by the city's Department of Development Services, the City of Corpus Christi has no plans to change this system. The limited space within the watershed precludes the possibility that a WWTF will be constructed within, or near, the watershed and that sanitary wastewater will be discharged in the vicinity of the AUs (City of Corpus Christi, 2019b).

TPDES/TCEQ Water Quality General Permits

Certain types of activities are required to be covered by one of several TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water
- TXG830000 – petroleum fuel or petroleum substances
- TXG870000 – pesticides
- TXG920000 – concentrated animal feeding operation
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations

A review of active general permit coverage (TCEQ, 2019b) in the TMDL watershed, as of December 2019 found two pesticide application authorizations. These authorizations allow mosquito and pest control activities and are not expected to impact indicator bacteria concentrations within the impaired AUs. No other general wastewater permits were found.

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. These overflows 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.

TCEQ maintains a database of SSOs collected from wastewater operators in Texas. Table 5 shows a summary of the reported events and the volume of overflow within the watershed from January 2016 through February 2019 (TCEQ, 2019c).

Table 5. Summary of SSO incidents in the TMDL watershed (in gallons)

Data Date Range: 2016-2019

Number of Occurrences	Total Volume	Mean Volume	Minimum Volume	Maximum Volume
40	22,202	5,550.5	2	10,000

TPDES-Regulated Stormwater

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

1) Stormwater subject to regulation, which is any stormwater originating from TPDES regulated MS4s, industrial facilities, and construction activities.
2) Stormwater runoff not subject to regulation.

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

- MS4 maintenance activities.
- Post-construction stormwater control measures.
- Detection and elimination of illicit discharges.
- Pollution prevention and good housekeeping for municipal operations.
- Industrial and high-risk runoff.
- Construction site stormwater runoff.
- Public education, outreach, involvement, and participation.
- Monitoring, evaluating, and reporting.

The geographic region of the TMDL watershed covered by Phase I and II MS4 permits is that portion of the area within the jurisdictional boundaries of the regulated MS4. For Phase I individual permits, the jurisdictional area is defined by the city limits. For Phase II general permit authorizations, the jurisdictional area is defined as the intersection of the city limits and the USCB 2000 or 2010 Census for urbanized areas.

The entire TMDL watershed is covered under the City of Corpus Christi Phase I MS4 permit (TPDES Permit No. WQ0004200000). The jurisdictional boundary of the Corpus Christi Phase I MS4 permit is dictated by the corporate boundary of the City of Corpus Christi. Under the City of Corpus Christi MS4, the City of Corpus Christi, Del Mar College East Campus, Port of Corpus Christi Authority of Nueces County, and Texas A&M University Corpus Christi are designated as co-permittees. The Texas Department of Transportation (TPDES Permit No. WQ0005011000) maintains a state-wide MS4 permit for rights-of-ways in Phase I MS4 areas, including Corpus Christi.

Cole Park, Ropes Park, and adjacent land contain 13 stormwater outfalls (Figure 3) which discharge directly to Corpus Christi Bay. The entire TMDL watershed is covered under the City of Corpus Christi Phase I MS4 permit and is described in Table 6.

Table 6. MS4 permits in the TMDL watershed

AUs	TPDES Permit No.	NPDES* Permit No.	Permittee
Cole Park 2481CB_03 (Beach ID TX259473) Ropes Park 2481CB_04 (Beach ID TX821303)	WQ0004200000	TXS000601	City of Corpus Christi, Del Mar College East Campus, Port of Corpus Christi Authority of Nueces County, and Texas A&M University Corpus Christi
Cole Park 2481CB_03 (Beach ID TX259473) Ropes Park 2481CB_04 (Beach ID TX821303)	WQ0005011000	TXS002101	Texas Department of Transportation

*National Pollutant Discharge Elimination System

Illicit Discharges

Pollutant loads can enter water bodies from MS4 outfalls that carry authorized sources, as well as illicit discharges under both dry- and wet-weather conditions. The term “illicit discharge” is defined in TPDES General Permit No. TXR040000 for Phase II MS4s as “Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities.” Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the

Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities (NEIWPCC, 2003) include:

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.
- A cross-connection between the municipal sewer and storm sewer systems.

Indirect Illicit Discharges:

- An old and damaged municipal sewer line that is leaking fluids into a cracked storm sewer line.
- A failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint sources. Nonpoint source loading enters impaired segments through distributed, nonspecific locations, which may include urban runoff not covered by a permit, wildlife, failing on-site sewage facilities (OSSFs), unmanaged animals, and domestic pets.

Unregulated Agricultural Activities and Domesticated Animals

There are a number of non-permitted agricultural activities that can also be sources of fecal bacteria loading. Given the fact that the TMDL watershed is highly urbanized, livestock and other domesticated animals are not found in high quantities, and therefore, these sources are not considered significant contributors of bacteria loading to the impaired AUs.

Fecal bacteria from dogs and cats can be transported by runoff from urban and suburban areas and is a potential source of bacteria loading to Corpus Christi Bay. On average nationally, there are 0.58 dogs per household and 0.64 cats per household (American Veterinary Medical Association, 2012). Using the USCB Census data at the block level (USCB, 2010), the estimated dog and cat populations are shown in Table 7.

Table 7. Estimated numbers of pets in the TMDL watershed

Dogs	Cats
9,052	9,988

Wildlife and Unmanaged Animals

Fecal bacteria 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 potential bacteria contributions from wildlife. Fecal bacteria deposited on land surfaces may be carried into the municipal stormwater drainage system, with the direct deposition of wildlife waste on the beaches being a possible concentrated source of bacteria loading to the bay. Typically, in coastal watersheds there is a significant avian species population that frequents the watershed and beaches. However, there are insufficient data available to estimate populations and spatial distributions of wildlife and avian species by subwatershed. Consequently, it is difficult to assess the magnitude of bacteria contributions to the TMDL watershed from wildlife species as a general category.

On-site Sewage Facilities

Bacteria loading from failing OSSFs can be transported in a variety of ways, including runoff from surface ponding, drainage channels, or through groundwater. Fecal bacteria-contaminated groundwater can also be discharged to water bodies through springs and seeps. Over time, most OSSFs operating at full capacity will fail. The 1995 American Housing Survey conducted by USCB estimated that, nationwide, 10% of occupied homes with OSSFs experience malfunctions during the year (USCB, 1995). OSSFs were estimated to be households that were outside of either a Certificate of Convenience and Necessity (CCN) sewer area (PUCT, 2019) or a city boundary. Due to the watershed being entirely within city boundaries and within the City of Corpus Christi CCN, there are no reported OSSFs within the TMDL watershed, and a municipal sanitary sewer system has been available since the 1940s.

Bacteria Survival and Die-off

Bacteria are living organisms that survive and die under certain conditions. Some enteric bacteria can survive and reproduce in certain materials if appropriate conditions prevail (e.g., warm temperatures, moist environments, etc.). While the die-off of bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their replication is less understood. However, indicator bacteria survival and persistence in beach sand has been shown to be a source of bacteria in both saltwater and freshwater beaches (Hartz et al., 2008; Yamahara et al., 2012).

Linkage Analysis

Establishing the relationship between Corpus Christi Bay water quality at Cole Park and Ropes Park beaches and the source of loadings is an important component in developing these TMDLs. It allows for the evaluation of management options that will achieve the desired endpoint. This relationship may be established through a variety of techniques.

The open boundary of Corpus Christi Bay, and the tidal and long-shore current processes at the impaired AUs, complicates the linkage analysis for these TMDLs. However, the linkage can be derived from sampling data and through the application of a watershed model that simulates rainfall runoff using precipitation data and land use-based precipitation event concentrations (Appendix A).

A special study conducted by CCS at Cole Park and Ropes Park took place in 2011 and 2012 and is described in *TMDL Investigation for Bacteria in Corpus Christi Bay Beaches Interim Data Monitoring Report Fiscal Year 2011 (Year-one) and Fiscal Year 2012 (Year-two)* (Nicolau and Hill, 2013). The results of this sampling established the linkage between the possible sources within the TMDL watershed and water quality at the impaired AUs.

During the CCS study, sampling was conducted along transect lines that had three nearshore stations and one offshore station, each with its own TCEQ SWQM station ID. The intent of data collection at varying distances and depths from the shoreline was to determine if bacteria concentrations remained constant or if concentrations decreased as the distance from shore increased, where the influence of bay waters could impact concentrations. Additional sampling occurred at the SWQM stations within 24 and 48 hours following a rainfall event to collect data on bacterial concentrations entering the bay from stormwater runoff.

The majority of high Enterococci concentrations were associated with rainfall events, regardless of the sampling depth. Even though the majority of high concentrations were directly affected by rainfall, there are occasions when Enterococci concentrations were high during dry weather periods.

The clear relationship between rainfall runoff and increased Enterococci concentrations demonstrates that regulated and unregulated sources outlined in the Source Analysis section have the potential to contribute to beach impairments. Sources that contribute during dry weather periods are more difficult to identify but may include avian sources and contributions from human activity at the beaches.

The model used to determine the TMDLs for the impaired AUs is a watershed model that simulates stormwater runoff, bacteria loading, and bacteria concentrations at the stormwater outfalls associated with the subwatersheds modeled. Absent a detailed hydrodynamic model, the TMDL endpoints are established at the outfalls for the largest contributing subwatersheds. Given that 90% of the bacteria load contributing to the impairments at Cole Park (2481CB_03) and Ropes Park (2481CB_04) beaches emanate from subwatersheds 220 and 103, the endpoint for the TMDLs presented in this document are based on meeting the BAV used by TGLO to implement the BEACH Act and issue advisories (the basis for the impairments identified by TCEQ) at the stormwater outfalls associated with these subwatersheds.

Margin of Safety

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

1) Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
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 TMDLs covered in this report incorporate an explicit MOS by reducing the TMDL endpoint target concentration by 5%. For these TMDLs, the water quality target is 98.8 cfu/100 mL, which is 5% lower than the single sample water quality BAV for Enterococci (104 cfu/100 mL). Reduction of the target concentration by 5% (from 104 cfu/100 mL to 98.8 cfu/100 mL) equals an MOS load that is 15.09% of the TMDL for AU 24981CB_03 (Cole Park) and 13.22% of the TMDL in AU 2481CB_04 (Ropes Park).

Pollutant Load Allocation

The TMDLs represent the maximum amount of a pollutant that the two AUs can receive in a single day without exceeding the BAV. The pollutant load allocations were calculated using the following equation:

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

Where:

TMDL = total maximum daily load

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

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

FG = future growth loadings from potential regulated facilities

MOS = margin of safety load

TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures [40 CFR 130.2(i)].

The TMDLs for the two AUs covered in this report were established by using a watershed loading model (Appendix A) to determine the average daily load at each of the impaired AUs, and the reductions needed to meet the BAV, 104 cfu/100 mL of Enterococci, less than 25% of the days samples.

Load Allocation

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

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

Where:

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

TMDL = total maximum daily load

WLA_{WWTF} = sum of all regulated WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = future growth loadings from potential regulated facilities

MOS = margin of safety load

Dry weather loading (DWL) affects water quality at both Cole Park and Ropes Park. Although the sources of this loading are not well understood, they can be categorized as the unregulated, nonpoint source component of the TMDL. As such, DWL is captured within the LA portion of the TMDL calculation. Table 8 shows the LA, as the result of unregulated stormwater bacteria loading, fate, and transport within Corpus Christi Bay at the impaired AUs and is estimated by using the watershed loading model (Appendix A).

