Total Maximum Daily Loads for Fecal Pathogens

in the Clear Creek Watershed

Contract No. 582-6-70860
Work Orders No. 582-6-70860-03 and 582-6-70860-06

Quarterly Report No. 3

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY AND
U.S. ENVIRONMENTAL PROTECTION AGENCY

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INTRODUCTION

1.1 PROBLEM STATEMENT

The Texas Commission on Environmental Quality (TCEQ) is responsible for administering provisions of the constitution and laws of the State of Texas to promote judicious use of and the protection of the quality of waters in the State. A major aspect of this responsibility is the continuous monitoring and assessment of water quality to evaluate compliance with state water quality standards that are established within Texas Water Code, §26.023 and Title 30 Texas Administrative Code, §§307.1-307.10. Texas Surface Water Quality Standards 30 TAC 307.4(d) specifies that surface waters will not be toxic to aquatic life. Pursuant to the federal Clean Water Act §303(d), states must establish Total Maximum Daily Loads (TMDLs) for pollutants contributing to violations of water quality standards. The target water bodies for this project, segments 1101 (Clear Creek Tidal), 1101B (Chigger Creek), 1102 (Clear Creek Above Tidal) 1102A (Cowarts Creek), 1102B (Mary's Creek/North Fork Mary's Creek), and 2425C Robinson Bayou are located within the Clear Creek Watershed and these segments are on Texas' Clean Water Act §303(d) List because their waters do not meet the fecal coliform and *E. coli*-based water quality criteria for contact recreation.

The main objective of this TMDL is to develop the TMDL allocation equation for bacteria for the segments listed above. Two work orders have been issued for this project under Contract 582-6-70860. There are three main tasks to be completed for WO# 582-6-70860-03:

1. Administer project,
2. Participate in stakeholder process, and
3. Data analysis for determining and supporting TMDL equation.

Additionally, there are four main tasks to be completed for WO# 582-6-70860-06:

1. Administer project,
2. Participate in stakeholder process,
3. QAPP/Sampling Plan/Data Management, and
4. Data Collection.

1.2 DESCRIPTION OF THE REPORT

This document constitutes the third quarterly report for Work Orders No. 582-6-70860-03/06 (Contract No. 582-6-70860) of the Clear Creek Bacteria TMDL Project and summarizes the activities undertaken by the University of Houston during the period March 1, 2006 to May 31, 2006.

This report reflects the progress made towards the following tasks and subtasks delineated in the Project Work Plans:

<u>Task 2/WO3&6</u> – Participate in stakeholder process;

<u>Subtask 3.1/WO3</u> - Utilize all available information and the selected analysis method to determine the TMDL allocation equation;

<u>Subtask 3.2/WO3</u> - Determine what additional data are needed and if environmental samples need to be collected;

<u>Subtask 3.2/WO6</u> – Prepare and submit for approval a draft and final QAPP prior to the first scheduled monitoring event; and

<u>Task 4/WO6</u> – Data collection.

A summary of activities related to stakeholder participation is presented in Chapter 2. Chapter 3 presents a detailed analysis of methods and strategies that have been used for bacteria TMDL projects to date and their potential application for the Clear Creek watershed. Progress on the QAPP and sampling activities are detailed in Chapter 4. Finally, a summary of activities as well as a list of activities to be conducted in the next quarter of the project is presented in Chapter 5.

CHAPTER 2

STAKEHOLDER PARTICIPATION

A stakeholder meeting was held on April 5, 2006. The project team developed a project summary to support the meeting as requested by TCEQ. A member of the team, additionally, attended the meeting and responded to stakeholder queries and provided input as needed. The project summary is attached in Appendix A.

CHAPTER 3

ANALYSIS OF TMDL STRATEGIES

The subject of this chapter is the evaluation and discussion of modeling strategies that have been used for bacteria TMDLs around the country. The purpose is to develop and support the modeling strategy for the Clear Creek bacteria TMDL.

