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One Total Maximum Daily Load for Bacteria in Upper Oyster Creek

Segment 1245

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One Total Maximum Daily Load for Bacteria in Upper Oyster Creek

Executive Summary

This document presents the total maximum daily load (TMDL) for bacteria in Upper Oyster Creek (Segment 1245). Upper Oyster Creek extends for approximately 54 miles in rapidly urbanizing Fort Bend County, and has a watershed area of 110 square miles. It is located in the Brazos River Basin southwest of Houston.

Sampling conducted as part of this project confirmed that Upper Oyster Creek is not meeting its designated contact recreation use. The problem extends through much of the length of the segment and is highly influenced by rainfall runoff events. Potential sources of bacteria in the watershed include humans, pets, livestock, and wildlife. The goal of this project is to determine the allowable bacteria loading that will enable Upper Oyster Creek to meet its contact recreation use.

Upper Oyster Creek can be divided into two hydrologically distinct sections; load allocations were developed for both using the load duration curve method. Based on the analysis of the load allocation scenarios, a 73 percent reduction in bacteria loading in each section is required to meet the contact recreation use.

The TCEQ and its stakeholders will develop an implementation plan that will outline the management strategies needed to restore water quality to Upper Oyster Creek. The continued involvement of the TMDL steering committee will be essential to the success of implementation.

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 TMDL for each pollutant that contributes to the impairment of water. The priority for this TMDL development was medium. The Texas Commission on Environmental Quality (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 period of time, 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 an impairment to the contact recreation use due to elevated levels of bacteria in Upper Oyster Creek. The ultimate goal of this TMDL is to decrease bacteria concentrations in Upper Oyster Creek to the extent necessary to meet the contact recreation use.

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. The EPA provides further direction for developing TMDLs in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines. The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

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

The commission adopted this document on August 8, 2007. Upon EPA approval, the TMDL will become an update to the state's Water Quality Management Plan.

Problem Definition

Upper Oyster Creek was first placed on the state's 303(d) List for bacteria in 1996. However, high levels of indicator bacteria had been noted for many years before that. For example, a use attainability analysis conducted to assess the aquatic life use on Upper Oyster Creek in the early 1990s noted "…many exceedances of fecal coliform have occurred in the past 10 years, especially at US 90A" (Texas Water Commission, 1991). In more recent years (TCEQ, 2002 and 2004), the 303(d) List specified that the portion of the segment "from Highway 90A to Dam #1, located 1.5 miles upstream of Harmon St." was impaired due to the presence of bacteria.

Watershed Overview

Upper Oyster Creek is located in the Brazos River Basin, southwest of Houston, Texas, in northern Fort Bend County. It is identified as Segment 1245 in the *Texas Surface Water Quality Standards* (TCEQ, 2000). It has been subjected to significant hydrologic modification. The segment called “Upper Oyster Creek” actually includes portions of several water bodies. It begins at the Gulf Coast Water Authority (GCWA) Shannon Pump Station on the Brazos River and continues through Jones Creek to its confluence with Oyster Creek, through the City of Sugar Land to its confluence with Flat Bank Creek, through Flat Bank Creek to its confluence with a diversion canal, through the diversion canal to its confluence with Steep Bank Creek, and finally through Steep Bank Creek to its confluence with the Brazos River (Figure 1). Segment 1245 extends approximately 54 miles, and its watershed contains four incorporated areas: Fulshear, Sugar Land, Stafford, and Missouri City. The Upper Oyster Creek watershed covers approximately 110 square miles, about 12.5 percent of the area of Fort Bend County.

Three small dams on Upper Oyster Creek are located on the watercourse around the City of Sugar Land. The dams form impoundments to maintain nearly constant water levels for industrial and recreational uses. These off-channel lakes create “lakefront” property with commensurate aesthetic and monetary value. There are two distinct hydrologic reaches within the Upper Oyster Creek segment. The upper reach extends from the GCWA Shannon Pump Station on the Brazos River to Dam #3 within the City of Sugar Land. The lower reach begins at Dam #3 and continues downstream through Steep Bank Creek to its confluence with the Brazos River.

The GCWA uses the reach above Dam #3 as a section of its Canal System A, which supplies water for irrigation, industrial, and public drinking supply to areas southeast of the watershed in addition to uses in the vicinity of the City of Sugar Land. Dam #3 retains water for Alkire, Eldridge, and Horseshoe Lakes, and also serves to retain water for the GCWA Second Lift Station where water is pumped into the American Canal for transport to the Texas City area.

The hydrology of the reach below Dam #3 is highly influenced by the presence of the dam and the Second Lift Station. Small amounts of seepage do occur through Dam #3, and there is uncontrolled, excess rainfall runoff over the dam into the lower reach. The Second Lift Station, however, operates under most wet-weather conditions to capture portions of the rainfall runoff, which reduces the amount released below Dam #3. The lower reach contains no retention structures, and is characterized by reduced flow composed of small amounts of seepage from Dam #3, contributions from municipal dischargers, natural contributions from the drainage area below Dam #3, and excess rainfall runoff that is not diverted from the upper reach above Dam #3. The reach below Dam #3 is also hydrologically modified, though not for conveyance of water supplies and impoundment of water, but rather for flood prevention.

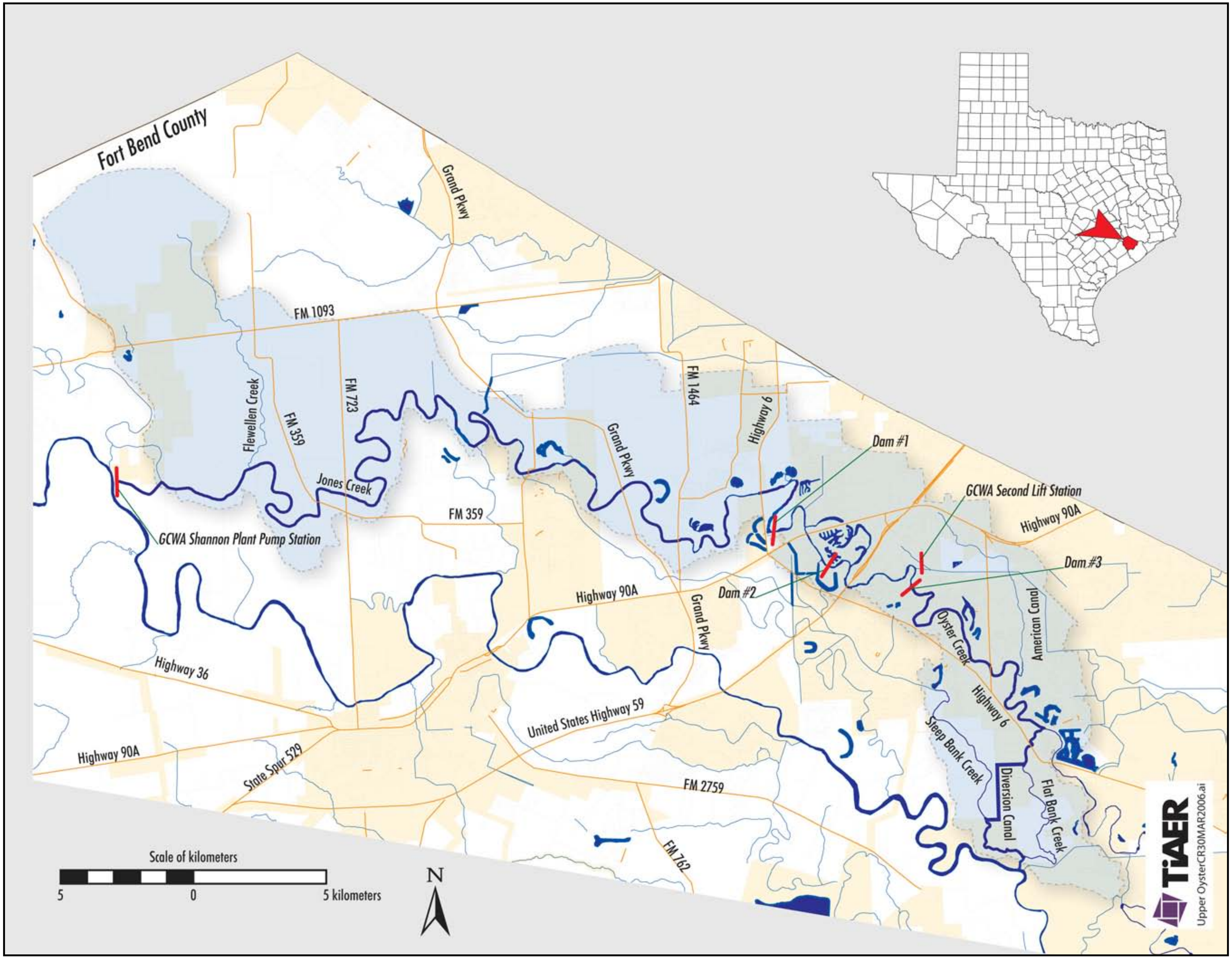


Figure 1. Upper Oyster Creek watershed

Data from GCWA Shannon Pump Station and the Second Lift Station were evaluated for trends and general characteristics for the period 1986 through 2000 (TIAER, 2006). Records from the Second Lift Station were used to characterize monthly hydrologic conditions in the upper reach of Upper Oyster Creek, because some, though not all, rainfall runoff is captured and pumped from that station.

Data for the Second Lift Station indicate that the pumped flow increases through the spring (between 1,000 to 3,000 acre-feet per month [ac-ft/mo] on average) to a maximum in July. Pumped flow decreases through the fall and winter to its lowest average rate of 1,325 ac-ft/mo in February. Average annual pumped flow through the segment is over 50,000 ac-ft per year. Annual flows range from a minimum of 28,889 ac-ft pumped in 1997, to a maximum of 69,670 ac-ft pumped in 1995. Existing flow data from the U.S. Geological Survey (USGS) station 08112500 (Brazos River Authority Canal A near Fulshear; no longer in operation) suggest similar characteristics and patterns of pumped flow for the period from 1931 to 1973. Seasonal high flow was observed in the USGS data for the months of April through September, while lower flow was noted in March and October. Flow is usually lowest in the months of November through February.

The dominant land use category in the watershed is pasture, which accounts for 56.1 percent of the total area. The urban areas (urban mixed and residential) occupy 24 percent of land cover within the watershed. Other land uses include rangeland at 9.5 percent, forest at 7.2 percent, and water at 3.2 percent (see Figure 2).

The climate in the Upper Oyster Creek watershed is classified as subtropical, which is defined as having hot, humid summers and dry winters. Between 1970 and 2000, the average annual rainfall was 49.3 inches, as measured at Sugar Land Regional Airport (NOAA, 2004). During this same period, rainfall events of at least 0.1, 0.5, and 1 inch of rain were observed on average 64, 31, and 16 days per year, respectively. The Upper Oyster Creek watershed is within the upper portion of the Gulf Coast Prairies and Marshes ecoregion, an area characterized as containing nearly level, un-dissected plains with native vegetation types composed of tall grass prairie and post oak savanna. The elevation of the area is approximately 80 feet above mean sea level.

Endpoint Identification

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

The *Texas Surface Water Quality Standards* (TCEQ, 2000) are rules developed by the TCEQ that provide a basis on which regulatory programs may be carried out. Categories are defined by the TCEQ to describe the way that water bodies in the state are used. Each use category is associated with a suite of criteria developed to protect the continued use of each water body in the state. According to Appendix A of the Standards, the designated

