Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria in Poenisch Park

Assessment Unit: 2481CB_06

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Abbreviations

ASCE	American Society of Civil Engineers
AU	assessment unit
BEACH	Beaches Environmental Assessment and Coastal Health
CCNAS	Corpus Christi Naval Air Station
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony forming unit
EC	event concentrations
EMC	event mean concentration
EPA	(United States) Environmental Protection Agency
FDC	flow duration curve
FG	future growth
I&I	inflow and infiltration
LA	load allocation
LDC	load duration curve
mL	milliliter
MOS	margin of safety
MPE	multi-sensor precipitation estimates
MS4	municipal separate storm sewer system
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewage facility
SSO	sanitary sewer overflow
TBW	Texas Beach Watch
TCEQ	Texas Commission on Environmental Quality
TGLO	Texas General Land Office
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TWDB	Texas Water Development Board
U.S.	United States
USCB	U.S. Census Bureau
WLA	wasteload allocation
WLA_{SW}	wasteload allocation from regulated stormwater
WLA_{WWTF}	wasteload allocation from wastewater treatment facilities
WQM	water quality monitoring
WWTF	wastewater treatment facility

Section 1. Introduction

1.1. Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a water body included on a state's 303(d) list of impaired waters. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet 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 (water bodies) 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.

In accordance with the federal Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act), the Texas General Land Office (TGLO) issues beach advisories as part of the Texas Beach Watch (TBW) Program when bacteria concentrations exceed 104 cfu (colony forming unit) per100 mL for the indicator bacteria Enterococci. The target of 104 cfu per 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 in the TBW in accordance with the BEACH Act. TCEQ uses beach advisories issued by TGLO to identify impairments as part of the *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 assesses TGLO information as part of the Texas Integrated Report to protect human health by identifying beaches with persistent advisories. Beginning in 2010, TCEQ began assessing recreational beaches along Corpus Christi Bay (Segment 2481CB) based on GLO Beach Watch data, resulting in the listing of Cole Park and Ropes Park assessment units (AUs) 2481CB_03 and 2481CB_04, respectively in the 2010 303(d) List of Impaired Waters as impaired for bacteria. In the 2014 303(d) List of Impaired Waters, Poenisch Park (AU 2481CB_06) was added to the list of Corpus Christi Bay (Recreational Beaches) impaired for bacteria.

The bacteria impairment of Poenisch Park has been identified in each subsequent edition of the Texas Integrated Report, including the most recent U.S. EPA-approved

2022 Texas Integrated Report. AU 2481CB_06 is listed in Subcategory 5a in the 2022 Texas Integrated Report, making it a high priority for TMDL development.

This document will consider one bacteria impairment in one AU of Corpus Christi Bay (Recreational Beaches). The impaired AU and its identifying number are:

- Poenisch Park – 2481CB_06

Previous iterations of the Integrated Report referred to this AU as Poenisch Park, and it will be referred to as Poenisch Park here and throughout the rest of this document.

1.2. Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, TCEQ established the *Texas Surface Water Quality Standards* (2018a). The Standards describe the limits for indicators that are monitored to assess the quality of available water for specific uses. TCEQ monitors and assesses water bodies based on these Standards and publishes the Texas Integrated Report list biennially.

The Standards are rules that do all of the following:

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

Standards are established to protect uses assigned to water bodies. The primary uses assigned to water bodies are:

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

Fecal indicator bacteria are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal indicator bacteria are bacteria that are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from fecal waste may be reaching water bodies because of such sources as inadequately treated sewage; improperly managed animal waste from livestock, pets, aquatic birds, wildlife; and failing septic systems (TCEQ, 2018a). The fecal indicator bacteria used for saltwater in Texas is Enterococci, a species of fecal coliform bacteria.

On Feb. 7, 2018, TCEQ adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2022b) and on May 19, 2020, EPA approved the categorical levels of recreational use and their associated criteria. Recreational use consists of several categories:

- **Primary contact recreation 1** – Activities that are presumed to involve a significant risk of ingestion of water (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing, and the following whitewater activities: kayaking, canoeing, and rafting). It has a geometric mean criterion for Enterococci of 35 cfu per 100 milliliters (mL) and an additional single sample criterion of 130 cfu per 100 mL.

- **Secondary contact recreation 1** – Activities that commonly occur but have limited body contact incidental to shoreline activity (e.g., fishing, canoeing, kayaking, rafting, and motor boating). These activities are presumed to pose a less significant risk of water ingestion than primary contact recreation 1 for saltwater streams. The geometric mean criterion for Enterococci is 175 cfu per 100 mL.

- **Noncontact recreation** – Activities that do not involve a significant risk of water ingestion, such as those with limited body contact incidental to shoreline activity, including birding, hiking, and biking. Noncontact recreation use may also be assigned where primary and secondary contact recreation activities should not occur because of unsafe conditions, such as ship and barge traffic. The geometric mean criterion for Enterococci is 350 cfu per 100 mL.

Poenisch Park is a recreational saltwater beach and has a primary contact recreation 1 use. However, recreational beaches are assessed using the total number of days a beach was under advisory (when Enterococci concentrations exceed 104 cfu/100 mL) and are listed as not supporting primary contact recreation 1 use when >25% of sampled days are under advisory.

1.3. Report Purpose and Organization

The Poenisch Park TMDL project was initiated through a contract between TCEQ and Texas A&M University – Corpus Christi. The tasks of this project were to (1) develop, have approved, and adhere to a quality assurance project plan; (2) develop a technical support document for the impaired watershed; and (3) assist TCEQ with public participation. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the impaired assessment unit. This report contains:

- Information on historical data.
- Watershed properties and characteristics.
- Summary of historical bacteria data that confirm the Texas 303(d) listings of impairment due to concentrations of Enterococcus.
- Development of simplified step model.
- Application of the simplified step model for developing a load duration curve (LDC).

Section 2. Historical Data Review and Watershed Properties

2.1. Description of Study Area

The Poenisch Park watershed, which contributes flow to the stormwater outfall in the impaired AU, is part of the City of Corpus Christi's stormwater drainage system. Corpus Christi is a large city of over 300,000 inhabitants (U.S. Census Bureau, 2010) in South Texas along the shoreline of the Gulf of Mexico. The city of Corpus Christi is part of Nueces County. The city surrounds the southern end of Corpus Christi Bay and extends to North Padre Island and Mustang Island. These islands are on the eastern side of Corpus Christi Bay and separate the Corpus Christi Bay from the Gulf of Mexico. On the western side of Corpus Christi Bay, there are a series of recreational parks within the City of Corpus Christi which are also locations of stormwater runoff outfalls. Such is the case for the impaired AU, as illustrated in Figures 1 and 2. The Poenisch Park watershed is identified in the City of Corpus Christi Storm Water Master Plan (Green & West, 2009) and the City of Corpus Christi Infrastructure Mapbook (City of Corpus Christi, 2006). The Poenisch Park watershed is 64.5 acres and is the largest in a series of small watersheds bordering the southern shoreline of Corpus Christi Bay (Figure 1).

December 17, 2019

Sources: USGS and City of Corpus Christi.

Figure 1. Map of the project watershed

The 2022 Texas Integrated Report (TCEQ, 2022) has the following water body and AU descriptions:

- AU 2481CB_06 – Poenisch Park (Beach ID TX682648)

2.2. Review of Routine Monitoring Data

There are four ambient water quality monitoring (WQM) stations located near the impaired AU (Figure 2. Detailed view of the study area, Poenisch Park, and the water quality monitoring stations). WQM data have been collected primarily by two entities: the TGLO under the TBW program and the Center for Coastal Studies at Texas A&M University – Corpus Christi under contract to TCEQ. The impairment of the AU, as defined in the 2022 Texas Integrated Report and 303(d) List, is based off data from TGLO station NUE026 between Dec. 1, 2013, and Nov. 30, 2020. However, recreational beaches are not assessed using a geometric mean as is common for non-beach water bodies, and a geometric mean is therefore not provided in the 2022 IR. Based on sampling data provided by TGLO for station NUE026 between Dec. 1, 2013 and Nov. 30, 2020, a geometric mean of 29.3 cfu/100 mL was calculated. The 2022 Texas Integrated Report summary for the Poenisch Park watershed is provided in Table 1.