Table 8. Load allocation calculation for the impaired AUs

All loads expressed as billion cfu/day

AU	TMDL	WLA_{WWTF}	WLA_{SW}	FG	MOS	LA
Cole Park 2481CB_03 (Beach ID TX259473)	1,186	0	734	0	179	273
Ropes Park 2481CB_04 (Beach ID TX821303)	5,007	0	4,199	0	662	146

Wasteload Allocation

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

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

Wastewater Treatment Facilities

TPDES-permitted WWTFs within a TMDL watershed are allocated a daily wasteload (WLA_{WWTF}) based on the full permitted flow of each facility. The TMDL watershed has been serviced by a municipal sanitary sewer system since the 1940s. All sanitary wastewater is conveyed out of the watershed and is not discharged to, or in the vicinity of, the impaired AUs. The City of Corpus Christi has no plans to change the collection system or locations of wastewater outfalls, and the limited space within the TMDL watershed precludes the possibility that a WWTF will be constructed within, or in the vicinity of the watershed. Hence, sanitary wastewater is not expected to affect the beaches. Because of this, the wasteload allocation for WWTFs in each impaired AU is zero:

$$WLA_{WWTF} = 0$$

Regulated Stormwater

The absence of WWTF discharges in the TMDL watershed limits the TMDL allocations to regulated stormwater (WLA_{SW}), LA, future growth (FG), and MOS. Table 9 shows the WLA for stormwater in each impaired AU. The WLA_{SW} is calculated by subtracting the LA and MOS from the TMDL:

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

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all regulated WWTF loads

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

FG = future growth loadings from potential regulated facilities

MOS = margin of safety load

Table 9. Regulated stormwater calculation for the impaired AUs

All loads expressed as billion cfu/day

AU	TMDL	WLA_{WWTF}	LA	FG	MOS	WLA_{SW}
Cole Park 2481CB_03 (Beach ID TX259473)	1,186	0	273	0	179	734
Ropes Park 2481CB_04 (Beach ID TX821303)	5,007	0	146	0	662	4,199

Once the WLA_{SW} and WLA_{WWTF} terms are known, the WLA term can be calculated as the sum of the two parts, as shown in Table 10.

Table 10. Wasteload allocation calculation for the impaired AUs

All loads expressed as billion cfu/day

AU	WLA_{WWTF}	WLA_{SW}	WLA
Cole Park 2481CB_03 (Beach ID TX259473)	0	734	734
Ropes Park 2481CB_04 (Beach ID TX821303)	0	4,199	4,199

The TMDL watershed is covered under the City of Corpus Christi Phase I MS4 permit (TPDES Permit No. WQ0004200000). In urbanized areas regulated by an MS4 permit the control measures/programs outlined in an approved SWMP must be implemented during development and/or re-development of land. Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation BMPs and MCMs as specified in both the TPDES permit and the SWMP.

Implementation of Wasteload Allocations

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

TCEQ intends to implement the WLA in this TMDL document through the permitting process as BMPs or monitoring requirements, as required by the amendment of Title 30 Texas Administrative Code Chapter 319 (30 TAC Chapter 319), which became effective November 26, 2009. An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality.

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

The Executive Director or Commission may establish interim permit requirements in a permit amendment or permit renewal. These interim requirements will allow a permittee time to modify discharge quality in order to attain the final requirements necessary to meet TCEQ- and EPA-approved TMDL allocations. The duration of any interim requirements may not be any longer than three years from the date of permit re-issuance.

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

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

> "Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality concerns, permits would be modified in subsequent terms to include "more specific conditions or limitations [which] may include an integrated

suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric WQBELs, action levels, etc."

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

Updates to Wasteload Allocations

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

Allowance for Future Growth

Allowance for future growth is zero for these TMDLs because the watershed has been serviced by a municipal sanitary sewer system since the 1940s. All wastewater is conveyed out of the watershed and there is limited space for growth. No WWTFs are expected to affect the impaired AUs in the future (City of Corpus Christi, 2019b).

Margin of Safety Calculation

The TMDL allocations for AU 2481CB_03 (Cole Park) and AU 2481CB_04 (Ropes Park) include an explicit MOS. The MOS was based on reducing the TMDL endpoint target Enterococci concentration in these AUs by 5%, from 104 cfu/100 mL to 98.8 cfu/100 mL. The bacteria load allocated to the MOS can be calculated for each AU by subtracting the TMDL load, estimated using watershed simulations with the reduced water quality target (i.e., 98.8 cfu/100 mL) as an endpoint, from the TMDL load, estimated using the full 104 cfu/100 mL BAV as an endpoint. Table 11 shows the results of the MOS load calculation for both AUs.

Table 11. Margin of safety calculation for the impaired AUs

All loads expressed as billion cfu/day

AU	Indicator Bacteria	TMDL (98.8 cfu/100 mL end point)	TMDL (104 cfu/100 mL end point)	MOS
Cole Park 2481CB_03 (Beach ID TX259473)	Enterococci	1,007	1,186	179
Ropes Park 2481CB_04 (Beach ID TX821303)	Enterococci	4,345	5,007	662

Summary of TMDL Calculations

The modeling approach used for these TMDLs is based on GIS datasets and dataset derivatives as model inputs and is described in detail in Appendix A. The watershed model in this report is also described in Appendix A and in the *Technical Support Document: Two Total Maximum Daily Loads for Indicator Bacteria in Corpus Christi Bay at Cole and Ropes Parks, Corpus Christi, Texas Segment 2481CB, Assessment Units 2481CB_03 and 2481CB_04*[1] prepared by CCS, Texas A&M University-Corpus Christi.

Due to 90% of the contributing load emanating from subwatersheds 220 and 103, the TMDLs were calculated based on the outfalls associated with these subwatersheds (Figure 3).

The TMDLs were calculated by estimating the existing bacteria loads and then running the model to determine the watershed loads associated with staying just below the exceedance frequency associated with the contact recreation BAV (i.e., 25%) over a specified time period (Appendix A).

Cole Park - 2481CB_03

The current average daily load of indicator bacteria generated from the model simulation from 2006 through 2013 (i.e., current base condition) is 1.790×10^{13} cfu/day. The TMDL for Cole Park, AU 2481CB_03, (the simulated loading resulting in compliance with the single sample BAV [104 cfu/100 mL]) is estimated at 1.186×10^{12} cfu/day. The TMDL for this AU resulting in compliance with the reduced endpoint (95% of the single sample BAV [98.8 cfu/100 mL]) is estimated at 1.007×10^{12} cfu/day.

TMDL = 1.186×10^{12} cfu/day

The MOS is 1.790×10^{11} cfu/day, which results from subtracting the TMDL estimated with the reduced single sample BAV (98.8 cfu/100 mL) from the TMDL estimated using the full single sample BAV (104 cfu/100 mL).

MOS = 1.790×10^{11} cfu/day

The DWL is estimated to be 2.730×10^{11} cfu/day and is the result of the analysis presented in Appendix A and represents the LA.

LA = 2.730×10^{11} cfu/day

[1] www.tceq.texas.gov/assets/public/waterquality/tmdl/97coastalbeaches/97-TSD_CCBayBeaches_TMDL20160210.pdf

The WLA for stormwater for this AU is calculated to be 7.340 x10^{11} cfu/day and is the result of subtracting the LA and MOS value from the TMDL value. WLA_{WWTF} is zero because there are no WWTF outfalls in the TMDL watershed. FG is zero because there are no permitted WWTF discharges to the impaired AU, and none are expected to affect the impaired AU in the future.

WLA_{SW} = 7.340 x 10^{11} cfu/day

Ropes Park - 2481CB_04

The current average daily load of indicator bacteria generated from the model simulation from 2006 through 2013 is 1.6150 x 10^{13} cfu/day. The TMDL for Ropes Park, AU 2481CB_04, (the simulated loading resulting in compliance with the single sample BAV [104 cfu/100 mL]) is estimated at 5.007 x 10^{12}. The TMDL for this AU resulting in compliance with the reduced endpoint (95% of the single sample BAV [98.8 cfu/100 mL]) is estimated at 4.345 x 10^{12} cfu/day.

TMDL = 5.007 x 10^{12} cfu/day

The MOS is 6.622 x 10^{11} cfu/day, which results from subtracting the TMDL estimated with the reduced single sample BAV (98.8 cfu/100 mL) from the TMDL estimated using the full single sample BAV (104 cfu/100 mL).

MOS = 6.622 x 10^{11} cfu/day

The DWL is estimated to be 1.460 x10^{11} cfu/day and is the result of the analysis presented in Appendix A and represents the LA.

LA = 1.460 x10^{11} cfu/day

The WLA for stormwater for this AU is calculated to be 4.199 x 10^{12} cfu/day and is the result of subtracting the LA and MOS value from the TMDL value. WLA_{WWTF} is zero because there are no WWTF outfalls in the TMDL watershed. FG is zero because there are no permitted WWTF discharges to the impaired AU, and none are expected to affect the impaired AU in the future.

WLA_{SW} = 4.199 x 10^{12} cfu/day

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are provided in Table 12. Appendix A provides guidance on the technical approach and method used to produce the allocations in Table 12.

Table 12. Final TMDL allocation for the impaired AUs
All loads expressed as billion cfu/day

AU	TMDL	WLA_{WWTF}	WLA_{SW}	LA_{TOTAL}	MOS
Cole Park 2481CB_03 (Beach ID TX259473)	1,186	0	734	273	179
Ropes Park 2481CB_04 (Beach ID TX821303)	5,007	0	4,199	146	662

Seasonal Variation

Seasonal variations (or seasonality) occurs when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations require that TMDLs account for seasonal variation in watershed conditions and pollutant loading [40 CFR 30.7(c)(1)].

Seasonal differences in indicator bacteria concentrations were assessed by comparing historical bacteria concentrations collected in the warmer months versus those collected during the cooler months (CCS, 2015). The monthly average temperatures for Corpus Christi (NCEI, 2010) were calculated based on observations at NAS-CC (12926). The data were divided into warmer (greater than 77ºF) and cooler months (less than 63ºF) with December, January, and February representing the cooler months and May, June, July, August, and September representing the warmer months. The remaining months are transitional months with temperatures between 63ºF and 77ºF.

The data were also evaluated based on wet and dry seasonality. A Welch t-test was conducted on $\log^{(10)}$ transformed bacteria values between the warmer months and cooler months as well as for dry versus wet months using TGLO data from 2003-2013. The geometric mean was then calculated for seasonal comparison.

Only two TGLO Beach Watch stations, NUE028 and NUE029 (both in AU 2481CB_04 – Ropes Park), show a statistically significant difference in seasonality (p-value less than 0.05), with higher bacteria geometric means during warm and wet months.

It should be noted that the protocol utilized by TGLO to assess recreational uses apply to water bodies during all seasons of the year. Therefore, seasonal variation is accounted for in the bacteria TMDLs presented in this document by virtue of the fact that these variations affect neither the calculation nor the implementation of bacteria TMDLs in Texas.

Public Participation

TCEQ maintains an inclusive public participation process and has sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

CCS and the Coastal Bend Bays Foundation provided coordination for public participation with this TMDL project and the associated TMDL Implementation Plan (I-Plan) development. Beginning in 2012 through 2016, a series of public meetings were held every year to discuss the TMDL. The meetings introduced the TMDL process, identified the impaired segments and the reason for the impairments, reviewed historical data, described potential sources of bacteria within the watershed, and presented the TMDL analysis, as well as preliminary and final load allocations. Since then, the stakeholders have been kept informed of the status of the TMDL. In addition to informing the public, the meetings gave TCEQ the opportunity to receive input on the TMDLs and I-Plan from all interested parties within the TMDL watershed.

From these meetings, a Coordination Committee was formed representing a balanced stakeholder group to represent interests in the TMDL watershed. Members included the City of Corpus Christi, other local agencies, recreational users, the public, and homeowners. The Coordination Committee was responsible for developing the I-Plan and for disseminating information on both the TMDL and I-Plan projects.

Beginning in 2012 through 2016, a total of 34 Coordination Committee meetings were held regularly, and committee members and other participants held 35 workgroup meetings to develop the individual implementation activities. Notices of meetings were posted on the project webpage and on the TMDL program's online calendar. Two weeks prior to scheduled meetings, emails were sent to formally invite stakeholders to attend.