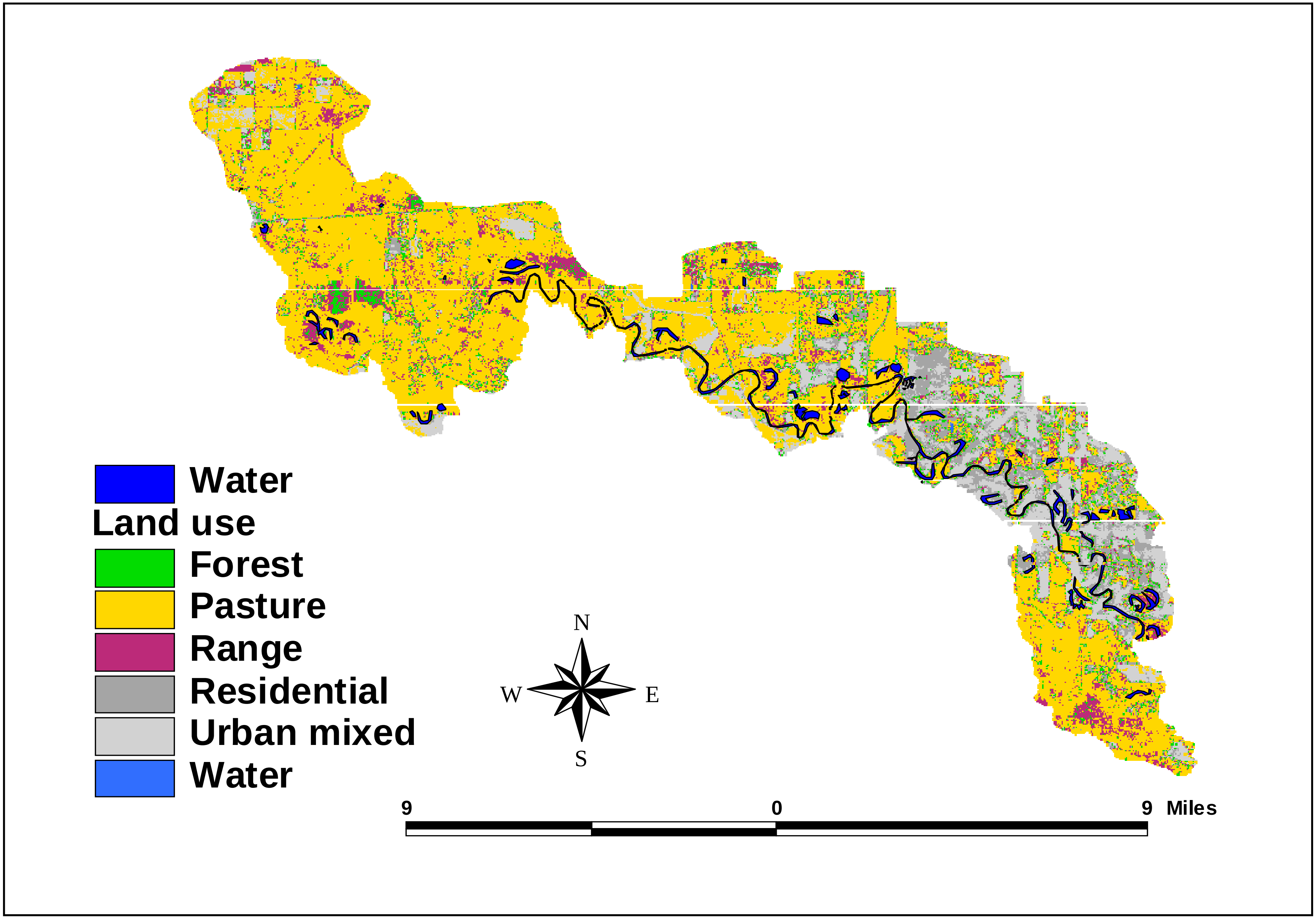


Figure 2. Land use/land cover for the Upper Oyster Creek watershed (Source: Baylor, 1997)

uses of Upper Oyster Creek include contact recreation, intermediate aquatic life use, and domestic water supply.

Upper Oyster Creek also fails to meet its aquatic life use due to depressed levels of dissolved oxygen. This TMDL document will only address the bacteria impairment. The dissolved oxygen TMDL will be presented in a separate document at a later date.

The water quality criteria for contact recreation in Upper Oyster Creek are expressed as the number of colony forming units (cfu) of *Escherichia coli* (*E. coli*) per 100 milliliters (mL) of water (Table 1). The contact recreation use is not met if bacteria concentrations exceed either the single sample or geometric mean criteria. However, 25 percent of the samples must exceed the criterion for single samples before the water body is assessed as not supporting the contact recreation use (TCEQ 2003).

Table 1. Numeric criteria for Upper Oyster Creek

Segment	**Contact Recreation Use Criteria (*E. coli*)**	
	Single Sample	**Geometric Mean**
1245 – Upper Oyster Creek	394 cfu/100 mL	126 cfu/100 mL

E. coli replaced fecal coliform as the preferred indicator bacteria for freshwater in Texas in revisions to the Standards in 2000. This change was anticipated while planning the project, and *E. coli* data were collected during all relevant sampling events. *E. coli* is typically not pathogenic. Its presence in water indicates *potential* contamination from the feces of warm-blooded animals. The use of indicator bacteria is necessary because it is not currently feasible to directly measure all potential pathogens in water.

The endpoint for this TMDL is based on the single sample criterion, which will be used for calculating the load allocation. As demonstrated later in the report, if the single sample criterion is met, the geometric mean criterion should be met as well.

Source Analysis

Pollutants may come from several sources, both point and nonpoint. Point source pollutants come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). Storm water discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution. Nonpoint source pollution originates from multiple locations, usually carried to surface waters by rainfall runoff, and is not regulated by permit under the TPDES. The possible sources of bacteria in Upper Oyster Creek are discussed in this section.

Permitted Discharges

Under TPDES, the TCEQ has issued permits to discharge treated wastewater to 15 facilities within the watershed (Table 2). All 15 are domestic wastewater (sewage) treatment facilities. Two additional facilities within the segment have been issued permits without provisions that allow discharge of wastewater—the Texas Department of Criminal Justice (TDCJ), for a confined animal feeding operation (CAFO) with land application of solid and liquid waste, and Bono Brothers Inc., for beneficial land application of sewage sludge and domestic septage. For completeness, these two facilities are also included in Table 2. Finally, Hines Nurseries has a permit for discharge of a small amount of domestic wastewater and a permit to discharge storm/irrigation waters.

From approximately 2000 to mid-2004, domestic wastewater facilities discharged a reported average of 11.9 million gallons per day (MGD) into Upper Oyster Creek, which is well below the total of 31.9 MGD allowed for all permitted discharges. A number of facilities have become operational since 2004; no monitored discharge information is provided for these facilities. Rapid urbanization of the watershed is correlated with a steadily increasing wastewater input into the segment, as indicated by increases in discharge limits for some municipal facilities within the segment and the addition of new discharge permits in recent years.

The City of Sugar Land and Fort Bend County Water Control and Improvement District (WCID) #2 permits allow the largest discharge of the wastewater facilities at over 5 MGD each. The other wastewater facilities with permitted wastewater discharges of greater than 1 MGD are Quail Valley Utility District, Missouri City, and Fort Bend County Municipal Utility Districts (MUDs) #s 25, 118, and 142. Except for the City of Missouri City, the wastewater permits do not include specific limits or monitoring requirements for indicator bacteria concentrations in their effluents. (Missouri City’s permit requires monitoring because the facility uses ultraviolet light disinfection rather than chlorination/dechlorination.) With the exception of Hines Nurseries (which is permitted to discharge domestic-type waste, but does not actually do so based on self-reporting data), all permitted facilities are required to disinfect their treated effluent prior to discharge (Table 2). Disinfection is designed to reduce or eliminate bacteria from the effluent.

In 2001, TIAER staff surveyed the TPDES permit files to identify enforcement actions or other persistent problems with permitted discharge facilities within Segment 1245. Staff updated the survey in 2005 by reviewing the discharge monitoring reports (DMR) from the Permit Compliance System (PCS) downloaded from the USEPA’s Envirofacts Data Warehouse (USEPA, 2005).

No enforcement actions were found in the screening. However, some self-reporting, operation, and administration violations were noted in the files. The TDCJ facility has had violations regarding uncertified personnel, operational requirements, and final effluent limitations. These violations surfaced during an annual inspection and were completely resolved within the required time frame. The TDCJ facility underwent a $4.5 million expansion during 2001 and 2002.

Table 2. Permitted wastewater discharges to Upper Oyster Creek and its tributaries

TPDES Permit No.	Facility	Dates Monitored	Monthly Average Discharge (MGD)	Final Permitted Discharge (MGD)	Selected Permit Requirements on Final Permitted Discharge	
					Report Fecal Coliform Bacteria	Disinfection Requirement[6]
WQ003742	Bono Brothers Inc. (Sludge)[1]	NA	NA	NA	NA	NA
WQ0013873-001	City of Missouri City	12/31/99-6/30/04	0.69	3.0	Yes (includes effluent limits)	Ultraviolet Light
WQ0012833-002	City of Sugar Land	1/31/00-6/30/04	4.61	10.0	No	Chlorination & Dechlorination
WQ0012003-001	Fort Bend County MUD # 25	9/30/99-7/31/04	0.42	1.6	Yes	Chlorination & Dechlorination
WQ0012475-001	Fort Bend County MUD # 41	11/30/99-5/31/04	0.25	0.86	No	Chlorination
WQ0013951-001	Fort Bend County MUD # 118	8/31/00-5/31/04	0.064	1.2	No	Chlorination & Dechlorination
WQ0014715-001	Fort Bend County MUD # 134[2]	NA[3]	—	0.30	No	Chlorination
WQ0014408-001	Fort Bend County MUD # 142	NA[3]	—	1.2	No	Chlorination & Dechlorination
WQ0014692-001	Fort Bend County MUD # 182	NA[3]	—	0.8	No	Chlorination
WQ0010086-001	Fort Bend County WCID #2	1/31/00-7/31/04	3.52	6.0	No	Chlorination & Dechlorination
WQ003015-000	Hines Nurseries Inc.[4]	NA[3]	—	0.0035	No	None
WQ0012937-001	Palmer Plantation MUD 001	11/30/99-6/30/04	0.29	0.60	No	Chlorination
WQ0011046-001	Quail Valley UD	1/31/00-7/31/04	1.77	4.0	No	Chlorination & Dechlorination
WQ0014100-001	Sienna Plantation MUD # 1	NA[3]	—	0.902	No	Chlorination
WQ0014064-001	Stafford Mobile Home Park, Inc.	NA[3]	—	0.10	No	Chlorination
WQ0011475-001	TDCJ Jester Unit # 1 – WWTF	5/31/01-2/29/04	0.27	0.315	No	Chlorination

TPDES Permit No.	Facility	Dates Monitored	Monthly Average Discharge (MGD)	Final Permitted Discharge (MGD)	Selected Permit Requirements on Final Permitted Discharge	
					Report Fecal Coliform Bacteria	Disinfection Requirement[6]
TXG920522[5]	TDCJ Jester (Swine CAFO) [1]	NA	NA	NA	NA	NA
Total			11.9	31.9		

NA = Not applicable; MGD = million gallons per day

Notes: [1] Permit does not contain a discharge provision
[2] Pending permit as of Oct. 2, 2006 (Ft. Bend Co. MUD # 134)
[3] New permit or not operational during period of dates monitored (1999-2004)
[4] Permit also includes storm water discharge not to exceed 1.0 MGD
[5] Concentrated Animal Feeding Operation (CAFO) general permit number
[6] An equivalent method of disinfection may be substituted with approval from TCEQ. Only chlorination (no dechlorination) is required for facilities operating under a capacity of 1 MGD

A violation at the Missouri City facility in August 2000 is of potential relevance to this study. The facility exceeded the daily maximum, the 7-day average, and the daily average criteria for fecal coliform bacteria. The problem occurred due to an off-line aerator that had accumulated a large amount of settled solids. Solids were redistributed throughout the facility when the unit was restarted, causing poor effluent quality. The problem was resolved immediately, and subsequent fecal readings indicated no long-term concerns. No other fecal coliform effluent quality violations have been reported at the facility since that time.

Because there is a long history of efforts to improve water quality problems in Upper Oyster Creek, a number of significant changes and improvements to regulated facilities have occurred, which probably resulted in improved water quality. Kolbe (1992) reports:

- the discharge from the City of Sugar Land's wastewater treatment facility (WWTF) was moved to its present location in 1975;
- the Hines Nurseries direct discharge was removed in 1990 and reduced to storm water overflow releases; and
- wastewater treatment of the TDCJ units has improved and feedlot runoff is better managed.

In addition, changes have been made over time to mitigate the effects of the permitted discharge from the Imperial Sugar facility, which ceased any discharge into Upper Oyster Creek in 2003. After June 1996, Imperial Sugar's major discharges were delivered to the Brazos River Authority's (BRA) regional WWTF for treatment and subsequent discharge outside the watershed. Kolbe (1992) states that from 1987 through 1990, Imperial Sugar discharged an average of 17 to 21 MGD of wastewater at elevated temperature, as allowed in their permit.

For any urban collection and treatment system, sanitary sewer overflows and WWTF bypasses are possible sources of bacteria loadings to receiving waters. Concerns related to overflows and bypasses are heightened in areas with relatively high rainfall, such as the Upper Oyster Creek watershed. Because of the rapid and continuing population growth in the watershed, some of the supporting infrastructure has been built recently and has underutilized capacity, which reduces the likelihood of overflow and bypass events. Nonetheless, occurrences of such events and their subsequent impacts on bacteria loading must be recognized.

The Storm Water Phase II rule, promulgated in 1999 as part of the National Pollutant Discharge Elimination System, requires small municipalities in urbanized areas to obtain permits for their storm water systems. In Texas, Small Municipal Separate Storm Sewer Systems (MS4) will be authorized under a general permit or Phase II (Small) MS4 general permit. The permit will require affected cities and other entities to reduce their discharges of pollutants in storm water to the "maximum extent practicable" by developing and implementing Storm Water Management Programs (SWMPs). The SWMPs must specify best management practices (BMPs) for seven minimum control measures:

- public education and outreach
- public involvement/participation
- illicit discharge detection and elimination
- pollution prevention/good housekeeping
- construction site runoff control
- post-construction runoff control
- authorization for municipal construction activities

The geographic region of Upper Oyster Creek covered by the pending Phase II MS4 general permit is that portion of the watershed contained within the urbanized area determined in the 2000 Decennial Census for the greater Houston area (U.S. Census Bureau, 2000a). Much of the eastern half of the Upper Oyster Creek watershed is included in this urbanized area.