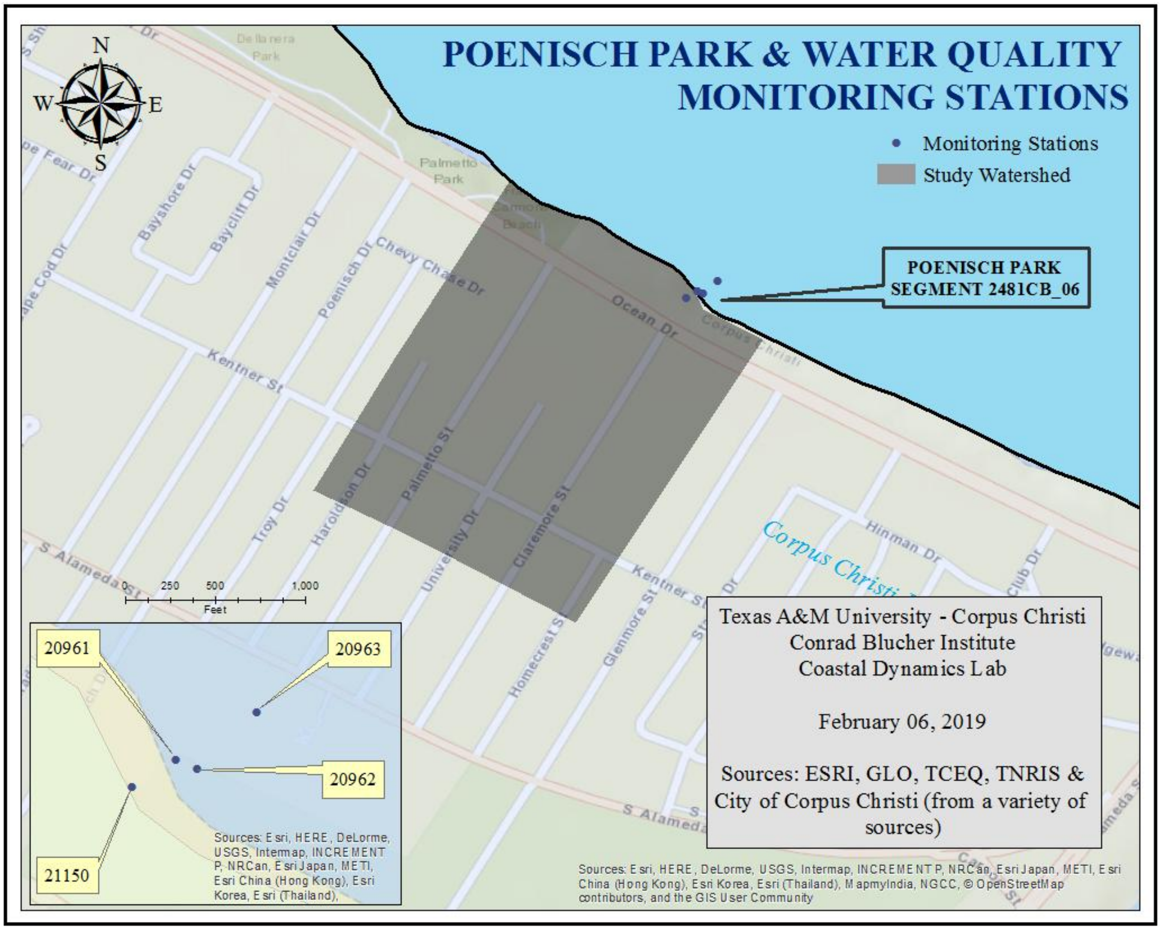

Figure 2. Detailed view of the study area, Poenisch Park, and the water quality monitoring stations

2.2.1. Analysis of Bacteria Data

Table 1. 2022 Texas Integrated Report summary for the Poenisch Park watershed

Watershed	AU	Parameter	TGLO Station	No. of Samples	Data Date Range	Geometric Mean* (cfu/100 mL)
Poenisch Park	2481CB_06	Enterococcus	NUE026	330	2013-2020	N/A[a]

[a] No geomean for the impaired AU was calculated in the 2022 IR due to the methodology used to list recreational beaches as impaired, as discussed above.

2.3. Climate and Hydrology

2.3.1 Temperature

Thirty-year normal monthly average temperatures, seen in Figure 3, were calculated based on the observations at Naval Air Station-Corpus Christi (NAS-CC – ID 12926) from 1991 through 2020 (Arguez et al. 2010).

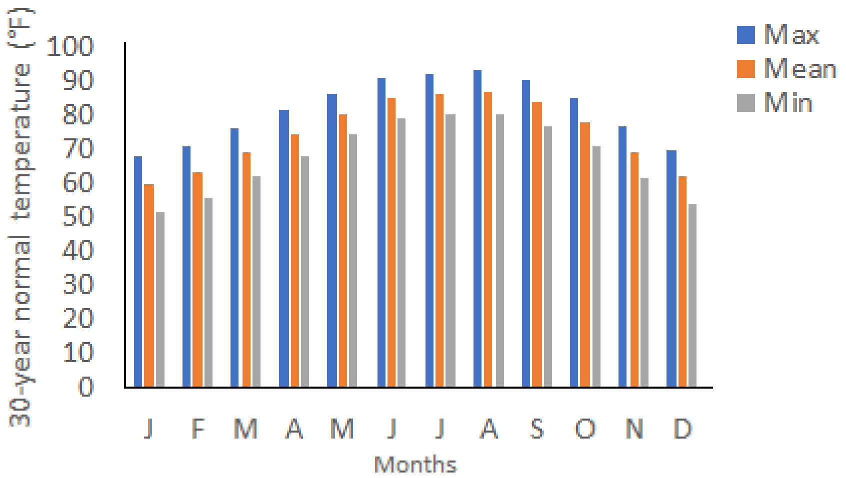

Figure 3. Thirty-year normal maximum, minimum, and mean monthly temperature (°F) at NAS-CC – ID 12926 between 1991 and 2020 (Arguez et al., 2010)

2.3.2 Precipitation

Precipitation is a key driver of *Enterococcus* concentration in the Poenisch Park watershed. There are two rain gauges located near Poenisch Park that are part of the National Weather Service meteorological network. One, located at the Corpus Christi Naval Air Station (CCNAS), Texas Automated Surface Observing Systems (ASOS) Station KNGP CCNAS, is about four miles southeast of Poenisch Park. The other station is located at the Corpus Christi International Airport (Texas ASOS Station KCRP), about 12 miles north northwest of the study area. As precipitation can be highly localized, precipitation information for the study watershed was extracted from the National Weather Service Multi-Sensor Precipitation Estimates (MPE) (National Weather Service, 2018) database. These weather radar-derived time series cover areas of about 4 km by

4 km. The MPE area covering the Poenisch Park watershed is illustrated in Figure 4. The MPE area to the east covers the CCNAS rain gauge.

A comparison of MPE precipitation and observed precipitation at the CCNAS gauge between 2004 and 2018 and for select large rain events (Figure 5) indicated that the timing of the precipitation generally matches the difference in the precipitation intensities between MPE and observed measurements. Further comparisons between the MPE estimates for the CCNAS area and the Poenisch Park watershed (Figure 5) indicate that timing and intensity of precipitation is very similar for the two neighboring MPE cells. Overall, the comparison between the CCNAS rain gauge and the corresponding MPE estimates, combined with a good match between the MPE estimates for the Poenisch Park and CCNAS MPE areas, gives confidence in the use of MPE estimates as the precipitation input for the study models.

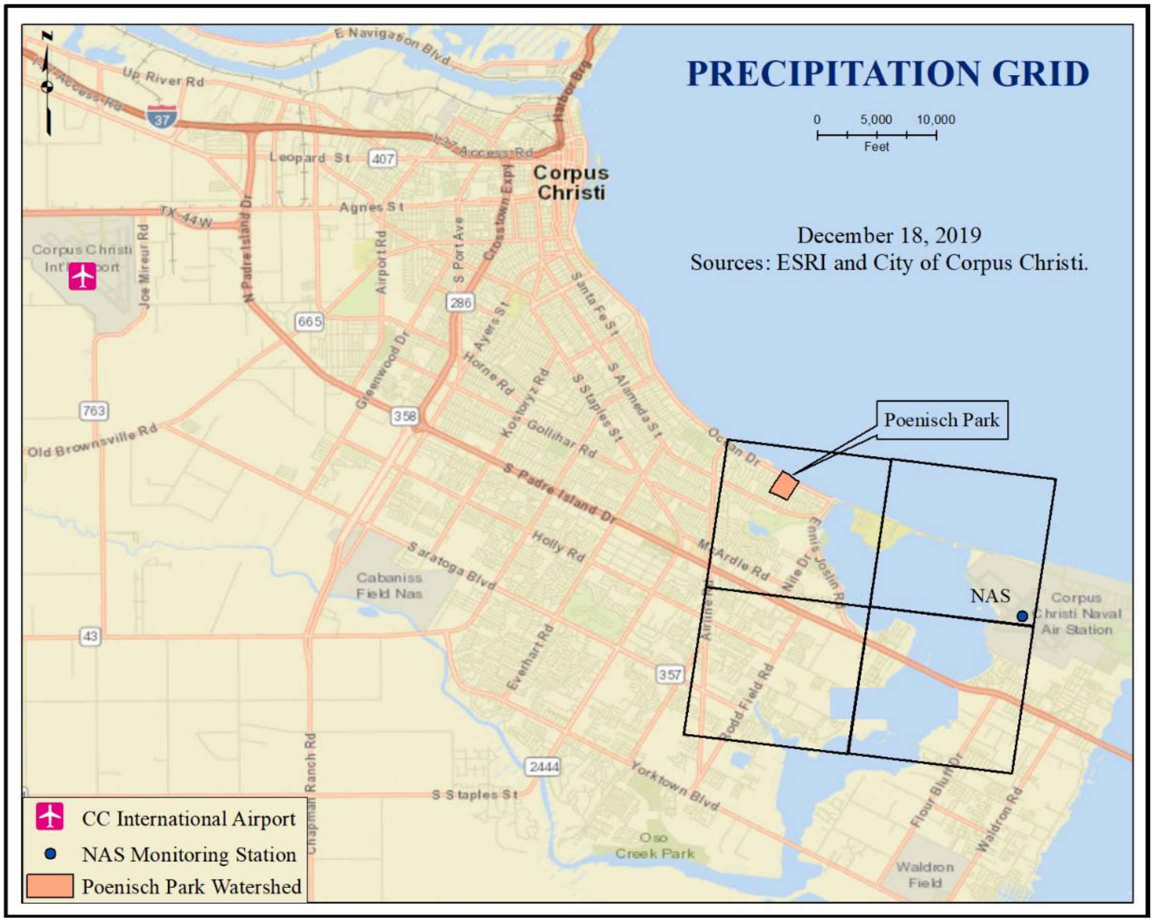

Figure 4. Precipitation grid showing areas over which the MPEs were computed, including the Poenisch Park watershed (top left square) and the CCNAS (top right square)

