TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

AGENDA ITEM REQUEST

AGENDA REQUESTED: May 9, 2007

DATE OF REQUEST: April 20, 2007

NAME & NUMBER OF PERSON TO CONTACT REGARDING CHANGES TO THIS REQUEST, IF NEEDED: Dania Grundmann, 239-3449.

CAPTION: Docket No. 2007-0379-TML. Consideration for approval to publish and solicit public comment on one draft TMDL for bacteria in Oso Bay (Segment 2485) of the Nueces-Rio Grande Coastal Basin, in Nueces County.
(Faith Hambleton, Marc Friberg)

P.C. Shanbacker

Chief Engineer

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY
2007 APR 19 AM 8:12
CHIEF CLERKS OFFICE

Texas Commission on Environmental Quality

INTEROFFICE MEMORANDUM

To: Commissioners Date: April 20, 2007

Thru: LaDonna Castañuela, Chief Clerk

Glenn Shankle, Executive Director

From: David C. Schanbacher, P.E., Chief Engineer DCS
Chief Engineer's Office

Subject: Release of Draft Total Maximum Daily Load for Bacteria in Oso Bay for Public Comment

Issue Consideration for approval to publish and solicit public comment on one draft TMDL for bacteria in Oso Bay (Segment 2485) of the Nueces-Rio Grande Coastal Basin, in Nueces County.

Background and Current Practice One draft TMDL has been prepared as required by Section 303(d) of the Clean Water Act. TMDLs must be submitted to U.S. EPA for approval as certified updates to the State of Texas Water Quality Management Plan (WQMP). Prior to submission of TMDLs to EPA, TCEQ staff request approval from the commission to release the draft TMDLs for a formal public review and comment period. After the public comment period, TCEQ staff make appropriate changes to the draft TMDLs and document public comments for the record. The next step is to request that the commission adopt and certify the final TMDL as an update to the State of Texas WQMP. The commission approved TMDLs are then forwarded to U.S. EPA for their final approval or disapproval within 60 days.

Question Does the commission approve the Executive Director's request to release for public review and comment the Draft TMDL for bacteria in Oso Bay?

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Attachments

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Oso Bay (Segment 2485) TMDL for Bacteria
Summary Outline – April 4, 2007

I. Introduction

- The goal of this TMDL is to attain water quality standards as defined in the *Texas Surface Water Quality Standards*. Current numeric standards to support contact recreation use are as follows: for *Enterococci,* a geometric mean of 35 colony forming units (cfu)/100mL and a grab sample standard of 89 cfu/100mL. However, the grab sample criterion is incorrect. It is anticipated that the pending revisions of the Surface Water Quality Standards will increase the grab sample criterion to at least 104 cfu/100mL. The anticipated corrected grab sample criterion of 104 cfu/100mL was used in the Oso Bay TMDL.

II. Background Information

- Oso Creek and Oso Bay are located in the Oso Watershed, a small watershed draining approximately 609 km^2 (235 sq. miles) in Nueces County, Texas (Figure 1). Oso Creek begins near the City of Robstown and flows 40 km (24.9 miles) southeast to Oso Bay in the City of Corpus Christi. Oso Bay is a shallow tertiary bay of about 1200 hectares (2,963 acres) connected to Corpus Christi Bay.

- The TMDL analyses and modeling addressed both Oso Bay and Oso Creek as an interconnected system. This TMDL covers only Oso Bay, and Oso Creek will be separately covered in another TMDL. That is because the analyses indicated very different management strategies are needed for the bay and the creek.

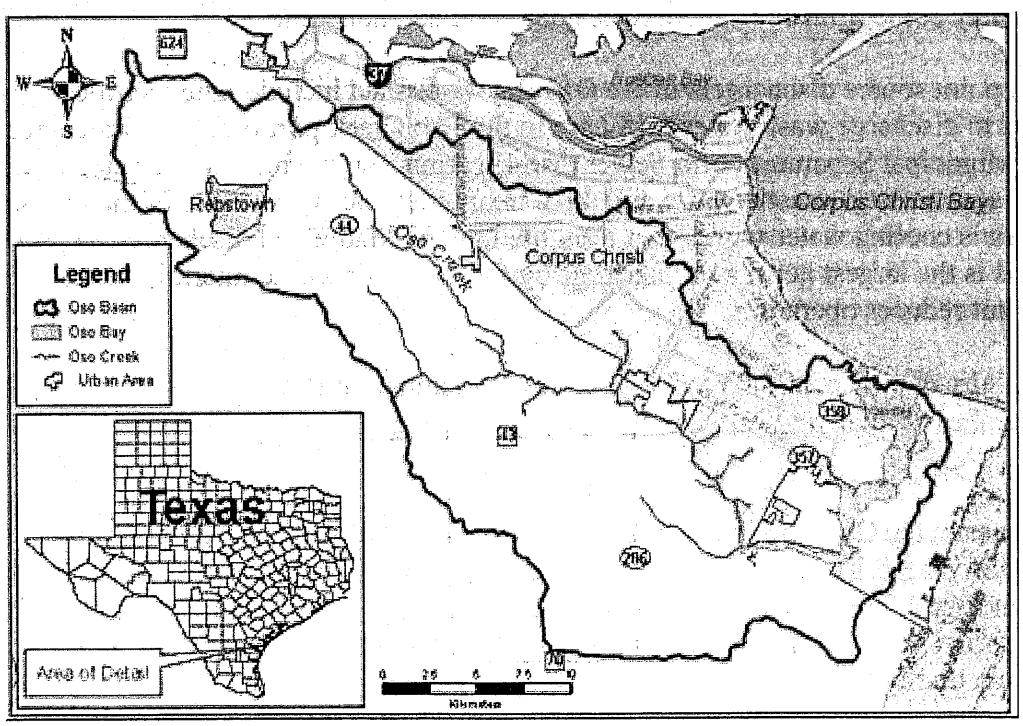


Figure 1. Oso Bay Watershed

III. Problem Definition

- In 2002, fecal coliform data indicated that Oso Bay supported contact recreation. Enterococci data were not sufficient to assess the bay in 2002, but the small amount of data then available indicated some reason for concern. For the 2002 assessment, Oso Bay was placed in Category 5c on the Water Quality Inventory, with a priority ranking of D (more data needed).

- Additional sampling of bacterial parameters in the Oso system was conducted prior to the 2004 assessment to assure sufficient data sets for assessment. In the 2004 assessment, part of Oso Bay was deemed impaired for contact recreation based on both Enterococci and fecal coliform data. For the 2004 assessment, Oso Bay was placed in Category 5a on the Water Quality Inventory.

- A TMDL project was initiated to quantify appropriate reductions of Enterococci necessary to comply with water quality standards.

IV. Endpoint Identification

- The primary endpoint for this TMDL will be based on the geometric mean criterion (35 cfu/100mL), assessed on an annual basis. Model analyses indicated that the anticipated grab sample criterion would also be met.

V. Source Analysis

- Bacteria may come from several sources, both point and nonpoint.

- Potential point source dischargers in the Oso Bay watershed include nine facilities permitted to discharge wastewater (most are in the Oso Creek portion of the watershed), and one Municipal Separate Storm Sewer (MS4) permit. Of the nine wastewater discharges, six treat domestic waste and three treat industrial waste. One of the industrial discharges is cooling water withdrawn from the Laguna Madre and discharged to Oso Bay – this is the largest permitted discharge by far, but has become intermittent as the power plant reduces operation.

- Probable "dry day" (i.e. not related to storm events) nonpoint pollution sources in the Oso Bay watershed include malfunctioning septic tanks, illegal dumping, livestock, pets, and wildlife.

- Storm water in the Oso watershed is another source of bacteria. The City of Corpus Christi MS4 permit includes multiple discharge points throughout the Oso Bay and Oso Creek watershed. Because of the MS4 permit, storm water runoff from within the City of Corpus Christi must be categorized as a point source for TMDL allocations. Storm water runoff from unincorporated areas is categorized as a nonpoint source.

VI. Linkage

- Water quality data, including Enterococci concentrations, were collected during 2005-2006 at 22 sites in the Oso watershed (includes creek). Eleven of the sites were sampled during normal flow to represent ambient conditions, and all 22 were sampled during several storm events to characterize storm water runoff.

- Concentrations of the indicator bacteria Enterococcus for all stations over the period of measurement ranged from one colony forming units (cfu)/100mL to 97,000 cfu/100mL with a mean value of 3,752 cfu/100mL and a geometric mean value of 483 cfu/100mL. Many of the highest Enterococcus concentration measurements occurred during wet weather. Enterococcus concentrations in Oso Bay ranged from 1 to 11,650 cfu/100mL with a geometric mean of 41 cfu/100mL. However, considering only dry weather sampling events the geometric mean concentration was only 17 cfu/100 ml. Enterococcus concentrations in Oso Creek were consistently higher than in Oso Bay.

- The assessment survey results showed that Oso Bay is much more saline than Oso Creek, largely due to the power plant discharge of hypersaline Laguna Madre water. The difference in salinity affects bacterial survival and resultant concentrations, and was reflected in model decay rates applied to the creek and bay.

- Survey results also indicated that one station in Oso Bay was consistently higher than the other bay sites. That station is located very near the discharge point for the City of Corpus Christi Oso Bay WWTP, and within a major bird rookery and observation point. Elevated bacteria concentrations are thought to be due to the extensive bird population, not the WWTP discharge. Birds are attracted to the site in part because of the freshwater inflow of the discharge, as well as the heavily vegetated marshland around the site and the extremely shallow (less than 6 inches) bay shore. Because of the low salinity, the station is not chemically representative of Oso Bay proper. Because of the bird population and rookery, the wetland vegetation, and the extremely shallow water, the site is considered by local inhabitants to be inappropriate and unsuitable for typical "primary contact recreation" uses like swimming or water skiing.

- A watershed model based on Geographic Information System (GIS) software and the data collected during 2005-2006 was developed and applied. The model included both Oso Creek and Oso Bay. Calibration of the model to the observed data defined the "existing condition" loading for the Oso watershed. Predictive model scenarios reduced loading until Enterococcus criteria were met at all output points in the creek and the bay.

- Model analyses indicated that very little reduction in loading to Oso Bay is needed, while very large reductions appear necessary for Oso Creek. In fact, additional loading to Oso Bay was simulated, and the model indicated that very sizable increases in loading to the bay could occur without exceeding bacteria standards. The only site on the bay that may need a small reduction in "dry day" loading is the bird rookery area. However, on the annual basis analyzed by the modeling, allowable increases in intermittent storm water loading greatly exceed the small dry-period reduction.

VII. Allocations

- Load allocations were calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where

WLA = wasteload allocation (point source contributions);
LA = load allocation (nonpoint source contributions); and
MOS = margin of safety.

- The model analysis of the Oso watershed included ten subbasins, each of which provided an output point for assessment and allocation purposes. Four of the subbasins comprise the Oso Bay portion, the other six comprise Oso Creek. The Oso Bay load allocation accounts for the four Oso Bay subbasins, plus the inflow from Oso Creek. The separate Oso Creek TMDL will be based on the six creek subbasins.

- The Oso Bay TMDL equation places storm runoff loading from the City of Corpus Christi into the WLA as a point source. That was done by estimating the portion of each model subbasin covered by the City MS4 permit, and proportionately converting storm runoff loading to the point source category. The LA portion of the Oso Bay allocation represents unincorporated areas.

- Compared to the "existing" model case, the allowable loading and the TMDL allocation for Oso Bay actually increase.

VIII. Margin of Safety

- This TMDL uses an implicit margin of safety. The model scenario that defined allowable loading for the Oso Bay and Oso Creek system predicted water quality better than the applicable criteria. Annual geometric means predicted at all stations were well below the criterion of 35 cfu/100mL. The "25% exceed" concentrations predicted at all stations were well below the 104 cfu/100mL that was used, and all in Oso Bay were below the 89 cfu/100mL currently in the Water Quality Standards. This means that the "allowable loading" characterized by the model is significantly less than might be allowed, but the amount cannot be quantified for explicit accounting.