Population Density: Humans and Pets

The population of the Upper Oyster Creek watershed in 2000 was estimated to be 96,273 people (31,573 households), with an overall average population density of 877 persons per square mile (U.S. Census Bureau, 2000b). The population of Fort Bend County is estimated by the U.S. Census Bureau to have increased approximately 6 percent per year since the 2000 census, so the current watershed population may exceed 125,000. Approximately 28,000 cats and 25,000 dogs are also estimated to reside at households within the watershed, based on the 2000 census data along with national averages of pets per household from the American Veterinary Medical Association (2002).

According to the Texas Water Development Board (TWDB), Fort Bend County is expected to increase in population by approximately 78 percent from 2000 to 2020 (TWDB, 2006). As a result, the county expects significant increases in water demand for municipal purposes (65 percent increase). Smaller increases are expected for manufacturing (17 percent), mining (8 percent), and steam electric (10 percent) uses.

Table 3 sets out TWDB population growth estimates for selected cities within Fort Bend County from 2000 to 2020.

The population estimates for Sugar Land are held constant after the year 2010 because the city is expected to be completely built-out by this date. However, TWDB estimates may not account for future annexations that could occur. Annexations were used to drive the city's population growth in the 1990s. The 2000 census figures show a 158 percent increase in the population of Sugar Land since 1990.

Table 3. Fort Bend County population and projected increases by city, 2000 to 2020

City	2000 Census Population	2010 Population	2020 Population	Growth Rate (2000-2020)
Fulshear	716	883	1,056	47%
Missouri City	47,419	76,768	96,601	104%
Stafford	15,371	23,026	30,959	101%
Sugar Land	63,328	72,500	72,500	14%

Source: TWDB (2006).

Sewage Disposal

The method of sewage disposal for housing units in the Upper Oyster Creek watershed was estimated from the 1990 federal census at the block group level because these data were not collected in the 2000 census (U.S. Census Bureau, 1990). Because of rapid urbanization in the watershed, estimates based on those data may no longer be accurate. At that time, approximately 7 percent of households (about 1,400 units) were not connected to a sanitary sewer system (the majority of those utilized septic tanks for sanitary waste disposal), while 93 percent were connected to a sanitary sewer system.

The more rural western half of the watershed was primarily served by septic tanks. However, the highest density of septic tanks was in two areas:

- the Fifth Avenue area southeast of Stafford and northwest of Missouri City, bounded roughly by Cartwright Road on the south, American Canal on the north and east, and farm-to-market (FM) Road 1092 on the west.
- the Four Corners area northwest of Sugar Land, bounded by SH 6 on the east, Old Richmond Road on the west, Voss Road on the south, and Boss-Gaston Road on the north.

The density of septic tanks in these two areas was approximately 0.3 per acre.

Livestock Populations

The smallest unit for which livestock census data are available is the whole of Fort Bend County, which show beef cattle to be the dominant livestock species in the watershed (Table 4). Other livestock species present in the watershed include horses, goats, chickens, and hogs. Livestock populations were estimated from the 2002 agricultural census of the National Agricultural Statistics Service of the U.S. Department of Agriculture (USDA), or from more recent estimates of the Texas Agricultural Statistics Service, when available.

Table 4. Estimated livestock populations in Fort Bend County

Livestock	Fort Bend County	Estimated Watershed Population††
Cattle & Calves-All	51,000 †	6,375
Horses	3,400 ‡	425
Mules, burros, & donkeys	116 ‡	14
Hogs & Pigs	1,367 ‡	171§
Goats-all	1,400 †	175
Sheep & Lambs	622 ‡	78
Rabbits	311‡	39
Bison	27 ‡	3
Domestic Deer	82 ‡	10
Chickens	2,226 ‡	278
Ducks-Domestic	172 ‡	22
Geese-Domestic	390 ‡	49
Turkeys-Domestic	49 ‡	6
Pheasants-Domestic	220 ‡	28
Quail-Domestic	1,382 ‡	173
Emus	47 ‡	6
Other poultry	200 ‡	25

† As of January 1, 2004 Texas Agricultural Statistics Service

‡ 2002 Agricultural Census, USDA

§ Probably an underestimate, based on observed population at prison farm

†† Based on watershed comprising 12.5% of county.

Wildlife and Feral Animals

An initial sanitary survey to identify potential bacteria sources within the Upper Oyster Creek watershed was performed from May 3 to 5, 2004. Note that this survey was not designed to quantify or estimate the population sizes of wildlife or feral animals, and that many additional observations of these animals (as well as fecal collections) took place over nine months of sampling in 2004. The most evident feces observed adjacent to water bodies in urban areas were from waterfowl, specifically ducks and geese. A large number of Muscovy ducks, a non-native resident, were observed in central portions of the watershed, particularly in the many residential lake areas. Duck fecal matter was very dense along the banks of impounded Upper Oyster Creek at Fluor-Daniel Road. Black-bellied whistling-ducks (a native species) were also observed to defecate at this same location.

Pigeons and various species of swallows were observed to be nesting on bridges over Oyster Creek at a number of locations, and perching on utility lines over the creek. Their dried fecal matter caked portions of the bridges. The swallows were only observed during the summer months. Other common birds in and near the creeks included several species of herons and egrets.

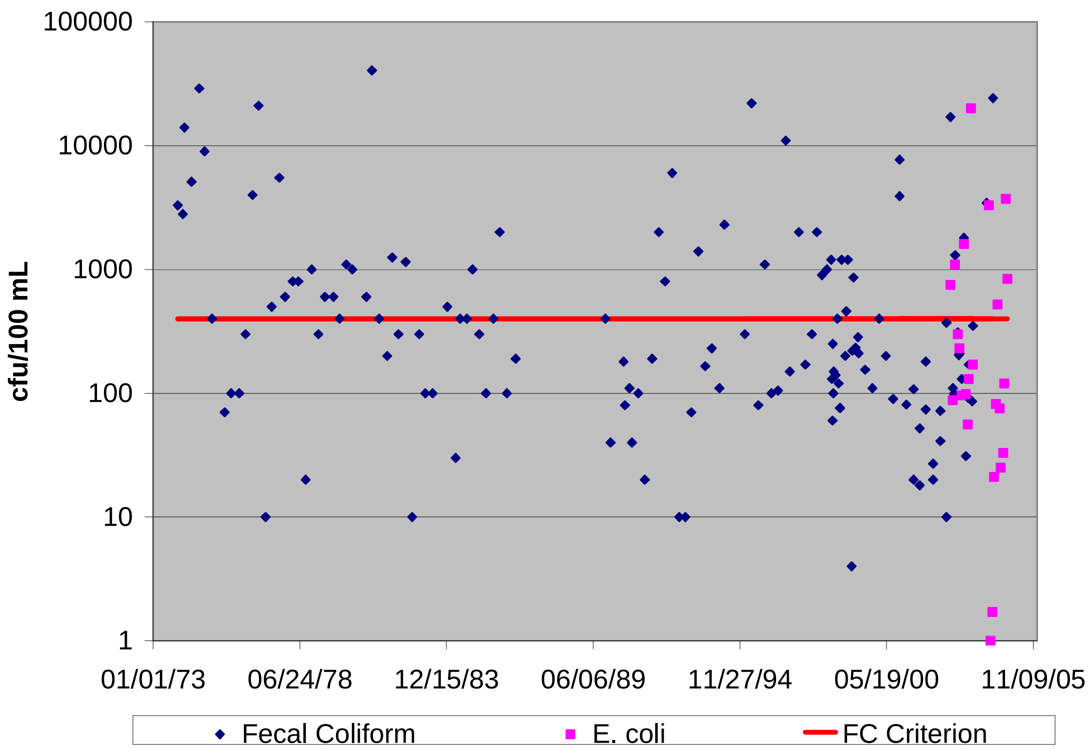
In rural areas, raccoon feces were frequently observed, especially adjacent to smaller, more sheltered waterways. During the March sampling event, the raccoon diet appeared to consist mostly of blackberries, but crayfish parts littered the banks of these smaller water bodies as well. Road kill indicated the expected fauna of southeast Texas, including skunks, raccoons, armadillos, and opossum. Local residents also commented that feral hogs are common in parts of the Upper Oyster Creek watershed.

Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques. This TMDL makes use of the load duration curve approach. The method has found relatively broad acceptance among the regulatory community, because of the simplicity of the approach and ease of application. The load duration curve approach provides a means to determine loading relationships, reductions, allocations, and possible sources at a broad level. It is discussed in much greater detail in the “Pollutant Load Allocation” section later in the document.

As a precursor to linking the potential sources of bacteria mentioned in the preceding section to Upper Oyster Creek, additional sampling was conducted to determine the severity and extent of the bacteria impairment. The TCEQ and its predecessor agencies have collected limited data for decades, particularly at Station 12083, located in the lakes region in Sugar Land. Figure 3 shows that high bacteria counts have been measured often at this station since the early 1970s. Despite this relatively long record for Station 12083, fecal coliform data were usually collected only quarterly, with gaps that sometimes stretched for several years at a time.

For the TMDL, additional *E. coli* sampling began in October 2002 and continued through November 2004. Two sampling programs were conducted for two different purposes. In Year 1 (October 2002 through August 2003), 12 surveys were performed approximately monthly to provide the data necessary to assess *E. coli* levels in Upper Oyster Creek. In Year 2 (from March 2004 through November 2004), 12 additional surveys were performed at selected stations with the intent of sampling to allow the capture of some rainfall-runoff events, which provide biased sampling not appropriate for assessment purposes. The later surveys were conducted as part of a bacterial source tracking study. Under the assessment surveys conducted from October 2002 through August 2003, sampling stations were located throughout the segment (including some tributaries and off-channel lakes) to give insight into the spatial distribution of the bacteria load in Upper Oyster Creek (Figure 4).



The single sample criterion used here is for fecal coliform [400 cfu/100 mL] since that bacteria accounts for the bulk of the historical data. The criterion for *E. coli* (394 cfu/100 mL) is not shown, since it would be indistinguishable from the fecal coliform criterion at the logarithmic scale used in this graph.

Figure 3. Bacteria Data for Station 12083, including single sample standard

The assessment survey for Year 1 (October 2002 – August 2003) showed *E. coli* exceeded the criteria for both geometric mean and single sample criteria through much of Upper Oyster Creek and its tributaries (Table 5 and Figure 4). The only areas where concentrations were consistently below the criteria were:

- the station just downstream from the GCWA pumping station on the Brazos River (Station 17685), and

Table 5. *E. coli* Sampling Results for Upper Oyster Creek

		Year 1 (Oct. 2002–Aug. 2003)			Year 2 (Mar. 2004–Nov. 2004)		
	Station	**# of Events**	**Geo. Mean**	**Percent Samples Exceeding SS Criterion[1]**	**# of Events**	**Geo. Mean**	**Percent Samples Exceeding SS Criterion[1]**
Upstream	17685	12	75	8	4	358	50
	17686	12	943	67	4	975	50
	12091	12	363	42			
	12090	12	427	58	12	563	50
	12089	12	364	50			
	12088	12	293	42			
	12087	12	301	50	12	268	33
	11516	12	98	42	4	219	50
	12086	12	154	42	12	227	33
	12083	12	333	33	12	114	33
	11510	12	59	17			
	17687	12	52	9			
	12079	12	65	18			
	17373	12	58	8			
	12077	12	104	25			
	17688	12	906	58	12	788	58
	12075	12	948	58			
	12074	12	512	67	12	341	50
	17689	12	522	58			
Downstream	17690	12	417	50			

[1] SS criterion is the single sample criterion. TCEQ applies the binomial method to establish the required number of exceedances to indicate nonsupport of the contact recreation use. To determine nonsupport (*i.e.*, greater than 25 percent of samples exceed the criterion) and to keep the percent probability at less than 20 percent of inappropriately assessing Upper Oyster Creek as not supporting when it is actually fully supporting, a minimum of five samples must be in exceedance for a sample size of 12—an exceedance of 42 percent.

- in and just below the lakes region (Stations 11510, 17686, 12079, 17373, and 12077), which appears to be because of enhanced bacteria settling due to conditions of reduced water velocities within the lakes.

In contrast, data collected in or just downstream of two major tributaries—Flewellen Creek–Station 17686 and Stafford Run—Stations 17688 and 12075—showed *E. coli* counts that were significantly higher than average. Another tributary, Red Gully—Station 11516—had lower *E. coli* numbers, which is attributed to chlorinated effluent from two small (less than 1 MGD) municipal wastewater treatment plants that reduce instream bacteria levels during low flows.