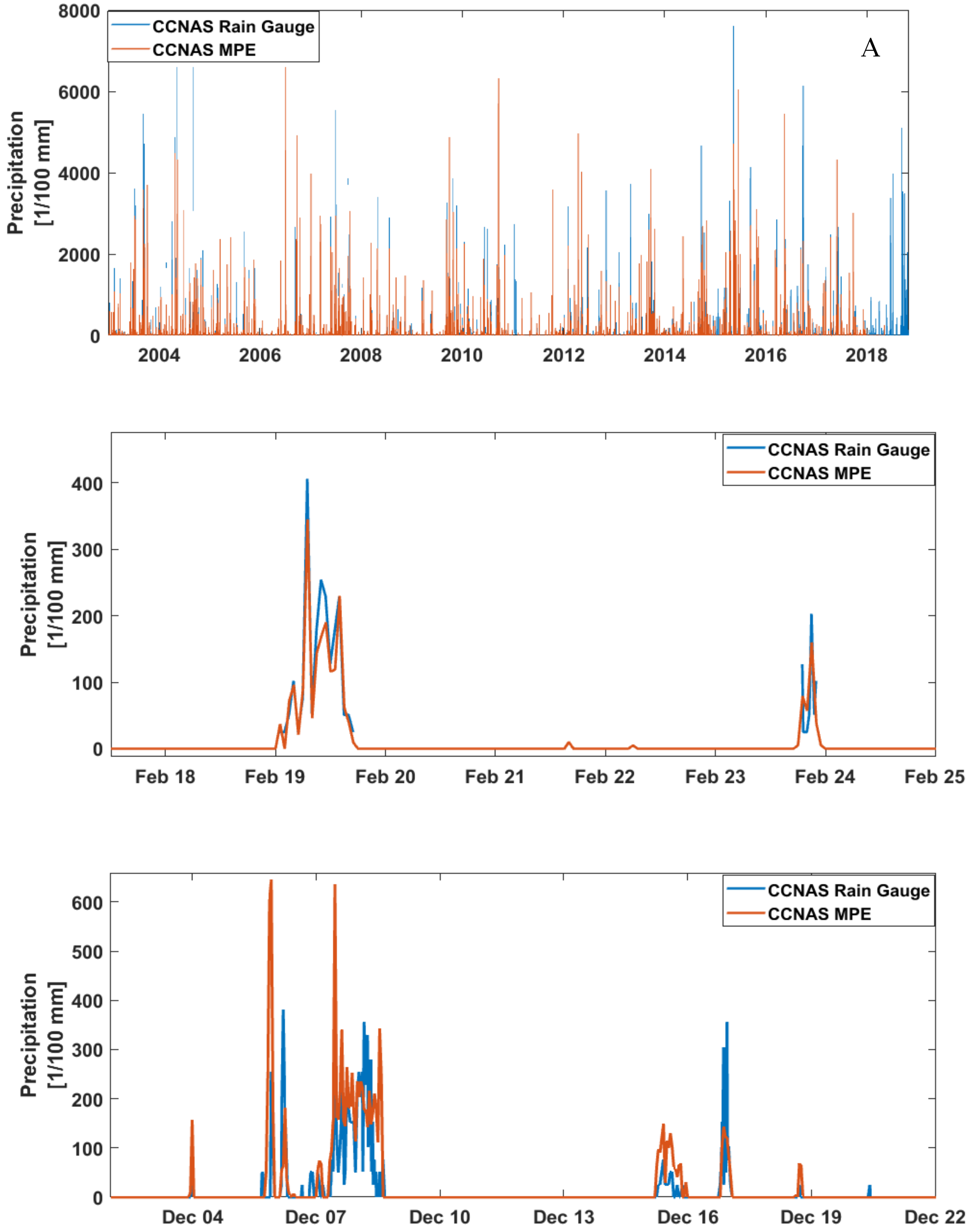

Figure 5. Comparisons of precipitation measurements at the CCNAS Rain Gauge with the co-located MPE estimates between 2004 and 2018 (A) and select large rain events during February 2010 (B) and December 2017(C)

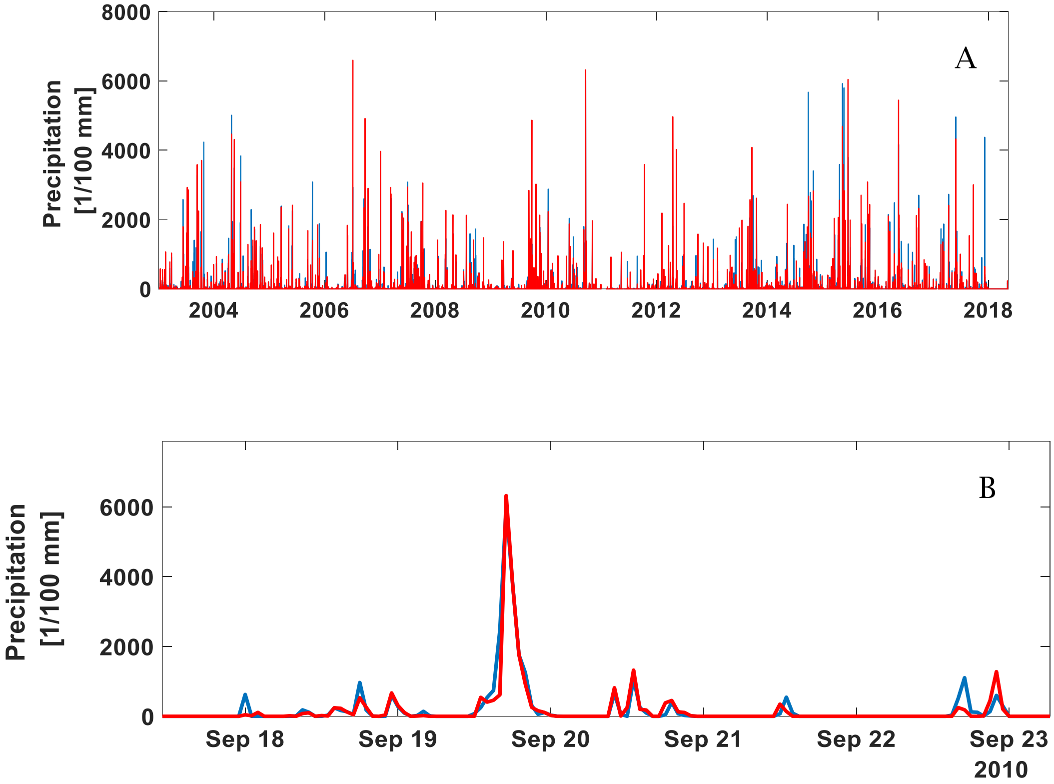

Figure 6. Comparisons of MPE at the CCNAS rain gauge and MPE at Poenisch Park between 2004 and 2018 (A) and during a large rain event September 2010 (B)

Average annual precipitation for the Poenisch Park watershed was 29.81 inches for the period 2003-2018. Annual precipitation ranged from 6.37 inches in 2011 to 48.67 inches in 2015 for the Poenisch Park watershed (Table 2).

Table 2. MPE annual totals for the Poenisch Park watershed

Year	Poenisch Park (MPE, inches)
2003	32.07
2004	38.74
2005	20.63
2006	21.83
2007	32.71
2008	20.71
2009	16.84
2010	32.89
2011	6.37
2012	17.25
2013	28.60
2014	39.53
2015	48.67
2016	36.55
2017	37.20
2018	46.37

2.3.3 Wind Direction

Wind conditions recorded at the CCNAS were for this analysis to determine dominant wind direction and compare wind conditions with water quality at the Poenisch Park watershed. Wind conditions could play a direct or indirect role in water quality. Wind generated waves in Corpus Christi Bay drive wave runup on the beach, leading, at times, to mixing of bay waters and stormwater runoff within the stormwater outlet. Wind and waves can also resuspend sediments, and potentially bacteria.

Wind analysis for the Poenisch Park watershed was based on wind measurements at NAS-CC – ID 12926 from Jan. 1, 2003, through Dec. 31, 2017. Wind speeds above 100 mph were removed (<0.02%) prior to the analysis to ensure accuracy. Of the remaining 15 years of hourly measurements, less than 1% of the data was removed from the analysis.

Southeasterly winds are dominant in the Poenisch Park watershed (Figure 7). The watershed is also influenced by less frequent northerly winds, associated with the passage of cold fronts during the period of October through April. Both wind directions generate slightly onshore but mostly longshore currents. Without other forces, this drives water along the coastline in the northwesterly direction during the usual southeasterly winds and in a southeasterly direction during frontal passages.

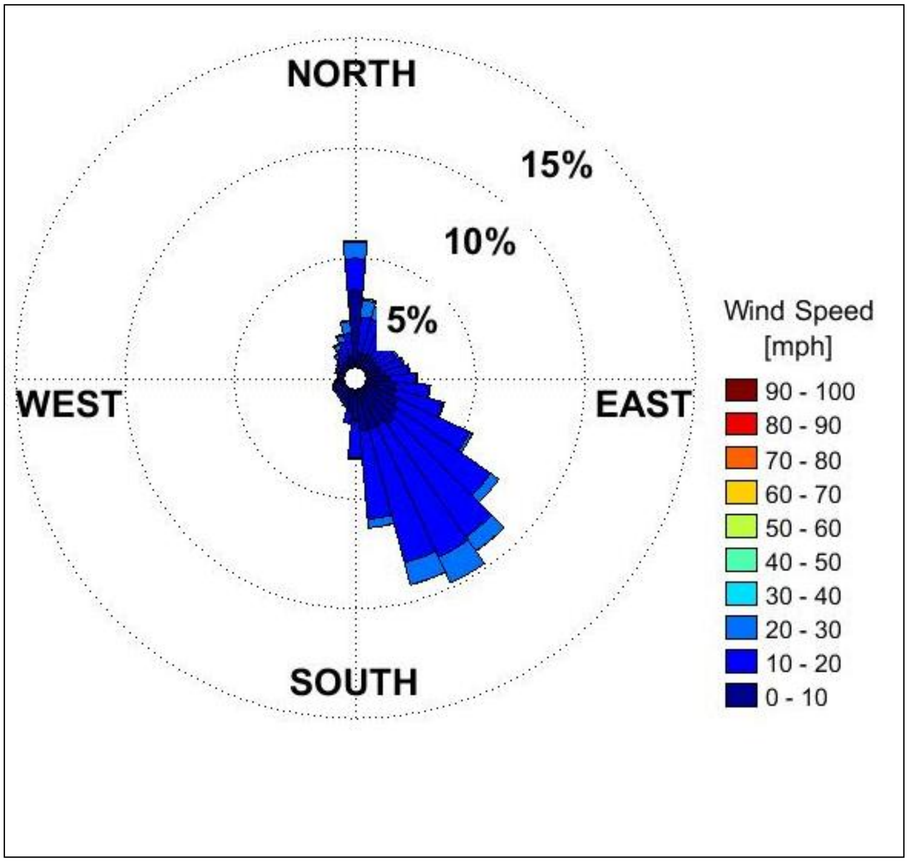

Figure 7. Dominant wind direction for the Poenisch Park Watershed, NAS-CC – ID 12926 (2003-2017)

2.3.4 Hydrogeomorphology

Strong winds also generate waves in Corpus Christi Bay, leading to sediment resuspension and transport along the beach front of Poenisch Park (Williams, 2002). Sediment resuspension will facilitate the transport of organisms and materials stored in sediments to the water column. Sediment transport leads to the formation and movement of a berm along the impaired AU, between Corpus Christi Bay and the distal inland portion of Poenisch Park, parallel to the shoreline. The berm moves depending on the season, wind direction, and water level of the bay. At the Poenisch Park outfall, the berm is breached during strong precipitation events (Figure 8a). During lighter rain events the berm, keeping its integrity, causes stormwater runoff to pool, slowing the rate of bacteria transport to the impaired AU through seepage of the berm materials (Figure 8b).