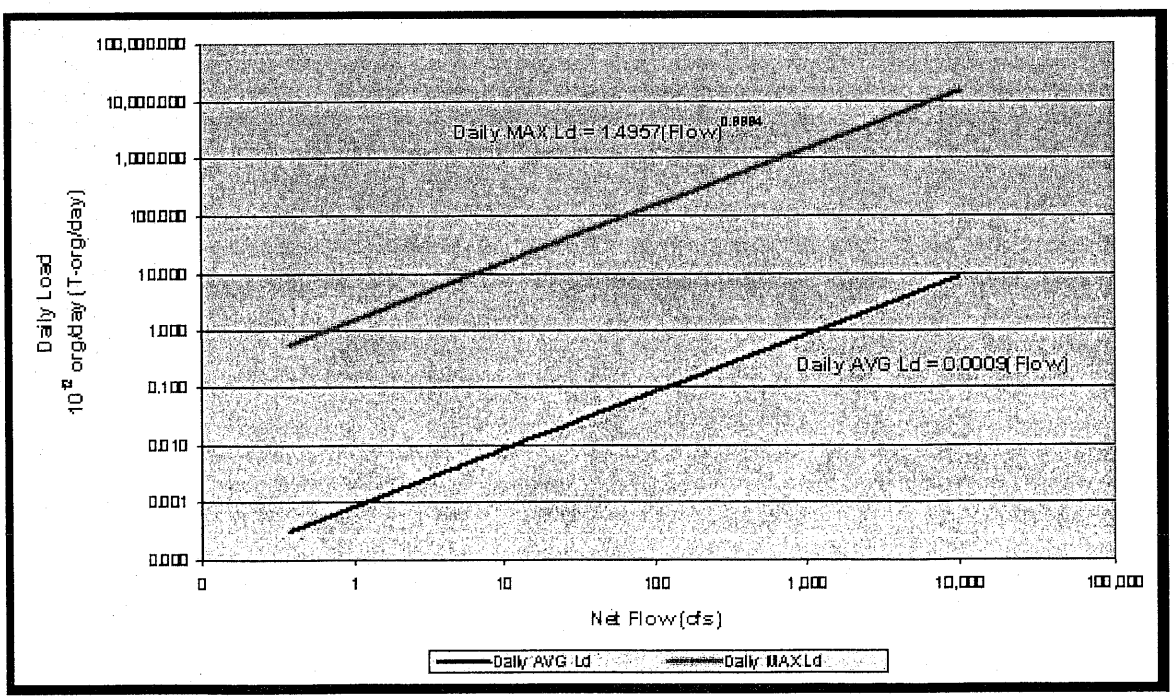
IX. TMDL

$$TMDL = \sum WLA + \sum LA + MOS \text{ (implicit)}$$

- The Oso Bay TMDL was analyzed and expressed in annual terms, which incorporates the variation between dry and wet periods as annual totals. Loading from the MS4 area is in the WLA category. The annual allocation is summarized as:

LA	+	WLA	=	TMDL	
91,101.11	**+**	**96,223.31**	**=**	**187,324.42**	**$x10^{12}$ cfu/year**

- While state implementation will use the annual allocation above, EPA requires that all TMDLs also be expressed in "daily units" in order to be consistent with the phrase "total maximum daily load." EPA guidance indicates that daily expressions may include average, maximum, and/or minimum load allocations. The Oso Bay TMDL proposes both daily average and daily maximum allocations, although these are not expected to be used for implementation or management activities. The daily allocations are expressed as curves representing allowable loading across the range of flow conditions that might occur during any single day, and regression equations that reproduce those curves. The daily average load is calculated from "net stream flow" and the geometric mean criterion (35 cfu/100mL), while the daily maximum load is calculated from "net stream flow" and the maximum 24-hr average concentration for each model subbasin from the model scenario that represented allowable loading (i.e. all criteria met on an annual basis). The daily load allocations are shown below.



Total Average Daily Load:

Daily Avg Load = 0.0009 · Flow

Total Maximum Daily Load:

Daily Max Load = 1.4957 · Flow$^{0.9994}$

In both equations, flows are entered as cubic feet per second (cfs) and loads are calculated as "trillion organisms per day" or "x10^{12} org/day" or "T-org/day".

For Public Comment, May 2007

One Total Maximum Daily Load for Bacteria in Oso Bay

Segment 2485

Prepared by the:
Chief Engineer's Office, Water Programs, TMDL Section

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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TMDL Project Reports are also available on the TCEQ Web site at:
<www.tceq.state.tx.us/goto/tmdl/>

This TMDL report is based in large part on technical reports prepared for the TCEQ by the Center for Coastal Studies at Texas A&M University, Corpus Christi.

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One Total Maximum Daily Load for Bacteria in Oso Bay

Executive Summary

This document describes a project to address a water quality impairment related to bacteria concentrations in Oso Bay (Segment 2485), a tertiary embayment adjoining the southwesterly portion of Corpus Christi Bay. Oso Creek, which flows into Oso Bay, is addressed in a separate total maximum daily load (TMDL) report that is based on analyses performed in conjunction with this TMDL.

In 2004, Oso Bay was identified on the state's 303(d) list as impaired because bacteria concentrations exceed the criterion established to evaluate the contact recreation use. The contact recreation use of Oso Creek was first identified as impaired on the 303(d) list for 2002. In accordance with the requirements of Section 303(d) of the federal Clean Water Act, the Texas Commission on Environmental Quality has developed a TMDL that will allow the bay to attain its designated uses and meet its water quality standards.

The combined watersheds of Oso Creek and Oso Bay drain a small area of approximately 235 square miles in Nueces County, Texas (Figure 1). Oso Bay is a shallow tertiary bay of about 1200 hectares (2,963 acres) that empties into Corpus Christi Bay. Oso Creek begins near the City of Robstown and flows 24.9 miles southeast to Oso Bay in the City of Corpus Christi. The creek's non-tidal section, 14.3 miles long, flows into a 10.6-mile tidal section before discharging to Oso Bay. Samples taken in the bay since 2002 have exceeded the *Enterococci* criterion. Model-based analyses have shown that high bacteria concentrations are sometimes due both to storm water runoff and to relatively small but diffuse sources that continue during dry weather. Dry-weather sources may include dysfunctional septic tank systems, illegal dumping, direct deposition, wildlife using stream banks or bridges as habitat, and resuspension of bottom sediment by wading wildlife, humans, or livestock. Municipal domestic wastewater treatment facilities are present in the watershed and discharge to several tributaries of Oso Creek and Oso Bay, but were not found to be significant contributors to elevated concentrations of bacteria in the bay.

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. For each listed water body that does not meet a standard, states must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of water. The TCEQ is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

In simple terms, a TMDL is like a budget that determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, 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 time period, but may be expressed in other ways. TMDLs must also estimate how much the pollutant load must be reduced from current levels in order to achieve water quality standards.

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

This TMDL will address impairment of the contact recreation use due to bacteria concentrations in Oso Bay (Segment 2485).

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) (40 Code of Federal Regulations, Part 130) describe the statutory and regulatory requirements for acceptable TMDLs. Following these guidelines, this TMDL document summarizes development of the TMDL in the following sections:

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

The document was adopted by the commission on Month Day, Year Upon EPA approval, the TMDL will become an update to the state's Water Quality Management Plan.

Problem Definition

The combined watersheds of Oso Creek and Oso Bay drain a small area of approximately 235 square miles in Nueces County, Texas (Figure 1). Oso Bay is a shallow tertiary bay of about 2,963 acres that empties into Corpus Christi Bay. Oso Creek begins near the City of Robstown and flows 24.9 miles southeast to Oso Bay in the City of Corpus Christi. It is the main channel for more than 60 miles of natural and constructed drainage. The creek's non-tidal section, 14.3 miles long, flows into a 10.6-mile tidal section before discharging to Oso Bay.

Topographically, the basin can be characterized as flat to gently sloping remnants of Pleistocene marine terraces. The total change in elevation within the basin, from just northwest of Robstown to Oso Bay is about 28 meters, for an overall slope of about 0.7 meters per kilometer.

Geologically, the watershed lies on the Pleistocene Beaumont Formation. The Beaumont Formation within the basin is largely made up of interdistributary muds, abandoned channel-fill muds, and fluvial over bank muds, all of low permeability. Other parts of the basin represent the low-moderate permeability of meander belt, levee, crevasse splay, and distributary sand deposits.

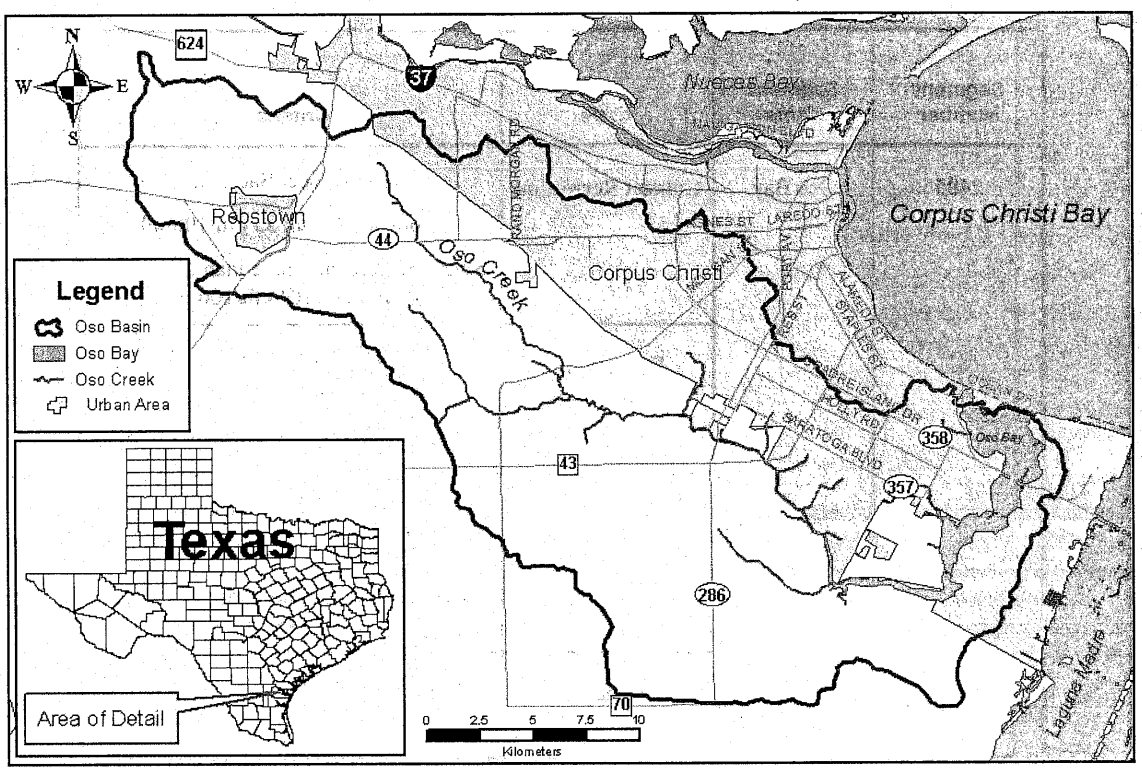


Figure 1: Project watershed

The *Texas Surface Water Quality Standards* (TSWQS) are rules developed by the TCEQ (Title 30 of the Texas Administrative Code (TAC) Chapter 307) that establish goals for water quality throughout the state and provide a basis on which regulatory programs may be carried out. The TSWQS define various categories of general criteria (§307.4) and site-specific uses and criteria (§307.7). The general criteria apply to any surface water in the state and establish basic standards for all uses a water body may support. Some of the general criteria are narrative in nature, while others are numeric. Site-specific uses are applied to defined areas of water bodies, including classified segments and some unclassified waters. The criteria associated with site-specific uses are all numeric. Both types of criteria are subject to the anti-degradation policy (§307.5) in the TSWQS.

Five main categories of use are defined by the TCEQ to describe the ways that water bodies in the state are used—aquatic life, contact recreation, fish consumption, public water supply, and general. Each use category is associated with a suite of criteria developed to protect and evaluate the designated uses of each water body in the state.

Oso Bay is a classified segment with site-specific uses and criteria stated in Appendix A of the TSWQS. The specific uses designated for Oso Bay are contact recreation, exceptional aquatic life use, and oyster water. Table 1 presents the uses and criteria currently applicable to Oso Bay.

Table 1: Water Quality Standards for Oso Bay

Segment Number	Segment Name	Uses	Criteria
2485	Oso Bay	Contact Recreation	Enterococci Bacteria: Geometric Mean: 35 cfu/100 mL Single Sample: not more than 25 percent of samples >104 cfu/100 mL*
		Exceptional Aquatic Life	Dissolved Oxygen: 24-hour average: ≥ 5.0 mg/L Daily Minimum: ≥ 4.0 mg/L
		Oyster Water	Fecal coliform Bacteria: Median: ≤ 14 cfu/100 mL Single Sample: not more than 10 percent of samples > 43 cfu/100 mL
		General	pH: 6.5 – 9.0 Temperature: 95° F

* This is the corrected value expected to be included in the next revision to the TSWQS; the currently established value is 89 cfu/100 mL.

Oso Bay has been designated for contact recreation use. The indicator bacteria criterion applicable to contact recreation in the bay is Enterococci, at a geometric mean not to exceed 35 colony forming units (cfu) per 100 milliliters (mL) of water. In addition, single samples analyzed for Enterococci should not exceed 89 cfu/100 mL; however, that value is an error, and a revision to the TSWQS during 2006-2007 is expected to change the single sample criterion for Enterococci to the correct value of 104 cfu/100 mL (Davenport 2006). This TMDL will use the correct single-sample value for its calculations and reduction targets.

The standards for the contact recreation use and associated Enterococci criteria had been recently adopted when water quality was assessed for the 2002 *Texas Water Quality Inventory and 303(d) List* (Inventory and List), so there were limited amounts of Enterococci data available for screenings. Consequently, the more abundant data on fecal coliform, the indicator bacteria used prior to 2002, were also used to assess contact recreation uses. When using fecal coliform data to assess contact recreation, the geometric mean should not exceed 200 cfu/100 mL, and single samples should not exceed 400 cfu/100 mL.

In 2002, fecal coliform data indicated that Oso Bay supported contact recreation (Table 2). Enterococci data were not sufficient to assess the bay in 2002, but the small amount then available indicated some reason for concern.

Additional sampling of bacteria in the Oso Bay system was conducted prior to the 2004 assessment to assure sufficient data sets for assessment. In the 2004 Inventory and List, part of Oso Bay was identified as impaired for contact recreation, based on both Enterococci and fecal coliform data (Table 2). Oso Bay was placed in Category 5(a) of the 303(d) List, and a TMDL project began.