Implementation and Reasonable Assurance

The issuance of TPDES permits consistent with TMDLs provides reasonable assurance that wasteload allocations in this TMDL report will be achieved. Per federal requirements, each TMDL is included in an update to the Texas WQMP as a plan element. The WQMP coordinates and directs the state's efforts to manage water quality and maintain or restore designated uses throughout Texas. The WQMP is continually updated with new, more specifically focused plan elements, as identified in federal regulations [40 CFR 130.6(c)]. Commission adoption of a TMDL is the state's certification of the associated WQMP update.

For MS4 entities, where numeric effluent limitations are infeasible, the permits require that the MS4 develop and implement BMPs under each MCM, which are a substitute for effluent limitations, as allowed by federal rules. How a regulated MS4 meets each MCM is not prescribed in detail in the MS4 permits but is included in the permittee's SWMP. During the permit renewal process, TCEQ revises its MS4 permits as needed to require the implementation of other specific revisions in accordance with an approved TMDL and I-Plan.

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

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

Key Elements of an Implementation Plan

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

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

TCEQ works with stakeholders and interested governmental agencies to develop and support I-Plans and track their progress. The cooperation required to develop an I-Plan will become a cornerstone for the shared responsibility necessary to carry it out.

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

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

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Appendix A.
Technical Approach to Developing the TMDL Allocations

A.1. Using Numerical Models to Develop TMDLs

Water quality, at any discrete point within a watershed, is the result of all processes that have occurred upstream of that particular point. Major watershed processes include the accumulation of pollutants on land surfaces (pollutant buildup), conversion of precipitation to runoff (overland and channelized flow), and removal of constituents on surfaces in contact with the water (wash off). Other processes may include dilution and decay (i.e., die-off, predation by other organisms, or inactivation through adhesion to colloidal particles).

Models can be used to aid in the understanding of physical systems. A model is any mechanism that can simulate a process or system (Anderson and Woessner, 1992). Models can be laboratory-scale devices constructed using actual materials and involving the same physical forces as found in nature, like a flume to model surface water flow (McDaniel et al., 2013) or a sand tank to model ground water movement (Anderson and Woessner, 1992). Many times, it is impractical to build a physical model, so numerical models can be created instead.

Numerical models often simulate natural systems using mathematical formulas (governing equations) or statistical relationships that represent the physical, chemical, and biochemical processes at work in the systems they simulate. Numerical models can be divided into two groups based on the methods used to represent the physical systems they simulate. Stochastic models use statistical probability to define the physical processes in the system. Deterministic (physical or process-based) models use governing equations to represent the physical processes involved in the actual system being modeled. Deterministic models do not contain the random elements that are inherent in probability-based models.

A numerical model can be used to produce continuous simulated flow and water quality data that can be used to forecast these parameters under future conditions or to fill gaps in observed field data. Model simulations can also be used to calculate loadings of modeled constituents at any discrete location and/or time within the model domain.

Numerical models have been applied to the Corpus Christi Bay area in the past. Quenzer et al. (1998) developed a GIS-based numerical model to assess nonpoint source loadings (primarily nutrients) to the Corpus Christi Bay system. A similar model was used in the Galveston Bay area (Zoun, 2003) to assess bacteria loading. A TMDL project conducted on Oso Creek and Oso Bay (Hay and Mott, 2005; Hay and Mott, 2006) also applied a GIS-based model to assess bacteria loadings and simulate the results of load reduction plans.

A.2. Development of the Numerical Model

A.2.1. Conceptual Model

The modeling approach used for the Cole Park and Ropes Park TMDLs is based on GIS-based datasets and dataset derivatives as model inputs. The conceptual model of the TMDL modeling system includes the following assumptions:

1) Bacteria from warm-blooded animals accumulate over time on surfaces exposed to the atmosphere. The quantity of accumulated fecal matter is a function of land cover and use. The accumulated fecal matter is always present.
2) A precipitation event with sufficient magnitude can generate overland flow of water that carries some of the fecal bacteria down slope until it becomes channelized flow.
3) Channelized flow containing the fecal bacteria enters the drainage channels and stormwater conduits and flows towards Corpus Christy Bay.
4) During the channelized flow process, fecal bacteria begin to die or inactivate due to various forces such as predation or inhospitable environments.
5) Flow is accumulated in the stormwater system, routed through channels and conduits, and discharged to Corpus Christi Bay at or near the impaired AUs, where mixing with bay water occurs.

The primary force in this modeled system is assumed to be runoff from precipitation. Studies (Hay and Mott, 2006; Stein and Ackerman, 2007; Mott and Hay et al., 2009) have noted that DWL can be a significant contributor to poor water quality, and some of the data collected by CCS in the TMDL watershed corroborate this observation. However, this type of loading is not driven by runoff events. DWL can be incorporated into a runoff-based model as a constant flux, provided there are enough data collected during dry weather to indicate its presence and to determine the flux rate. This is the case for the TMDL model presented in this document.

The model in this report was developed in the *Technical Support Document: Two Total Maximum Daily Loads for Indicator Bacteria in Corpus Christi Bay at Cole and Ropes Parks, Corpus Christi, Texas Segment 2481CB, Assessment Units 2481CB_03 and 2481CB_04*[2] prepared by CCS, Texas A&M University-Corpus Christi.

[2] www.tceq.texas.gov/assets/public/waterquality/tmdl/97coastalbeaches/97-TSD_CCBayBeaches_TMDL20160210.pdf

A.2.2. Modeling Process and Design

The major processes identified in the conceptual model are the accumulation of fecal bacteria on various surfaces, conversion of precipitation to runoff, routing of runoff to channelized flow, decay of bacteria during channelized flow, and mixing of the discharged runoff with the bay water at the impaired AUs. Each of these processes can be defined using a mathematical relationship (governing equation) that can use real field measurements as input variables to the calculations. The results of the calculations can then be used as inputs for subsequent processes. The model is divided into two simultaneous processes: the hydrologic component, which drives the movement of water through the system; and the physical-biological component, which describes the accumulation and decay of fecal bacteria.

The hydrologic component of the model is governed by the hydrologic equation (law of mass conservation):

Equation A.1. The Hydrologic Equation

Inflow = outflow +/- change in storage

Where:

Inflow = precipitation within the model boundaries

Outflow = discharge to the impaired AUs minus infiltration to the soil

Storage = precipitation intercepted by vegetation, buildings, and/or depression storage

Model boundaries are defined by the limits of the contributing subwatersheds of the stormwater collection systems that discharge closest, or are most likely to affect, the impaired AUs (see Figure 3). Within the boundaries of the model, runoff is calculated based on the Rational Equation:

Equation A.2. The Rational Equation

(Fetter, 2001)

$$Q = C \times I \times A$$

Where:

Q = peak runoff rate

C = runoff coefficient

I = rainfall intensity

A = area

The peak runoff rate, calculated in the Rational Equation (Equation A.2), is the volume of water that is expected to become runoff over the unit of time defined by the rainfall intensity. Peak runoff, as used in this modeling effort, represents the total runoff generated during the interval of the rainfall intensity. Runoff is accumulated over the subwatersheds and routed to the stormwater collection system, calculated by grid multiplication, with the mean of range runoff coefficient (C), as described in Table A.1.

Table A.1. Land use code and associated American Society of Civil Engineers (ASCE) runoff coefficients for grid incorporation

City of Corpus Christi Land Use Code	ASCE Area Description	C Range (Fetter, 2001)	C Mean (calculated from range)
AG, CP, PARK	Parks, Cemeteries	0.10 - 0.25	0.175
ROW, VAC	Unimproved	0.10 - 0.30	0.20
PO, COM	Downtown (business)	0.70 - 0.95	0.825
LI	Light Industrial	0.50 - 0.80	0.65
HI	Heavy Industrial	0.60 - 0.90	0.75
MDR	Detached Multi Units	0.40 - 0.60	0.50
HDR	Attached Multi Units	0.60 – 0.75	0.675
ER	Residential Suburban	0.25 - 0.40	0.325
LDR	Single-family	0.30 - 0.50	0.40
PSP	Neighborhood (business)	0.50 - 0.70	0.60
TRANS	Asphalt and Concrete	0.70 - 0.95	0.825

Once runoff has been accumulated and enters channelized flow (for discharge and water quality determinations), each subsection of the drainage system is treated as a constantly stirred reactor tank (Aris, 1999; Denbigh and Turner, 1971).

Following the law of mass conservation (Equation A.1), the channelized flow is routed along the stormwater collection system using Manning's Equation and the dimensions and altitude gradients of the stormwater conveyance channels to determine the flow velocity of runoff discharging to the bay (Equation A.3).

Equation A.3. The Manning Equation (Fetter, 2001)

$$V = \frac{1.49 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$

Where:

V = velocity

R = hydraulic radius

S = gradient

n = Manning roughness coefficient

The water quality component of the model tracks the bacteria as it moves through the system, driven by the forcing of the hydrologic component of the model. Accumulation of fecal bacteria in the runoff is based on (1) land use that has been described by the City of Corpus Christi, (2) event mean concentrations (EMCs) that describe the total constituent mass washed off of the land surface divided by the total runoff volume for a particular land use over a rainfall event (EPA, 1983) and (3) event concentrations (ECs) that describe the concentration of bacteria (Enterococci) that is continuously available for transport in runoff (Hay and Mott, 2006). ECs can be viewed as EMCs adjusted to site-specific conditions.

While EMC values represent the average concentration of a contaminant in runoff from a particular type of land use over a runoff event, they inherently contain decay and dilution factors that occur over the duration of the event. For this reason, they are not particularly well suited for modeling runoff at shorter time intervals than the runoff event itself.

In another TMDL study on a neighboring watershed (Oso Creek), a method was implemented that produced values for contaminant availability that could be used to modify literature-based EMC values. This method captured the entrainment process of the pollutant while the precipitation portion of the runoff event proceeded (Hay and Mott, 2006). The adjusted values were described as ECs.

EC values were conceptualized and developed when it was noted that a simulation, iterating at two-hour intervals, produced in-stream concentrations of Enterococci consistently lower than the measured values at the same time and location. To develop the ECs, the researchers chose a SWQM station that measured flow and water quality from a small subwatershed of Oso Creek (completely within the City of Corpus Christi) that contained all land use types from the main Oso Creek watershed. Initial loads (concentrations divided by flow) were estimated by back calculation from field water quality measurements at the subwatershed outlet, then solving for initial load in Equation A.4 for several runoff events. This value was then distributed proportionally to each land use in the TMDL watershed based on the area represented in the subwatershed and the ratio of magnitudes between land use types from Baird et al. (1996).

Equation A.4. Calculation of event mean concentration

(Lee, 2002)

$$EMC_T = \frac{\sum[C_t Q_t \Delta t]}{\sum[Q_t \Delta t]}$$

Where:

EMC_T = total Enterococci EMC of runoff

C_t = time variable concentration (cfu/100 mL)

Q_t = time variable flow (meters^3 day^{-1})

Δt = discrete time interval

Once the bacteria are entrained in the runoff and enter channelized flow, they are subject to decay. Decay is the loss of bacteria due to die-off, settling, predation, inactivation due to adhesion, or exposure to inhospitable environments (such as low temperatures, high salinity, or bright sunlight). Values for bacteria decay in surface water can be found in scientific literature (Alkan et al., 1995; Boehm et al., 2005; Medema et al., 1997; Noble et al., 2004). Decay rates vary for fresh water and salt water. Bacteria decay rate is calculated using Equation A.5.

Equation A.5. First order decay rate for bacteria

(Crysup, 2002)

$$K_B = K_{B1} + K_{BL} + K_{BS}K_a$$

Where:

K_B = overall first order decay rate

K_{B1} = death rate as a function of temperature, salinity, and predation

K_{BL} = death rate due to exposure to sunlight

K_{BS} = net loss due to settling

K_a = after growth rate

During transport, the bacteria load decays based on the period of time it spends in a particular AU, using Equation A.6.