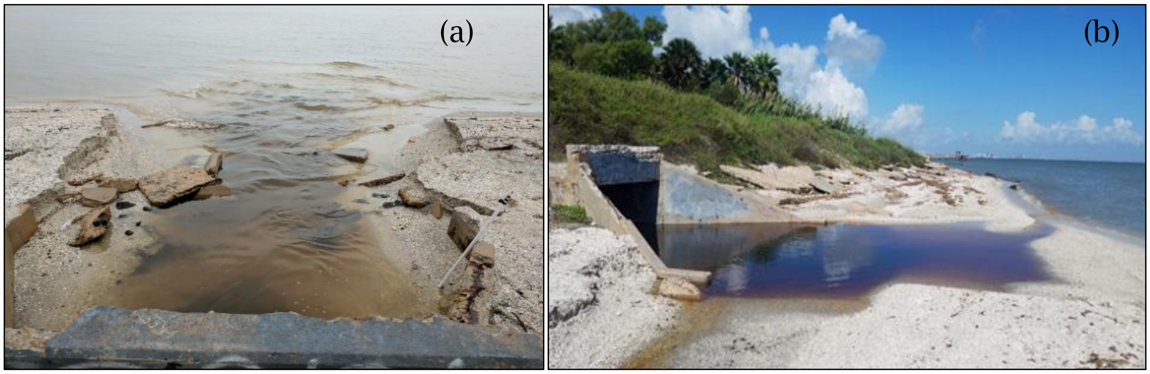

Figure 8. Morphologies along Poenisch Park beach, dependent on wind and precipitation patterns. (a) June 19, 2018, the berm is breached, (b) Oct. 2, 2018, the stormwater is pooled with only light flow to the bay

2.4. Population and Population Projections

Population estimates for the Poenisch Park watershed were developed by intersecting block-level census data with the watershed boundaries and determining the proportion of the watershed within each census block. This proportion was multiplied by the census block population to determine the estimated 2020 census population for the watershed. This analysis found an estimated population of 329 people within the Poenisch Park watershed.

Population projections in Table 3 were estimated based on population projections for the City of Corpus Christi using data from the Texas Water Development Board (TWDB) 2021 Regional Water Plan Population and Water Demand Projection data (2019). The rate of change between each decade between 2020 and 2070 was calculated for the City of Corpus Christi. The rate of change was then multiplied by, and then added to, the 2020 population estimate for the Poenisch Park watershed.

Table 3. Population estimates and projections

AU	2020 U.S. Census	2030 Population Projection	2070 Population Projection	Projected Increase (2020-2070)	Percentage Increase (2020-2070)
2481CB_06	329	356	392	63	19.14%

2.5. Land Cover

Land use and land cover for the watershed was obtained from the 2021 National Land Cover Database (NLCD; Dewitz, 2023) and is displayed in Figure 9 and Table 4. The following categories and definitions represent land use/land cover from NLCD:

- **Open Water** – Areas of open water, generally with less than 25% cover of vegetation or soil.

- **Developed, Open Space** – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

- **Developed, Low Intensity** – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.

- **Developed, Medium Intensity** – Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of total cover. These areas most commonly include single-family housing units.

- **Developed, High Intensity** – Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80% to 100% of total cover.

- **Barren Land (Rock/Sand/Clay)** – Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

- **Deciduous Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

- **Evergreen Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. More than 75% of the species maintain their leaves all year. Canopy is never without green foliage.

- **Mixed Forest** – Areas dominated by trees generally greater than five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% total tree cover.

- **Shrub/Scrub** – Areas dominated by shrubs; less than five meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

- **Grasslands/Herbaceous** – Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

- **Pasture/Hay** – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.

- **Cultivated Crops** – Areas used to produce annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class includes all land being actively tilled.

- **Woody Wetlands** – Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

- **Emergent Herbaceous Wetlands** – Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil substrate is periodically saturated with or covered with water.

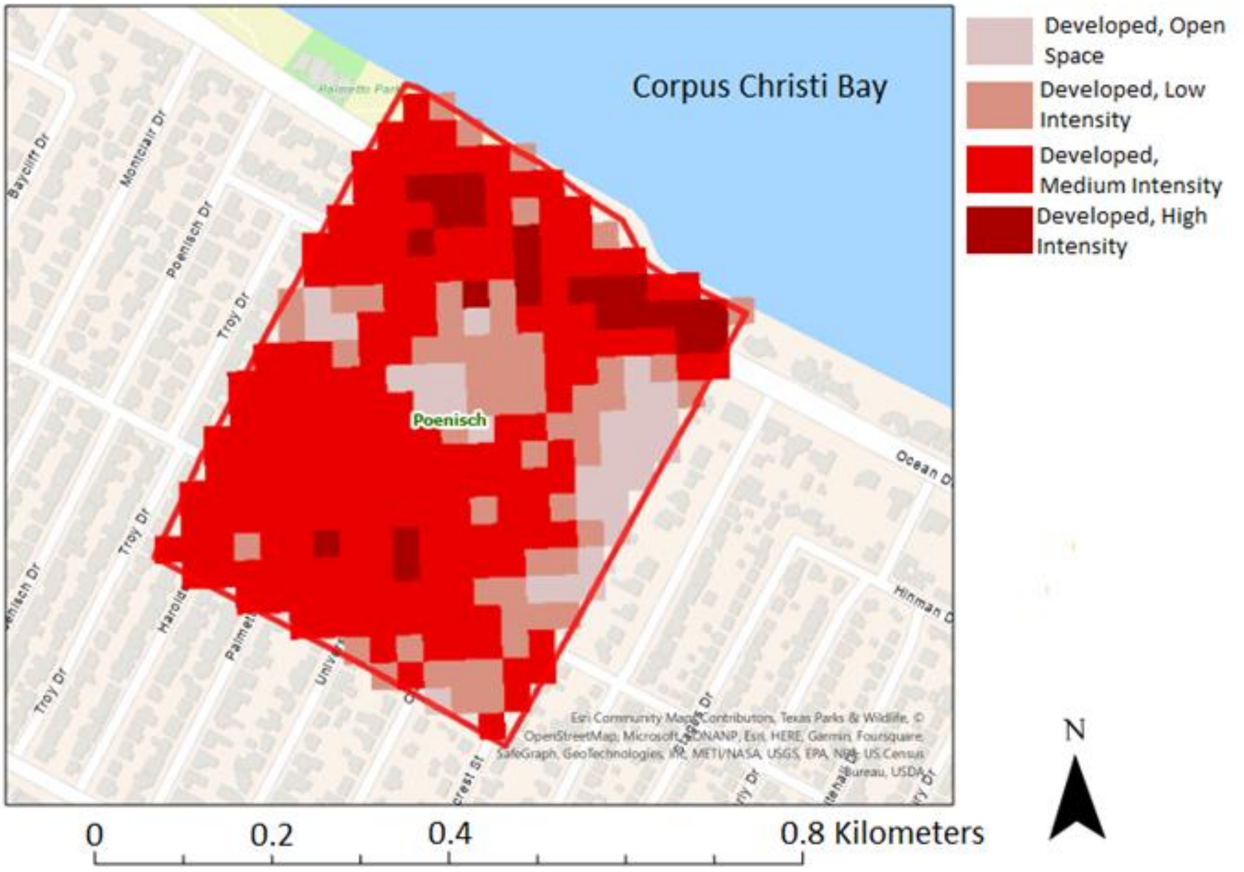

Figure 9. 2021 NLCD land cover classifications within the Poenisch Park watershed

Table 4. 2021 NLCD land cover classifications as a percentage of the Poenisch Park watershed

Land Cover Classification	Percentage of Watershed
Developed, Open Space	10.17%
Developed, Low Intensity	18.98%
Developed, Medium Intensity	63.05%
Developed, High Intensity	7.80%

2.6. Soils

Soils within the Poenisch Park watershed are characterized by hydrologic groups that describe infiltration and runoff potential. These data are provided by the United States Department of Agriculture Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO) (2015). The SSURGO data assigns different soils to one of seven possible runoff potential classifications or hydrologic groups. These classifications are based on the estimated rate of water infiltration when soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The four main groups are A, B, C, and D, with three dual classes (A/D, B/D, C/D). The SSURGO database defines the classifications below.

- Group A – Soils having high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well-drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

- Group B – Soils having a moderate infiltration rate when thoroughly wet. These consist of moderately deep or deep, moderately well-drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

- Group C – Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

- Group D – Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

- Soils with dual hydrologic groupings indicate that drained areas are assigned the first letter, and the second letter is assigned to undrained areas. Only soils that are in group D in their natural condition are assigned to dual classes.

The predominant soil type for Nueces County is the Victoria Series, a Group A soil. 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 can absorb large quantities of water (NRCS, 2005). As seen in Figure 10, the Poenisch Park watershed is 100% Victoria Clay (NRCS, 2020).