3.1 TYPES OF WATER QUALITY MODELING STRATEGIES

A number of various modeling strategies have been employed to simulate water quality in the environment and develop a TMDL. These strategies range from the use of simple mass balance “box” models, where the environment is depicted as one or more boxes with uniform properties, to deterministic, complex, data intensive, and multidimensional dynamic models. Table 3.1 presents a listing of available models and their applications; some of these are further described in more detail below. For an extensive review of the models in Table 3.1, the reader is referred to Ward and Benaman (1999a&b).

Analytical Tools

This type of modeling tool is usually a mass balance that considers neither variations over time nor space and that typically assumes all losses of a contaminant (degradation, loss to sedimentation, *etc*.), are relatively small compared to the overall mass of the contaminant in the system. This type of simple analytical tool, developed via a simple spreadsheet, is used where limited data are available or as a screening tool prior

Table 3.1. Existing TMDL Models and Strategies

Strategy	Tool/Model	Full Name	Source of Model	Watercourse Application	Remarks
Analytical	Load Duration Curve				Easy to develop. Not data intensive
	Mass Balance				Easy to develop. Not data intensive
Steady State	QUAL2E	Enhanced Stream Quality Model	CEAM	rivers, 1-D estuaries, main-stem reservoirs	limited to steady-state conditions
	QUALTX	Enhanced Stream Quality Model	TCEQ	rivers, 1-D estuaries, main-stem reservoirs	limited to steady-state conditions, specific to Texas watercourses
	GWLF	Generalized Watershed Loading Functions	Unknown	watersheds	inadequate documentation, limited history
	PRMS	Precipitation-Runoff Modeling System	USGS	watersheds & vadose zone	input demands less than HSPF, limited water-quality capability, GUI input management system under development
Dynamic	CE-QUAL-ICM	3D Eutrophication Model	WES	streams, lakes, estuaries	insufficient application
	CE-QUAL-RIV1	N/A	WES	streams & rivers	insufficient application
	DYNHYD	Dynamic Hydrodynamics Program	CEAM	surface waterbodies	link-node 1-D, dated code
	HSPF	Hydrological Simulation Program – FORTRAN	USGS/CEAM	watersheds, streams & rivers, small reservoirs	process models, data intensive
	SWAT	Soil and Water Assessment Tool	ARS	watersheds, lakes, vadose zone	lumped formulation, statistical process models
	SWMM	Storm Water Management Model	CEAM	watersheds	emphasis on urban catchments
	WASP	Water-quality Analysis Simulation Program	CEAM	surface waterbodies	must be coupled with suitable hydro-dynamic/transport model

ARS Agricultural Research Service, U.S. Department of Agriculture
CEAM Center for Exposure Assessment Modeling, U.S. Environmental Protection Agency
TCEQ Texas Commission for Environmental Quality
USGS U.S. Geological Survey
WES Waterways Experiment Station, U.S. Corps of Engineers

to applying a more sophisticated model. The following is a brief discussion of two simple analytical models; the Load Duration Curve and Mass Balance analyses.

Load Duration Curve Analysis

Load Duration Curve analysis (LDC) is one of the simplest, most widely used, and most cost effective tools for TMDL development. Virtually every state has used this tool in one application or another for TMDL development. In a recent review of twenty-two bacteria TMDLs, this method was used over 23% of the time (Table 3.2). As part of an emerging statistical methodology, LDC is gaining many followers, especially as applied to pathogen load modeling. The advantage of this method is its simplicity, and the need for minimal data requirements. LDCs, additionally, can be used to identify broad sources of bacteria, assess water quality throughout the full range of flows in the stream, and can be used to establish confidence intervals for uncertainty in the estimation of TMDLs.

The approach uses traditional flow frequency distributions for streams as a basis to analyze type and magnitude of pathogen loading. Flow duration curves identify intervals that can be used as a general indicator of hydrologic condition (i.e., wet versus dry). This indicator can help focus problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms.

The LDC approach recognizes that the assimilative capacity of a water body depends on the flow, and that maximum allowable loading varies with the flow condition. Existing loading, and load reductions required to meet the TMDL water quality target, can also be calculated under different flow conditions. The difference between existing loading and the water quality target is used to calculate the load reductions required.