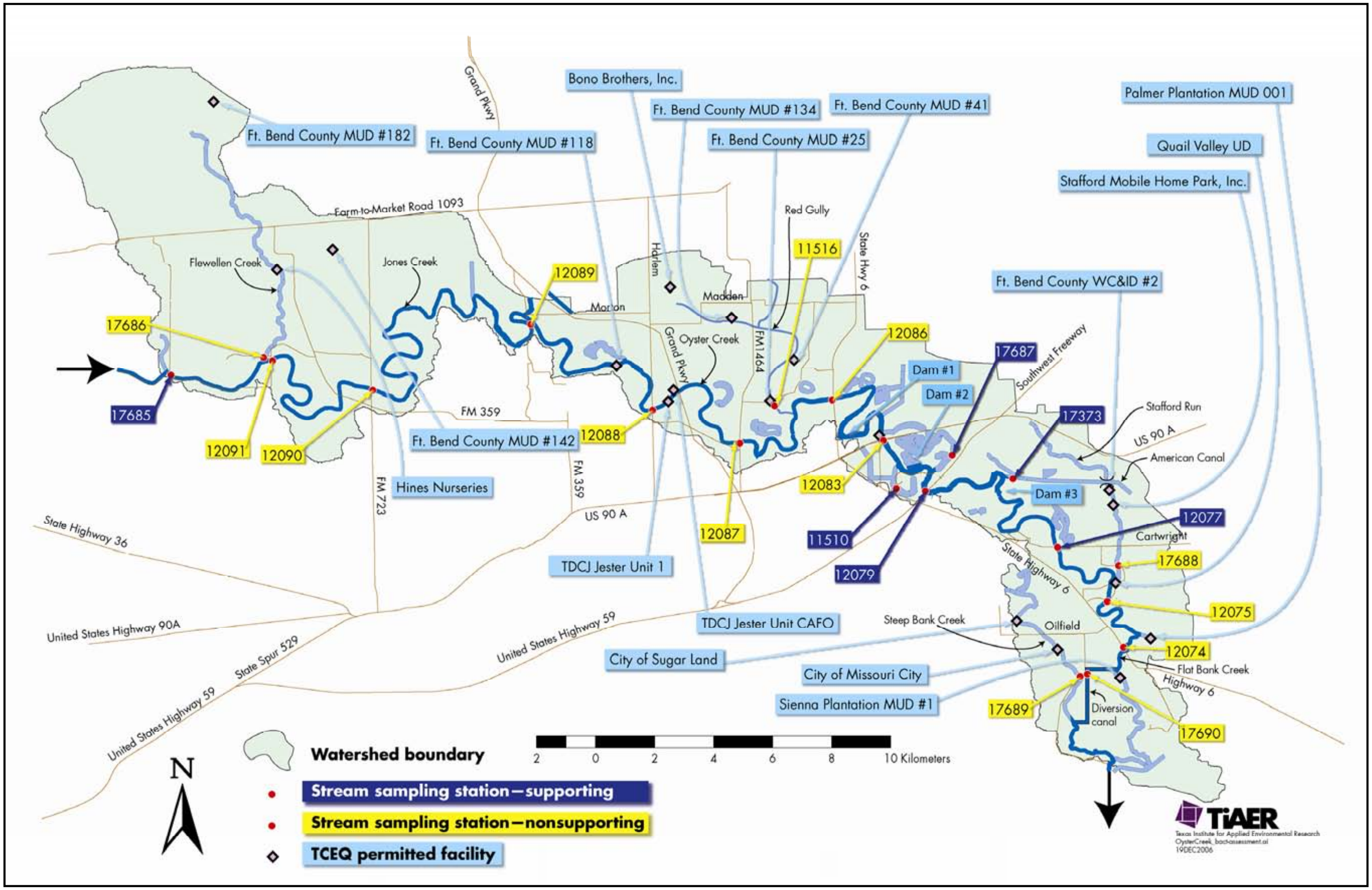


Figure 4. Upper Oyster Creek showing bacteria assessment stations, permitted facilities, and support or nonsupport of contact recreation use by station.

Bacterial Source Tracking

This TMDL project employed a bacterial source tracking (BST) method referred to as manual ribotyping, performed at the laboratories of the Institute for Environmental Health, Inc. in Seattle, Washington. The BST study involved three steps:

- collecting bacterial (in this case *E. coli*) isolates from fecal samples of known origin to create a watershed-specific library;
- collecting water samples (under both runoff and non-runoff conditions) from which fecal bacteria of unknown origin were cultured; and
- employing a genotypic-based method to compare method-specific characteristics of bacteria from the water to the same characteristics of the bacteria in the library. Since the bacteria are considered to be generally host-specific, exact matches of characteristics implicate a particular animal species (or group of related animals) as the contributor of that bacterial strain in the unknown sample collected from the ambient water.

The preliminary results of the BST study confirmed that the bacteria in Upper Oyster Creek come from a variety of sources, including humans, pets, livestock, and wildlife (avian and mammalian). No particular source group dominated any of the sampling stations (TIAER, 2006). The BST results provided qualitative information that did not modify the allocations presented in this TMDL, but will likely be used more extensively during the implementation phase of this project. At that time a broad array of control measures targeted to specific sources will need to be considered.

Seasonal Variation

Both high and low *E. coli* measurements were observed throughout the year. This observation suggests a lack of seasonality for bacteria in Upper Oyster Creek. However, bacteria levels in Upper Oyster Creek are clearly tied to rainfall-runoff events. In that sense, it is reasonable to assume that wetter parts of the year are more likely to have exceedances of the water quality standards. In Table 6, the *E. coli* data from the second year of the study are separated into runoff and non-runoff events. A sampling event was considered to be influenced by runoff if more than one-quarter inch of rain was measured at the Sugar Land Regional Airport on the day of sampling (before the sample was collected) or on the previous day. Without exception, the sampling from the runoff events resulted in much higher *E. coli* counts.

Margin of Safety

The margin of safety (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 MOS provides a higher level of assurance that the goal of the TMDL will be met. The MOS may be incorporated using two methods:

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

Table 6. *E. coli* Sampling Results in Runoff vs. Non-Runoff Conditions

		Runoff Conditions			Non-Runoff Conditions		
	Station	Number of Events	Geo. Mean	Percent Samples Exceeding SS Criterion[1]	Number of Events	Geo. Mean	Percent Samples Exceeding SS Criterion[1]
Upstream	17685	2	3,913	100%	2	33	0%
↓	17686	2	12,411	100%	2	76	0%
	12090	5	4,165	100%	7	135	17%
	12087	3	3,392	100%	9	121	18%
	11516	2	10,871	100%	2	4	0%
	12086	3	6,265	100%	9	75	11%
	12083	3	2,355	100%	9	41	11%
Downstream	17688	3	8,565	100%	9	356	42%
	12074	3	3,509	100%	9	157	36%

[1] SS Criterion is Single Sample Criterion

This TMDL uses an implicit MOS. The bacteria load allocation is based on the difference between the load duration curve of the single sample criterion and the exponential regression line through sampled data that exceed the criterion for each of the six stations used in this analysis (see the "Pollutant Load Allocation" section). The exponential regression line based on the exceedances gave a reasonable representation of existing bacteria loadings for those monitored periods when contact recreation was not supported.

Using only data that exceeded the single sample criterion to develop the exponential regression line provides an implicit margin of safety, since *E. coli* concentrations with values ≤394 cfu/100 mL were measured with relatively high frequency at each of the six stations but were not included in the analysis. Additionally, the state's water quality assessment methodology provides a further implicit margin of safety because it specifies that the contact recreation use is still supported when 25 percent or less of the individual samples exceed the single sample criterion (TCEQ, 2003); the data for these allowable exceedances were not factored into the load reduction analysis.

Pollutant Load Allocation

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

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

Where:

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

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

The pollutant load allocation for the Upper Oyster Creek bacteria TMDL was performed using a hybrid approach, using load duration curves with a mechanistic hydrologic watershed model (TIAER, 2006). The pollutant load allocation involved several steps:

- development of load duration curves
- definition of allocation reaches
- analysis of load reductions
- analysis of geometric mean criterion analysis
- allocation process
- future growth and other considerations

Each of these steps is discussed in the following section.

Development of Load Duration Curves

The load allocation tool selected for this TMDL is the load duration curve method with the necessary hydrologic information provided by the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998). The absence of recent, long-term daily streamflow data for any location on Upper Oyster Creek and the complexities of the watershed's hydrology (*e.g.*, water pumping from the GCWA, small dams, flood control practices, and several wastewater treatment plant discharges) necessitated that a mechanistic watershed hydrologic model, in this application SWAT, be used to develop the necessary daily streamflow data at several locations in the Upper Oyster Creek system (TIAER, 2006). Based on availability of daily pumping records from the GCWA for the period 1993–2004, this 12-year period was selected to define the hydrologic record used in the developing the duration curves. The period 1993–2004 is sufficiently long to include a reasonable variety of weather conditions and hydrologic responses (*e.g.*, high and low rainfall periods).

Using the calibrated SWAT2003 model of Segment 1245, simulated daily streamflow data for 1993–2004 were combined with existing *E. coli* data to develop the bacteria load duration curve tool for desired locations in the watershed. Six stations were selected for development of load duration curves based on availability of sufficient *E. coli* data: 12074, 17688, 12083, 12086, 12087, and 12090 (Figure 4). The following steps were undertaken to develop the desired bacteria load duration curves.

Step One

The predicted daily streamflow data for 1993–2004 at each of the six selected stations were obtained as model output. The daily data were used to develop a flow duration curve for each station. The flow duration curve was generated by:

1) ranking the daily flow data from highest to lowest,
2) calculating the exceedance value for each ranked daily flow (rank ÷ number of data points), and
3) plotting each flow value (y-axis) against its exceedance value (x-axis).

Step Two

In the next step, the flow duration curve was combined with the pertinent numeric water quality criterion (the single sample criterion in this case) to develop a load duration curve for that criterion. The single sample criterion is defined as an *E. coli* concentration not to exceed 394 cfu/100 mL. The load duration curve was calculated by multiplying each ranked flow (obtained in Step One) by the *E. coli* criterion (394 cfu/100 mL) and by the conversion factor (8.64×10^8), giving units of colonies per day.

Step Three

For each station, each existing *E. coli* measurement was associated with the predicted streamflow on the day of that measurement. The bacteria measurement and predicted flow measurement were then converted to a bacteria loading in units of colonies per day (using the same method described in Step Two for expressing the bacteria criteria as loadings). The associated daily streamflow for each daily bacteria loading was then compared to the flow duration curve data to determine its value for "percent days flow exceeded." Each existing loading was then plotted on the load duration curve at its percent exceedance. This process was repeated for each *E. coli* measurement at each station.

Points above a curve represent exceedances of that bacteria criterion and its associated allowable loadings. To provide as much data as possible for developing the analysis, *E. coli* data were combined from both the October 2002 through August 2003 assessment effort and the March through November 2004 BST study.

The flow duration curve and the *E. coli* load duration curve with the single sample exceedance line shown are provided in Figures 5–10 for stations 12074, 17688, 12083, 12086, 12087, and 12090, respectively. The flow duration and corresponding load duration curves for stations 12083, 12086, 12087, and 12090 (Figures 7–10) reflect a shape highly influenced by the GCWA pumping at the Shannon and Second Lift Stations, which results in the relatively constant flows between 1 and 8 m^3/s that occur about 70 percent of the time.

Stations 12074 and 17688 (Figures 5 and 6), which are outside the influence of the pumping, had flow duration curves with shapes typical of streams in which flow is not as heavily dominated by large amounts of nearly constant pumped flows. The flow duration