Equation A.6. Decayed bacteria load

$$L = L_0 e^{-K_B t}$$

Where:

L = decayed load

L_0 = initial load from watershed

e = base of natural logarithm

K_B = overall first order decay rate

t = travel time

Since decay is so closely coupled with time in channelized flow, it is beneficial to break the contributing area into subwatersheds to provide a more detailed tracking of bacteria loads and a more representative time for calculating decay. The subwatersheds are well defined in the City of Corpus Christi Stormwater Master Plan (Green and West, 2009) and the City of Corpus Christi Infrastructure Mapbook (City of Corpus Christi, 2006).

Other non-runoff processes may exist in the contributing area, including the beach itself, that can generate additional bacteria loadings to the system. These processes are generally characterized as DWL and can contribute significantly to the total pollutant load. DWL from direct deposition of fecal matter into the impaired AU may be naturally present in beach sands. A flux from dry weather events can be determined if sufficient data are available. This type of loading can be represented in the model as a constant flux.

A.2.3. Data Preparation and Processing

ArcGIS was used to prepare spatial datasets as model inputs. Spatial datasets include precipitation grids, EC grids, and subwatershed grids/polygons. The spatial datasets were then converted to time series text files that were processed using the open-source mathematical modeling software R (R Development Core Team, 2005).

Governing equations cited in Section A.2.2 of this document were coded into R following the conceptual model process. The model can run on various time steps depending on the temporal resolution of the input data. Previous models have run at a two-hour temporal resolution. This frequency of iteration requires a different approach to EMC values as described in Section A.2.1 and uses the event concentration values described in Table A.2. A concurrent water quality monitoring effort collected bacteria (Enterococci) concentrations at stormwater outfalls at nominal intervals through runoff events. These data were used for model calibration.

Calculation of bacteria (Enterococci) load from a subwatershed was done at a nominal temporal frequency (e.g. one-hour intervals) by multiplying the hourly values from the precipitation grid by the runoff coefficients and ECs in the land use grids (Equations A.7 and A.8).

Equation A.7. Computation of runoff volume using ArcGIS

Runoff volume = precipitation grid * C

Equation A.8. Computation of load using ArcGIS

Load = runoff volume * EC grid

Loading for each subwatershed is calculated using the zonal statistics tool in ArcInfo (ESRI, 2013). These loadings are calculated for each time step of the simulation and then exported to the mathematical modeling software R as a text file.

Table A.2. Event concentration values (cfu/100 mL) as applied in gridded dataset for initial loading calculations

Type	City of Corpus Christi Land Use Code	Revised EMC Oso Creek (Hay and Mott, 2006)	EMC (Baird et al., 1996)	EC from Oso Creek (Hay and Mott, 2006)
Residential	LDR, MDR, HDR, ER	41,320	20,000	305,316
Commercial	COM, PO, PSP	14,246	6,900	105,264
Industrial	LI, HI	20,027	9,700	147,981
Transportation	TRANS	109,427	53,000	808,562
Crop/ Range Land	AG, VAC, PARK, CP	8,500	0/37	62,807
Not Classified	DC, WATER	8,500	0	62,807

With the initial loadings, R performs the hydrologic functions of routing the flow volume from each subwatershed to the main conduit(s) at a prescribed time step using Manning's Equation (with conduit dimension and slope) to calculate flow and current velocity and, hence, residence time. The model simultaneously moves the bacteria load through the conduits using the residence time for each subwatershed conduit to decay the load using a specified decay constant. The model produces an hourly runoff volume and bacteria load at each outfall of each modeled stormwater subwatershed to Corpus Christi Bay.

A.3. Estimating Loading and Simulations

The TMDL model described in previous sections was used to calculate discharge volume, bacteria (Enterococci) load, and concentrations at the major contributing Louisiana Avenue and Brawner Parkway outfalls (subwatersheds 220 and 103) in the vicinity of Cole Park and Ropes Park (AUs 2481CB_03 and 2481CB_04). The intended use of this information is to calculate the total loading to the Corpus Christi Bay beaches near these outfalls.

The calibrated model can be used to simulate conditions under different climate conditions (wet year vs. dry year) or various load reduction plans. Desired load reductions can be simulated by evaluating each land use/land cover EC to see which contribute the most loading to the system, and by systematically reducing ECs from the most significant sources (land uses) until a loading is achieved that results in an end concentration that meets the contact recreation BAV (the TMDL endpoint) in the impaired AUs.

A.3.1. Initial Simulations

During the initial simulations, several factors became apparent that would limit the ability of the model to produce reliable output. These factors initiated a review of the conceptual model and the model code to address the limiting factors. Primary calibration of the model was performed on the hydrologic component of the model using the Brawner Parkway (subwatershed 103) discharge. This subwatershed was selected for primary calibration because of the small interquartile range of values seen in the water quality measurements taken at and near Ropes Park, and because it represents a large portion of the TMDL watershed (see Figure 3).

During the calibration process, and also during field data collection, it was noted that the hydrologic system (stormwater sewer) responded rapidly to precipitation events and quickly emptied the event-generated runoff into Corpus Christi Bay. During large events, the simulated volume of runoff overloaded the model's ability to move fluid through the system. Precipitation depths, which drive the runoff portion of the model, are not available in time intervals shorter than one hour for this particular dataset. To prevent the model from overloading during large runoff events, the model code was modified to subdivide each hourly time step into four sub-steps by dividing the runoff and bacteria load input by four and processing them at this shorter input time step (moving the water and bacteria down gradient and simultaneously decaying the bacteria load).

A secondary calibration was performed on the bacteria component of the model. During this process, it was observed that some mixing between the runoff in the conduit and the bay water occurred upstream of the SWQM stations used for calibration of the model, because the outfalls are partially submerged box culverts that open directly into the bay and, during periods of no runoff, bay water intrudes a significant distance into the stormwater culverts. This situation was evident at the two major outfalls (Brawner Parkway and Louisiana Avenue), which together account for 90% of the drainage from the TMDL watershed. This situation required a mixing factor to be applied to the model code to account for the mixing of stormwater with the bay water prior to its arrival at the confluence with the bay, where bacteria concentrations were measured.

Challenges in collecting water quality measurements and discharge data for model calibration resulted in only a few usable calibration targets over two runoff events. The primary challenge was the swiftness of flow through the system and the mobilization time needed to capture discharge and water quality measurements. This also imposes a limited ability to match model output (concentration and discharge) with measured data to calculate model error.

A.3.2. Model Modification and Calibration

In order to address the issues described in Section A.3.1, there were several modifications made to the model to improve its performance in predicting discharge and bacteria loading.

Modifications

The first modification made to the model was discussed in Section A.3.1. Hourly input data (runoff and bacteria load) generated by the GIS software were split into four to generate 15-minute inputs. This provided a means to keep runoff and bacteria load moving through the system at a faster rate without overwhelming the model code with large runoff volumes during a particularly intense precipitation event.

The second modification made to the model, also discussed in Section A.3.1., eliminated the process-based modeling of bacteria in the bay at the TMDL AUs and multivariate linear regression methods for relating bacteria concentrations measured at the stormwater outfalls to bacteria concentrations measured at compliance points and introduced a constant mixing factor as a simplified replacement. This simplified approach led to a modification in the conceptual model which posited that the modeled concentrations at the discharge points were similar enough to those measured at the compliance points (TGLO Beach Watch stations) and that the load reductions evaluated by assessing the change in the bacteria concentrations modeled at the discharge points (i.e., stormwater outfalls) could be used to assess compliance at the SWQM stations. This is a reasonable, albeit slightly conservative, approach, as during high volume storm events, flow from the Brawner Parkway and Louisiana Avenue outfalls push stormwater several hundred feet in several directions into the bay, and the beaches at Cole Park and Ropes Park are adjacent to these, and several other, stormwater outfalls.

Calibration

The model was calibrated using discharge and bacteria concentration measurements collected by the CCS and the Center for Water Supply Studies over two precipitation events, one occurring on June 30, 2013, and the other occurring on July 17, 2013.

Primary calibration (discharge) data and secondary calibration (bacteria concentration) data were applied to the Brawner Parkway outfall first for the two runoff events, where field measured calibration points were available. Calibration was achieved by adjusting initial inputs (runoff and bacteria load) either up or down until the model output agreed with on-site measurements (calibration points) within a reasonable error. Runoff input, which used a mean C for each land use type (Table A.1) produced higher than measured discharge volumes and was gradually reduced until the modeled discharge approximated the measured discharge. Final calibration of discharge on average required only 33.3% of the runoff volume calculated by GIS using the ASCE C mean value. The bacteria loading was adjusted in two parts. The first adjustment to the bacteria loading involved a 25% reduction in the input bacteria load calculated by the GIS analysis to reduce the outfall concentrations to within an order of magnitude of the measured values. The second part of the calibration adjusted to the concentration measured at the outfall using the conduit bay water mixing factor.

Once the calibration process was complete on the Brawner Parkway outfall, the same values were tested on all other subwatersheds. This allowed the modeler to evaluate the calibration adjustments, assessing how well they represented the overall watershed.

A.3.3. Model Results and Performance

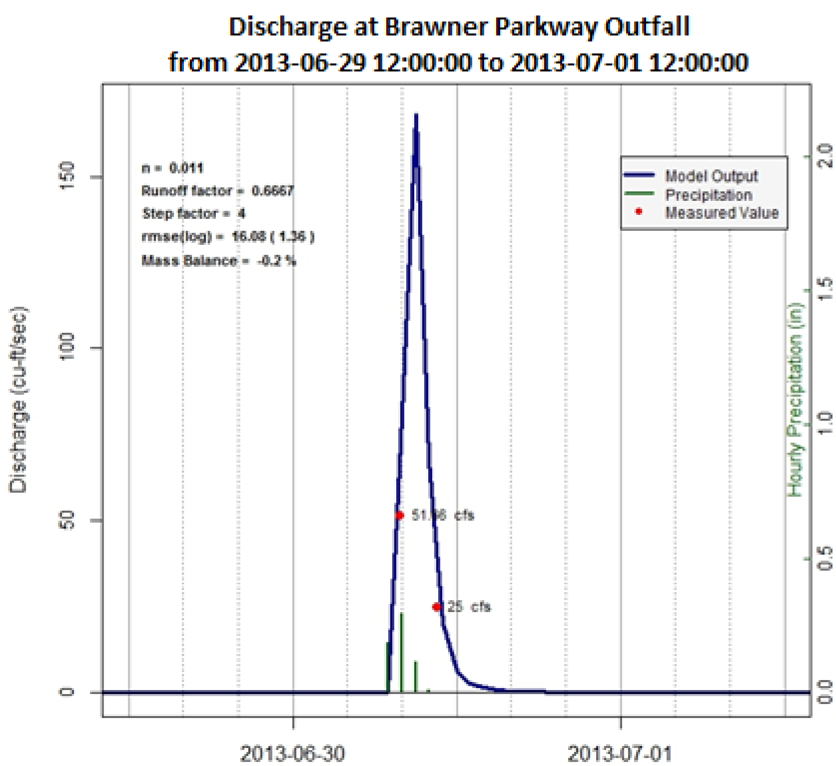
Using the calibration target values, the model achieved an overall root mean square error (RMSE) for the modeled bacteria concentrations of $0.79 \times \log_{10}$. This value represents a lower (better) value than the objective ($1 \log_{10}$) stated in the Quality Assurance Project Plan. The RMSE (bacteria concentration) for the subwatershed used for calibration (Brawner Parkway outfall) was $0.74 \times \log_{10}$.

As previously discussed, discharge during runoff events in the TMDL watershed occurs over a short period of time due to the intensity and brevity of precipitation events and the lack of retention and absorption of runoff provided by the urban land cover. The modeled discharge and concentrations for the Brawner Parkway outfall, along with measured values, are presented in Figures A.1 and A.2. The information for the Louisiana Avenue outfall is presented in

Figures A.3 and A.4. In general, measured values are usually below the modeled values. In smaller subwatersheds a very small discharge was measured within three hours of peak discharge. This indicates that in some cases the model may not be routing water as fast as the engineered system transmits it to the impaired AU.