Table 2: Water Quality Assessment Results for Oso Bay

Indicator Parameter	# samples	Was Geometric Mean assessment exceeded?	Was Single Sample assessment exceeded?
Oso Bay 2002 (assessment based on one station: 13440)			
Fecal Coliform	12	No (Geomean = 60)	No (1/12 =8.3% exceeded)
Enterococci	6	Insufficient Data (Geomean = 43)	Insufficient Data (3/6 = 50% exceeded)
Oso Bay 2004 (assessment based on three stations: 13440, 13441, 13442)			
Fecal Coliform	68	Yes Geomeans were: 23 at stn 13440 307 at stn 13441 48 at stn 13442	Yes (at one station) 3/18 = 16.7% at stn 13440 8/18 = 44.4% at 13441 3/32 = 9.4% at 13442
Enterococci	68	Yes Geomeans were: 36.6 at stn 13442 295 at stn 13441 54 at stn 13440	Yes 6/18 = 33.3% at stn 13442 16/18 = 88.9% at stn 13441 12/32 = 37.5% at 13440

Endpoint Identification

TMDL projects must identify a quantifiable water quality endpoint for each parameter that causes a body of water to appear on the state's 303(d) list. Those endpoints are indicators of the desired water quality condition and provide measurable goals for the

TMDL. For certain parameters, the primary water quality endpoint for the TMDL is explicitly set forth in the TSWQS. In other cases, the state standards may not establish a numeric criterion for the parameters of concern. In those cases, current scientific literature, cause-and-effect relationships established from scientific studies, or other appropriate means are used to establish the endpoint for the TMDL. The TMDL endpoint serves to focus the technical work to be accomplished during TMDL development, and is applied to future monitoring data to determine whether the TMDL is successful.

The establishment of the endpoint for the TMDL is an integral part of the TMDL process, and manifests many of the same complexities as the development of TMDLs. Through the analysis of water quality data and modeling exercises, it becomes possible, at least to some degree, to define quantitative values of various parameters that can serve as target conditions. The TMDL is, by definition, the set of external loadings that result in a predicted concentration in the water body equal to the target condition. The TMDL determination and the endpoint specification are coordinated, parallel activities. Specification of endpoint conditions implies a corresponding set of critical conditions; yet there is not necessarily one unique set of these critical conditions. The parameter for which an endpoint condition is defined may not be the parameter that characterizes pollutant loading, and may not be in itself sufficient to ensure attainment of the desired use of the water body.

The endpoint for this TMDL is expressed as concentrations of Enterococci bacteria. Concentration endpoints use cfu/100 mL, a number per volume rather than mass per volume. Model simulations to determine allowable loads and the necessary reductions were based on satisfying both the geometric mean and percent exceedance method defined in the TSWQS and the *Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data*, 2004. The allowable loading was determined from model simulations that were compared to the numeric endpoints listed below.

The endpoints for this TMDL are that, for surface water samples collected from monitoring stations within Oso Bay to represent ambient water quality:

- The annual geometric mean of Enterococci concentrations should not exceed 35 cfu/100 mL.
- Enterococci concentrations should not exceed 104 cfu/100 mL more often than 25 percent of the time (or 25 percent of samples).

Source Analysis

Pollutants may come from several sources, both point and nonpoint. The possible sources of pollutants are discussed in this section.

Land Use

There are a variety of land uses within the watershed of Oso Bay and Oso Creek (Figure 2, Table 3). Land use data layers were acquired from the United States Geological Survey

Earth Resource Observation and Science Data Center (NCDC 2005), depicting the 2003 National Land Cover Dataset (NLCD) as shown in Figure 2. For modeling purposes, the 20 land use categories in the NLCD dataset were clustered into four larger categories, as shown in Table 3.

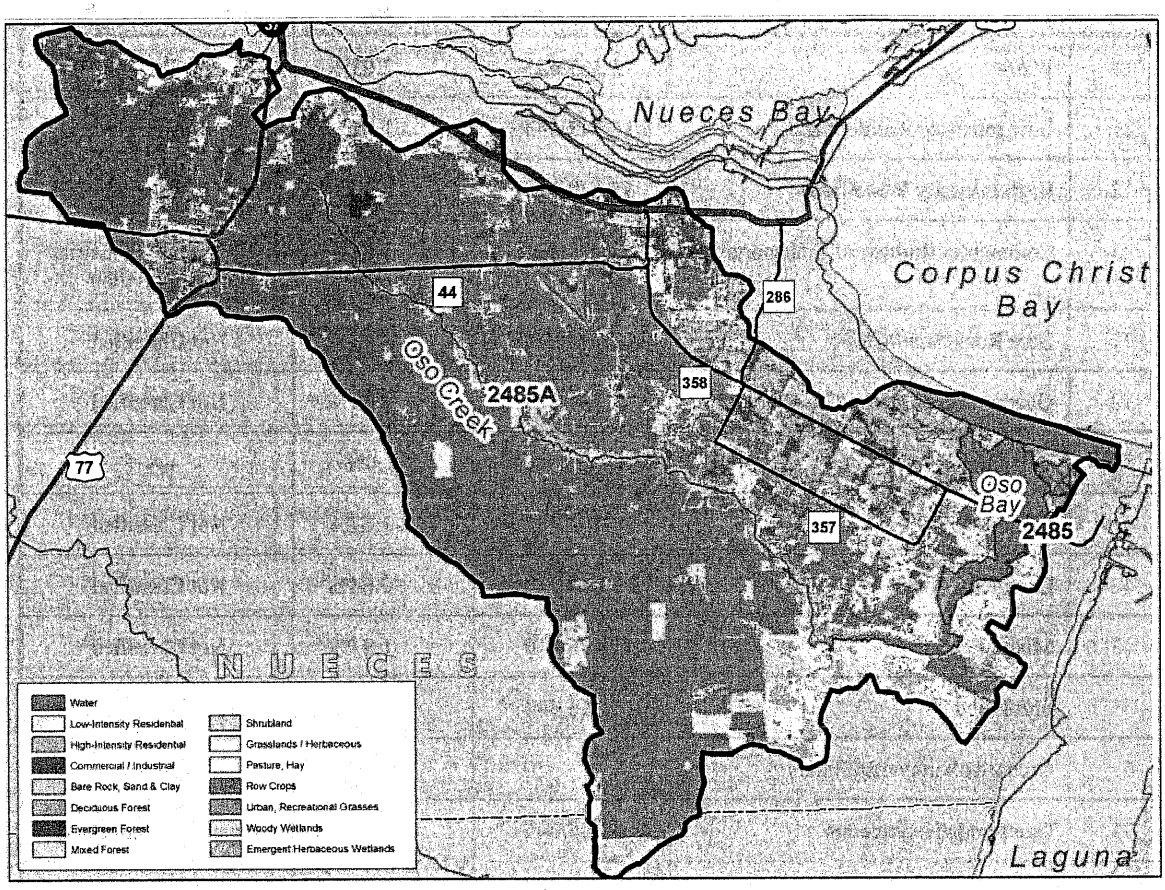


Figure 2: Land use, 2003

Agricultural row crops are the predominant land use by far, but urban residential and commercial land uses are significant in areas near some of the monitoring sites where bacteria concentrations have exceeded criteria. There are also small areas of concentrated residential land use outside of city limits or municipal jurisdiction. Storm water runoff from both agricultural and urban areas may be a source of bacteria loading.

Point Sources

A sanitary survey was conducted to identify possible sources of bacteria within the watershed. The survey included literature and database searches, historic GIS datasets, and field observations. There are 10 permitted discharges to Oso Bay and Oso Creek, with permitted daily average discharge volumes ranging from 1,500 gallons per day to 540 million gallons per day (MGD) (Table 4). The approximate locations of permitted discharges are shown in Figure 3.

Table 3: Land Use Distribution, 2003

NLCD Classifications for Oso Basin				Oso Model Classifications
Class ID	Type	Area (square meters)	Percent of Total	
11	Water	12,365,625	2.03%	Not Classified
21	Low Intensity Residential	11,045,693	1.81%	Residential
22	High Intensity Residential	35,128,910	5.77%	Residential
23	Commercial/Industrial/Transportation	27,908,531	4.58%	Commercial/ Industrial/ Transportation
31	Bare Rock/Sand/Clay	12,942,915	2.13%	Not Classified
32	Quarries/Strip Mines/Gravel Pits	7,789,829	1.28%	Not Classified
33	Transitional	0	0%	-----
41	Deciduous Forest	10,150,382	1.67%	Not Classified
42	Evergreen Forest	3,874,244	0.64%	Not Classified
43	Mixed Forest	11,596,810	1.91%	Not Classified
51	Shrubland	6,716,444	1.10%	Cropland/ Rangeland
61	Orchards/Vineyards/Others	0	0%	-----
71	Grasslands/Herbaceous	64,285,045	10.56%	Cropland/ Rangeland
81	Pasture/Hay	8,821,194	1.45%	Cropland/ Rangeland
82	Row Crops	381,741,357	62.71%	Cropland/ Rangeland
83	Small Grains	0	0%	-----
84	Fallow	0	0%	-----
85	Urban/Recreational Grass	6,654,853	1.09%	Cropland/ Rangeland
91	Woody Wetland	3,642,858	0.60%	Not Classified
92	Emergent Herbaceous Wetlands	4,037,207	0.66%	Not Classified
Total		608,701,897	100.00%	

There are six domestic wastewater treatment plants. Three of the domestic wastewater plants have permits for discharges greater than one million gallons per day (>1.0 MGD), one in Robstown, and two in Corpus Christi. The other three domestic wastewater plants have small permitted discharge rates (<1.0 MGD). All domestic wastewater facilities are

required to disinfect effluent before discharge, using chlorination or ultra-violet light, and facilities larger than 1.0 MGD that use chlorination must also de-chlorinate to reduce toxic effects on stream organisms. The Corpus Christi Greenwood facility also has an effluent limit for fecal coliform. Self-reporting data (Beaber 2005) indicate that fecal coliform concentrations range from 0 to 800 cfu/100ml with a mean value of 10.5 and a geometric mean of 3.53. Two other permitted facilities discharge treated wastewater from industrial facilities. These industrial wastewater discharges are typically not expected to have high concentrations of pathogens or bacteria.

The majority of daily discharges are from wastewater treatment plants, but the largest volume (540 MGD) is cooling water from the Barney Davis Power Plant. Cooling water is withdrawn from the very salty Laguna Madre, passes through the power plant and its cooling ponds, and is then discharged into the upper end of Oso Bay. However, the Barney Davis facility has recently been producing less power than its capacity, so cooling water discharge is often much less than the permitted amount, and sometimes there is no discharge.

Table 4: Discharge Permits in the Oso Watershed

Permittee	Texas Permit Number	Maximum Permitted Daily Average Flow (MGD)
Tennessee Pipeline Construction Co.	14228-001	0.06
Texas A&M University – Agricultural Extension Service	11345-001	0.0015
Corpus Christi Peoples Baptist Church – Roloff WWTP	11134-001	0.02
City of Corpus Christi – Oso WWTP	10401-004	16.2
City of Corpus Christi – Greenwood WWTP	10401-003	8.0
City of Robstown WWTP	10261-001	3.0
City of Corpus Christi – Storm Water	04200-000	NA
Texas A&M University – Shoreline Env Res Facility	03646-000	0.99
Equistar Chemical LP – Corpus Christi Plant	02075-003	2.0
American Electric and Power – Barney Davis Power Station	01490-000	540.0

There is also one Municipal Separate Storm Sewer System (MS4) permit for storm water discharge issued to the City of Corpus Christi. MS4 permits do not impose maximum daily flow limits, since the quantity of storm water on any day or within any month cannot be controlled by human endeavor. Storm water effluent is typically controlled through best management practices (BMPs). Storm water discharge is categorized as a

point source for TMDL purposes if there are permits that cover the discharges, as may be the case for cities, industries, or other entities. In the Oso watershed, the storm water discharges from areas covered by the City of Corpus Christi storm water permit are therefore point sources, while other storm water discharges are nonpoint sources. Figure 3 depicts the Corpus Christi city limit in relation to monitoring sites and permitted discharges within the Oso Bay watershed.