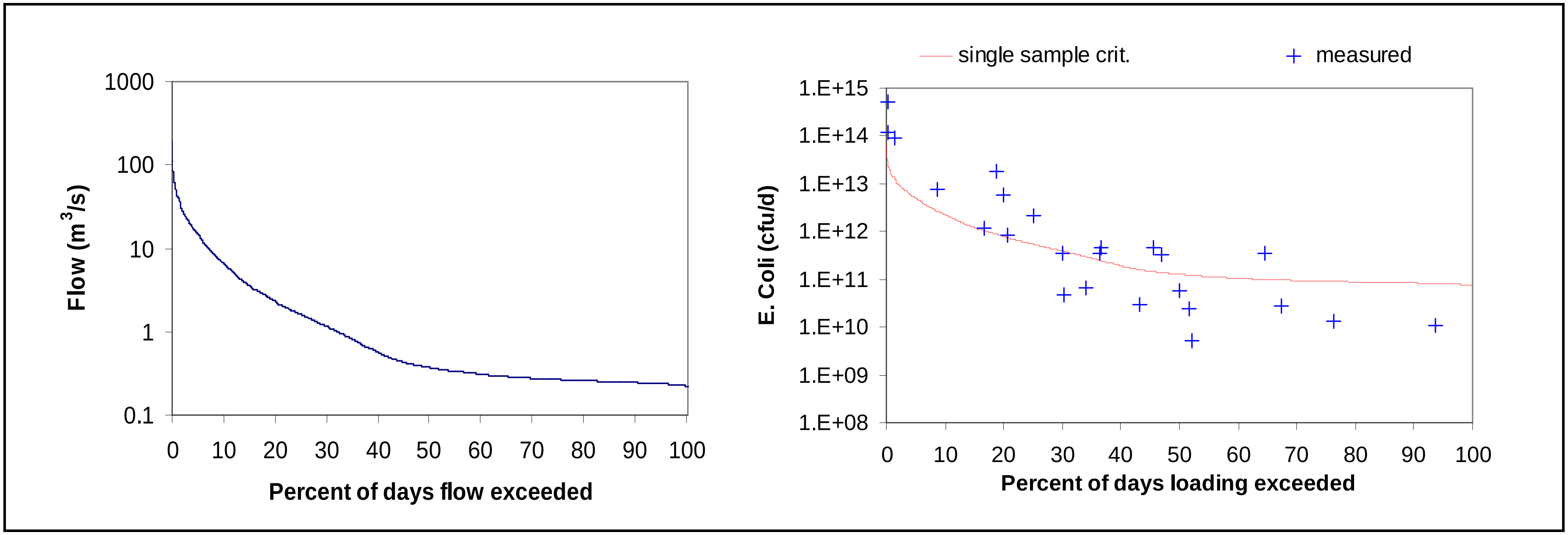


Figure 5. Flow duration and bacteria load duration curves, Station 12074

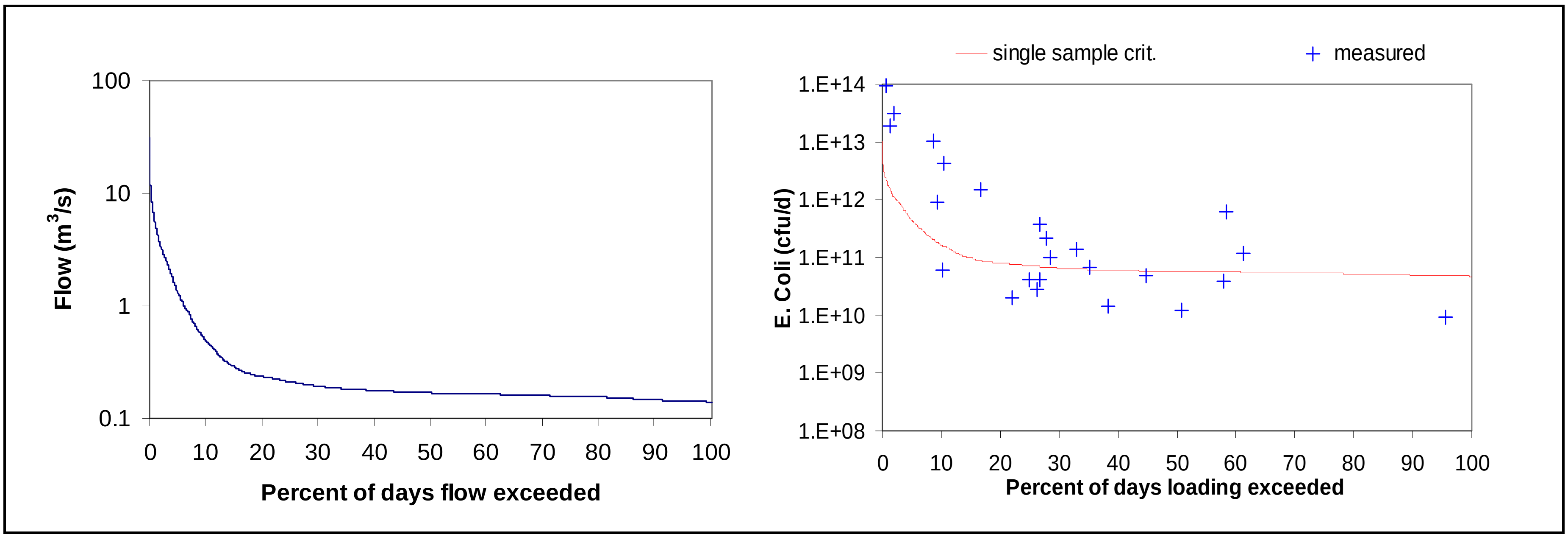


Figure 6. Flow duration and bacteria load duration curves, Station 17688

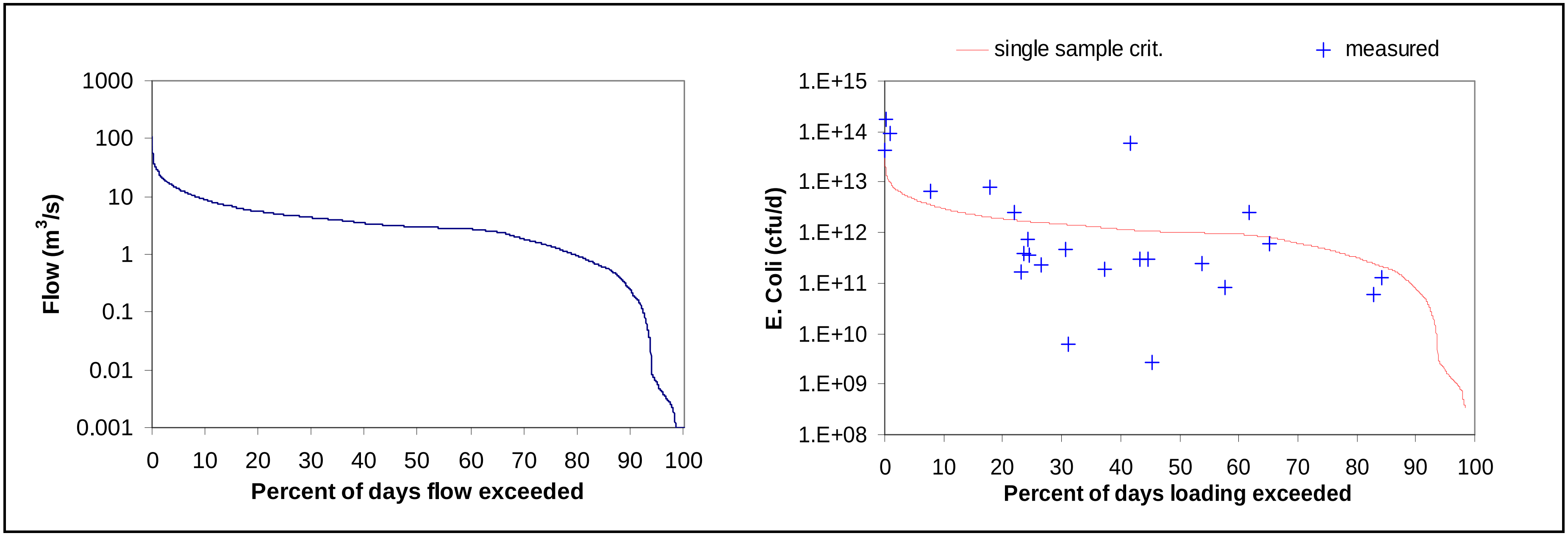


Figure 7. Flow duration and bacteria load duration curves, Station 12083

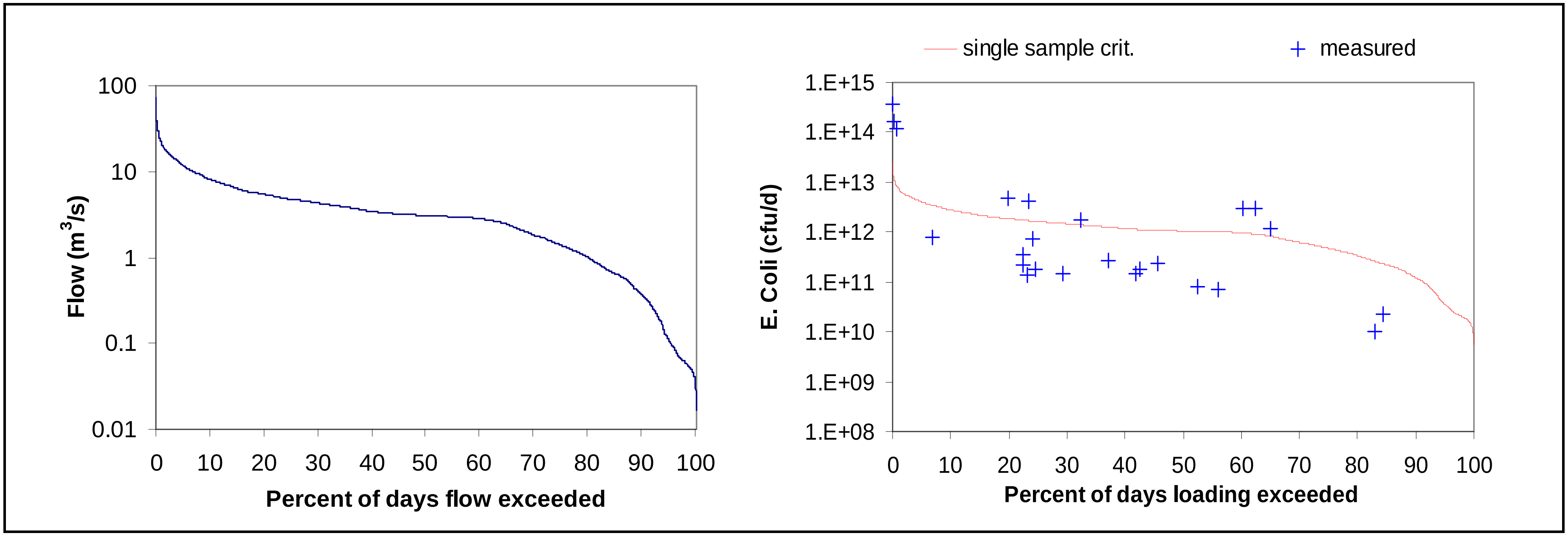


Figure 8. Flow duration and bacteria load duration curves, Station 12086

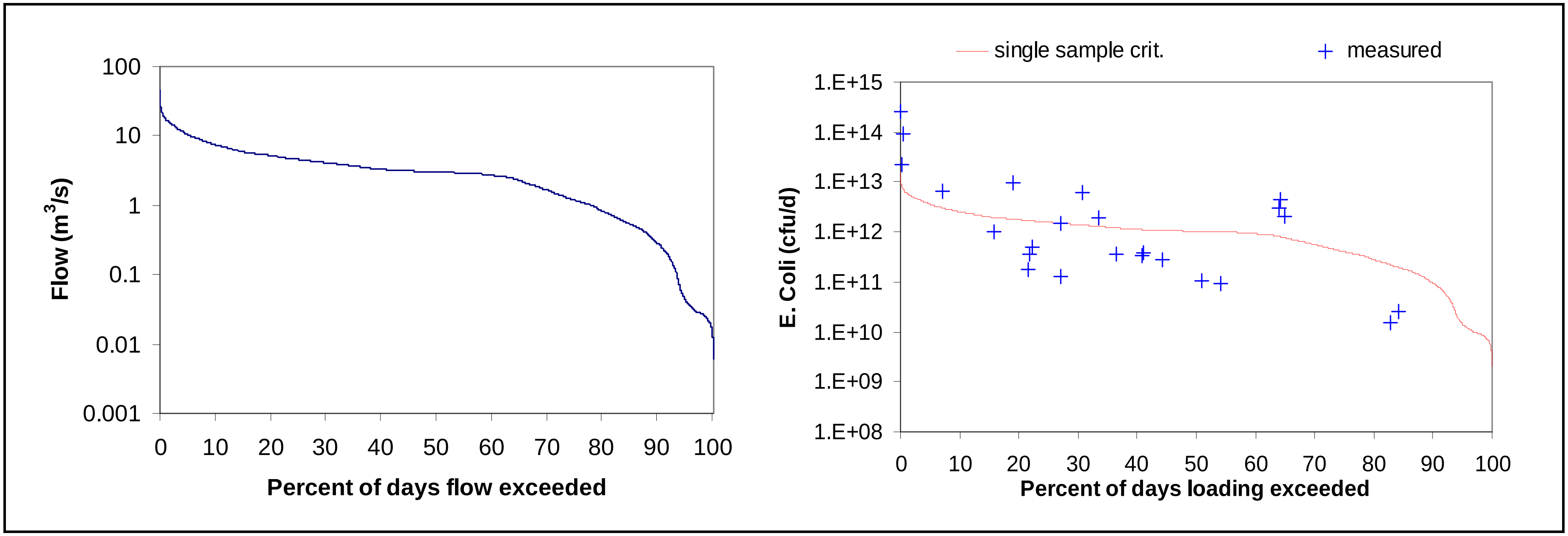


Figure 9. Flow duration and bacteria load duration curves, Station 12087

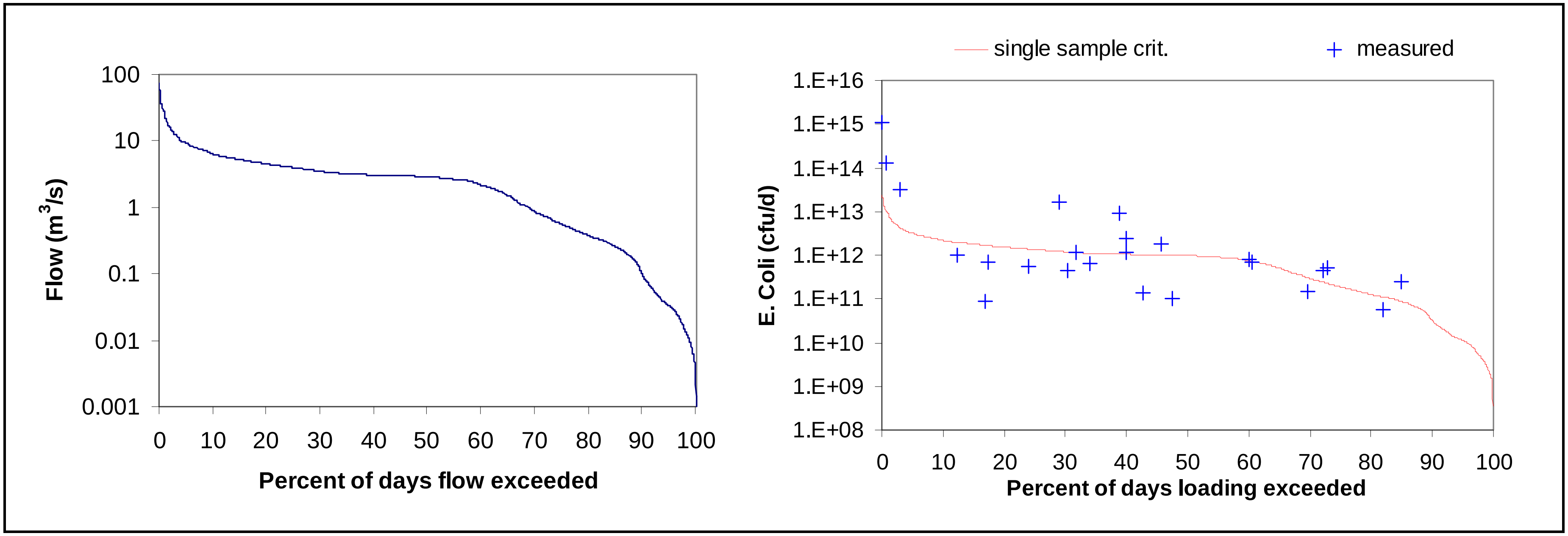


Figure 10. Flow duration and bacteria load duration curves, Station 12090

curves for both stations do, however, show the influence of continuous discharges from municipal WWTFs. Flows at these stations are typically below about 0.2 m^3/s.