Model-predicted discharge had an overall RMSE of 25 cubic feet per second. However, since the range of discharge values through a runoff event encompassed several orders of magnitude, a $\log_{10}$ RMSE is probably a more realistic way of evaluating the model's ability to forecast discharge. The $\log_{10}$ RMSE for discharge in the model was 0.56.

Mass balance error for individual subwatersheds was small (+/- 0.1%), indicating that the runoff generated was being passed completely through the system. Mass balance error for bacteria loads was less than 5%, a value that can be partially attributed to uncertainty in the representation of bacteria decay/regrowth processes.



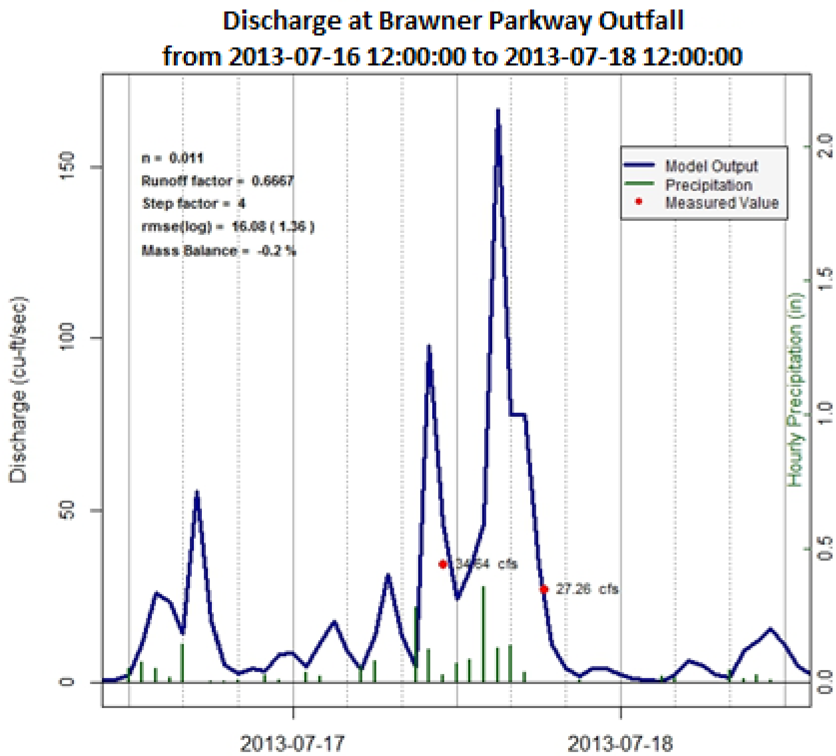
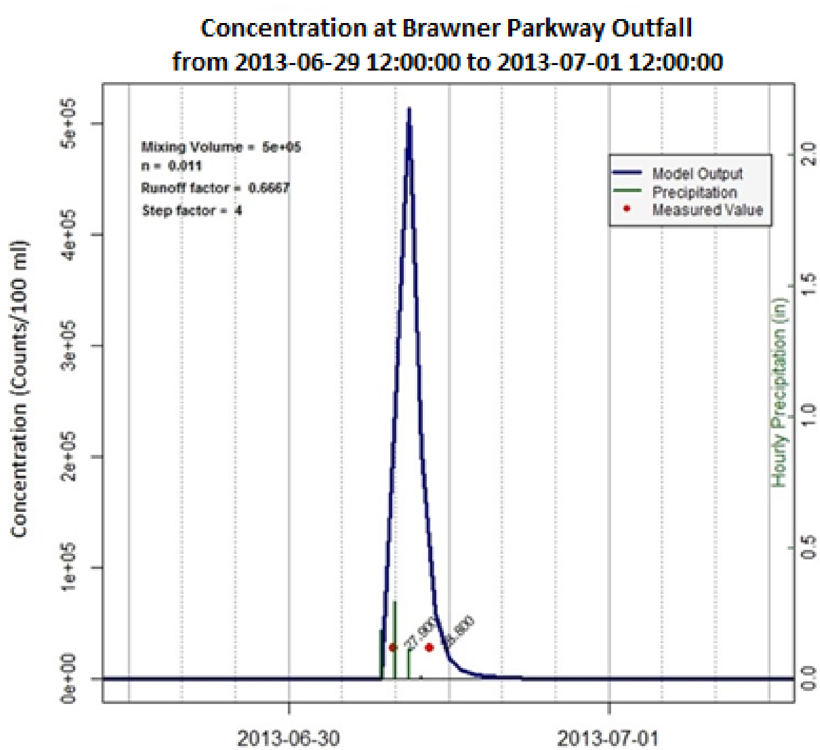


Figure A.1. Modeled discharge, precipitation, and calibration points at Brawner Parkway Outfall near Ropes Park on June 30, 2013 and July 17, 2013



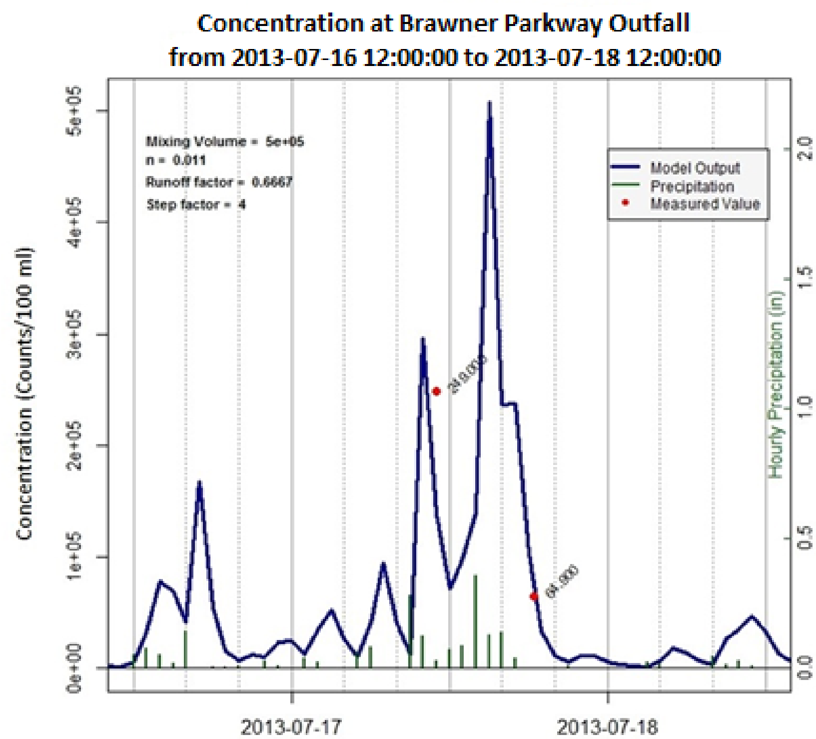
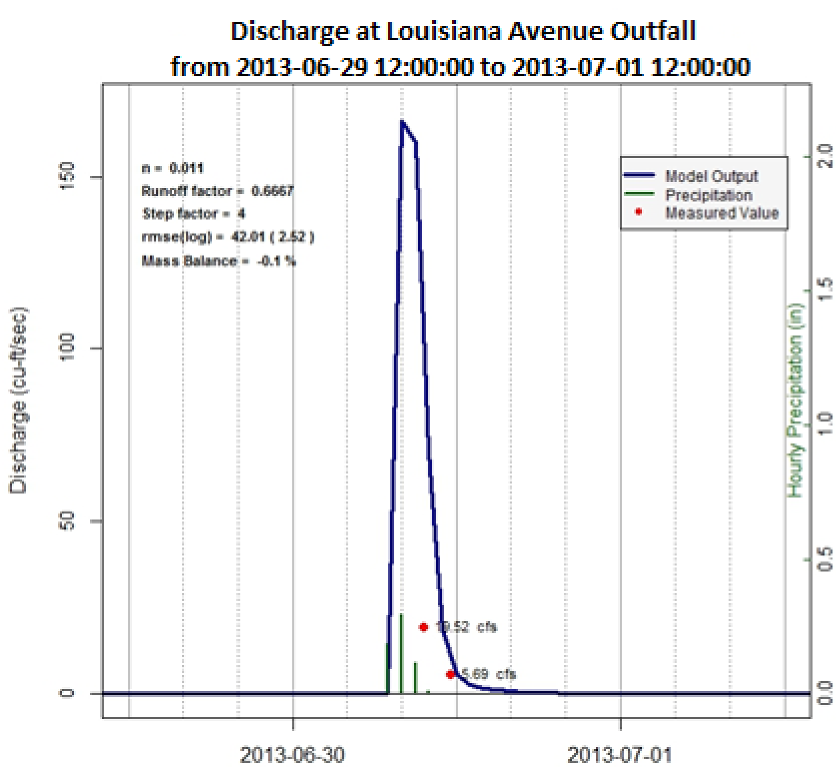


Figure A.2. Modeled bacteria concentrations, precipitation, and calibration points at Brawner Parkway Outfall near Ropes Park on June 30, 2013 and July 17, 2013



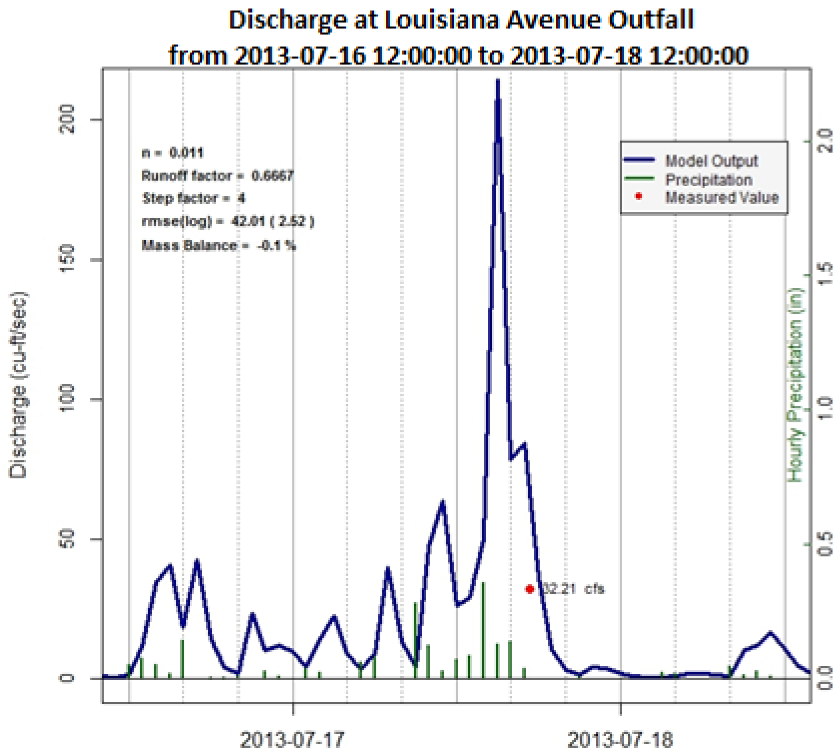
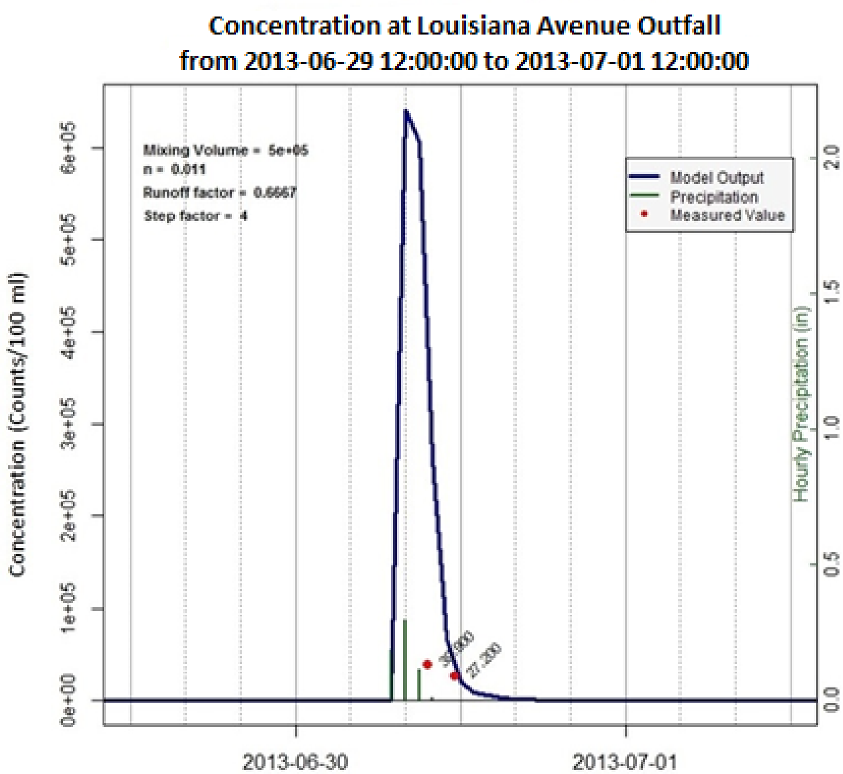