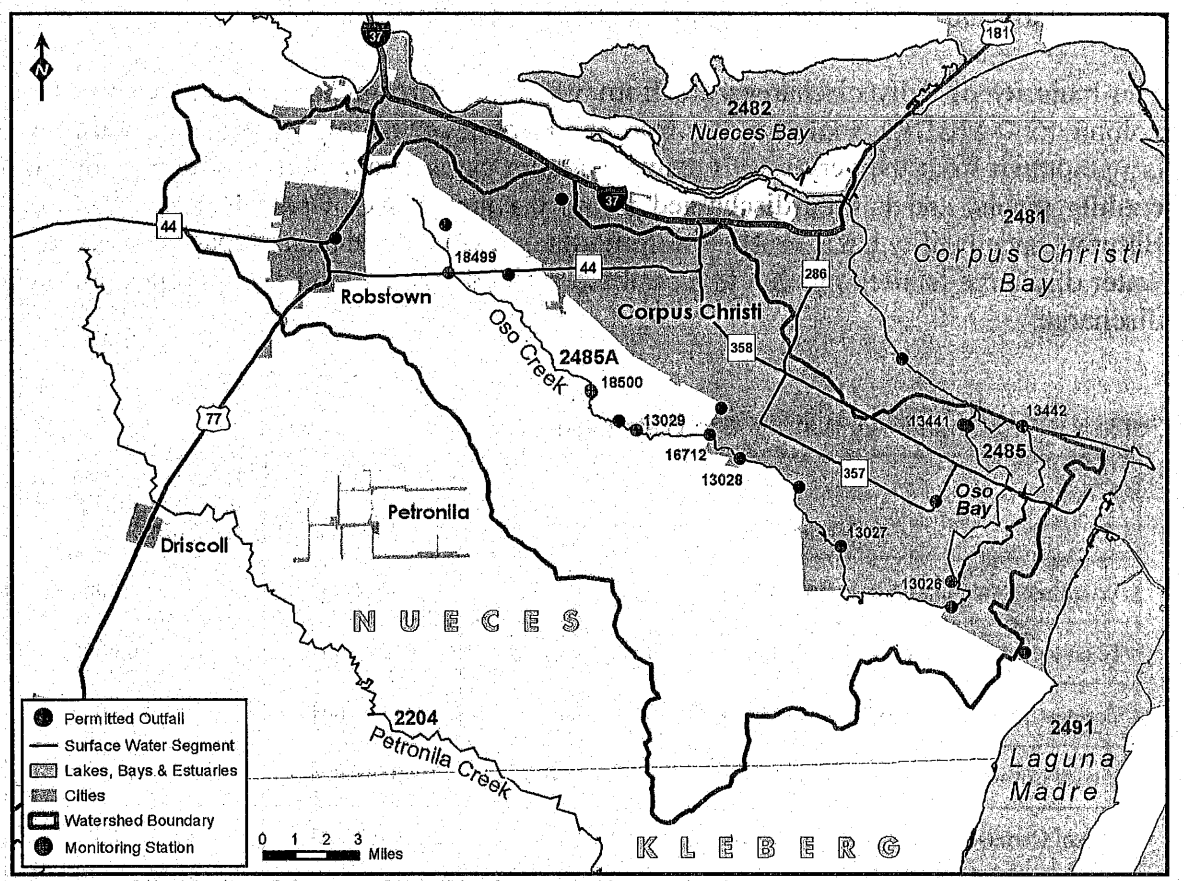


Figure 3. City Limits of Corpus Christi in Oso Bay Watershed

Nonpoint Sources

The Oso Bay watershed was first assessed using aerial imagery to examine land use and accessibility for sampling. The Texas A&M University-Corpus Christi project managers, the lab's quality assurance officer, the lab's manager, and the field supervisor conducted a field survey on January 7, 2005. Each ambient site was visited. Locations along the creek that were accessible by road were noted, and the staff determined whether water access was possible either by wading from the banks or by bridge. Livestock, colonias, and any other potential sources of bacteria were observed, recorded, and marked on a map (Figure 4). Geographic coordinates of each potential site were taken using a hand held Global Positioning System (GPS) device.

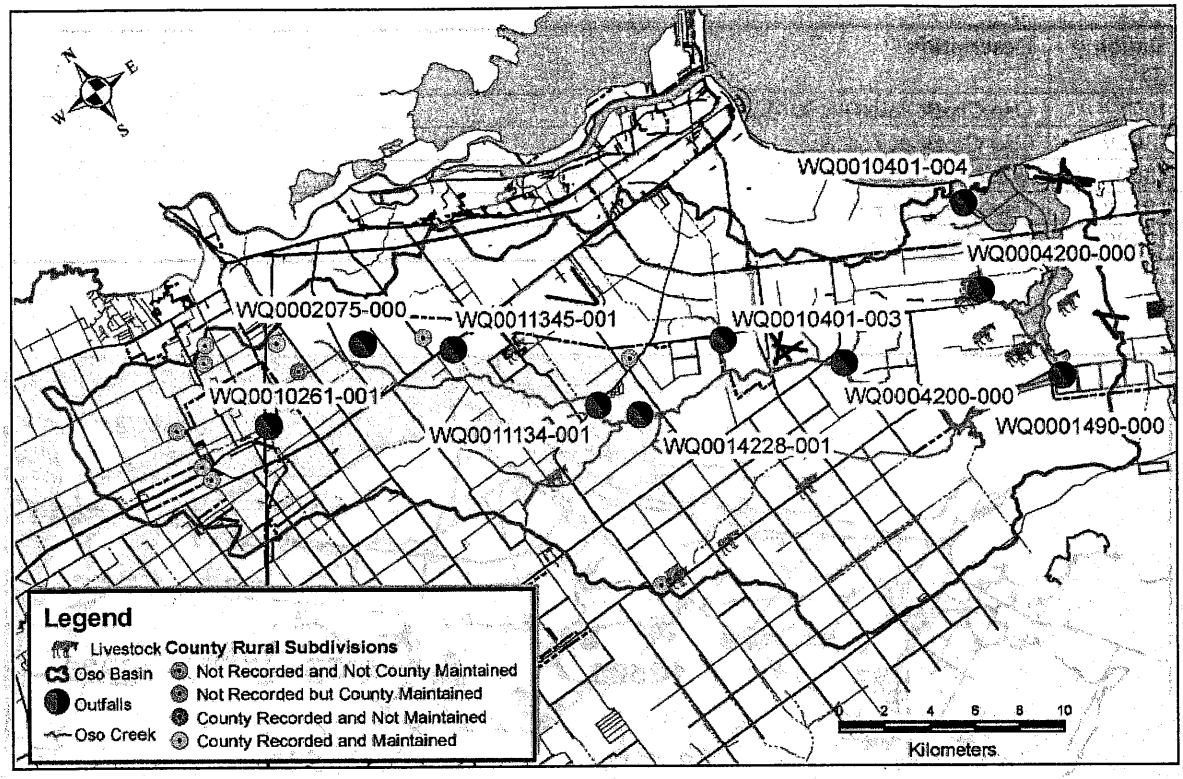


Figure 4: Location of potential bacteria sources from sanitary survey.

The following sites were identified for field sampling to assess sources based on the sanitary survey, historic data locations, and stakeholder input. The locations of the sampling sites are shown in Figure 5.

Table 5: Targeted Monitoring Stations

Station ID	Description
S1	Oso WWTP outfall
S2	Corpus Christi urban storm-water drainage ditch
S3	Robstown urban storm-water drainage ditch
S4	Colonia with various livestock and septic systems
S5	Flour Bluff storm water ditch with livestock, primarily horses, grazing close by
S6	Corpus Christi storm water ditch with some nearby livestock
S7	Ditch downstream from Robstown WWTP
S8	Ditch collecting runoff from Elliot landfill
S9	Ditch at Colonia with septic systems
S10	Ditch collecting agriculture field runoff
S11	Creek flowing from Pharos Golf Course into Oso Bay
13442	Oso Bay at Ocean Drive
13441	Oso Bay at the Hans Suter Park
13440	Oso Bay at South Padre Island Drive
13026	Oso Bay at Yorktown Road
13027	Oso Creek (tidal) at FM 2444
13028	Oso Creek (tidal) at SH 286

Station ID	Description
16712	Oso Creek (tidal) at La Volla Creek
13029	Oso Creek at FM 763
18501	West Oso Creek at FM 665
18500	Oso Creek at FM 665
18499	Oso Creek at SH 44

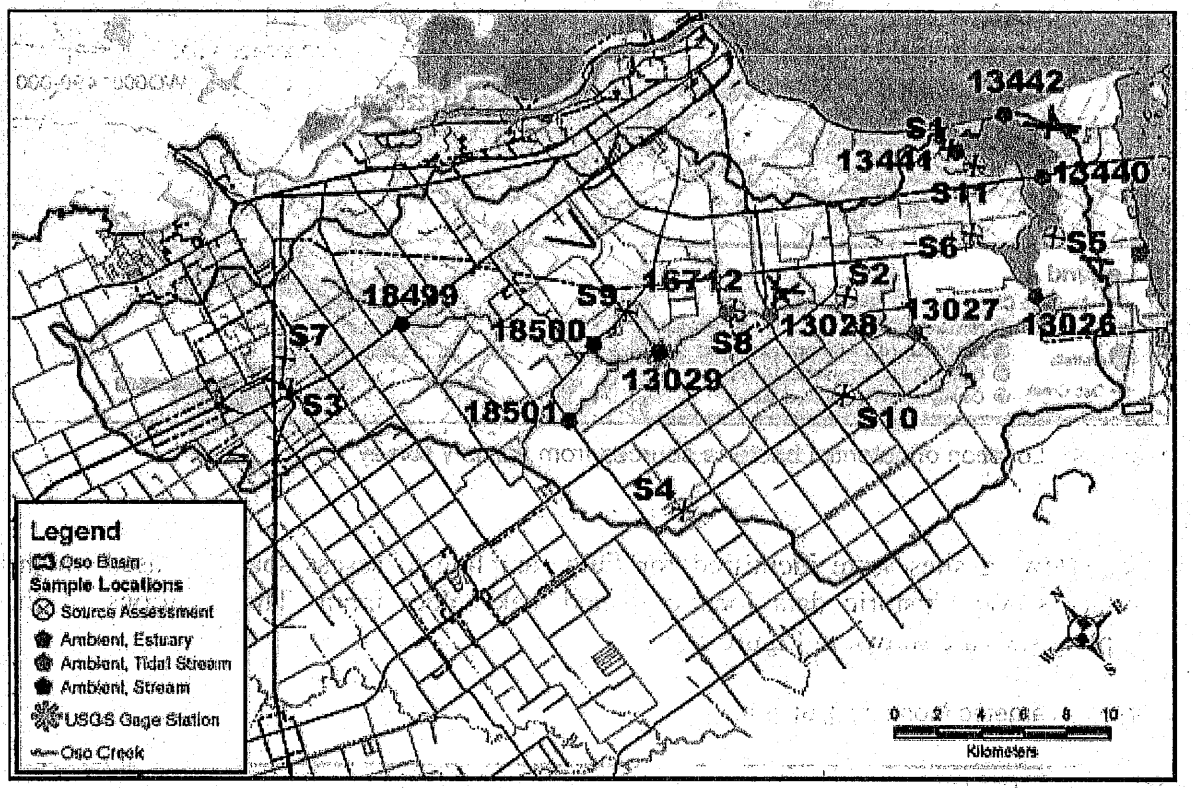


Figure 5: Sampling locations

Field data collection began on May 19, 2005. Weekly samples were collected at 11 ambient stations on Oso Creek and Oso Bay. Storm water runoff was sampled for significant events at the 11 ambient stations and 11 source assessment sites. All sampling and measurements took place under an approved Oso Creek and Oso Bay Bacteria TMDL Project Quality Assurance Project Plan (QAPP).

Data Analysis

All data was analyzed to evaluate processes that may generate bacteria, contribute to flow in the creek, impede or enhance water flow through the Creek/Bay system, or affect the survival of bacteria. Much of the data analysis was performed using geographic information system (GIS) software. More information about analyses of the data is available in supporting documents (Hay & Mott 2005; Hay & Mott 2006).

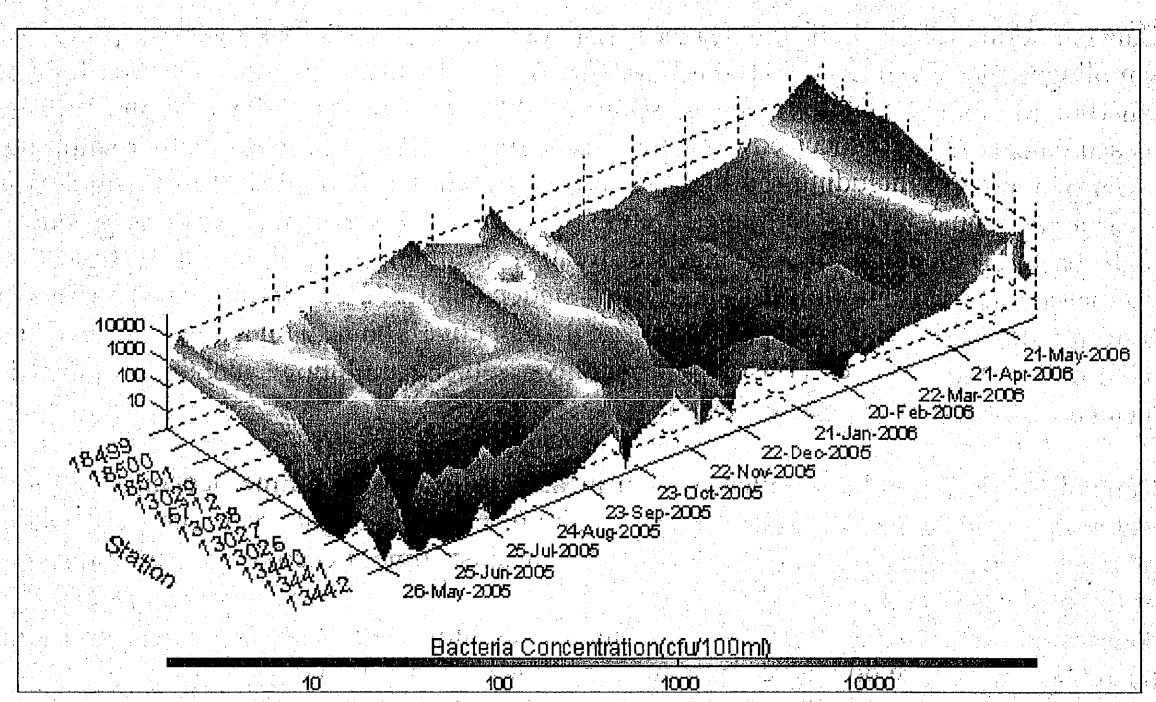
Concentrations of the indicator bacteria Enterococci for all stations over the period of sampling ranged from one cfu/100 mL to 97,000 cfu/100 mL, with a mean value of 3,752 cfu/100 mL and a geometric mean value of 483 cfu/100 mL. Many of the highest measurements of Enterococci concentrations occurred during the wet-weather sampling event of June 2006, including the highest concentration (97,000 cfu/100 ml), which was measured on June 2, 2006, at targeted station S6. Many of the targeted stations produced high bacteria concentrations during wet-weather sampling, yielding a wet-weather geometric mean concentration for all targeted stations of 1,572 cfu/100 mL. Enterococci concentrations in Oso Bay ranged from one to 11,650 cfu/100 mL, with a geometric mean of 41 cfu/100 mL. However, considering only dry-weather sampling events, the geometric mean concentration for Oso Bay was only 17 cfu/100 mL.