Definition of Allocation Reaches

For purposes of performing load reduction analysis, Upper Oyster Creek was separated into two distinct hydrologic reaches. As previously presented in this report (see "Watershed Overview"), the portion of Upper Oyster Creek above Dam #3 serves as conveyance for water pumped by the GCWA from the Brazos River (see Figure 1) and annually diverts approximately 50,000 acre-feet of Brazos River water.

Much of the creek below Dam #3 has characteristics of a typical southeast Texas urban/suburban creek including modifications to reduce flooding potential and enhancements to speed water conveyance. Based on these hydrological distinctions, Upper Oyster Creek was divided into two allocation reaches for this bacteria load reduction analysis (Figure 17 in the section "Allocation Process" shows the areas of the reaches along with other details).

- **Allocation Reach 1:** Segment 1245 from its downstream confluence with the Brazos River up to Dam #3.
- **Allocation Reach 2:** Segment 1245 from Dam #3 up to the GCWA Shannon Pump Station.
-

While portions of both allocation reaches contain monitoring stations where data indicate support of contact recreation (see Table 5), *E. coli* levels are elevated throughout most of the length of Segment 1245. Therefore, to ensure the desired bacteria load reductions are achieved throughout the entire watershed, the two allocation reaches make up the entire length of the segment.

Load Reduction Analysis

For each allocation reach, a percent load reduction was determined using the differences between the loadings (represented by an exponential regression line) and the single sample criterion at each of the six stations for which load duration curves were developed. The following steps were used to determine the percent reduction by allocation reach:

1) Obtain the load duration curves by station for each reach. For Allocation Reach 1, stations 12074 and 17688 were used. For Allocation Reach 2, stations 12083, 12086, 12087, and 12090 were used.

2) For each station, develop an exponential regression line through relevant *E. coli* data points to characterize the existing loading of bacteria (Figures 11-16). Data considered relevant for determining the regression line were those at concentrations that exceeded the single sample criterion and also occurred at a flow exceeded on more than 0.27 percent of days (or on average, occurring at a flow exceeded more than one day per year).

   By happenstance, the bacteria sampling events on November 2 and 23, 2004, occurred during periods of high rainfall, and at several stations, these events produced data points that had a very small exceedance percentage (<0.27 percent). These data points became "leverage" points in the exponential regression, which increased the downward (left to right) slope of the regression at these stations. Removal of the data points for the two November sampling events provided a regression line that more closely fit through more of the relevant data points, thus better reflecting the existing loading that exceeded the single sample criterion.

3) For each station, determine the required percent removal at 5 percent intervals along the x-axis (*i.e.*, 5 percent intervals of days the loading was exceeded). The extreme high-flow interval was defined at 1 percent, which represented a reasonably extreme event occurring three or four days a year, on average.

   Thus, the first interval was defined as 1 percent, the next as 5 percent, and then at 5 percent intervals thereafter. Intervals were restricted to either the closest 5 percent interval near the last *E. coli* data point that exceeded the criterion or to the last 5 percent interval that had an associated positive load reduction (*i.e.*, where the regression line lies above the criterion line). This restriction was necessitated by the paucity of *E. coli* data with associated low daily streamflows for which loadings were exceeded greater than 70 percent of days. Collectively, these refinements allowed determination of percent reduction for load duration curves by station in both allocation reaches for the range of streamflow conditions under which bacteria exceedances occurred (Table 7).

4) For each station, the required load reduction to meet the single sample criterion was calculated as the arithmetical average of the percent reductions at the defined intervals derived in step 3 (Table 7). As the final step, the required load reduction in both allocation reaches was calculated as the average of the percent reductions determined in step 4. Averaging the percent load reductions in Allocation Reach 1 yielded a value of 73 percent. Likewise, averaging the four stations in Allocation Reach 2 also yielded a value of 73 percent.

Therefore, the percentage reduction in loads of E. coli required to meet the single sample criterion are as follows:

- **Allocation Reach 1**: 73 percent
- **Allocation Reach 2:** 73 percent

The fact that the load reductions calculated for both reaches are the same is coincidental.

Geometric Mean Criterion Analysis

Though the primary endpoint for this bacteria TMDL is the single sample criterion, the geometric mean criterion was considered a secondary criterion that should also be met in order for Segment 1245 to fully support its contact recreation use. In both allocation reaches, when the average reduction of 73 percent was applied to the combined dataset (all stations with existing *E. coli* data not supporting contact recreation), the results indicated that *E. coli* concentrations would be at or below the geometric mean criterion

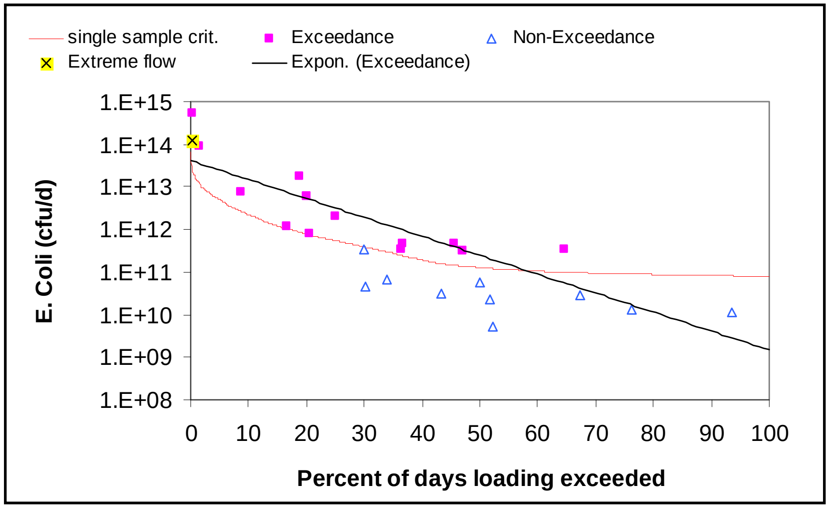


Figure 11. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 12074 in Allocation Reach 1

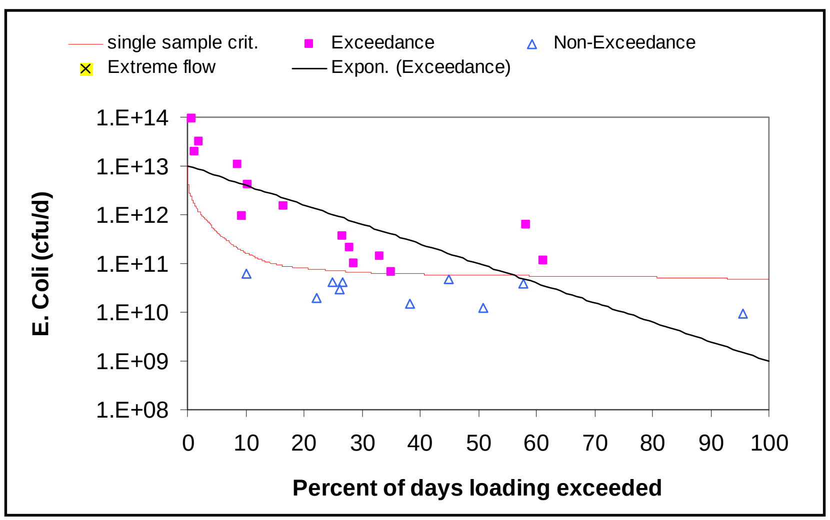


Figure 12. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 17688 in Allocation Reach 1

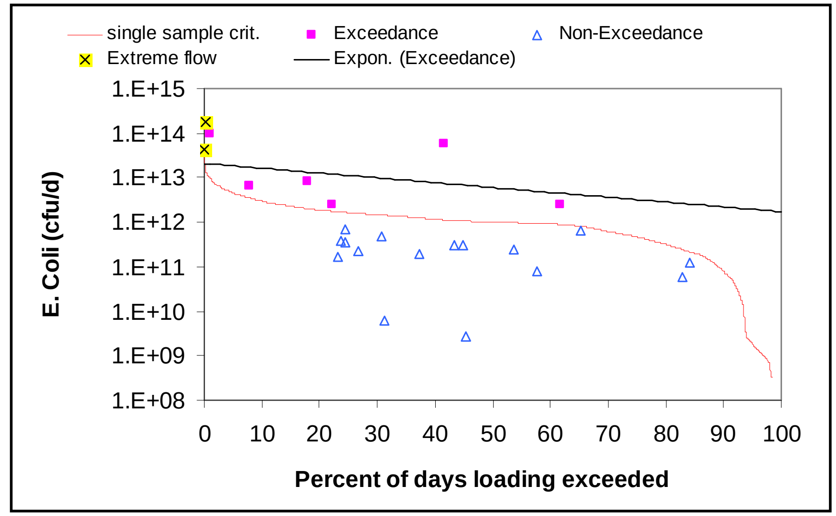


Figure 13. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 12083 in Allocation Reach 2

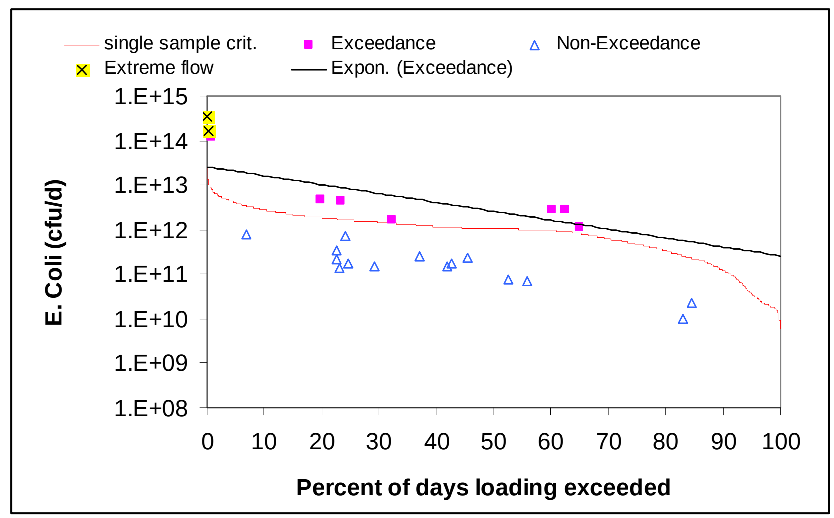


Figure 14. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 12086 in Allocation Reach 2

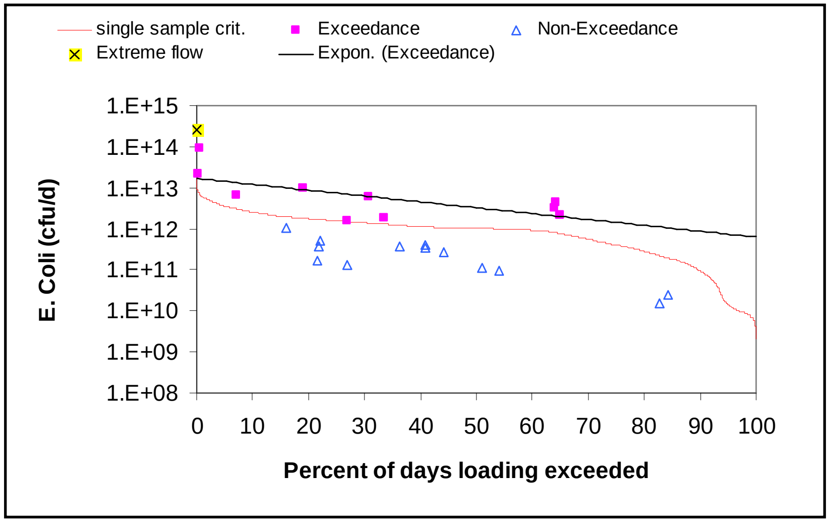


Figure 15. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 12087 in Allocation Reach 2