Figure A.3. Modeled discharge, precipitation, and calibration points at Louisiana Avenue Outfall in Cole Park on June 30, 2013 and July 17, 2013



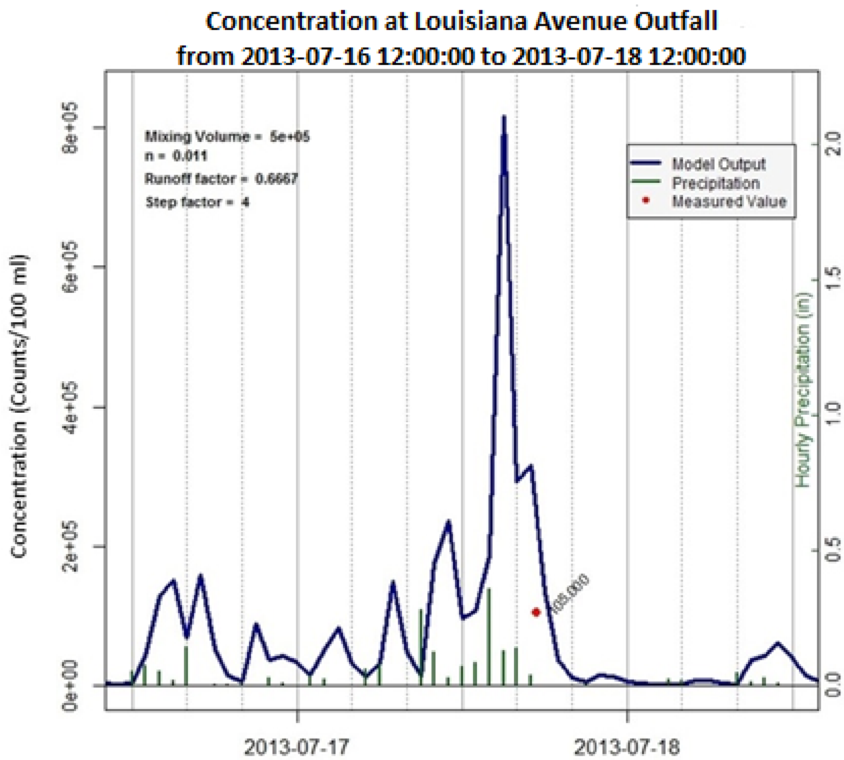


Figure A.4. Modeled bacteria concentrations, precipitation, and calibration points at Louisiana Avenue Outfall in Cole Park on June 30, 2013 and July 17, 2013

A.3.4. Other Considerations

Although the model effectively simulated runoff discharge and bacteria loads through the system, the paucity of calibration points limits the robustness of the model. Also, as with any modeling effort, there are certain limitations in the ability of a numerical model to make extremely accurate predictions of natural systems.

Model Limitations

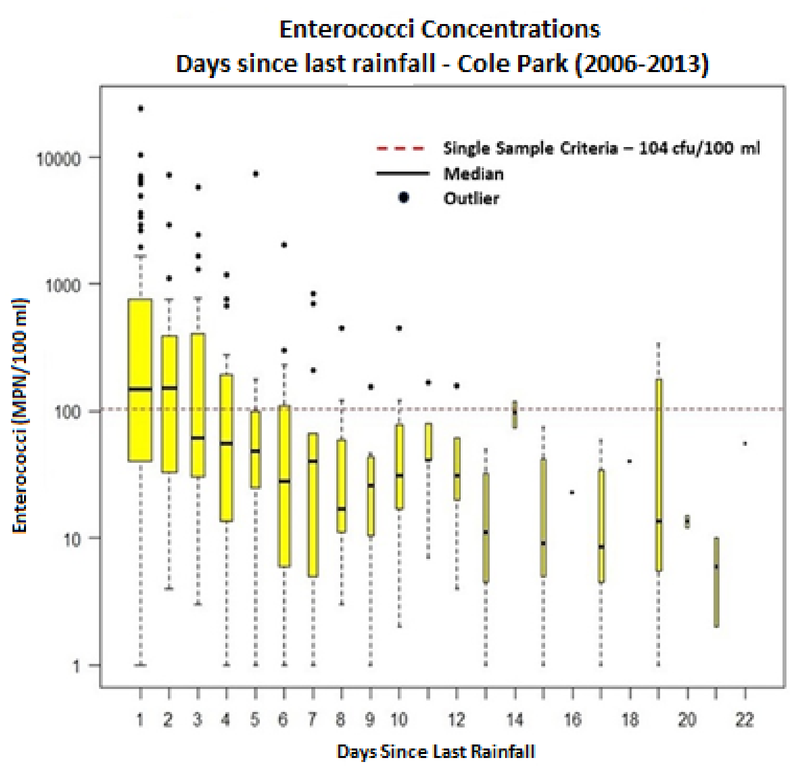
This model was developed to simulate flow through a stormwater system and is initiated and driven by precipitation. The model can be used to make predictions about what the range of bacteria concentrations might be when stormwater discharges to the bay. Since the ditches, channels, and conduits of the stormwater sewer system are not naturally flowing streams, with components such as base flow to maintain year-round flow, there is only water flowing in this system when there is runoff from a precipitation event. So, forecasts of bacteria loading only occur when there has been a precipitation event. As mentioned in previous sections, these flows occur over a very short period of time and it is only over these periods that bacteria concentrations are forecast.

Dry Weather Loads

Data show elevated bacteria concentrations occur at times when no runoff discharges to the bay. Figure A.5 demonstrates the relationship between Enterococci concentrations and days since last rainfall and shows that the highest concentrations occur directly after rainfall events. However, concentrations can be elevated (exceed the BAV (TMDL endpoint) of 104 cfu/100 mL) even when measurements take place four days or more after a rainfall event.

These values cannot be explained or simulated using the model developed for this TMDL effort, but they represent a significant contribution to the exceedances reported at AUs 2481CB_03 and 2481CB_04. To examine this phenomenon further, it is best to simplify each AU's bacteria data by aggregating the values collected at multiple monitoring stations, thereby creating a single "synthetic" station that is made up of the maximum measured bacteria concentrations from all the monitoring stations (TGLO and CCS) near the impaired AUs.

This synthetic station then, has values that are likely to trigger a beach advisory. A recurrence graph (Figure A.6) shows the significance of DWL at Cole Park using the synthetic station bacteria concentration values. The dry weather measurements in this case are those water quality samples taken more than four days after a precipitation event.



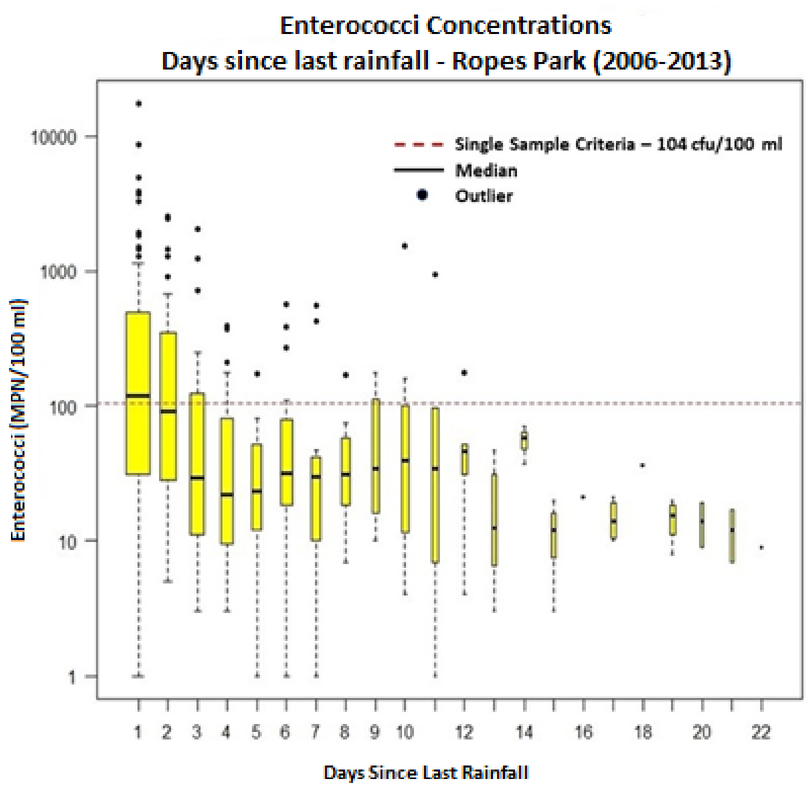


Figure A.5. Box and Whisker Plots of sampling events at Cole Park and Ropes Park

In Figure A.6, the dry weather values can be seen to exceed the BAV of 104 cfu/100 mL almost 20% of the time, while all the measured values for that AU exceed the BAV about 40% of the time.

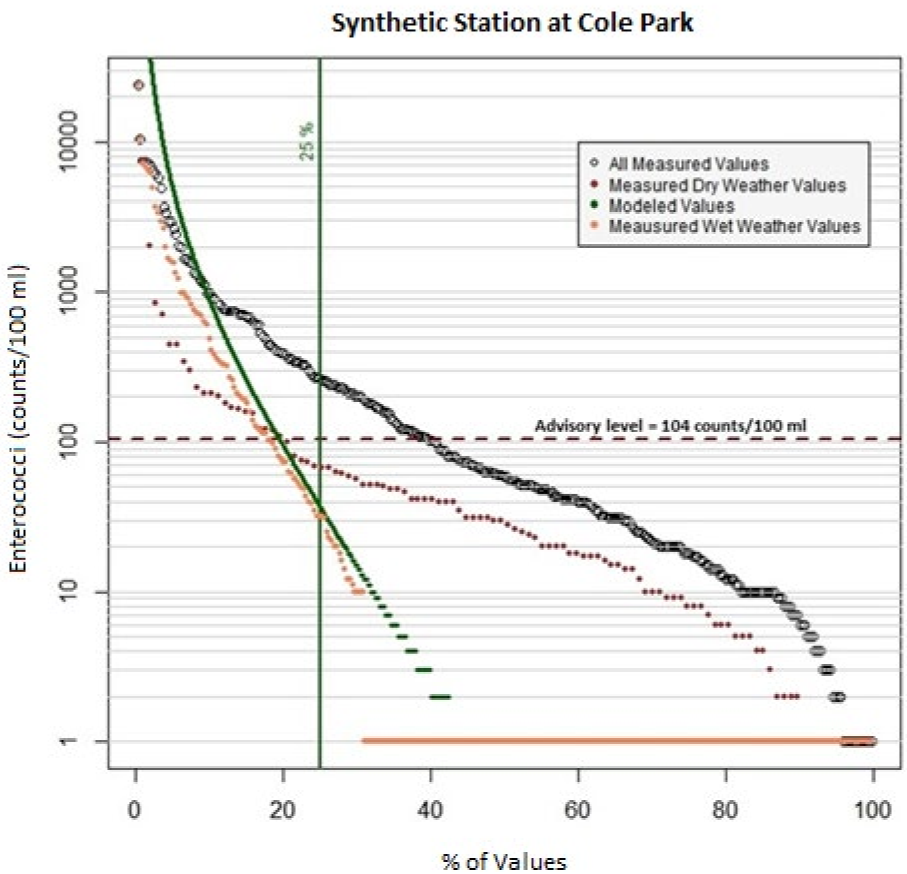


Figure A.6. Recurrence graph of a synthetic station representing all monitoring stations at Cole Park

Combining Measured Dry Weather Values with Simulated Wet Weather Values

Comparing the recurrence frequency of bacteria concentrations forecast by the model output to the recurrence frequency of measured bacteria values that only occur during runoff events, it is apparent that the model performs reasonably well in producing concentrations similar to what was measured in the field (Figure A.6). By replacing the zero values forecast by the model during periods of no runoff with bacteria values known to occur during dry weather, a recurrence frequency plot is developed that closely resembles the recurrence frequency of the synthetic station created for Cole Park (Figure A.7). Ropes Park shows similar results (Figure A.8).