General trends in data can be clearly seen in the surface plots of Enterococci, salinity, water temperature, and dissolved oxygen (Figure 6, Figure 7, Figure 8, Figure 9) where parameter concentrations (z-axis) are plotted against time (x-axis) and monitoring stations listed in sequence from upstream to downstream (y-axis). Enterococci concentrations (Figure 6) were generally higher at stations upstream of station 13026 (Oso Creek) than those downstream of and including station 13026 (Oso Bay).

Seasonal Trends

Higher Enterococci concentrations were observed during warmer periods and lower concentrations during colder periods, as reflected by water temperature measurements (Figure 8). The abrupt change in salinity between Oso Creek and Oso Bay due to the influx of cooling water diverted from a hyper-saline lagoon (Laguna Madre) at the Barney Davis Power Plant is clearly evident (Figure 7) and elevated values of dissolved oxygen (Figure 9) can be observed in response to colder water temperatures.

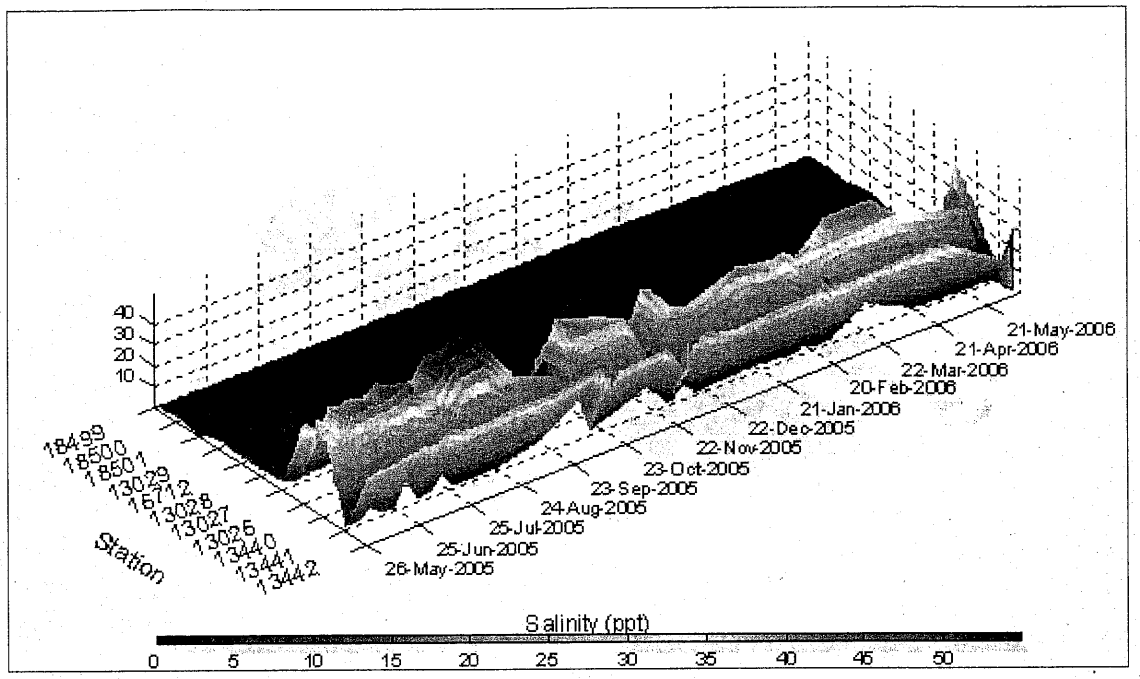
Linear features oriented along the y-axis (stations listed in sequence) are evident in Figure 6 (Enterococci), Figure 7 (salinity), Figure 8 (water temperature), and Figure 9 (dissolved oxygen). These features can be associated with runoff events that alter the water chemistry for a short time period. These linear features indicate an increase in Enterococci concentrations, a decrease in salinities in Oso Bay, some decrease in dissolved oxygen, and a contrast in water temperatures depending on the seasonal climate, as a response to runoff and its associated parameters entering the Oso hydrologic system.



Stations are listed from furthest upstream (back) to furthest downstream (front).

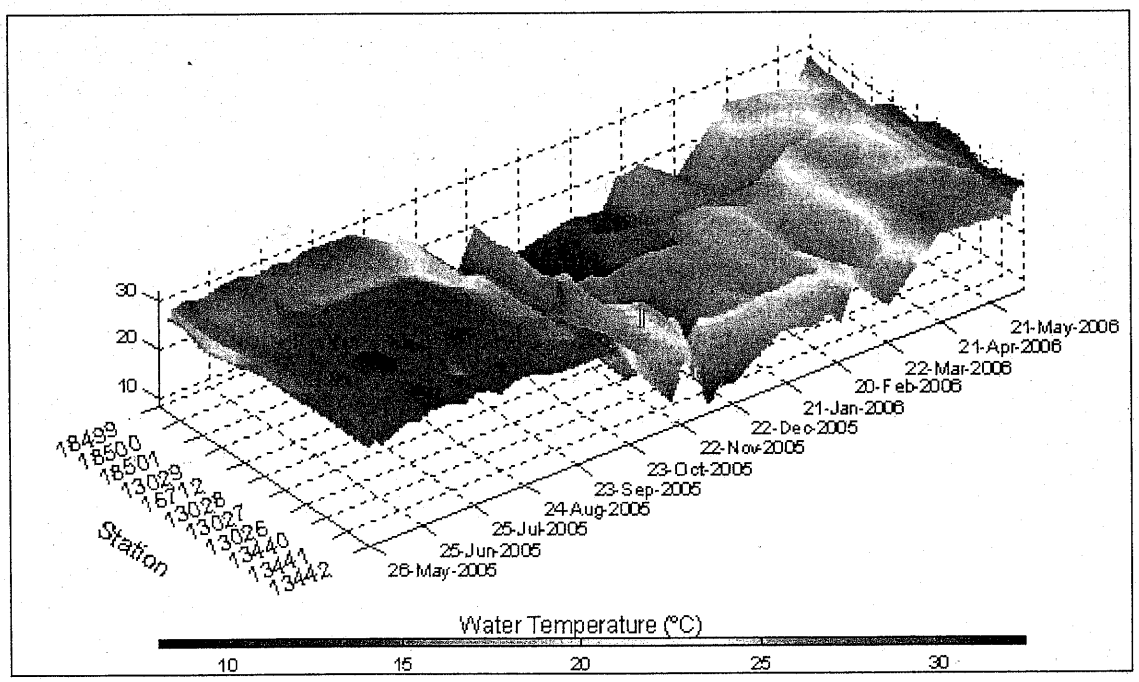
Figure 6: Enterococci concentrations measured at ambient monitoring stations from May 19, 2005 through June 8, 2006.

Linear features oriented along the x-axis (time) are also evident, indicating anomalies or events specific to a particular station. X-axis linear features can be observed in Figure 6, where high Enterococci concentrations are persistent at station 13027 when compared to upstream and downstream stations during July and August 2005, as well as for station 13441 where generally higher concentrations are found compared to other Oso Bay stations. Other x-axis oriented linear features are observed for station 13441 on plots of salinity (Figure 7), where fresher water at this station is persistent throughout the period of measurements, and where warmer temperatures (Figure 8) are persistent throughout the colder months of December, January, and February.



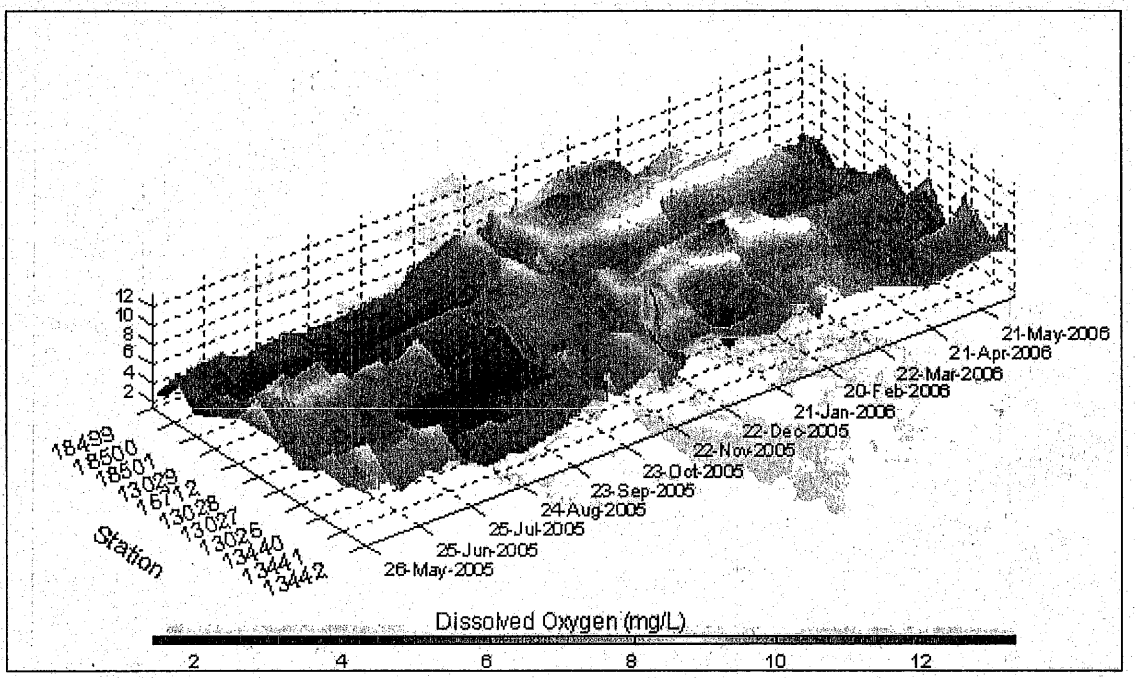
Stations are listed from furthest upstream (back) to furthest downstream (front).

Figure 7: Salinity concentrations measured at ambient monitoring stations from May 19, 2005 through June 8, 2006.



Stations are listed from furthest upstream (back) to furthest downstream (front).

Figure 8: Water temperature measured at ambient monitoring stations from May 19, 2005 through June 8, 2006.



Stations are listed from furthest upstream (back) to furthest downstream (front).

Figure 9: Dissolved oxygen measured at ambient monitoring stations from May 19, 2005 through June 8, 2006.

The occurrence of time oriented linear features at station 13441, such as elevated temperature during cold periods, higher Enterococci values, and persistently lower salinities, indicate that this station is strongly influenced by the neighboring Oso WWTP and is best treated as a tributary feeding into the Oso hydrologic system rather than being representative of broader conditions in Oso Bay. The time oriented linear features at station 13027 indicate higher concentrations of Enterococci bacteria during condition devoid of runoff. This strongly suggests that another source of Enterococci is present between this station and the next station upstream (station 13028). Since stream flow during this period is very low, potential sources for this flux can include leaking or failed septic systems in a nearby subdivision, leaking municipal sewer lines near the creek, wildlife activity in and around the creek (nesting under bridges, feeding at waters edge), equestrian activities (exercising horses in the creek), and illegal discharge/disposal of sewage in the creek.

Linkage Analysis

The connection between watershed sources of bacteria and concentrations of bacteria within Oso Creek and Oso Bay was further examined using a computer simulation model. The model utilizes geographic information system (GIS) software to organize and manage data, calculations, and output. Important inputs to the model included GIS layers depicting land use (Figure 2), digital elevation data, stream hydrography, and precipitation intensity. The basic calculation structure of the final model is illustrated in Figure 10. These calculations were performed for each subwatershed within the model,

and each land use present in a subwatershed had event concentration (EC) values assigned. More detailed discussion of the model theory, structure, and application are presented in the supporting documents (Hay & Mott 2005, Hay & Mott 2006), from which this description is extracted and compiled.

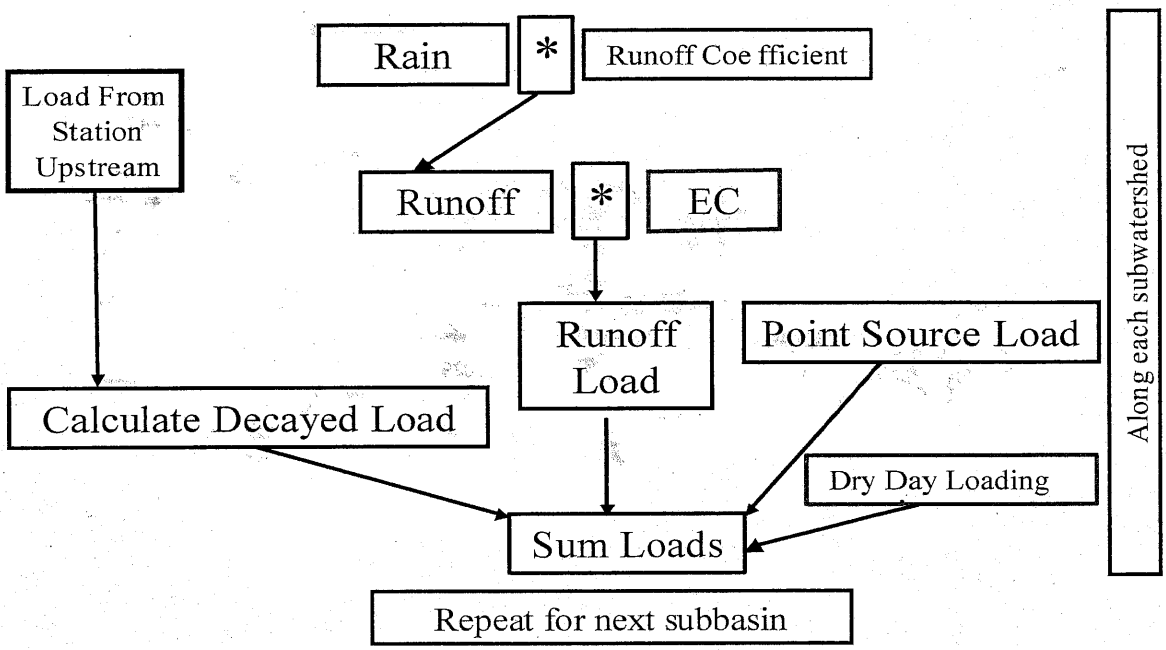


Figure 10: Revised bi-hourly model process flow chart with modifications highlighted in red.