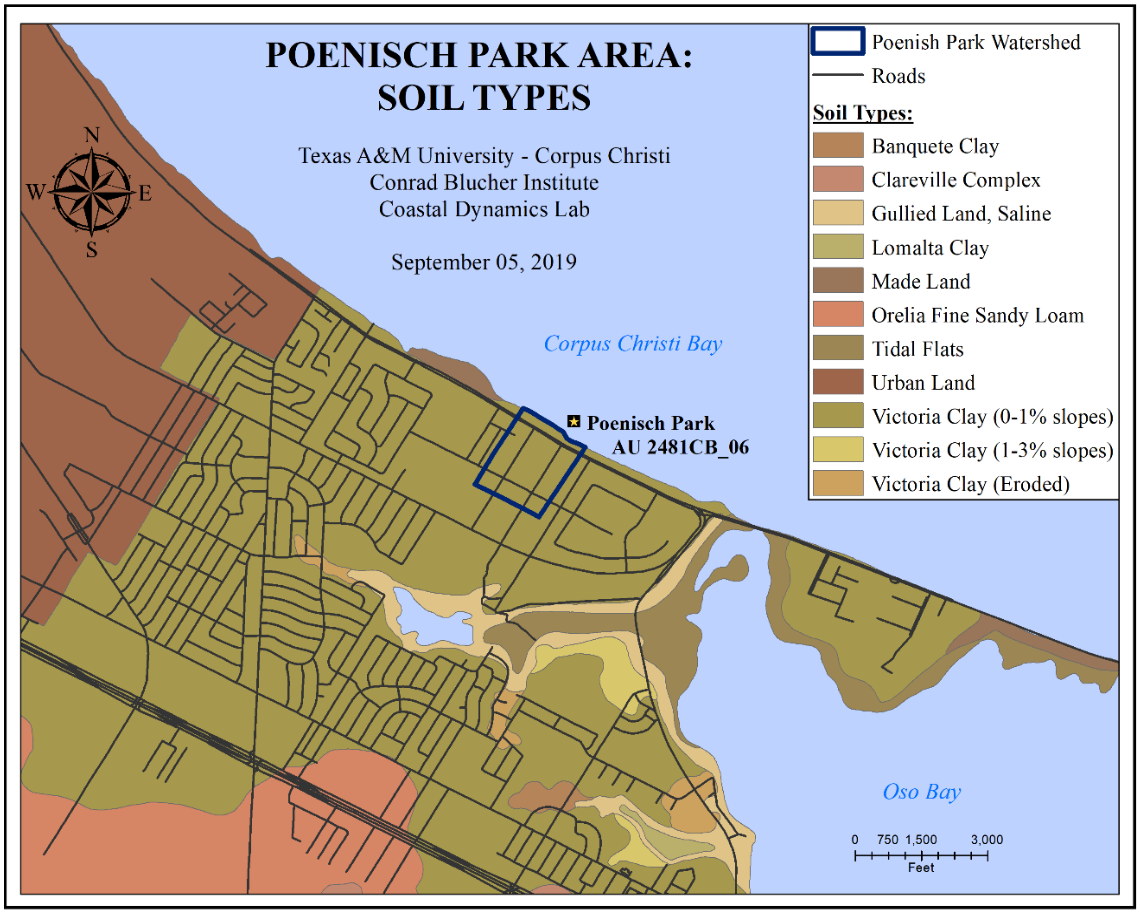

Figure 10. Soil types for the Poenisch Park watershed and surrounding area

2.7. Potential Sources of Fecal Indicator Bacteria

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 controlled by permit under the Texas Pollutant Discharge Elimination System (TPDES) program. Wastewater treatment facilities (WWTFs) and stormwater discharges from industrial sites, regulated construction activities, and the separate storm sewer systems 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.

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

2.7.1. Regulated Sources

Regulated sources are controlled by permit under the TPDES program. Regulated sources can include WWTF outfalls, sanitary sewer overflows (SSOs), stormwater discharges from industrial and regulated construction sites, municipal separate storm sewer systems (MS4s), and other miscellaneous sources.

2.7.1.1. Domestic and Industrial Wastewater Treatment Facilities

The Poenisch Park watershed is serviced by a municipal sanitary sewer system. 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 AU. 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 watershed.

2.7.1.2 TCEQ/TPDES General Wastewater Permits

Certain types of activities must be covered by one of several TCEQ/TPDES wastewater general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production
- TXG340000 – petroleum bulk stations and terminals
- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations (irrigation only)

Discharges related to the following general permit authorizations are not expected to affect the bacteria loading in the TMDL watershed and were excluded from this investigation:

- TXG640000 – conventional water treatment plants
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)

- WQG100000 – wastewater evaporation

As of December 2023, there were no active general wastewater permit authorizations in the Poenisch Park watershed.

2.7.1.3. TPDES-Regulated Stormwater

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

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

TPDES MS4 Phase I and II rules require municipalities and certain other entities in urbanized areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 United States Census, while the Phase II General Permit regulates other MS4s within a United States Census Bureau (USCB) defined urbanized area.

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 the regulated entity will implement, consistent with permit requirements, to minimize the discharge of pollutants. MS4 permits require that SWMPs specify the best management practices (BMPs) to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving water bodies. Phase II MS4 MCMs include all of the following:

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

Phase I MS4 individual permits have their own set of MCMs that are similar to the Phase II MCMs, but Phase I permits have additional requirements to perform water quality monitoring and implement a floatables program. The Phase I MCMs include all of these activities:

- MS4 maintenance activities.
- Post-construction stormwater control measures.
- Detection and elimination of illicit discharges.
- Pollution prevention and good housekeeping for municipal operations.
- Limiting pollutants in industrial and high-risk stormwater runoff.
- Limiting pollutants in stormwater runoff from construction sites.
- Public education, outreach, involvement, and participation.
- Monitoring, evaluating, and reporting.

Discharges of stormwater from a Phase II MS4 area, regulated industrial facility, construction area, or other facility involved in certain activities must be authorized under one of the following general permits:

- TXR040000 – Phase II MS4 General Permit for MS4s located in urbanized areas (discussed above)
- TXR050000 – Multi-Sector General Permit for industrial facilities
- TXR150000 – Construction General Permit for construction activities disturbing more than one acre or are part of a common plan of development disturbing more than one acre

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 Poenisch Park 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.

Poenisch Park and adjacent watershed land contains one stormwater outfall which discharges directly to Corpus Christi Bay. The entire watershed is covered under the City of Corpus Christi Phase I MS4 permit and is described in Table 5.

Table 5. TPDES MS4 permits

Regulated Entity	Authorization Type	TPDES Permit No./ [a]NPDES ID	Location
City of Corpus Christi, Del Mar College East Campus, Port of Corpus Christi Authority of Nueces County, and Texas A&M University-Corpus Christi	Phase I	WQ0004200000/ TXS000601	Area within the boundary of the City of Corpus Christi served by MS4
Texas Department of Transportation	Phase I/ Phase II Combined	WQ0005011000/ TXS002101	TXDOT[b] rights-of-way located within Phase I MS4s and Phase II UAs[c]

[a] NPDES: National Pollutant Discharge Elimination System
[b] TXDOT: Texas Department of Transportation
[c] UA: urbanized area

2.7.1.4. 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 overflows under conditions of high flow in the WWTF system. Blockages in the line may worsen the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition. There were no reported SSOs within the Poenisch Park watershed between January 2019 and April 2024.

2.7.1.5. Dry Weather Discharges/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 TXR040000 for Phase II MS4s as “Any discharge to a municipal separate storm sewer system 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 included 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 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 sanitary sewer and storm sewer systems.

Indirect Illicit Discharges:

- An old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line.

- A failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

2.7.2. Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters the impaired water body through distributed, nonspecific locations, which may include urban runoff not covered by a permit. Potential sources, detailed below, include wildlife, urban runoff not covered by a permit, and domestic pets.

2.7.2.1. 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 by watershed the potential for bacteria contributions from wildlife. Typical of coastal watersheds, there is a significant population of avian species that frequent the Poenisch Park watershed and nearby riparian corridors (e.g., Oso Creek). However, there are insufficient data available to estimate populations and spatial distribution of wildlife and avian species by watershed. Consequently, it is difficult to assess the magnitude of bacteria contributions from wildlife as a general category.

2.7.2.2. Unregulated Agricultural Activities and Domesticated Animals

Several agricultural activities that do not require permits can be potential sources of fecal bacteria loading. However, there are no agricultural activities within the small Poenisch Park watershed, which is 100% developed land use (Table 4).

Fecal bacteria from dogs and cats can be transported by runoff from urban and suburban areas and is a potential source of bacteria loading. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association 2017–2018 U.S. Pet Statistics (AVMA, 2018). Due to the Poenisch Park watershed being at a scale smaller than USCB census blocks, Google Map Pro was used to identify the number of households in the watershed, which was determined to be 151 households. The number of cats and dogs per household was then used to compute the number of dogs and cats for the Poenisch Park watershed, shown in Table 6.

Table 6. Estimated number of households and dog and cat populations

AU	Estimated Households	Estimated Dog Population	Estimated Cat Population
2481CB_06	151	93	69

2.7.2.3. On-Site Sewage Facilities

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

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters if the systems are not properly operating. Properly designed and operated, however, OSSFs contribute virtually no fecal bacteria to surface waters. For example, Weiskel et al. (1996) reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system. Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The Poenisch Park watershed is located within the Region 4 area, which has a reported failure rate of about 12%, providing insights into expected failure rates for the area.

Due to the watershed being entirely within city boundaries and within the City of Corpus Christi, there are no reported OSSFs within the TMDL watershed, and a municipal sanitary sewer system has been available since the 1940s.

2.7.2.4. Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if the right conditions prevail (such as warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic-rich materials such as improperly treated compost and sewage sludge (or biosolids). While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both replication and die-off are water column processes and are not considered in the bacteria source loading estimates in the TMDL watershed.

Section 3. Simplified Step Model

This section describes the rationale for developing a simplified step model to be used for TMDL development and details the procedures and results of the model.

3.1 Modeling Processes Design

Discharge and bacteria concentration at the outfall were measured and described in the QAPP "TMDL Investigation for Bacteria in Poenisch Park Quality Assurance Project Plan for Water Quality Monitoring Revision 0," approved July 26, 2018. During the field measurements of flow from the outfall, the transit time of runoff through this system was found to be very rapid, with most of the runoff occurring within less than two hours of the precipitation reaching the ground. Because the watershed is small, all portions of the watershed have similar transit times to the outlet. This finding led to the design of a simplified step model to predict both runoff and bacteria concentration. The simplified step model was run using MATLAB statistical software (2019).