Table 3.2 Existing Bacteria TMDLs and Methods Used

STATE	TMDL (YEAR)	WATERBODY NAME	INDICATOR	MODEL DESCRIPTION	TIDAL
ALASKA	2004	FISH CREEK WATERSHED/FISH CREEK	FECAL COLIFORM	SIMPLE METHOD (L = CF • P • PJ • RV • C • A)	
ARKANSAS	2001	L'ANGUILLE RIVER	FECAL COLIFORM	SPREADSHEET	
CALIFORNIA	2004	TOMALES BAY, SAN FRANCISCO, CA	FECAL COLIFORM	DENSITY-BASED LOAD ALLOCATION FOR ALL NPS LOAD	TIDAL
FLORIDA	2004	LOWER SWEETWATER CREEK	FECAL AND TOTAL COLIFORM	PERCENT REDUCTION METHOD	TIDAL
INDIANA	2004	TRAIL CREEK	E. COLI	GWLF AND WASP6	
KANSAS	2002	ALLEN CREEK, NEOSHO HEADWATERS SUBBASIN	FECAL COLIFORM	LOAD DURATION CURVE	
KENTUCKY	2001	FLEMING CREEK WATERSHED	FECAL COLIFORM	SIMPLE LOAD CALCULATIONS	
LOUISIANA	2004	"BAYOU SEGNETTE	FECAL COLIFORM	EPA BACTERIAL INDICATOR TOOL SPREADSHEET	TIDAL
MASSACHUSETTS	2002	SHAWNSHEEN RIVER BASIN	FECAL COLIFORM	SIMPLISTIC	
MINNESOTA	2002	LOWER MISSISSIPPI BASIN	FECAL COLIFORM	SPREADSHEET MODEL	
MISSISSIPPI	2004	YAZOO RIVER BASIN, LITTLE TALLAHATCHIE RIVER	FECAL COLIFORM	MASS BALANCE APPROACH	
MISSOURI	2004	JACKS FORK RIVER	FECAL COLIFORM	LOAD DURATION CURVE ANALYSIS AND EXCEL SPREADSHEET MODEL	
NEBRASKA	2003	MIDDLE PLATTE RIVER	FECAL COLIFORM	FLOW DURATION CURVE	
NEW JERSEY	2000	WHIPPANY RIVER	FECAL COLIFORM	WHIPPANY RIVER WATERSHED MODEL	
NEW MEXICO	2002	RIO GRANDE RIVER BASIN/MIDDLE RIO GRANDE	FECAL COLIFORM	SPREADSHEET MODEL	
NORTH CAROLINA	2004	CHICOD CREEK IN TAR RIVER WATERSHED	FECAL COLIFORM	LOAD DURATION CURVE	
OREGON	2003	NORTH COAST BASIN	FECAL COLIFORM	SWAT	TIDAL
SOUTH CAROLINA	2003	ALLISON CREEK STATION CW-171	FECAL COLIFORM	LOAD DURATION CURVE	
SOUTH CAROLINA	2004	PEE DEE BASIN	FECAL COLIFORM	MASS BALANCE APPROACH	TIDAL
UTAH	2002	SPRING CREEK	FECAL COLIFORM	QUAL2E	
WASHINGTON	2004	UPPER CHEHALIS RIVER	FECAL COLIFORM	LOG-NORMAL DISTRIBUTION STOICAL METHOD TO ESTABLISH FC REDUCTION TARGETS	
WEST VIRGINIA	2004	GUYANDOTTE RIVER WATERSHED	FECAL COLIFORM	HSPF	

Existing loading is traditionally calculated as the 90^{th} percentile of measured bacteria concentrations under each hydrologic condition class multiplied by the flow at the middle of the flow exceedance percentile. For example, in calculating the existing loading under dry conditions (flow exceedance range = 60-90 percent), the 75^{th} percentile exceedance flow is multiplied by the 90^{th} percentile of bacteria concentrations measured under 60-90^{th} percentile flows.

After existing loading and percent reductions are calculated under each hydrologic condition class for bacteria, the largest percent reduction required dictates the critical condition and the bacteria indicator that will be used to derive the TMDL. This approach can be used for non-tidal, fresh and saltwater bodies but not for the tidal segments.