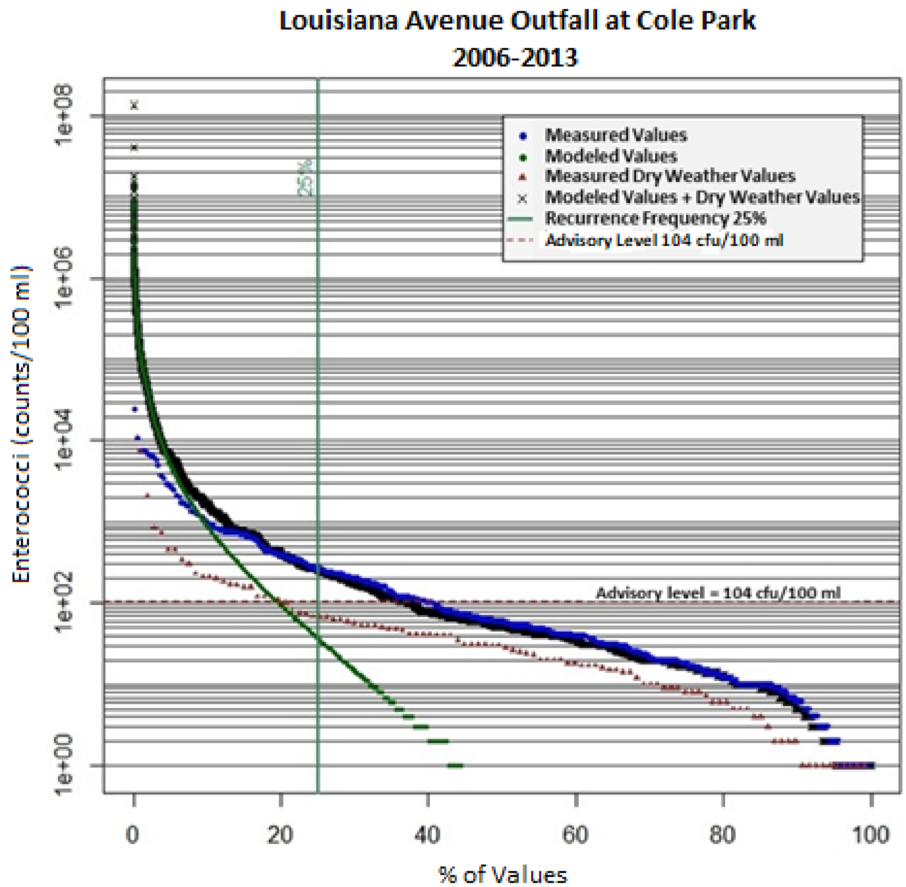


Figure A.7. Recurrence graph showing the combination of modeled bacteria concentrations and measured dry weather bacteria concentrations at Cole Park

A.3.5. Tertiary Calibration Using Recurrence Graph Curves

The results of combing DWL with model results previously described above also provide a visual affirmation that the character (frequency and distribution) of the bacteria loading values forecast by the TMDL model reflect the same response observed in the natural system. Additional confidence in the ability of this TMDL model to provide realistic load reduction requirements to meet the BAV for AUs 2481CB_03 and 2481CB_04 can be gained by examining Figures A.7 and A.8 and by noting the closeness of fit in the area of the graphs where the BAV (dashed red line) intersects the compliance frequency of 25%.

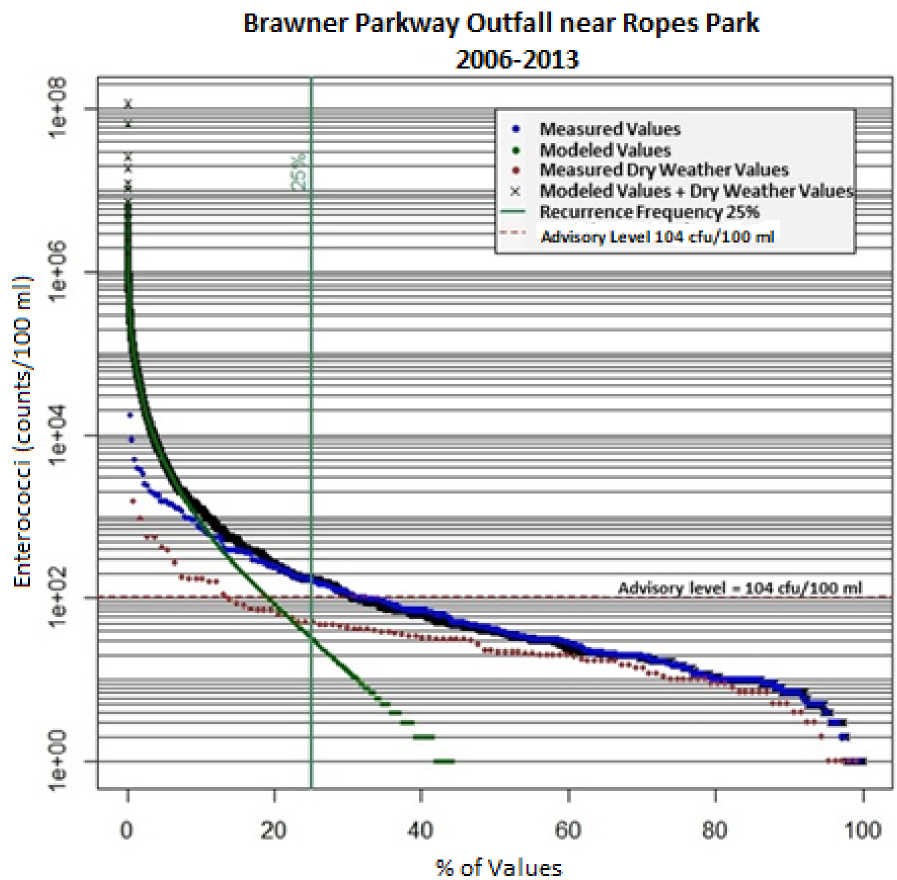


Figure A.8. Recurrence graph showing the combination of modeled bacteria concentrations and measured dry weather bacteria concentrations near Ropes Park

A.4. Development of Bacteria TMDLs Using Numerical Modeling

Computations using the numerical model developed for these TMDLs are necessary to derive a percent reduction goal for the TMDL. The following subsections provide a step-by-step description of how the TMDLs for AUs 2481CB_03 and 2481CB_04 were developed.

A.4.1. Step 1: Estimate Current Bacteria Loadings

The model outputs were first summed over 24-hour periods from the smaller one-hour model time steps to provide total daily loads to the bay in counts per day. The model can also be used to generate instantaneous quality values in terms of cfu/100 mL. These two values are used in conjunction to determine the range of concentrations occurring at sampling locations and also the corresponding loading for any given day. When these data were compiled for the entire time period of interest, the percentage of time that the BAV is exceeded is calculated, and the corresponding loading associated with that exceedance can also be calculated.

There are two components to which the bacteria loading can be attributed (i.e., dry and wet weather loadings). The dry weather component is not well understood. However, it can be represented in the load reduction process using the method described in Section A.4.5. A pollutant load reduction goal can be calculated by comparing the pollutant loads modeled under current conditions with the modeled loads that are commensurate with staying just below the 25% frequency of exceedance of the BAV.

A.4.2. Step 2: Estimate TMDL Loadings

As described above, the TMDL load can be calculated by estimating the watershed loads that correspond to the loading associated with staying just below the exceedance frequency of the BAV (i.e., 25%) over the entire time period of interest.

A.4.3. Step 3: Estimate Load Reductions

After existing loading estimates are computed, load reduction estimates for the subwatersheds associated with each impaired AU are estimated by calculating the difference between existing loading and the allowable load. Existing and compliance loads were determined using modeling results.

A.4.4. Step 4: Calculate an Explicit Margin of Safety

An explicit MOS can be calculated by reducing the estimated TMDL loading value to account for uncertainty in the TMDL analysis. This is done by subtracting the TMDL load, estimated using 95% of the BAV (i.e., 98.8 cfu/100 mL) from the TMDL load estimated using the full 104 cfu/100 mL.

A.4.5. Step 5: Estimate Load Allocation

DWL is a significant contributor to water quality at both Cole Park and Ropes Park. Although the sources of this loading are not well understood, they can be categorized as the non-permitted, nonpoint source components of the TMDLs. As such, DWL represents the LA portion of the TMDL calculation.

DWL to the impaired AUs can be estimated if the following factors are known:

1) Area influenced by the DWL.
2) Volume of water in the area of the DWL.
3) Median concentration of bacteria in that area.
4) Decay rate for the bacteria.

Area Affected by DWL

Data collected by CCS provide bacteria concentrations at discrete water depths and distances from the shore at both Cole Park and Ropes Park. Figure A.9 shows box plots of bacteria concentrations measured at the beaches of Cole Park and Ropes Park during dry weather. As seen from the box plots, DWL affects only the stations at 0.6-meter depth, which are located between 5 and 29 meters from the shoreline at Cole Park, while at Ropes Park, DWL influences water quality in stations at all three seafloor depths, with less influence at the deepest station (located 24 meters from the shoreline). From this information, it can be inferred that the areas influenced by DWL are probably best defined by distance from shoreline rather than by seafloor depth. Therefore, an average distance from shore of 26.5 meters must contain the majority of the flux from DWL.

Using ArcGIS, a polygon was created using an approximation of the shoreline as seen in the 2008-2009 Texas Orthoimagery Project images of the Corpus Christi Quadrangle's southeast quarter at Cole Park and Ropes Park (TNRIS, 2015). The seaward edge of the polygon is the paralleled shoreline offset by 26.5 meters. These polygons represent the areas influenced by DWL and are referred to as the DWL zones (Figure A.10). Note that the maps in Figure A.10 are at different scales.

Volume of the DWL Zone

The average seafloor depth at a distance of 29 meters from shore at Cole Park is 1 meter. This gives an average slope of 0.034483 (meter rise/meter run). At a distance of 26.5 meters, the average seafloor depth is 0.914 meters. Using Equation A.9 with a DWL zone area of 46,883 meters^2 and seafloor depth of 0.914 meter, a volume of 21,426 meters^3 is calculated for Cole Park.