The simplified step model (Equation 1) estimates that one-half of the runoff from the watershed takes place during the same hour as the precipitation, one-third during the following hour, and one-sixth two hours later. Equation inputs are the MPE hourly time series quantifying the precipitation over the watershed, watershed area, the respective runoff coefficients of the watershed's 30m x 30m cells (Table 7), and watershed land use (Figure 9). Because the Poenisch Park watershed is smaller than the 4 km^2 MPE cell, the same precipitation rate can be used for the entire watershed.

Equation 1. Poenisch Park Outfall Runoff Volume Computed by the Simplified Step Model

$$\mathrm{RV(t)} = \left[{}^{1}\!/_{2}\,\mathrm{MPE(t)} + {}^{1}\!/_{3}\,\mathrm{MPE(t-1)} + {}^{1}\!/_{6}\,\mathrm{MPE(t-2)}\right]\mathrm{x}\sum(A_{Cell}\mathrm{x}RC_{Cell})$$

Where:

$\sum(A_{Cell}\mathrm{xR}C_{Cell})$ = Runoff per unit of rainfall

RV(t) = Hourly runoff volume at time (t) in cubic feet per hour

MPE(t) = Hourly MPE precipitation at time (t) in feet per hour

A_{Cell} = Area of cell (30m x 30m)

RC_{Cell}= Runoff coefficient of each 30m x 30m cell

Table 7. 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 (Agriculture), CP (County Park), PARK (Park)	Parks, Cemeteries	0.10-0.25	0.175
ROW (Right-of-Way), VAC (Vacant)	Unimproved	0.10-0.30	0.20
PO (Professional Office), COM (Commercial)	Downtown (business)	0.70-0.95	0.825
LI (Light Industrial)	Light Industrial	0.50-0.80	0.65
HI (Heavy Industrial)	Heavy Industrial	0.60-0.90	0.75
MDR (Medium Density Residential)	Detached Multi units	0.40-0.60	0.50
HDR (High Density Residential)	Attached Multi units	0.60-0.75	0.675
ER (Estate Residential)	Residential Suburban	0.25-0.40	0.325
LDR (Low Density Residential)	Single-family	0.30-0.50	0.40
PSP (Public/Semi Public)	Neighborhood (business)	0.50-0.70	0.60
TRANS (Transportation)	Asphalt and Concrete	0.70-0.95	0.825

Based on field measurements of discharge at the outfall at Poenisch Park, this model best reflects how quickly the runoff reaches the impacted recreational waters and does not require a high-performance computer to run. The model still accounts for watershed characteristics but removes the need to have precise information about the storm water infrastructure within the watershed, and the need for resource-intensive computations of water transport and accumulation through the watershed.

The water quality component of the model estimates Enterococci indicator bacteria concentrations by combining the estimated outflow runoff volume computed in Equation 1 with watershed information. Accumulation of fecal bacteria in the runoff is based on land cover/land use, event mean concentrations (EMCs), and event concentrations (ECs). Land cover information was extracted from the 2016 NLCD dataset (Dewitz, 2019). EMCs describe the total constituent mass washed off the land surface divided by the total runoff volume for a particular land use over a rainfall event (EPA, 1983). ECs describe the concentration of bacteria that is continuously available for transport in runoff (Hay & Mott, 2006). Indicator bacteria concentrations are measured in CFUs per 100 milliliters of water. 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. EC values for different types of land use are presented in Table 8 and are used for this project. A map of the land use distribution (Dewitz, 2023) is presented in Figure 9.

Table 8. Event Concentration values (counts/deciliter) as applied in gridded dataset for initial loading calculations. Table recreated from Hay & Nicolau (2015). See Table 8 for abbreviation definitions

Type	City of Corpus Christi Classification	Revised EMC Oso Creek (Hay & Mott, 2006)	EMC (Baird et al., 1996)	EC from Oso Creek (Hay & Mott, 2006)
Residential	LDR, MDR, HDR, ER	41320	20000	305316
Commercial	COM, PO, PSP	14246	6900	105264
Industrial	LI, HI	20027	9700	147981
Transportation	TRANS	109427	53000	808562
Crop/Range Land	AG, VAC, PARK	8500	0/37	62807
Not Classified	DC, WATER	8500	0	62807

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). Decay rates vary for fresh water and salt water. Decay rate for the simplified step model was selected based on the decay rate used in the nearby Cole and Ropes Park (Hay & Nicolau, 2015) and was derived from the following equation:

Equation 2. First Order Decay Rate for Bacteria (Crysup, 2002).

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

Where:

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

K_{BL} = death rate due to sunlight

K_{BS} = net loss due to settling

K_a = after growth rate

During transport, the bacteria load is decayed based on the period of time it spends in transit and is modeled using the following equation:

Equation 3. Decayed Bacteria Load.

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

Where:

L = decayed load

L_0 = initial load from watershed

K_B = overall first order decay rate

t = travel time

For larger watersheds, decay is coupled with time in channelized flow with transport of the bacteria and change in load following the series of sub-watersheds from the location of the precipitation to the outlet or measurement/modeling point. However, given the small size of the watershed and the very fast transport to the outlet, the use of sub-watersheds was not necessary for the simplified step model.

For the simplified step model, loadings are calculated by multiplying each of the 30 x 30 meter runoff coefficient by their respective ECs, followed by summing these values for the entire Poenisch Park watershed. This approach is possible because only one MPE value covers the entire watershed. This value is explicitly based on the land use of the watershed and can therefore be changed to compare alternatives to reduce bacterial load.

The load at the stormwater outfall is obtained by multiplying the runoff per unit of rainfall from Equation 1 by the overall average EC (Table 9) of the watershed, resulting in a load of CFUs per inch or foot of precipitation (Equation 4).

No decay is associated with the first one-half portion of the runoff concurrent with the precipitation. The one-third of runoff exiting the Poenisch Park watershed an hour after the precipitation is decayed by one hour and the final one-sixth of the runoff exiting two hours after precipitation is decayed by two hours. A decay rate of 3.0 day^{-1} or (3/24) hour^{-1} is selected, using the average of the two decay rates used for the Cole Park and Ropes Park models (2.72 day-1 for Cole Park and 3.30 day-1 for Ropes Park, [Hay & Nicolau, 2015]), as guidance. As the delays are of one and two hours, the decay coefficients are relatively close to one, at 0.99 and 0.97 respectively, which is not a significant adjustment given the variability of Enterococci concentrations measured. Based on Equation 3, the load prediction from the simplified step model including decay is described in Equation 4.

Equation 4. Bacteria Load Computed with the Simplified Step Model

$$\mathrm{L(t)} = \left[{}^{1}\!/_{2}\,\mathrm{MPE(t)} + {}^{1}\!/_{3}\,\mathrm{MPE(t-1)e^{-K_B}} + {}^{1}\!/_{6}\,\mathrm{MPE(t-2)e^{-2K_B}}\right] \sum (A_{Cell} \mathrm{x} RC_{Cell}) x EC_{av}$$

Where:

$\sum (A_{Cell} \mathrm{x} RC_{Cell}) x EC_{av}$ = CFU load per unit of rainfall

L(t) = Hourly freshwater load in CFU entering the watershed at time (t)

K_b = Enterococci decay rate within the watershed (3.0 day-1 or 72 hr-1)

MPE(t) = Hourly MPE precipitation at time (t) in feet per hour

A_{Cell} = Area of cell (30m x 30m)

RC_{Cell}= Runoff coefficient of each 30m x 30m cell

E_{Cav}= Average EC for Poenisch watershed

Other non-runoff processes may exist in the contributing area that can generate additional bacteria loadings to the system. These processes are generally characterized as dry weather loading and can be significant sources of elevated bacteria loadings.

Given that no specific sources of the dry weather loading were identified, the dry weather load will be modeled as an average or random component based on TBW measurements during periods of dry weather, defined as beginning 72 hours after the last rainfall event. Two methods were compared to model dry weather loadings in this watershed:

1. Averaging water quality measurements of the Poenisch Park receiving waters available from the TBW program for days not influenced by precipitation.
2. Estimating the distribution of the TBW dry weather water quality measurements, and then adding a random daily dry weather loading to replicate this overall distribution.

The second approach is more realistic for metrics based on a percentage of cases exceeding the standard (104 CFU/100 mL), but both methods will be used for comparison. In addition to potential sources of bacteria within the segment watershed, other impacted watersheds are located to the north, Cole and Ropes Park (Hay & Nicolau, 2015), and to the south, Oso Bay watershed (Hay, 2014). These watersheds may also be sources of bacteria to the study area, but more research is needed to better understand the nearshore dynamics in Corpus Christi Bay, and therefore these dynamics will not be estimated in this model.

The total load to the AU will be modeled as the sum of the dry weather and precipitation driven contributions (Equation 5). The Enterococci concentrations will be computed by summing up the dry weather and precipitation driven contributions using the two different approaches for the dry weather contributions discussed above. In Equation 6, the dry weather contribution is estimated as a constant contribution following the approach developed in the Cole and Ropes Parks TMDLs (Hay & Nicolau, 2015). In Equation 8, the dry weather contribution is modeled to replicate the distribution of the TBW dry weather measurements.

Equation 5. Total Bacteria Concentration Predictions for Nearshore Bay Waters (Simplified Step model with Constant Dry Weather Contribution)

Enterococci Concentration in the bay (t) = $C_{bay}(t) = C_{DWL} + C_{PRECIP}(t)$

Where:

C_{bay} = concentration in the bay at TBW sampling location

C_{DWL} = Constant dry weather concentration

$C_{PRECIP}(t)$ = Concentration from precipitation predicted by the simplified step model at timestep t

t = time

The constant dry weather contribution will be computed as the average of all the TBW dry weather measurements. The predictive model for the Enterococci concentration with constant dry weather contribution is expressed below as Equation 6.