The Oso watershed was initially divided into 14 subwatersheds for modeling purposes, as shown in Figure 11. Those 14 subwatersheds generally corresponded to potential sources (Figure 4), and monitoring stations (Figure 5) used by the project. For load allocation simulations, locations S7 and S3 were incorporated into subwatershed 18499, location 18501 was incorporated into subwatershed 13029, and location S6 was incorporated into subwatershed 13440. Model input and output summaries were ultimately compiled for the 10 subwatersheds thus defined. Figure 11 also depicts the approximate city limit of Corpus Christi relative to the model subwatersheds, which is used to estimate sub-watershed areas for allocating MS4 storm water loading.

The subwatersheds upstream from station 13027 comprise the Oso Creek watershed for modeling and load allocation purposes, while the subwatersheds downstream from station 13027 are the immediate Oso Bay watershed. Load allocations for model subwatersheds may be aggregated to define load allocations for the larger Oso Creek and Oso Bay watersheds.

Model Calibration

The Oso Bay watershed model was calibrated to stream and runoff data collected during 2005-2006. Calibration of the model focused on decay rate, runoff event concentrations, and other sources of bacteria loading not characterized by data.

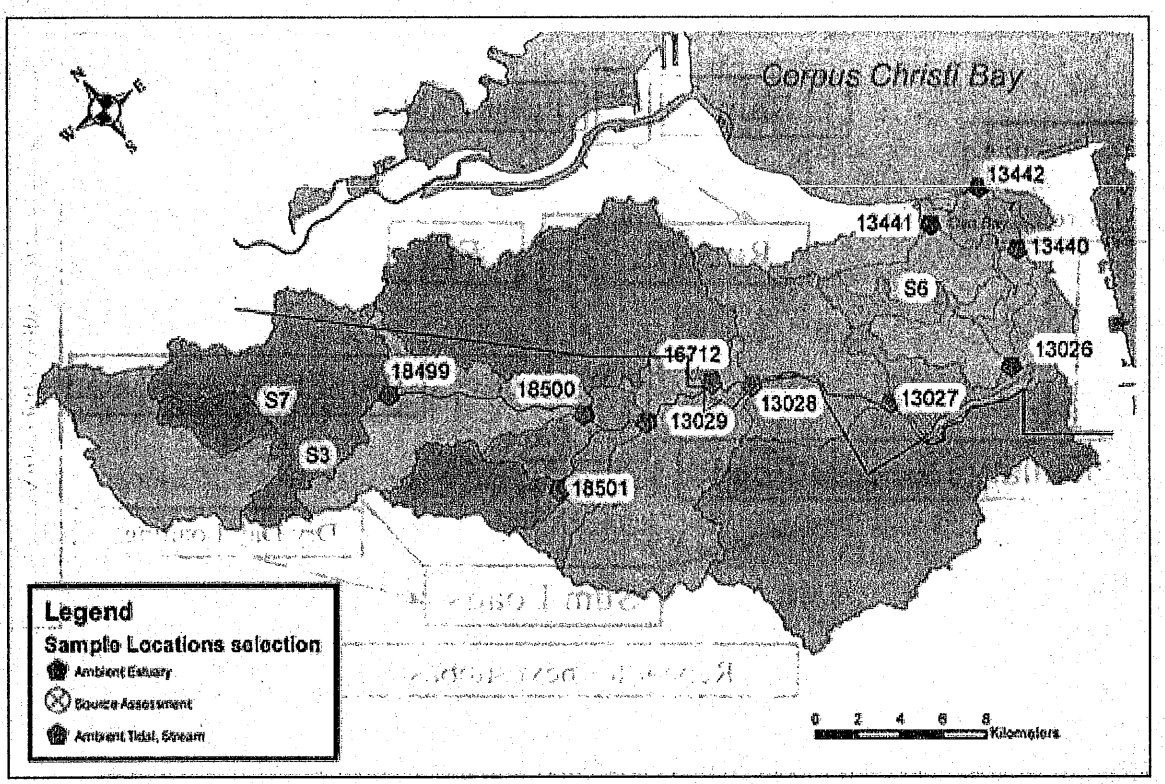


Figure 11: Subwatersheds with sampling point at outlets (pour points). Red line approximates current Corpus Christi boundary and MS4 permit coverage.

Decay Rate

Decay rate is a first order parameter that determines die off, sequestration, uptake, or predation of the bacteria and allows for the removal of bacteria from the model. Initial estimates of decay rate were based on literature reviews and observed rates of change in stream bacteria concentrations between stations. Those observations suggested that decay rates in fresh and salt water were different. Final decay rates were constrained within the range reported in literature, and balanced against the runoff concentrations and other loads in the calibration runs. The decay rates that were chosen for the final model were 2.0 day^{-1} in Oso Creek, and 4.0 day^{-1} in Oso Bay (Hay & Mott 2006).

Event Concentrations

The Oso model initially used event mean concentrations (EMCs) to characterize surface runoff quality, a common approach for watershed loading models. However, the model iterates in 2-hr time steps, much shorter than a complete rain event, and EMC values did not fit this model appropriately. Since the model is calculating concentrations that represent discrete intervals within the rain event, values representing the Enterococci

concentrations of the runoff before it enters channel flow and begins decaying (event concentrations) are required. Using the new decay rate of 2.0 day^{-1} for fresh water segments, event concentration (EC) values were back-calculated from EMC values assuming the EMC values represented about 1 day of decay. The final EC values for the land use categories used in the model are shown in Table 6. These values are comparable to the bacteria concentrations for fecal coliform observed by the City of Corpus Christi in its storm water, which had concentrations as high as 445,000 cfu/100 mL (City of Corpus Christi 2003).

Cropland was not well represented in the development of EMC values from the subwatershed for station S6. However, station 18501 on West Oso Creek, a tributary of Oso Creek, was used earlier in model development to determine a cropland EMC value appropriate for this area. This value was then used to calculate the EC for cropland.

Table 6: Land Use Types and ECs for Oso Model

Enterococci EC Value (cfu/100 mL)	Land Use Type
353,829	Residential
305,332	Commercial/Industrial/Transportation
62,807	Cropland/Rangeland
0	Not Classified

(See Table 3 for NLCD equivalents)

Dry-Day Loading

Early calibration runs of the model revealed a tendency to under-predict bacteria concentrations during dry weather periods when storm runoff is not affecting stream concentrations. Adjusting only decay rates would have required the use of decay rates well outside published values to account for the elevated bacteria levels observed in the dry periods. With addition of a dry-day loading parameter for each basin, the decay rates could be restricted to those observed in the literature.

The initial bi-hourly model was based on the assumption that the only sources of bacteria to the creek and bay were runoff and known point sources (i.e., WWTFs) and that the Enterococci bacteria die off when removed from their natural habitat (feces). However, persistently elevated bacteria concentrations in the fresh water portion of the system suggested that another flux of bacteria to the creek exists that is not related to runoff or known point sources. This flux, referred to in this report as dry-day loading, has a profound influence on the geometric mean value of Enterococci concentrations that determine whether a stream segment meets water quality objectives, and could have a number of various sources.

Fecal Enterococci are naturally found in the intestines of warm-blooded animals. Their egress to extra-intestinal environments is primarily via the feces of warm-blooded animal. There are numerous potential sources for the dry-day loading, including leaking or failed septic systems in a nearby subdivision, leaking municipal sewer lines near the creek, wildlife activity in and around the creek (nesting under bridges, feeding at waters edge), equestrian activities (exercising horses in the creek), and illegal discharge/disposal of sewage in the creek.

In rural and suburban areas, septic systems provide a steady source of fecal bacteria to the ground. Ideally the chemical and bacterial processes in the septic tank and mechanical processes and bacteria in the soil will serve to eliminate the fecal bacteria. Poorly maintained or leaking septic systems can undermine these processes. Clay soils, dominant in the Oso Creek watershed, are poorly suited for septic systems. Low permeability in soils such as clay require additional planning because they must have significantly larger leaching fields to effectively treat the water without contaminating the groundwater. Many studies suggest that Enterococci may be capable of surviving and growing within certain soil environments (Cools et al 2001). Groundwater, once contaminated, can be a steady long lasting flux of bacteria to surface waters.

Based upon the results of the initial bi-hourly model, the residence times and decay rate for any one segment of the creek are insufficient to remove all the bacteria in that segment and so each stream (or bay) segment transfers some bacteria load to the segment immediately downstream. Therefore, calculation of dry-day loads must begin at the uppermost stream segment in the hydrologic system. Since the temporal resolution of data collection was at intervals not less than daily, dry-day loading was represented in the model as a constant loading (flux) applied to each bi-hourly time step. To determine the dry-day load a model simulation was run to equilibrium (seven days) prior to the date of a sampling event. A binary search algorithm was used to determine, to the nearest hundredth of a $\log_{10}$, the bacteria load that would yield the observed concentration after the model reaches equilibrium. If the resulting load at a station was sufficient to generate the observed concentrations at the next station down stream, then the dry-day loading determined for the down stream station was limited to a value two orders of magnitude less than the load receive from upstream. This was done to constrain the log values of concentrations to the measurement limits of the analytical technique. Once dry loads were determined for each dry-day of each segment, the average dry-day loading was calculated for each of the segments. The dry-day loads for the revised bi-hourly model are listed in Table 7.

The dry-day loading rates for 2-hour model time steps may be converted to daily or annual loading rates for load allocation purposes, or to ease comparison to load allocation values. Table 7 shows dry-day loading rates used for each model subwatershed for bi-hourly, daily, and annual time periods. Daily loads in Table 7 are calculated as 12 times the bi-hourly loads used in modeling, and annual loads are calculated as 365 times the daily loads.

Table 7: Dry-Day loading Rates Used in Oso Model

Station ID	Enterococci Dry-Day loading Rates ($x10^{12}$ cfu/time unit)		
	per 2-hr time step	per day	per year
18499*	0.00459	0.05508	20.104
18500	0.00544	0.06528	23.827
13029	0.000640	0.00768	2.803
16712	0.0113	0.13560	49.494
13028	0.0379	0.45480	166.002
13027	0.141	1.69200	617.580
13026	0.0246	0.29520	107.748
13440	0.0307	0.36840	134.466
13441	0.00168	0.02016	7.358
13442	0.0650	0.78000	284.700

*Numbers in gray are associated with Oso Creek.

Existing Loads

The calibrated model characterized a yearlong period, using source loadings that were estimated from recent data (e.g., wastewater treatment facility effluent monitoring) or from the calibration process itself (e.g., storm runoff and dry-day loading). Therefore, the calibrated model also defines the magnitude of existing sources that affect bacteria concentrations in the Oso system.

A summary of the total annual loading from each source type for each model subwatershed was extracted from the calibrated model to represent the existing (i.e., pre-TMDL) conditions, and is presented in Table 8. For load allocation or management purposes, the annual loading rates shown in Table 8 may be mathematically manipulated to aggregate and express loading at different subwatershed scales (e.g., for Oso Creek and Oso Bay) rather than for each model subwatershed.

Model output concentrations corresponding to the existing loads in Table 8 are shown in Table 9. Concentrations shown in bold font in Table 9 exceeded the relevant goal, while those shown in italic font met the goals.

Table 8: Existing Loading by Model Subwatershed

Sub-watershed	Enterococci Loads x10^{12} cfu/year						
	Annual Dry Loading	WWTP Annual Loading	RESID	URBAN	CROP	RANGE	Total Sub-watershed Loads
18499*	20	0.07	341	219	886	67	1533
18500	24	0.00	5	2	263	12	307
13029	3	0.00	2	2	219	8	235
16712	50	0.40	299	575	753	117	1793
13028	166	0.00	14	23	453	33	689
13027	616	0.00	1154	631	294	76	2770
13026	108	0.00	144	125	737	422	1536
13440	134	0.00	668	300	84	156	1343
13441	7	0.79	516	178	0	14	716
13442	285	0.00	448	403	38	59	1233

*Numbers in gray are associated with Oso Creek.

Table 9: Model Output Concentrations from the Existing Load Simulation

Subwatershed	Enterococci Concentrations from Model, in cfu/100 mL	
	Geometric Mean	25% Exceed
18499*	1366.3	1199.9
18500	1321.6	1471.3
13029	909.0	1108.7
16712	569.1	797.5
13028	367.6	434.5
13027	349.3	380.0
13026	*7.9*	*5.8*
13440	*7.7*	*5.7*
13441	**80.5**	*50.1*
13442	*12.6*	*9.3*

*Numbers in gray are associated with Oso Creek.

Model Predictions

After the model was calibrated to observed data, which also defined the existing loads, additional model simulations predicted the effects of load reductions.