Mass-Balance Analysis

Mass Balance (MB) analysis is another simple and cost effective tool to use for TMDL development. It is usually used when water quality data during the modeling time frame are limited or not readily available. The mass balance concept is based on the fundamental physical principle that matter can neither be created nor destroyed. Therefore, the mass of inputs to a process balances the mass of outputs plus any change in storage. MB calculations can be readily developed as a spreadsheet model for impaired water segments. The main step to estimating bacteria loading, if MB method is used, is to construct a flow balance of the system. Loads can be calculated by multiplying fecal coliform or E. coli concentrations by stream flow rates. The principle of the conservation of mass allows for the addition and subtraction of those loads to determine the appropriate values necessary for the TMDL. This approach could be used for both fresh and saltwater bodies including tidal and non-tidal systems.

Steady State Analytical Models

In a steady state strategy all flows, loadings, and other inputs are assumed to be constant over time. In addition, kinetics are assumed to be constant over time. Most steady state models do allow spatial variations in flow, loads, other inputs, and kinetics, and calculate variation of concentration with distance. Most steady state models are one-dimensional with respect to space. In other words, they predict variations in concentrations in only one dimension, usually upstream to downstream, and assume complete mixing across the cross section. QUALTX and QUAL2E are examples of two steady state models that work well in both fresh and salt waters. Their main disadvantage is that they are both data intensive when compared with the LDC and mass balance analytical tools discussed previously.

Dynamic Analytical Tools

A dynamic strategy allows variations over space and time for flows, loadings, and other inputs, and sometimes kinetics. Results from dynamic modeling also vary in both space and time. There are a number of different types of dynamic models, each with associated advantages and disadvantages. Often dynamic models are utilized to simulate episodic events such as high flow storm water events. Generally, dynamic models are very resource intensive from the standpoint of data requirements, effort to develop, and required computer resources. Dynamic models are often two or three dimensional with respect to space, allowing variation in simulated results longitudinally, laterally, and with depth. HSPF and WASP are two examples of dynamic models. WASP has tidal capabilities while HSPF does not.

Watershed Models vs. Instream Strategies

Another way to differentiate water quality strategies for TMDL development is according to watercourse type: watershed and in-stream. Watershed strategies focus primarily on processes occurring outside the water body, and usually address processes such as sediment and contaminant loadings due to infiltration, runoff, and erosion. In-stream water quality strategies primarily address processes occurring within the water body: channel hydraulics; in-stream sediment load and transport; and water quality parameters and response.

According to Ward and Benaman (1999a), since the specific technical aspects of a TMDL strategy differ according to the watercourse addressed, a distinction is made between the criteria appropriate for the watershed vs. those for receiving streams. By definition, a TMDL addresses the quality of a surface-water resource (since, in Texas, the target water quality is defined in terms of a surface-water standard or related criteria), so the strategies under consideration specifically address surface watercourses. On the other hand, typically, the ultimate source of water is precipitation, and the inter-medium through which precipitation is transformed to stream flow is the watershed. In the physical system, therefore, the watershed occupies a central role in the quantity and quality of water in the watercourses in that it acts as a processor of precipitation to create stream flow. The importance of the watershed as a processor is indicated by the fact that only a fraction of the quantity of precipitation falling on a watershed actually reaches the drainage system. Since a TMDL must address both point and non-point sources, it is often necessary to simulate both the watershed and the receiving water. As a result, the final strategy for a TMDL often must include both a watershed model and a receiving stream model linked in some fashion.

3.2 TMDL STRATEGY FOR CLEAR CREEK WATERSHED

The selection of an appropriate TMDL strategy for a given situation is a function of site characteristics, available data and resources and, perhaps most importantly, the objective that the TMDL is intended to achieve. A clear definition of the question the strategy is expected to resolve then dictates the physical processes and kinetics requiring simulation and, ultimately, the selection of the strategy to be employed.