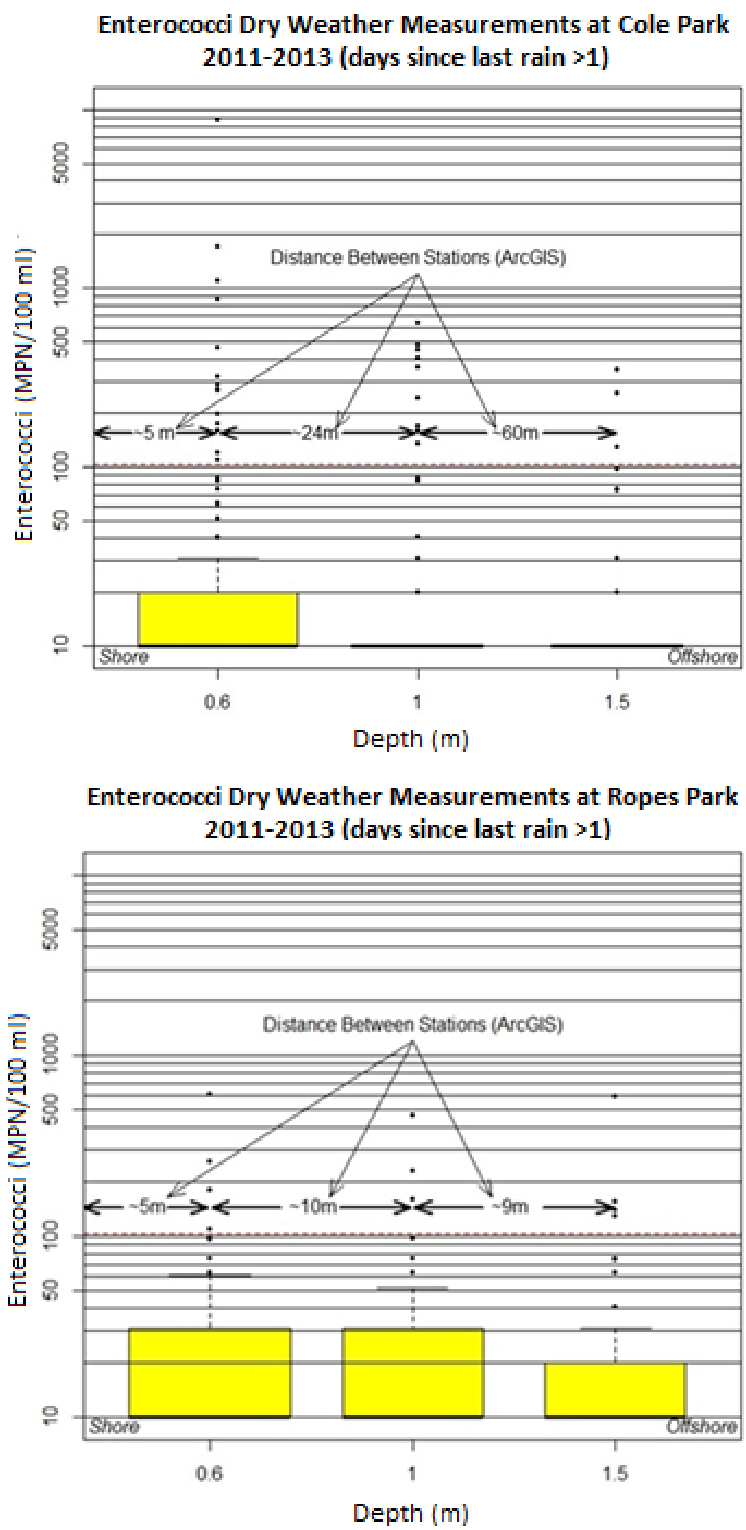


Figure A.9. Box and Whisker Plot of Enterococci concentrations during dry weather by seafloor depth

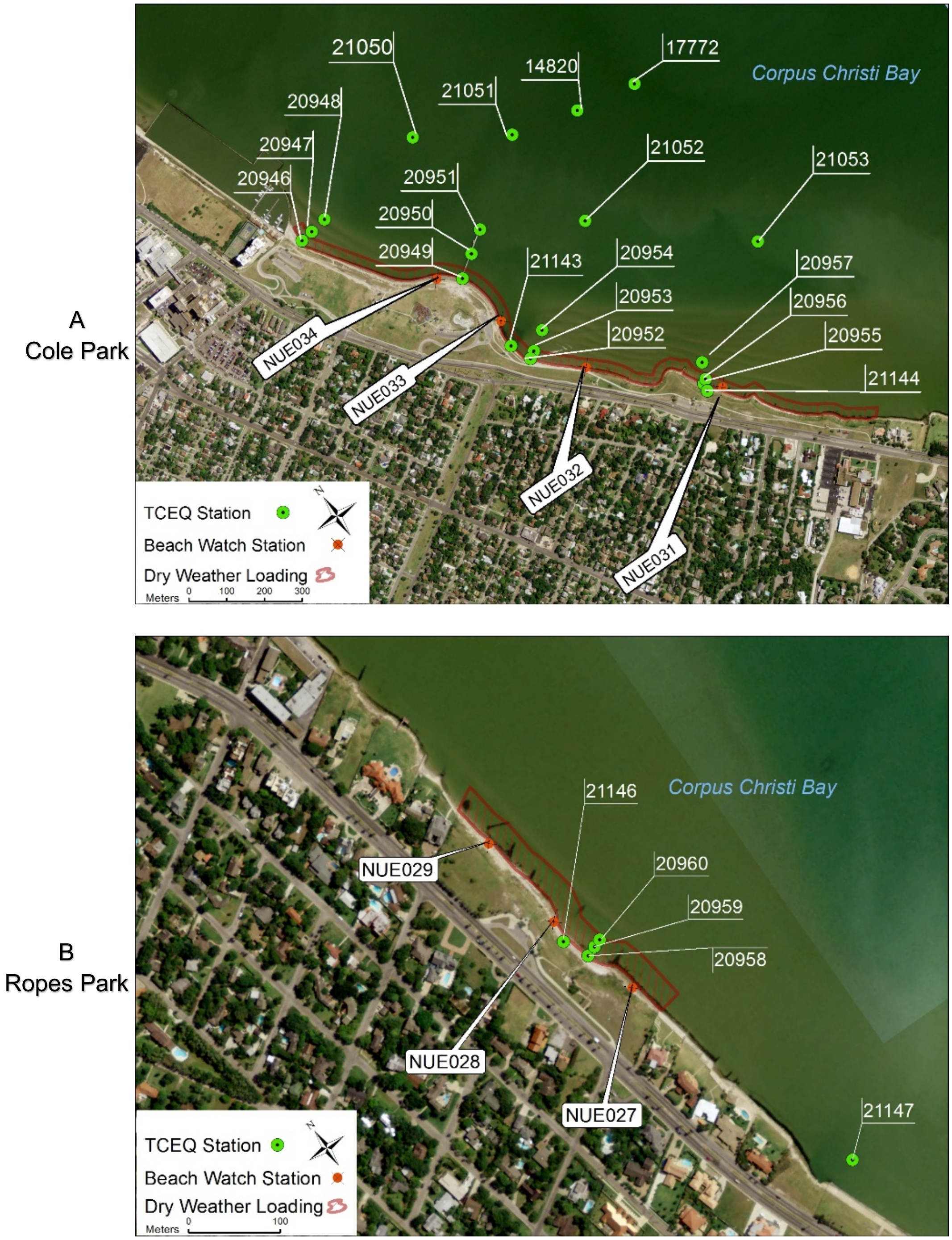


Figure A.10. DWL zones in A) Cole Park and B) Ropes Park (2008-2009 Texas Orthoimagery)

The average seafloor depth at a distance of 24 meters from shore at Ropes Park is 1.5 meters. This gives an average slope of 0.0625 (meter rise/meter run). At a distance of 26.5 meters, the average seafloor depth is 1.66 meters. Using Equation A.9 with a DWL zone area of 8,629 $meters^2$ and seafloor depth of 1.66 meters, a volume of 7,162 $meters^3$ is calculated for Ropes Park.

Equation A.9. Volume of a wedge

$$V = \frac{1}{2} * A * D$$

Where:

V = volume

A = amount of water surface in the DWL zone

D = maximum average depth along the seaward perimeter of the zone

Calculating an Average Decay Rate for Bacteria at Cole Park and Ropes Park

In order to calculate an average decay rate, bacteria measurements collected over consecutive days (or other time-consistent intervals) are required. There were no consecutive time intervals available during dry weather; however, 20 pairs of bacteria concentrations that occurred on consecutive days and were collected at the 0.6-meter seafloor depth interval were selected from the CCS dataset for analysis (Table A.3). A decay rate was calculated for each pair and then averaged for each park. The average decay rate at Cole Park is 2.72 day^{-1} and the average decay rate for Ropes Park is 3.30 day^{-1}. This difference reflects the steeper slope at Ropes Park, meaning a greater volume of water, which allows for more mixing and settling to occur, thus expediting the decrease of bacteria concentrations near this impaired AU (2481CB_04).

Calculating Bacteria Flux from DWL

The median concentrations for dry weather bacteria measurements were extracted from the TGLO water quality monitoring data in a fashion similar to the development of the synthetic SWQM station, previously described, to represent the median (rather than the maximum) concentration of bacteria in the DWL zone waters on the measurement day. This median concentration was then converted to cfu of bacteria present in the DWL zone by multiplying the volume of water in the DWL zone by the median concentration (converted to cfu/$meter^3$). Since bacteria decay over time, the decay rate resulting from the calculations described above can be used to estimate the flux of bacteria required to maintain the median concentration by inversing the decay rate (Equation A.10).

Table A.3. Decay rates calculated from data pairs collected at Cole Park and Ropes Park

Location	Variable ID	Decay Rate (day^{-1})	Event	Co*	Cd**
Cole Park	kbc1.1	4.2	1	650	10
Cole Park	kbc1.2	3.0	1	570	30
Cole Park	kbc1.3	4.6	1	10,000	98
Cole Park	kbc1.4	3.4	1	6,900	230
Cole Park	kbc2.1	6.6	2	7,700	10
Cole Park	kbc2.2	2.6	2	1,840	138
Cole Park	kbc2.3	1.0	2	138	52
Cole Park	kbc2.4	3.2	2	24,196	1,010
Cole Park	kbc2.5	1.3	2	1,010	266
Cole Park	kbc2.6	2.4	2	8,160	776
Cole Park	kbc2.7	1.5	2	776	175
Cole Park	kbc3.1	2.2	3	29,100	3,260
Cole Park	kbc3.2	2.0	3	3,260	431
Cole Park	kbc3.3	0.5	3	3,260	1,990
Cole Park	kbc3.4	2.3	3	1,990	200
Ropes Park	kbr1.1	6.1	1	24,196	52
Ropes Park	kbr1.2	3.9	2	24,196	512
Ropes Park	kbr1.3	2.8	3	512	31
Ropes Park	kbr1.4	0.8	1	24,196	10,500
Ropes Park	kbr1.5	2.9	1	10,500	591

* Co is the initial concentration (MPN/day) used in the decay rate calculation

**Cd is the decayed concentration (MPN/day) over one day at the same station.

Equation A.10. Inverse Decay.

$$Lo = \frac{Ld}{e^{-Kb*dT}}$$

Where:

Lo = original load

Ld = decayed (measured) load

Kb = decay constant

dT = elapse time for the decay to occur (1 day)

This calculation was applied to all dry weather data (2006-2013), as described above, for each park. The mean of these flux values represents the average daily load from the unknown source of DWL bacteria loading to each park's DWL zone.

Load Allocation from DWL

For Cole Park, with a decay rate of 2.72 day^{-1}, the average daily flux of bacteria required to maintain measured DWL concentrations is 2.728674 x 10^{11} cfu/day. This represents the LA from DWL at Cole Park.

At Ropes Park, using a decay rate of 3.30 day^{-1}, the average daily flux of bacteria required to maintain measured DWL concentrations is 1.464951 x 10^{11} cfu/day. This represents the LA from DWL at Ropes Park.

A.4.6. Step 6: Calculate Wasteload Allocation

As previously stated, the pollutant load allocation for permitted (point) sources is defined by the WLA. EPA guidance includes TPDES-permitted stormwater discharges as permitted discharges and they are, therefore, part of the WLA. Having estimated the TMDL load (Step 2), calculated the MOS (Step 4) and estimated the LA (Step 5), the WLA is calculated by subtracting the LA and MOS from the TMDL. For these TMDLs the FG calculation is not included because the FG is zero.