Dry-Day loading Removed

Since the dry-day loadings are the most significant factor in meeting the geometric mean criteria, this input was removed from the model at all stations and a new simulation was run. Table 10 shows loading by subwatershed for the scenario without dry-day loading, which is very similar to Table 8—only the Annual Dry Loading and Total Subwatershed Load columns are different between Tables 8 and 10.

Table 10: Modeled Loading with Dry-day Loads Removed

Subwatershed	Enterococci Loads $x10^{12}$ cfu/yr						
	Annual Dry Loading	WWTP Annual Loading	RESID	URBAN	CROP	RANGE	Total Subwatershed Load
18499*	0	0.07	341	219	886	67	1513
18500	0	0.00	5	2	263	12	283
13029	0	0.00	2	2	219	8	232
16712	0	0.40	299	575	753	117	1743
13028	0	0.00	14	23	453	33	523
13027	0	0.00	1154	631	294	76	2155
13026	0	0.00	144	125	737	422	1428
13440	0	0.00	668	300	84	156	1209
13441	0	0.79	516	178	0	14	709
13442	0	0.00	448	403	38	59	948

*Numbers in gray are associated with Oso Creek.

Although dry-day loading comprises a relatively small percentage of the existing load, removing it has a dramatic effect on predicted concentrations (Table 11). The results of that simulation displayed lower geometric mean concentrations at all stations, with some values meeting or only slightly higher than the water quality objectives. Additionally, the 25 percent single-sample values are much closer to meeting the 104 cfu/100 mL goal. With dry-day load removed, all of Oso Bay is predicted to meet the evaluation criteria. Concentrations shown in italic font in Table 11 met the goals.

Table 11: Model Output Concentrations from the No Dry-Day Load Simulation

Subwatershed	Enterococci Concentrations from Model, in cfu/100 mL	
	Geometric Mean	25% Exceed
18499*	36.0	419.4
18500	39.4	929.0
13029	38.6	793.4
16712	45.9	558.1
13028	26.4	247.4
13027	20.8	175.7
13026	2.7	2.3
13440	2.5	2.2
13441	13.6	5.4
13442	2.5	2.1

*Numbers in gray are associated with Oso Creek.

Allowable Loads

The allowable loads were determined using an iterative process, beginning with the station furthest upstream. Runoff loadings were reduced uniformly in the subwatershed furthest upstream and the model simulation rerun with incremental reductions until the station met both water quality criteria. Then the same process was repeated on the next station down stream until all stations met water quality goals. In some cases (subwatersheds 13029 and 13026), where the subwatershed received large loadings from the upstream subwatershed, the process of reduction to meet water quality goals at the upstream station resulted in the downstream station also meeting water quality goals. No reductions in runoff loadings were made to subwatersheds that met water quality goals.

Finally, in order to estimate the maximum allowable load, loading was added to the model Oso Bay subwatersheds that had not required large load reductions to produce simulated concentrations that meet the goals (subwatersheds 13026, 13440, 13441, and 13442). The existing storm runoff loads associated with the residential, urban, crop, and range land use categories in those subwatersheds were incrementally and evenly increased until the model predicted concentrations closer to but not exceeding the goals. The allowable additional loading calculated this way ranged from 10 to 80 times the existing amounts for those subwatersheds, reflecting the ability of Oso Bay to assimilate the

bacteria loading better than Oso Creek. The maximum allowable loads calculated by the model exercise are summarized in Table 12. Model output concentrations corresponding to the allowable loads in Table 12 are shown in Table 13. Concentrations shown in italic font in Table 13 met the goals.

Table 12: Allowable Loading by Model Subwatershed

Sub-watershed	Enterococci Loads $x10^{12}$ cfu/year						
	Annual Dry Loading	WWTP Annual Loading	RESID	URBAN	CROP	RANGE	Total Subwatershed Load
18499*	0	0.07	24	15	62	5	106
18500	0	0.00	1	0	26	1	28
13029	0	0.00	2	2	219	8	232
16712	0	0.40	30	57	75	12	175
13028	0	0.00	14	23	453	33	523
13027	0	0.00	577	316	147	38	1077
13026	108	0.00	11486	10028	58988	33729	114340
13440	134	0.00	20049	9003	2535	4677	36398
13441	0	0.79	5159	1780	1	138	7080
13442	285	0.00	13446	12083	1143	1778	28734

*Numbers in gray are associated with Oso Creek.

The existing and allowable loading rates shown in Tables 8 and 12 provide the information needed to calculate the percent reductions in loading simulated by the model analyses. The calculated percent reductions are shown in Table 14, for modeled bay subwatersheds and source types, with overall reductions for the subwatersheds also. Since the critical concentrations shown in Table 13 are well below the respective criteria, the percent reductions in Table 14 should be more than adequate to achieve water quality goals in Oso Bay.

Model analyses indicated that Oso Bay could assimilate more loading than currently exists. As reported by Hay & Mott (2005, 2006), only one small area of Oso Bay exceeded the contact recreation criteria during the study, and that exceedance was caused solely by the relatively small dry-day loading near station 13441. Removing the dry-day load from model simulations for subwatershed 13441 is adequate to achieve goals, but that is a very small percentage of the existing load and is less than the allowable increase in storm runoff loading. The initial dry-day loading at station 13441 was approximately

7 x 10^{12} cfu/year out of 716 x 10^{12} cfu/year total loading (Table 8), or less than one percent of the existing load. Allowable annual loading for that subwatershed (Table 12) is 7,080 x 10^{12} cfu/year, so the allowable loading would result in a negative percent reduction for annual loading to Oso Bay. Percent reductions are therefore considered not applicable (NA) to Oso Bay.

Table 13: Model Output Concentrations from Allowable Load Simulation

Subwatershed	Enterococci Concentrations from Model, in cfu/100 mL	
	Geometric Mean	25 % Exceed
18499*	*13.5*	*31.8*
18500	*10.8*	*68.6*
13029	*13.2*	*96.6*
16712	*15.7*	*67.7*
13028	*10.8*	*59.9*
13027	*11.6*	*78.7*
13026	*20.0*	*68.1*
13440	*21.3*	*71.4*
13441	*23.5*	*15.6*
13442	*28.4*	*58.2*

*Numbers in gray are associated with Oso Creek.

Hay & Mott (2005, 2006) also noted that station 13441 is unrepresentative of ambient conditions in Oso Bay and unsuitable for characterizing Oso Bay in assessments, as the station is essentially monitoring a freshwater inflow rather than ambient saline bay water (see Figure 6). Furthermore, station 13441 is in a well-known and popular bird watching and rookery area, where large concentrations of water birds nest in brushy wetland and feed in the extremely shallow water (several inches) along the Oso Bay shoreline. A boardwalk provides access for bird watching, but the density of both wetland vegetation and birds makes the area inhospitable for water-based contact recreation activities, and the site is very seldom if ever used that way. Local residents have indicated, in the course of various stakeholder meetings and conversations, that waterfowl habitat is considered the primary and most appropriate water body use in that vicinity, and should not be disrupted for the sake of inappropriate and theoretical contact recreation.

Table 14: Percent Reductions for Oso Bay by Model Subwatershed and Source Type

Subwatershed	Annual Dry Loading	WWTF Annual Loading	RESID	URBAN	CROP	RANGE	Total Subwatershed Load
13026	0.00%		NA	NA	NA	NA	NA
13440	0.00%		NA	NA	NA	NA	NA
13441	100.00%	0.00%	NA	NA	NA	NA	NA
13442	0.00%		NA	NA	NA	NA	NA

Permitted wastewater discharges were not major sources of bacteria loading (Hay & Mott 2005). Several of the permitted discharges are industrial and were not deemed likely sources by the sanitary survey. Discharges of treated domestic waste contributed a very small portion of the existing load, and were generally compliant with bacterial criteria, so reductions in that source were not necessary or simulated.

Attainment of the geometric mean criterion for Enterococci at the Oso Bay stations will primarily depend on managing the dry-day loads near station 13441. Storm runoff loading has not impaired Oso Bay.

Margin of Safety

The margin of safety (MOS) should 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. The margin of safety may be incorporated into the analysis using two methods:

- implicitly incorporating the MOS using conservative model assumptions to develop allocations, or
- explicitly assigning a loading amount for the MOS.

The margin of safety 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 a margin of safety.

The Oso Bay allocation includes an implicit margin of safety in that the predicted geometric mean and 25 percent exceedance concentrations based on the load allocation (see Table 13) are well below the respective criteria. Annual geometric means predicted at all stations were well below the criterion of 35 cfu/100mL. The "25% exceed" concentrations predicted at all stations were well below the 104 cfu/100mL that was used, and all in Oso Bay were below the 89 cfu/100mL currently in the Water Quality

Standards. The margin of safety has not been explicitly calculated for expression as a load or percentage.

Pollutant Load Allocation

The TMDL represents the maximum amount of pollutant that the water body can receive without exceeding the water quality standard. The load allocations for the selected scenarios are summarized using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where

WLA = wasteload allocation (point source contributions);
LA = load allocation (nonpoint source allocation); and
MOS = margin of safety.

As mentioned in the previous section, the margin of safety for the Oso Bay TMDL is implicit, so does not appear as an explicit amount in the TMDL summation.

Typically, several potential allocation strategies would achieve the TMDL endpoint and water quality standards. Available control options depend on the number, location, and character of pollutant sources.

Parsing of the sources into point and nonpoint categories is not simple in this case. As mentioned previously, storm water runoff from areas covered by a storm-water discharge permit must be categorized as a point source, while storm runoff from other areas is a nonpoint source. The modeled subwatersheds were based on the physical topography of the watershed, and do not conveniently match the boundaries of the area covered by the City of Corpus Christi MS4 permit. Also, the dry-day loading was modeled as a point source, but will be considered a nonpoint source for allocation purposes since no specific point of origin or responsible parties can be identified at this time. However, as specific dry-day load sources are identified, some may be considered point sources and some may not.

In order to determine how much of the runoff loading allocation must be placed in the point source category because of the City of Corpus Christi MS4 permit, the city limits boundary was used. The storm water permit in effect as this report was compiled covers all areas within the corporate boundary of the City of Corpus Christi served by municipal separate storm sewers owned or operated by the City, and the assumption was made that all parts of the Oso watershed within the city limits are included. Map overlays were used to estimate the amount of each model subwatershed within the Corpus Christi city limits (Table 15). The sum of allowable loading from the residential, urban, cropland, and range land uses for each subwatershed was then multiplied by the fraction of each subwatershed area within Corpus Christi, and that portion of the runoff loading was placed in the point source (WLA) allocations.

Table 15: Portion of Each Subwatershed within Corpus Christi City Limits

Model Subwatershed	Fraction in CC
18499	0.06
18500	0.00
13029	0.00
16712	0.85
13028	0.05
13027	0.64
13026	0.21
13440	1.00
13441	1.00
13442	1.00

Table 16 shows the subwatershed total allowable loads (from Table 12) redistributed between "point" and "nonpoint" categories as required for the TMDL equation, using the method described above.

After redistribution of loading to point and nonpoint categories, allowable loads from the individual subwatersheds were aggregated to represent the Oso Bay watershed. The bottom row of Table 16 summarizes loading from the four subwatersheds that comprise the proximate Oso Bay watershed. The TMDL for Oso Bay must also account for loading that is delivered to the bay by the creek. The total load passing from station 13027 (lower end of creek) into the bay over the simulated annual period was 772.81×10^{12} cfu/yr. That amount is added to the nonpoint source total from the bay subwatersheds to calculate the total maximum annual load for Oso Bay.

The resulting equation shown below is the TMDL for Oso Bay, expressed in annual units. These values will be the bases for administering the implementation plan and evaluating success of the TMDL.

Table 16: Allowable Loading Redistributed to LA and WLA Categories

All loads 10^{12} cfu/yr

	"Nonpoint"	"Point"	
Subwatershed	**LA +**	**WLA =**	**TMDL**
Oso Creek annual export to Oso Bay = 772.81 (part of LA)			
13026	90328.30	24011.32	114339.62
13440	0.00	36398.41	36398.41
13441	0.00	7079.79	7079.79
13442	0.00	28733.79	28733.79
Oso Bay total	**90328.30**	**96223.31**	**186551.61**

*Numbers in gray are associated with Oso Creek.

Oso Bay TMDL in Annual Units

LA	+	WLA	=	TMDL
91,101.11	+	96,223.31	=	187,324.42 x 10^{12} cfu/year ("T-org/yr")

Note on units:
Other sources or documents may use different terminology for the units in which this TMDL is expressed, as shown below.

1x10^{12} cfu or organisms per year	=	trillion/yr	= 1 tera-org or "T-org" per year
1x10^{9} cfu or organisms per year	=	billion/yr	= 1 giga-org or "G-org" per year
1x10^{6} cfu or organisms per year	=	million/yr	= 1 mega-org or "M-org" per year

This TMDL is consistent with the anti-degradation policy established in the TSWQS (30TAC§307.5). This TMDL will not authorize discharges of pollutants in amounts that would degrade existing or designated contact recreation use of Oso Bay.

Expressing Load Allocation in Daily Units

While the annual load allocation described above will be the basis for State management and implementation, it is desirable to express the allocation in daily units as well. The daily unit expression is designed to satisfy any concern that the load allocation is not strictly consistent with the phrase "total maximum daily load."

Daily loading that is primarily affected by storm water runoff varies dramatically in time. Both the average and the maximum amount of loading allowable on any specific day is a

function of the stream flow on that date. The analyses and annual load allocation described above were converted to daily unit expressions as follows.