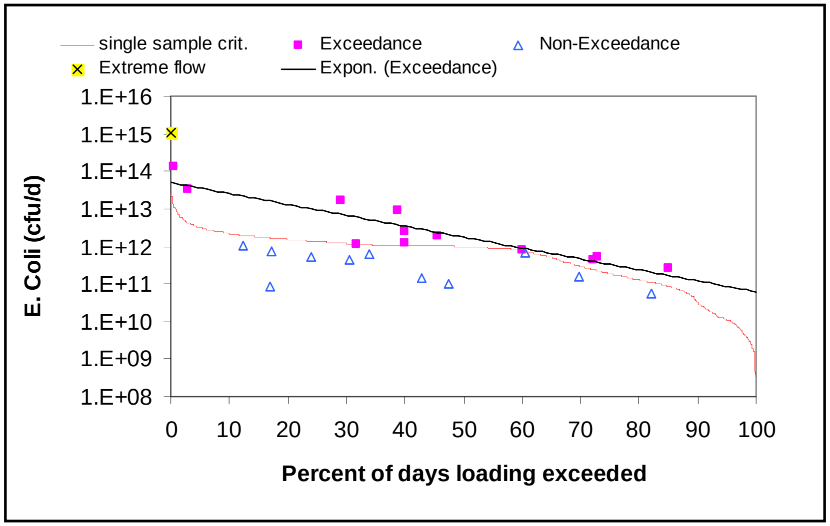


Figure 16. Load duration curve single sample criterion and exponential regression line for sampled population exceeding criterion, Station 12090 in Allocation Reach 2

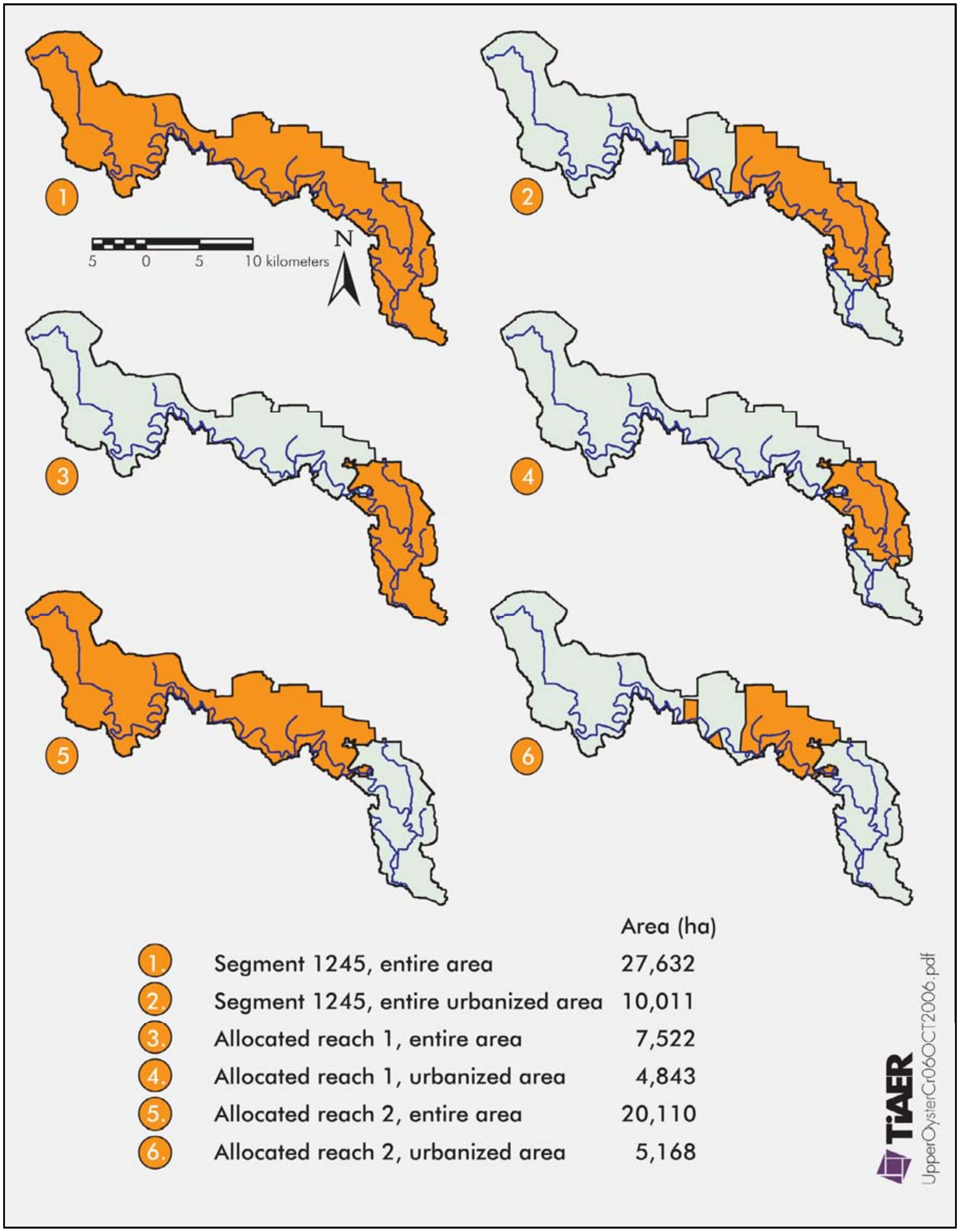


Figure 17. Upper Oyster Creek showing allocation reaches and urbanized area

Table 7. Percent reduction to meet single sample criterion for exponential regression line of sampled data exceeding criterion

(Highlighted table entries are those used in the computation of the average percent reduction.)

	Allocation Reach 1		Allocation Reach 2			
% Exceed.	Station 12074	Station 17688	Station 12083	Station 12086	Station 12087	Station 12090
1	60	80	50	73	69	80
5	79	93	74	83	79	91
10	85	96	81	85	82	92
15	86	96	83	86	84	90
20	85	95	85	85	83	88
25	82	93	85	83	82	86
30	79	90	85	81	81	82
35	75	84	84	78	80	78
40	71	76	84	76	79	70
45	63	63	84	71	77	59
50	47	42	82	65	73	44
55	20	9	81	58	70	29
60	0	0	79	50	67	19
65	0	0	79	45	67	21
70	0	0	82	49	72	38
75	0	0	85	51	76	43
80	0	0	88	56	80	47
85	0	0	92	63	85	49
90	0	0	96	74	91	74
95	0	0	100	91	98	87
99	0	0	100	95	99	96
Average	**69**	**76**	**80**	**73**	**77**	**61**

(Table 8). The calculated value for Allocation Reach 1 is equivalent to the geometric mean criterion concentration of 126 cfu/100 mL, while the calculated value for Allocation

Reach 2 is 76 cfu/100 mL. Therefore, the required load reduction to achieve the single sample criterion should also achieve the geometric mean criterion in both reaches.

Existing Loads

For each allocation reach, the existing daily *E. coli* loading was estimated using data from the most downstream station for which the load reduction analysis was performed—Station 12074 for Allocation Reach 1 and Station 12083 for Allocation Reach 2. By selecting the most downstream station, the greatest amount of each allocation reach was included, based on data availability.

Table 8. Geometric mean of existing *E. coli* concentrations and predicted geometric mean with load reduction of 73 percent uniformly applied

Allocation Reach	# Samples	Geometric Mean of Existing data (cfu/100 mL)	Geometric Mean with Percent Reduction Applied (cfu/100 mL)
1	83	467	126
2	123	282	76

For all stations in allocation reaches with data that indicated nonsupport of the contact recreation use.

The exponential regression line through *E. coli* data points that exceeded the single sample criterion was the basis for estimating existing loadings. Existing loadings were estimated by averaging the daily loadings from the exponential regression line over the entire range of flows (i.e., exceedances from 1 % to 99 %) (Table 9). This method of estimating the existing loading is accepted when using load duration curves, and also provides an implicit margin of safety as discussed previously (see the "Margin of Safety" section). Based on this approach, the following average daily loadings were estimated:

- **Allocation Reach 1:**
  existing daily average *E. coli* loading = 4,570 billion cfu per day
- **Allocation Reach 2:**
  existing daily average *E. coli* loading = 7,492 billion cfu per day

Allocation Process

The TMDL load allocation for Segment 1245 was performed to account for the pending general permit for Small Municipal Separate Storm Sewer Systems (Phase II MS4s), which will provide authorization for storm water discharges which are already occurring, but not currently permitted.

The geographic region of Segment 1245 that will be covered by the Phase II MS4 general permit is that portion of the watershed contained within the urbanized area defined in the 2000 Census for the greater Houston vicinity (see Figure 17). Approval of the general permit (and subsequent applications from dischargers) is expected to occur in 2007.

TMDL Allocation for Allocation Reach 1

The allowable loading of *E. coli* that Allocation Reach 1 can receive on an average daily basis was determined using:

- the single sample criterion load duration curve for station 12074 (Figure 11), and
- the same percent exceedance intervals used to estimate the existing loading.

The average maximum allowable daily loading determined from the load duration curve was increased to reflect the additional loading that would originate from the difference

Table 9. Estimates of existing daily load and maximum allowable daily load by allocation reach

(Data based on Figures 11 and 13)

Reach	Allocation Reach 1 (station 12074)		Allocation Reach 2 (station 12083)	
Percent Exceeding	Existing daily load (billion cfu/d)	Maximum allowable daily load (billion cfu/d)	Existing daily load (billion cfu/d)	Maximum allowable daily load (billion cfu/d)
1	36,100	14,400	19,500	9,810
5	24,000	5,100	17,600	4,610
10	14,400	2,210	15,600	3,000
15	8,610	1,210	13,700	2,310
20	5,160	791	12,100	1,860
25	3,090	549	10,700	1,630
30	1,850	394	9,450	1,460
35	1,110	279	8,340	1,320
40	666	194	7,360	1,170
45	399	147	6,490	1,060
50	239	127	5,730	1,010
55	143	114	5,060	970
60	86	105	4,460	930
65	52	99	3,940	819
70	31	94	3,480	615
75	19	91	3,070	467
80	11	88	2,710	321
85	7	86	2,390	202
90	4	84	2,110	79
95	2	81	1,860	2
99	2	77	1,680	0
Average	4,570	1,253	7,492	1,602

Additional Loading[1]	—	200	—	80
Total	**—**	**1,453**	**—**	**1,682**

[1] Additional loading is the increase in allowable *E. coli* loading from the existing discharge condition of WWTFs used to develop the single sample criterion load duration curve to the allowable loading for the final permitted discharge from WWTFs.

between loadings if WWTFs operated at their full allowable daily discharges and the loadings that would be allowable under the average WWTF discharges reported for years 2000-2004. With the additional loading included, the maximum allowable daily average loading is estimated at 1,453 billion cfu per day (Table 9). The reason for including this additional load follows.

The daily streamflow record used in developing the load duration curve for the single sample criterion was based on recent discharge information from permitted discharge facilities, and this information was used as input in the SWAT model (see TIAER (2006), Section 4 for more details). However, the TMDL allocation must be based on the full allowable discharge for each facility, not the recent discharges, to account for increased loadings that may occur if or when facilities discharge at their maximum allowable levels.

In Allocation Reach 1, the combined allowable discharge of all facilities is 24.602 MGD (as shown in more detail later in this section). The recent combined discharge averaged 11.204 MGD, resulting in a difference between recent and allowed discharges of 13.398 MGD. Because this allowable increase in discharge and the associated allowable loading would be continuous (*i.e.*, would apply equally to all days of each year regardless of streamflow), the difference between the two discharge rates multiplied by the single sample criterion is the additional allowable loading, as reflected at the bottom of Table 9. The computed, additional allowable bacteria loading for the 13.398 MGD, at an assumed rate equal to the single sample criterion concentration of 394 cfu/100 mL, is 200 billion cfu per day.

Wasteload Allocation (Continuous) for Allocation Reach 1

Seven municipal wastewater treatment plants operate within Allocation Reach 1. Several of these facilities operate under a phased permit that allows progressively higher daily average discharges as facility expansions are made in response to anticipated growth. The final and largest discharge for each facility was used in the load allocation process. A list of the seven facilities and their final allowable daily average discharges follows.