Equation 6. AU Enterococci Concentration with Constant Dry Weather Contribution

$$C_{bay}(t) = \text{constant dry weather contribution } + \sum_{t\prime=t-n}^{t\prime=t} \alpha L_{watershed}(t') \, e^{-K_{bay1}(t-t')} \text{ CFU per 100 mL}$$

Where:

α: calibration coefficient to quantify the precipitation driven contribution to the enterococci concentration for the dry weather constant case

$C_{BAY}(t)$ = Concentration from precipitation predicted by the simplified step model at time t

K_{bay1} = calibration coefficient for precipitation driven contribution to the enterococci concentration for the dry weather constant contribution case

$L_{watershed}$ = decayed bacteria load from the watershed

t = model time for which Enterococci concentration is computed

t' = hourly time steps to compute the past precipitation driven contributions to the AU

n = maximum number of hours considered in the computations prior to the model time

Equation 7. Total Bacteria Concentration Predictions for Nearshore Bay Waters; Simplified Step model with Randomly Assigned Dry Weather Contribution

Enterococci Concentration (t) = C_{DWL} (day) + $C_{BAY}(t)$

Where:

C_{DWL} (day) = Probabilistic Enterococci concentration dry weather concentration for the day corresponding to time t

$C_{BAY}(t)$ = Concentration from precipitation predicted by the simplified step model at time t

t = model time for which Enterococci concentration is computed

For this case, the dry weather contribution will also be calibrated using the TBW record.

Equation 8. AU Enterococci Concentration with Probabilistic Dry Weather Contribution

$$C_{bay}(t) = C_{DWL}(\text{day}) + \sum_{t\prime=t-n}^{t\prime=t} \beta L_{watershed}(t') \, e^{-K_{bay2}(t-t')} \text{ CFU per 100 mL}$$

Where:

β: calibration coefficient to quantify the precipitation driven contribution to the Enterococci concentration for the dry weather probabilistic case

$K_{bay}2$: calibration coefficient for precipitation driven contribution to the Enterococci concentration for the dry weather probabilistic case

C_{DWL} (day) = Probabilistic Enterococci concentration dry weather concentration for a day of the type C_{DWL} (day) = $(\ln(rnd) - \mu)/_{\sigma}$, where μ and σ are the parameters of a log normal distribution and rnd is a random number between zero and one.

$L_{watershed}$ = decayed bacteria load from the watershed

t = model time for which Enterococci concentration is computed

t' = hourly time steps to compute the past precipitation driven contributions to the AU

n = maximum number of hours considered in the computations prior to the model time

In both cases above, the coefficients, α K_{bay1}, β, K_{bay2}, μ and σ, will be determined by minimizing the difference between measured and predicted values. The optimization will be conducted by varying systematically the two pairs of parameters over large ranges. For both models, the parameter selection will be based on seeking a low Root Mean Square Error (RMSE), average absolute error (AAE), absolute maximum error and absolute bias, as well as a high coefficient of determination.

Equation 6 (constant dry weather contribution) and Equation 8 (probabilistic dry weather contribution) are the final equations to predict Enterococci bacteria concentrations in this model.

3.2 Flow Duration and Load Duration Curves

Flow Duration Curves (FDCs) and Load Duration Curves (LDCs) are graphs that visualize the percentage of time during which a value of flow or load is equaled or exceeded. To develop an FDC for a location, all of the following steps were taken in the order shown:

- Order the hourly flow data for the location from highest to lowest and assign a rank to each data point (one for the highest flow, two for the second highest flow, and so on).
- Compute the percentage of hours each flow was exceeded by dividing each rank by the total number of data points plus one.
- Plot the corresponding flow data against exceedance percentages.

Further, when developing an LDC:

- Multiply the flow in cubic feet per second (cfs) by the appropriate water quality criterion for Enterococci (geometric mean of 104 cfu/100 mL or 1.04 cfu/mL) and by a conversion factor (2.44658×10^9), which gives you a loading unit of cfu/day.
- Plot the exceedance percentages, which are identical to the value for the flow data points, against the geometric mean criterion for Enterococci.

The resulting curve represents the maximum daily allowable loadings for the geometric mean criterion. The next step was to plot the measured Enterococci data on the developed LDC using the following steps:

- Compute the daily loads for each sample by multiplying the measured Enterococci concentrations on a particular day by the corresponding flow on that day and the conversion factor (2.44658×10^9).
- Plot on the LDC the load for each measurement at the exceedance percentage for its corresponding flow.

The plots of the LDC with the measured loads (Enterococci concentrations times daily flow) display the frequency and magnitude at which measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

3.2.1 Flow Duration Curves

An FDC was developed for the Poenisch Park watershed based on flow estimates from the simplified step model (Figure 11). For this report, the FDC was developed by using estimates from the model for wet conditions only as there is no flow from the outfall in the absence of precipitation.

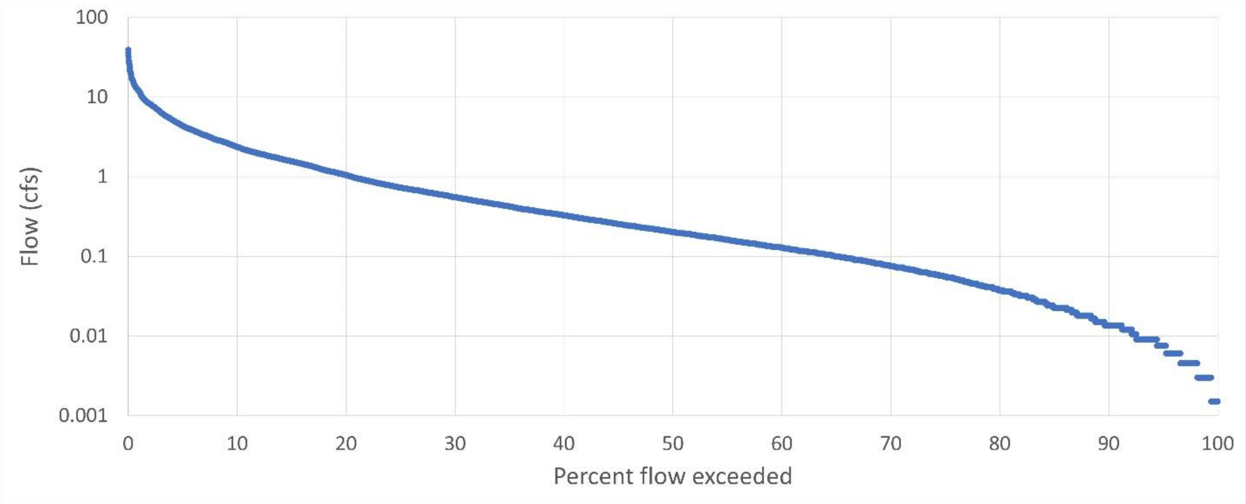

Figure 11. FDC for Poenisch Park watershed during wet conditions

3.2.2 Load Duration Curves

An LDC was developed using load estimates from the simplified step model and Enterococci data from collected at TBW Station NUE026. Similar to the FDC above (Figure 11), the developed LDC only uses load estimates from the model during wet conditions (Figure 12).

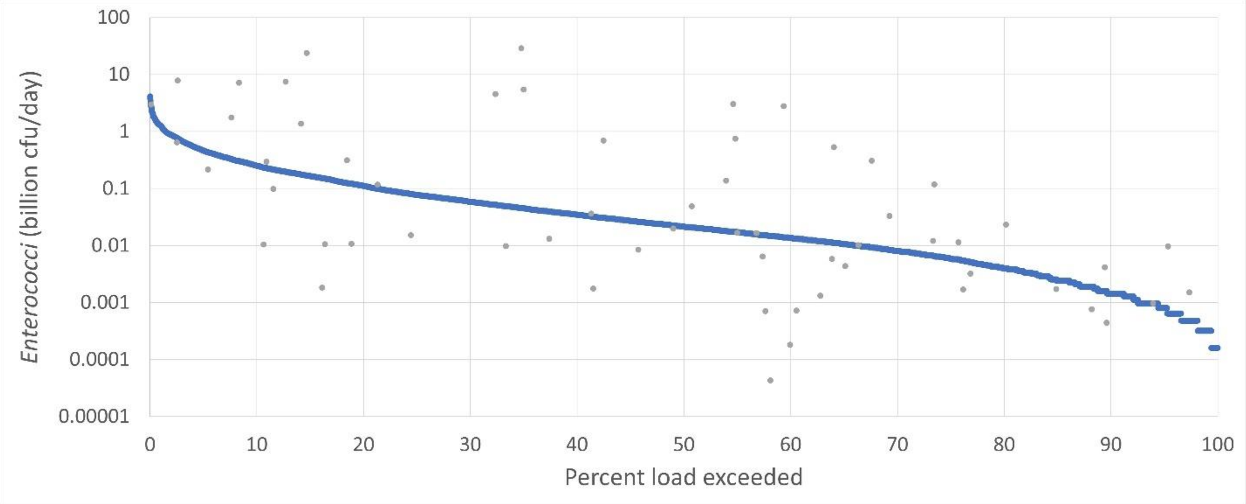

Figure 12. LDC for Poenisch Park watershed during wet conditions

Section 4. TMDL Allocation Analysis

4.1. Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work needed and as a criterion against which to evaluate future conditions. Please note that some calculations completed in this section have been rounded and may not lead to the exact final amounts listed in the text, tables, or figures.

The endpoint for the TMDL is to maintain the concentration of Enterococci below the geometric mean criterion of 104 cfu/100 mL, which has been accepted by EPA as the Beach Action Value (BAV) to issue beach advisories under TBW in accordance with the BEACH Act. TCEQ uses beach advisories issued by TGLO to identify impairments as part of the Texas Integrated Report.

4.2. Seasonal Variation

Seasonal variations occur when there is a cyclic pattern in flow and, more importantly, in water quality constituents. TMDLs must account for seasonal variation in watershed conditions and pollutant loading, as required by federal regulations [Title 40, Code of Federal Regulations (CFR), Chapter 1, Part 130, Section 130.7(c)(1) (or 40 CFR 130.7(c)(1))].

Seasonal differences in Enterococci concentrations were assessed by comparing historical bacteria concentrations collected in warmer months (May-September) versus those collected during cooler months (December-January). For Jan. 5, 2009, the Enterococci concentration was assigned a value of one cfu/100 mL instead of zero. Enterococci concentrations measured by TGLO at TBW Station NUE026 were used to analyze the seasonal variation between warm and cool months (Table 9). Mean log transformed concentrations were greater during cool months than during warm months ($p = 0.009$).