There are two U. S. Geological Survey (USGS) stream flow gauging stations in the Oso watershed: "08211520 Oso Creek at Corpus Christi, TX" and "08211517 W Oso Ck at Merret Rd nr Corpus Christi, TX." The West Oso Creek gauge was established in 2005, and does not have sufficient period of record to be used for statistical analyses. The Oso Creek gauge (08211520) has a period of record extending back to 1972, and provided daily average flow data used to derive daily load allocation units.

The daily average flows for the entire period of record were downloaded from the USGS on-line data, and inserted into a spreadsheet. A percentile function within the spreadsheet was used to extract flow values that correspond to a frequency of occurrence. For instance, the spreadsheet function derives a "10^{th} percentile" flow that is larger than 10 percent of the daily average values in the record, or smaller than 90 percent. The "0 percent" flow is the smallest recorded; the "100 percent" flow is the largest recorded. The resulting list of percentiles and flows can define a "flow duration curve" or the potential flow range at the gauge site, which is at station 13029 previously described in this report.

The range of flows defined by that extraction process can be extrapolated to other areas within the watershed, or in nearby areas, using the "Drainage-Area Ratio Method" described by a recent USGS Scientific Investigation Report (Asquith et al 2006). The method is based on the equation:

$$Qu = Qg \times \left(\frac{Au}{Ag} \right)^{\phi}$$

Where:

Qu = flow at ungauged site
Qg = flow at gauged site
Au = drainage area at ungauged site
Ag = drainage area at gauged site
ϕ = exponent corresponding to flow percentile

The percentile intervals used to extract flow values corresponded to the intervals presented in the USGS report Table 5, so corresponding "phi" exponents could be used for converting flows to other sites.

Next, drainage areas for each of the Oso model subwatersheds were assembled, and summed as appropriate to derive the total upstream drainage area for each subwatershed outlet point. Then the equation above was applied to each flow percentile value using the appropriate drainage area ratios and exponent values, to derive estimated flow ranges for each of the Oso Bay subwatershed outlets (13026, 13440, 13441, 13442) and for the Oso Creek outlet that discharges to Oso Bay (13027).

Records of the Oso modeled bacteria concentrations at each subwatershed outlet for each two-hour time step were also loaded into a spreadsheet. A running 24-hour average concentration was calculated for each subwatershed, and the maximum 24-hr average concentration selected for each. Those represent the "maximum daily concentration" from the allowable load scenario on which this TMDL is based.

The flow range thus derived for Oso Bay is broadly characterized by the net flow predicted at station 13442, the outlet from Oso Bay. The spreadsheet was used to "balance" that flow by distributing it among the subwatershed of origin, thus determining how much came in from Oso Creek (13027), and how much entered incrementally from each of the Oso Bay subwatersheds (13026, 13440, 13441, 13442). The balancing distribution was applied to each percentile flow in the list originally derived.

The total *average* daily load was calculated by multiplying the subwatershed components of the balanced flow times the geometric mean criterion of 35 cfu/100 mL. The total *maximum* daily load was calculated by multiplying the subwatershed component flows times the respective maximum 24-hr average concentrations from the model runs. The result is a list of flows (cubic feet per second) and loads (10^{12} org/day). Figure 12 presents the results graphically.

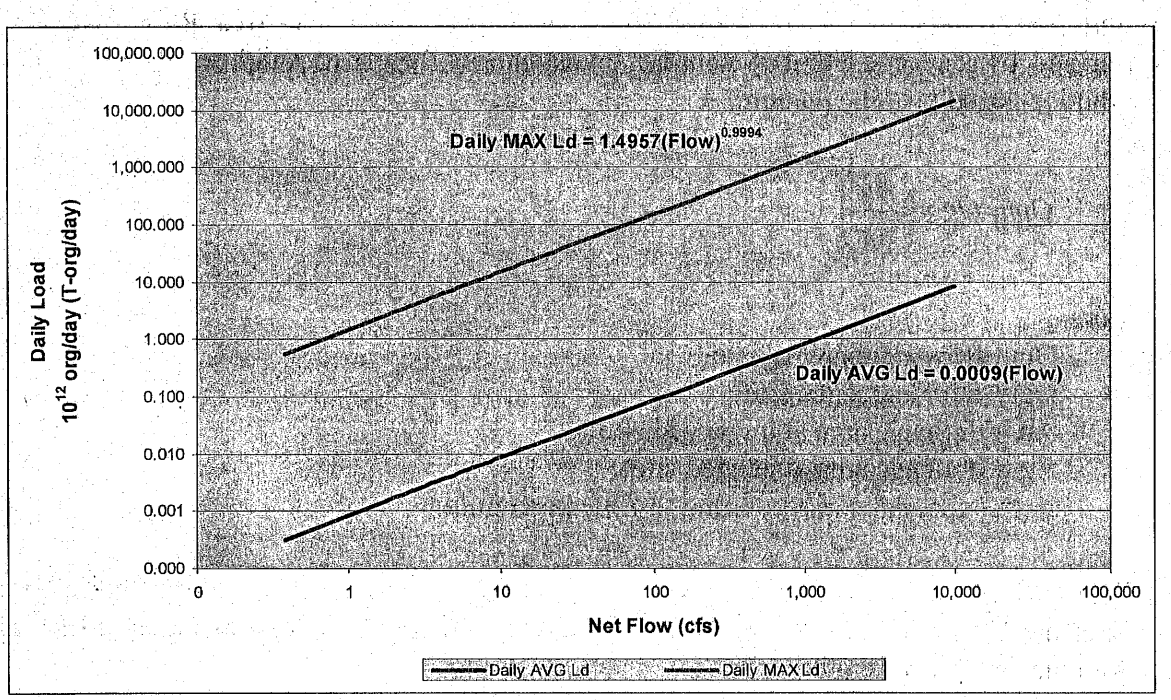


Figure 12: Daily load allocations as function of flow rate

Power-function trend lines were fit to the curves produced shown on Figure 12. The daily average curve is linear, and the daily maximum curve very nearly linear. The trend line equations, as shown below, thus can be used to calculate the daily unit load allocation for any amount of net flow through Oso Bay.

Total Average Daily Load:

$$\text{Daily Avg Load} = 0.0009 \times \text{Flow}$$

Total Maximum Daily Load:

$$\text{Daily Max Load} = 1.4957 \times \text{Flow}^{0.9994}$$

In both equations, flows are entered as cubic feet per second (cfs) and loads are calculated as trillion organisms per day or "$x10^{12}$ org/day" or "T-org/day."

Seasonal Variation

Seasonal variation was considered while developing the Oso Bay load allocation. The model analyses simulated an entire year, with 2-hour time steps, thus accounting for seasonal and daily variation in rainfall patterns and surface runoff loading. The annual allocation summarizes loading for the range of conditions that occur across all seasons. The daily-unit expression of maximum load considers loading that could occur under the most extreme variations in flow.

Public Participation

Public participation is important to the success of a TMDL project. The TCEQ formed a stakeholder group for development of the Oso TMDLs. The group includes representatives from state and federal agencies, the local estuary program, industries, citizen groups, local governments and non-governmental organizations, universities, water districts, agricultural interests, environmental groups, and other water user groups.

The Oso Bay advisory group provided advice and comment to the TCEQ on its project to improve water quality in the watersheds of Oso Bay and Oso Creek in Nueces County. Participation was voluntary. Anyone who was interested could attend meetings of this advisory group. Time was set aside at each meeting for questions and comments from all stakeholders in attendance.

- The first stakeholder meeting was held on January 18, 2005, at the Texas A&M University - Corpus Christi campus in the Natural Resources Center.
- The second stakeholder meeting was held on June 21, 2005, at the Natural Resources Center, TAMUCC. An update on the status of the project was presented.
- A third stakeholder meeting was held on August 23, 2005, at the Natural Resources Center, TAMUCC. A preliminary model run was presented.
- The fourth stakeholder meeting was held on January 17, 2006. A project update was presented, along with a presentation on septic system permitting by the City-

County Health Department. The group also began to brainstorm ideas for ways to control the various sources of bacteria throughout the watershed.

- The fifth stakeholder meeting was held on May 16, 2006. The modeling analysis was discussed.
- The sixth stakeholder meeting was held on February 8, 2007. A quick review of the modeling analysis was followed by an outline of how the model results would be crafted into the load allocation expressed by the TMDL equations, and discussion of possible implementation measures.

Implementation and Reasonable Assurances

All TMDL projects of the TCEQ include two components (or phases). These phases are:

1) TMDL development
2) TMDL implementation

During TMDL development, the TCEQ determines the acceptable pollutant load for impaired water bodies and apportions the load among broad categories of pollutant sources in the watershed. This information is summarized in a TMDL report such as this document.

During TMDL implementation, the TCEQ helps develop the management strategies needed to restore water quality to an impaired water body, in conjunction with area stakeholders. This information is summarized in an implementation plan (I-Plan) which references, but is separate from, the TMDL document. The I-Plan details load reduction and other mitigation measures planned to restore water quality in an impaired water body.

I-Plans to achieve the recommended loadings may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. An adaptive management approach allows for development or refinement of technologies that achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation measures assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency while maintaining the objective of compliance with water quality standards.

This approach provides reasonable assurances that the necessary regulatory and voluntary activities to achieve the pollutant reductions identified will be implemented.

Implementation of the Oso Bay TMDL may need to address permit conditions for one large municipal WWTP, one large cooling water discharge, and an MS4 permit. None of those sources are considered causes of impairment. Revisions to these permits would not be expected to be onerous or difficult.

An important issue in implementation will be the status of the monitoring station located in a bird rookery area. Removing the birds is neither practical nor desired by citizens of the area. The approach will be to either change the designated recreation use level for that site (i.e. from "primary contact recreation" to "secondary contact recreation") once such changes are enabled by revision of the Water Quality Standards, or to establish that the station is not representative of Oso Bay and contact recreation sites and therefore not used for impairment assessments.

Implementation Processes to Address the TMDL

Together, a TMDL and a TMDL I-Plan direct the correction of unacceptable water quality conditions that exist in an impaired surface water in the state. A TMDL broadly identifies the pollutant load goal after assessment of existing conditions and the impact on those conditions from probable or known sources. A TMDL identifies a total loading from the combination of point sources and nonpoint sources that would allow attainment of the established water quality standard.

A TMDL I-Plan specifically identifies required or voluntary implementation actions that will be taken to achieve the pollutant loading goals of the TMDL. Regulatory actions identified in the I-Plan could include adjustment of an effluent limitation in a wastewater permit, a schedule for the elimination of a certain pollutant source, identification of any nonpoint source discharge that would be regulated as a point source, a limitation or prohibition for authorizing a point source under a general permit, or a required modification to a storm water management program (SWMP) and pollution prevention plan (PPP). 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.

A TMDL and the underlying assumptions, model scenarios, and assessment results are not and should not be interpreted as required effluent limitations, pollutant load reductions that will be applied to specific permits, or any other regulatory action necessary to achieve attainment of the water quality standard. In simple terms, a TMDL is like a budget that determines the amount of a particular pollutant that the water body can receive and still meet a water quality standard. The I-Plan adopted by the Commission will direct implementation requirements applicable to certain sources contributing a pollutant load to the impaired water.

The I-Plan will be developed through effective coordination with stakeholders affected by or interested in the goals of the TMDL. In determining which sources need to accomplish what reductions, the I-Plan may consider factors such as cost, feasibility, the current

availability or likelihood of funding, existing or planned pollutant reduction initiatives such as watershed-based protection plans, whether a source is subject to an existing regulation, the willingness and commitment of a regulated or unregulated source, and a host of additional factors. 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 adopted may not approximate the predicted loadings identified category by category in the TMDL and its underlying assessment, but with certain exceptions, the I-Plan must nonetheless meet the overall loading goal established by the Commission-adopted and EPA-approved TMDL.

An exception would include an I-Plan that identifies a phased implementation that takes advantage of an adaptive management approach. 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 was required by the TMDL, high uncertainty with the TMDL analysis exists, 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. Instead, activities contained in the first phase of implementation may be the full scope of the initial I-Plan and include strategies to make substantial progress towards source reduction and elimination, refine the TMDL analysis, conduct site-specific analyses of the appropriateness of an existing use, and monitor in stream water quality to gauge the results of the first phase. Ultimately, the accomplishments of the first phase would lead to development of a phase two or final I-Plan or revision of TMDL. This adaptive management approach is consistent with established guidance from EPA (See August 2, 2006 memorandum from EPA relating to clarifications on TMDL revisions).

The TCEQ maintains an overall water quality management plan (WQMP) that directs the efforts to address water quality problems and restore water quality uses throughout Texas. The WQMP is continually updated with new, more specifically focused WQMPs, or "water quality management plan elements" as identified in federal regulations (40 Code of Federal Regulations (CFR) Sec. 130.6(c)). Consistent with federal requirements, each TMDL is a plan element of a WQMP and Commission adoption of a TMDL is state certification of the WQMP update.

Because the TMDL does not reflect or direct specific implementation by any one pollutant discharger, the TCEQ certifies additional "water quality management plan elements" to the WQMP once the I-Plan is adopted by the Commission. Based upon the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits. The TCEQ would normally establish best management practices (BMPs), which are a substitute for effluent limitations in TPDES MS4 storm water permits as allowed by the federal rules where numeric effluent limitations are infeasible (See November 22, 2002 memorandum from EPA relating to establishing TMDL WLAs for storm water sources). Thus, TCEQ would not identify specific implementation requirements applicable to a specific TPDES storm water permit through an effluent limitation update. However, the TCEQ would revise a storm water permit,

require a revised SWMP or PPP, or implement other specific revisions affecting storm water dischargers in accordance with an adopted I-Plan.

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