1) City of Missouri City (WQ0013873-001) 3.0 MGD
2) City of Sugar Land (WQ0012833-002) 10.0 MGD
3) Fort Bend Co. WCID # 2 (WQ0010086-001) 6.0 MGD
4) Palmer Plantation MUD # 1 (WQ0012937-001) 0.60 MGD
5) Quail Valley UD (WQ0011046-001) 4.0 MGD
6) Sienna Plantation MUD # 1 (WQ0014100-001) 0.902 MGD
7) Stafford Mobile Home Park (WQ0014064-001) 0.10 MGD

The combined permitted discharge from these facilities is 24.602 MGD. The maximum allowable *E. coli* concentration for each of these facilities is assumed to be the single sample criterion (394 cfu/100 mL). The combined discharge and single sample criterion were multiplied together, yielding a WLA for continuous discharges of 367 billion cfu per day. However, based on the requirements in permits for disinfection and the limited bacteria data available for effluents from permitted facilities in the Upper Oyster Creek watershed (i.e., City of Missouri City in Allocation Reach 1 and Fort Bend Co. MUD #25 in Allocation Reach 2), these treatment facilities are routinely expected to discharge well below the allowable single sample criterion.

Load Allocation and Non-Continuous WLA for Allocation Reach 1

The remaining allowable load was computed by subtracting the WLA from the allowable TMDL, yielding a total of 1,086 billion cfu per day. This was separated into two components: the urbanized area that is expected to be included under the Phase II MS4 general permit ("WLA Non-continuous") and the LA, which consists of all non-regulated, nonpoint sources. Note that for this document, the WLA Non-continuous also includes permitted storm water components from construction sites and certain industrial activities, as well as "allowable non-storm water" discharges defined by the pending Phase II MS4 general permit. This applies to both allocation reaches.

The drainage area of Allocation Reach 1 includes 7,522 hectare (ha), of which 4,843 ha are within the urbanized area. To divide the remaining load between the urbanized area and the LA category, the urbanized area was computed as the ratio of its area to the total drainage area: 4,843 / 7,522 = 0.6438). In a similar manner, the LA category was computed (7,522-4,843) / 7,522 = 0.3562). Multiplying the total allowable load by the appropriate area ratios yields a WLA Non-continuous for the urbanized area of 699 billion cfu per day, and an LA of 387 billion cfu per day.

The total load allocation for Allocation Reach 1 with the Phase II MS4 general permit is provided in Table 10. The total WLA is 1,066 billion cfu per day and the total LA is 387 billion cfu per day.

TMDL Allocation for Allocation Reach 2

The allowable loading of *E. coli* that Allocation Reach 2 of Upper Oyster Creek can receive on an average daily basis was determined using:

- the single sample criterion load duration curve for station 12083 (Figure 13), and
- the same percent exceedance intervals used to estimate the existing loading.

As was required for Allocation Reach 1, the average maximum allowable daily loading determined from the load duration curve was increased to reflect the additional loading that would originate if WWTFs operated at their allowable daily discharges rather than at their recent discharges.

The combined allowable WWTF daily discharge for facilities in Reach 2 is 6.2785 MGD. The recent combined discharges were 0.9292 MGD (used in the SWAT model). The combined allowable additional loading is 5.3493 MGD (6.2785 – 0.9292). Using the assumed single sample criterion concentration of 394 cfu per day, the additional bacteria loading would be 80 billion cfu per day. Adding this increase gives an adjusted maximum allowable daily average loading of 1,682 billion cfu per day (Table 9).

Table 10. TMDL allocation summary for Allocation Reach 1

Allocation Reach	TMDL	WLA Continuous	WLA Non-continuous	LA Other	MOS
(all units in billion cfu per day)					
1	1,453	367	699	387	Implicit

Wasteload Allocation (Continuous) for Allocation Reach 2

Eight domestic wastewater treatment plants operate, or are in the process of being permitted to operate, within Allocation Reach 2. Several of these facilities operate under phased permits, which allow progressively higher daily average permitted discharges as facilities expand in response to anticipated growth. The final and largest discharge for each facility was used in the load allocation process. The eight facilities and their final allowable daily average discharges follow.

1) Fort Bend Co. MUD # 25 (WQ0012003-001) 1.6 MGD
2) Fort Bend Co. MUD # 41 (WQ0012475-001) 0.86 MGD
3) Fort Bend Co. MUD # 118 (WQ0013951-001) 1.2 MGD
4) Fort Bend Co. MUD # 134 (WQ0014715-001) 0.30 MGD
5) Fort Bend Co. MUD # 142 (WQ0014408-001) 1.2 MGD
6) Fort Bend Co. MUD # 182 (WQ0014692-001) 0.80 MGD
7) Hines Nurseries (WQ003015-000) 0.0035 MGD
8) TDCJ Jester Unit # 1 (WQ0011475-001) 0.315 MGD

The combined allowable discharge from these facilities is 6.2785 MGD. The allowable *E. coli* concentration for each of these facilities is assumed to be the single sample criterion (394 cfu/100 mL). The WLA from regulated continuous discharges is estimated to be 94 billion cfu per day (the combined allowable discharge multiplied by the single sample criterion for *E. coli*).

Load Allocation and Non-Continuous WLA for Allocation Reach 2

The remaining components in the computation of the TMDL allocation include the Non-continuous WLA and the LA. Because of the nature of sources in Allocation Reach 2 and the complicating factor of the GCWA's pumping of Brazos River water into the reach, these remaining components were computed in a progressive manner, as explained in the next paragraphs.

The bacteria loading from GCWA pumping of Brazos River water was included as a portion of the LA. The bacteria contribution of the pumped water throughout Allocation Reach 2 is difficult to estimate due to the extremely dynamic response of *E. coli* to die-off, settling, and other processes. The allowable load from the Shannon Lift Station pumping was determined using the average daily pumping rate at the lift station (2.05 m^3/s) and the geometric mean *E. coli* concentration (75 cfu/100 mL) that was measured at station 17685 (Jones Creek at Bois D'Arc Lane; Figure 4 and Table 5) during October 2002 through August 2003. The computed loading is 133 billion cfu per day. The geometric mean concentration was used rather than the single sample criterion to reflect the fact that observed *E. coli* concentrations in water pumped from the Brazos River were typically lower than the criteria.

As in Allocation Reach 1, portions of the drainage area of Allocation Reach 2 are within the urbanized area defined in the 2000 Census that will be included within the Phase II MS4 general permit. The drainage area of Allocation Reach 2 includes 20,110 ha, of which 5,168 ha are within the urbanized area.

Two other complexities to the developing the load allocation exist in the watershed of Allocation Reach 2. First, Hines Nurseries has a storm water permit in addition to its wastewater discharge permit, the latter of which is already included under the Continuous WLA component. Second, Bono Brothers Inc. and the TDCJ's Jester Unit CAFO each have permits that do not provide for discharge, but do allow use of agricultural lands for the beneficial land application of organic wastes. These three permitted facilities were included within the non-continuous WLA category, and their allowable loading was estimated based on their combined operational areas of approximately 451 ha.

An area ratio procedure similar to that used for Allocation Reach 1 was used to separate the allowable load in Reach 2 into the two components of LA and "WLA Non-continuous." The loading to be allocated to these two components is 1,455 billion cfu per day, which is equal to the total allowable loading (1682) minus both the Continuous WLA (94) and the GCWA pumping load (133). After the area ratio computations were completed, the additional loading from the GCWA pumping was added to the LA.

The following area ratios were used in the computation of the remaining TMDL loadings:

- WLA Non-continuous: (451 + 5,168) / 20,110 = 0.2794
- LA (20,100 – 5,168 - 451) / 20,110 = 0.7206

Multiplying 1,455 billion cfu per day by the appropriate area ratio and adding the previously computed allowable GCWA load to the LA category provides:

- WLA Non-continuous load of 407 billion cfu per day
- LA load of 1,181 billion cfu per day

The total load allocation for Allocation Reach 2 with the Phase II MS4 general permit is provided in Table 11. The total WLA is 501 billion cfu per day and the total LA is 1,181 billion cfu per day.

Table 11. TMDL allocation summary for Allocation Reach 2

Allocation Reach	TMDL	WLA Continuous	WLA Non-continuous	LA Other	MOS
(all units in billion cfu per day)					
1	1,682	94	407	1,181	Implicit

Future Growth

Because of the rapid urbanization of much of the Upper Oyster Creek watershed, additional increases in permitted discharges for treating domestic wastes are expected. In accordance with this bacteria TMDL, any new permitted discharges and any additional increases in permitted daily flow for existing facilities will be held to the same bacteria criteria used in this allocation process. The disinfection requirements on existing facilities are expected to meet the ambient stream criteria for bacteria in Segment 1245. Therefore, the effluent of any additional permitted facilities should not result in nonsupport of the contact recreation use. At worst, additional discharges should result in a neutral impact on Segment 1245 by increasing streamflow while adding bacteria at concentrations meeting protective criteria.

Because of disinfection requirements in their permits, existing and future facilities are typically expected to discharge at concentrations less than the bacteria criteria. As a means of providing reasonable assurance that permit requirements are being met, various methods may be employed to determine that discharges are meeting these criteria. Options could include TCEQ inspections and monitoring of WWTF effluent, routine monitoring by WWTFs (at a frequency and duration to be determined during the implementation phase of the project, if deemed necessary), routine examination of self-reporting data for chlorine residuals, or other methods.

The rapid urbanization in Upper Oyster Creek watershed will change land uses in addition to increasing permitted discharges. Urban lands will increase and agricultural and rural lands will decrease. Relative contributions to bacteria loadings by different sources would also change, though it is not possible to reasonably estimate whether bacteria loadings to Upper Oyster Creek will increase or decrease. Bacteria control practices may need to be adjusted in the future to respond to these changing conditions.

Summary of the TMDL Allocation

The load duration curve method was used to develop the load allocation for Upper Oyster Creek (Segment 1245). Because of distinct hydrologic differences, Segment 1245 was separated into two allocation reaches:

- **Allocation Reach 1:** Segment 1245 from its downstream confluence with the Brazos River up to Dam #3.

- **Allocation Reach 2:** Segment 1245 from Dam #3 up to the GCWA Shannon Pump Station.

An implicit margin of safety was used in calculating the TMDL based on the use of the exponential regression line through measured *E. coli* data exceeding the single sample criterion of 394 cfu/100 mL. The calculated percent reduction required to meet the allowable loading for the single sample criterion also meets the geometric mean criterion in both allocation reaches. The TMDL allocations for both reaches with Phase II MS4 general permit conditions are summarized in Table 12.

Table 12. TMDL allocation summary for Allocation Reaches 1 and 2 of Upper Oyster Creek

Allocation Reach 1	
Existing Loading	4,570 billion cfu/day
Allowable Loading	1,453 billion cfu/day
Waste Load Allocation (Continuous)	367 billion cfu/day
Waste Load Allocation (Non-continuous)	699 billion cfu/day
Waste Load Allocation (Total)	1,066 billion cfu/day
Load Allocation	387 billion cfu/day
Margin of Safety	Implicit
Required Percent Reduction	73 %
Allocation Reach 2	
Existing Loading	7,492 billion cfu/day
Allowable Loading	1,682 billion cfu/day
Waste Load Allocation (Continuous)	94 billion cfu/day
Waste Load Allocation (Non-continuous)	407 billion cfu/day
Waste Load Allocation (Total)	501 billion cfu/day
Load Allocation	1,181 billion cfu/day
Margin of Safety	Implicit
Required Percent Reduction	73 %

Note that if a final percentage load reduction is calculated using the existing and allowable loading values shown in Table 12, the results will be different from the final reductions of 73 percent calculated for both reaches in the section “Load Reduction Analysis” (see Table 7). There are two reasons for this difference. First, the final percent reduction for each allocation reach was based on the average for two or more locations (stations) within each reach to ensure an average percent reduction that will achieve support of the contact recreation use along the entire length of the reach, rather than at just one location. Second, the final percent reduction for each station was computed as the average of the individual percent reductions calculated at 5 percent increments. In contrast, the load allocations were determined for the most downstream station in each reach so that the greatest amount of each allocation reach was included, based on data availability.

Public Participation

The public and stakeholder participation process in TMDL development, “Public Participation in TMDL Projects: A Guide for Lead Organizations,” is available on the Web at <www.state.tx.us/implementation/water/tmdl/tmdlresources.html>.

In accordance with requirements of Texas House Bill 2912, an official steering committee of stakeholders was established for the Upper Oyster Creek TMDL project in 2002. The first steering committee meeting was held in June 2003, and one or two meetings have been held each year since that time at facilities in Sugar Land. The steering committee members represent a broad array of interests in the watershed, such as local industries (including wastewater treatment facilities), landowners, environmental groups, and local and regional government groups. The stakeholder committee has had very little turnover over the life of the project. Their knowledge of the watershed and consistency in attending meetings and providing input have been—and will continue to be—a valuable resource for restoring the beneficial uses of Upper Oyster Creek.

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

1) a TMDL, which determines the maximum amount of pollutant a water body can receive in a single day and still meet applicable water quality standards, and
2) an implementation plan (I-Plan), which is a detailed description and schedule of the regulatory and voluntary management measures necessary to achieve the pollutant reductions identified in the TMDL.

The TCEQ is committed to developing I-Plans for all TMDLs adopted by the commission and to ensuring the plans are implemented. I-Plans are critical to ensure water quality standards are restored and maintained. They are not subject to EPA approval.

The TCEQ works with stakeholders to develop the strategies summarized in the I-Plan. I-Plans may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary regulatory and voluntary activities to achieve the pollutant reductions will be implemented.

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 gage 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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