Table 9. Seasonal differences for Enterococci concentrations (warm vs. cool months)

Station ID	Warm ([a]n)	Warm [c]Geomean	Cool ([a]n)	Cool [c]Geomean	[b] p-value
NUE026	399	16.7	108	31.6	0.009

[a] n = number of samples

[b] p-value is based on a t-test conducted on the means of the log transformed single sample concentrations for each station.

[c] All concentrations are in cfu/100 mL.

The data were also evaluated based on wet and dry seasonality. November through April were classified as wet months, while May through September were classified as dry months. Results are presented in Table 10. Mean log transformed concentrations were greater during wet months than during dry months ($p < 0.001$).

Table 10. Seasonal differences for Enterococci concentrations (wet vs. dry months)

Station ID	Dry ([a]n)	Dry [c]Geomean	Wet ([a]n)	Wet [c]Geomean	[b] p-value
NUE026	394	17.24	289	34.56	<0.001

[a] n = number of samples

[b] p-value is based on a t-test conducted on the means of the log transformed single sample concentrations for each station.

[c] All concentrations are in cfu/100 mL.

4.3. Linkage Analysis

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

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

Bacteria load contributions from regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, can carry bacteria from the land surface into the receiving waterbody. Generally, this loading follows a pattern of higher concentrations in the water body as the first flush of storm runoff enters the receiving waterbody. Over time, the concentrations decline as runoff washes fecal bacteria from the land surface and the volume of runoff decreases following the rain event.

An LDC was used to examine the relationship between outfall water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a direct relationship between pollutant load sources (regulated and unregulated) and outfall loads. Further, this one-to-one relationship was inherently assumed when using an LDC to define the TMDL pollutant load allocation (Section 4.7). That allocation was based on the flows associated with the watershed areas under stormwater regulation, and the remaining portion was assigned to the unregulated stormwater.

4.4. Load Duration Curve Analysis

LDC analyses were used to examine the relationship between outfall water quality and the broad sources of indicator bacteria loads, and they are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. An LDC is a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders and uses available water quality and flow data. The LDC method does not require any assumptions about loading rates, hydrology, land use conditions, or other conditions in the watershed. EPA supports the use of this approach to characterize pollutant sources. In addition, many other states are using this method to develop TMDLs.

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

The LDC method allows for estimation of existing and TMDL loads by using the cumulative frequency distribution of flow and measured pollutant concentration data (Cleland, 2003). In addition to estimating discharge loads, this method allows for the determination of the hydrological conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater), and provides a means to allocate allowable loadings.

For the LDC developed for this report, only estimates of non-zero flow were included. Because the Poenisch Park watershed is small and stormwater-driven, there is only flow at the outlet during, and immediately after, precipitation. The simplified step model assumes that runoff from precipitation completely exits the watershed at the outfall after three hours following the end of precipitation. Because pollutant loading is a product of flow and pollutant concentration, loads cannot be estimated for periods when there is no flow. An important caveat is that pollutant concentrations in the Poenisch Park watershed are likely influenced by other factors that the simplified step model is not able to account for and were therefore left out of this analysis. Therefore, the LDC and the resulting TMDL only apply during rainfall events.

4.5. Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (1991), the MOS can be incorporated in 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 TMDL in this report incorporates an explicit MOS of 5%.

4.6. Pollutant Load Allocations

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

Equation 9. Pollutant load allocations

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

Where:

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

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

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures [40 CFR130.2(i)]. For Enterococci, TMDLs are expressed as billion cfu/day, and represent the maximum one-day load the waterbody can assimilate while still attaining the standards for surface water quality.

4.6.1. Assessment Unit-Level TMDL Calculations

The bacteria TMDL for the water body was developed as a pollutant load allocation based on information from the LDC developed for the Poenisch Park watershed (Figure 2). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the Enterococci TBW criterion (104 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the “Allowable Load” displayed in the LDC at 5% exceedance is the TMDL. In non-beach TMDLs, 5% is used as the median value of the high flow regime and is used here to be consistent with other TMDLs.

Equation 10. Allowable loading within the watershed

$$TMDL\ (cfu/day) = Criterion * Flow\ (cfs) * Conversion\ Factor$$

Where:

Criterion = 104 cfu/100 mL (Enterococci)

Conversion Factor (to billion cfu/day) = 28,316.846 mL/cubic feet (ft^3) * 86,400 seconds/day (s/d) ÷ 1,000,000,000

The allowable loading of Enterococci that the impaired water body can receive on a daily basis was determined using Equation 10 based on the use of 5% flow exceedance value.

Table 11. Summary of allowable loading calculation

Water Body Name	AU	5% Exceedance Flow (cfs)	5% Exceedance Load (cfu/Day)	TMDL (Billion cfu/Day)
Poenisch Park	2481CB_06	4.365	1467.212	11.107

4.6.2. Margin of Safety Allocation

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

Equation 11. Margin of safety allocation

MOS = 0.05 * TMDL

Where:

TMDL = total maximum daily load

Using the value of TMDL for the AU provided in Table 11, the MOS may be readily computed by proper substitution in Equation 11 (Table 12).

Table 12. MOS calculations

Load units expressed as billion cfu/day Enterococci

Water Body Name	AU	TMDL[a]	MOS
Poenisch Park	2481CB_06	11.107	0.555

[a] TMDL from Table 12.

4.6.3. Wasteload Allocations

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}).

Equation 12. Wasteload allocation

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

4.6.3.1. Wastewater

TPDES-permitted WWTFs are allocated a daily wasteload calculated as their full permitted discharge flow rate multiplied by the outfall geometric criterion. The water quality criterion (104 cfu/100 mL) is used as the WWTF target to provide outfall and downstream load capacity. Thus, WLA_{WWTF} is expressed in the following equation:

Equation 13. Wasteload allocation for WWTFs

WLA_{WWTF} = Target * Flow * Conversion Factor

Where:

Target= 104 cfu/100 mL

Flow = full permitted flow (million gallons per day)

Conversion Factor (to billion cfu/day) = 3,785,411,800 mL/million gallons ÷ 1,000,000,000

Using this equation, each WWTF's allowable loading is normally calculated using the permittee's full permitted flow. However, due to the small size of the Poenisch Park watershed, there are no WWTFs within the watershed, and the WLA_{WWTF} is zero.

4.6.3.2. Regulated Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered regulated point sources. Therefore, the WLA calculations must also include an allocation for regulated stormwater discharges. A simplified approach for estimating the WLA for these areas was used in the development of this TMDL due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading.

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

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

Equation 14. Wasteload allocation for regulated stormwater

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

Where:

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

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

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. As described in Section 2.7.1.3, the Poenisch Park watershed is covered at 100% by the City of Corpus Christi's MS4 permit. To arrive at the proportion, the area under stormwater jurisdiction is divided by the total watershed area. The results were then used to compute an area of regulated stormwater contribution (Table 14).

Table 13 Basis of unregulated stormwater area and computation of FDA_{SWP} term

Watershed	AU	Watershed Area (acres)	MS4 Area of Watershed (acres)	Beach Area (acres)	FDA_{SWP}
Poenisch Park	2481CB_06	64.500	64.371	0.130	0.998

The daily allowable loading of Enterococci assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. To calculate the WLA_{SW} (Equation 14), the FG term must be known. The calculation for that term is presented in the next section, but the results are included here for continuity. Table 15 provides the information needed to compute WLA_{SW}.

Table 14 Regulated stormwater WLA calculations

Load units expressed as billion cfu/day *Enterococci*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}	FG	FDA_{SWP}[c]	WLA_{SW}[f]
Poenisch Park	2481CB_06	11.107	0.555	0.000	0.000	0.998	10.531

[a] TMDL from Table 11

[b] MOS from Table 12

[c] FDA_{SWP} from Table 14

[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) *FDA_{SWP}$ (Equation 14)

4.6.4. Future Growth

The FG component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component accounts for the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of water bodies increases as the amount of flow increases. Because there are no WWTFs that discharge within the Poenisch Park watershed and there is no possibility that one will be constructed in the future due to the watershed's small size and existing residential development, the FG component for this TMDL is zero.

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 both point and nonpoint source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality. The TMDL in this document will result in protection of existing uses and conform to Texas' antidegradation policy.

4.6.5. Load Allocations

The LA is the load from unregulated sources, and is calculated as:

Equation 15. Load allocation

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

Where:

$TMDL$ = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 16.

Table 15 LA calculation

Load units expressed as billion cfu/day *Enterococci*

Water Body Name	AU	TMDL[a]	MOS[b]	WLA_{WWTF}	WLA_{SW}[c]	FG	LA[f]
Poenisch Park	2481CB_06	11.107	0.555	0.000	10.531	0.000	0.021

[a] TMDL from Table 11

[b] MOS from Table 12

[c] WLA_{SW} from Table 15

[f] $LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$ (Equation 15)

4.7. Summary of TMDL Calculations

Table 16 summarizes the TMDL calculation for the TMDL watershed. The TMDL for Poenisch Park was calculated using the 95-percentile range (5% exceedance) for flow exceedance from the outfall. Allocations are based on the current geometric mean criterion for Enterococci of 104 cfu/100 mL for each component of the TMDL. The TMDL allocation summary for the Poenisch Park watershed is summarized in Table 16.

Table 16 TMDL allocation summary

Load units expressed as billion cfu/day Enterococci

AU	TMDL[a]	MOS[b]	WLA_{WWTF}	WLA_{SW}[c]	LA[d]	FG
2481CB_06	11.107	0.555	0.000	10.531	0.021	0.000

[a] TMDL from Table 11
[b] MOS from Table 12
[c] WLA_{SW} from Table 15
[d] LA from Table 16

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

Table 17 Final TMDL allocation

Load units expressed as billion cfu/day Enterococci

AU	TMDL	MOS	WLA_{WWTF}[a]	WLA_{SW}	LA
2481CB_06	11.107	0.555	0.000	10.531	0.021

[a] WLA_{WWTF} includes the FG component

Section 5. References

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