As stated above, available data and resources are crucial considerations in the selection of an appropriate TMDL strategy. The historical and current water quality data for Clear Creek were presented in FY05 reports. These reports concluded that at fifteen of the twenty monitoring stations (75%) with data analyzed, the geometric mean of the indicator concentrations exceeded the standards (fecal coliform - 200 per 100 ml, Enterococci - 35 per 100 ml, and *E.coli* - 126 per 100 ml) that have been recommended by the EPA and adopted by the TCEQ. In addition, at sixteen of the twenty stations (80%) over twenty five percent of the samples analyzed exceeded the standards (fecal coliform - 400 per 100 ml, Enterococci - 89 per 100 ml, *E. coli* - 394 per 100 ml) placed on single sample concentrations. The stations located along segment 1101 (Clear Creek Tidal) showed a decreasing concentration trend as one moves downstream. However, there were no statistically significant trends in the data collected at either of the two stations within segment 2425. Similarly, for stations along segment 1102 (Clear Creek Above Tidal), the indicator concentrations exhibited no clear trends.

The Clear Creek watershed covers more than 200 square miles, and stretches through Harris, Fort Bend, Brazoria and Galveston Counties. Approximately 24 to 26 percent of the land in the watershed is developed land, but a significant portion (approximately 34 to 39%) is used for agricultural purposes. Table 3.3 shows the land use distribution within the Clear Creek watershed. The watershed is thus a mix of rural and urban land uses. As a result, it is expected that un-sewered areas may be an important consideration for water quality (see Table 3.4 for sewered and non-sewered data sorted by segment). Additionally, and due to its rural nature, contributions from livestock may also be significant (see Table 3.5 for livestock population counts by segment). Another consideration for Clear Creek is the tidal and non-tidal nature of the segments under study. Considering these factors and the nature of exceedances in the watershed, the LDC and MB approaches will be used as shown in Table 3.6. Additional analyses with more sophisticated tools may be required once the sampling and data analysis from FY06 are complete.

Table 3.3 Land Use Acreages within the Clear Creek Watershed

LAND USE	1101	1101B	1102	1102A	1102B	2425C
Bare Rock/Sand/Clay	78.35	53.47	94.46	35.98	30.33	6.06
Deciduous Forest	3,123.86	1,146.43	9,508.01	633.52	1,178.91	521.29
Deciduous Shrubland	186.64	113.14	832.29	195.77	100.88	26.50
Emergent Herbaceous Wetlands	877.61	338.01	1,101.67	538.94	236.08	322.63
Evergreen Forest	3,248.35	1,377.50	2,482.87	701.12	1,493.67	661.21
Grassland/Herbaceous	1,047.70	565.82	1,902.57	341.99	557.91	228.52
High Intensity Commercial/Industrial/Transportation	1,655.23	260.13	3,269.38	368.67	985.28	276.63
High Intensity Residential	1,991.65	392.20	3,819.10	185.52	801.95	306.64
Low Intensity Residential	1,515.12	1,827.32	4,004.83	2,534.09	1,825.62	277.27
Mixed Forest			25.39			
Open Water	701.34	64.47	265.90	15.23	81.26	56.70
Other Grasses (Urban/recreational)	182.99	230.68	1,902.26	52.35	141.80	57.02
Pasture/Hay	3,622.96	3,571.92	19,234.80	2,886.09	5,362.02	580.59
Quarries/Strip Mines/Gravel Pits			26.13		20.15	
Row Crops	139.99	1,133.43	1,929.01	647.24	1,492.29	32.79
Small Grains	27.77	14.83	437.31	7.82	22.80	
Woody Wetlands	497.63	45.57	539.10	5.72	130.78	114.75

Table 3.4. Clear Creek Watershed Septic Data by Segment*

Segment	Connected to Public Sewer	Connected to Septic Tank	Other
1101	20,147	1,756	82
1102	31,479	2,744	127
2425	12,592	1,098	51

Source: U.S. Census Bureau 1990

Notes: * Estimates for the Clear Creek watershed segments is calculated by multiplying the total connections for the Census Tracts in/around the Clear Creek watershed by the percentage of the total watershed area in square miles.

Table 3.5. Livestock Population in Clear Creek Segments*

	Estimated Watershed Population per Segment		
Livestock	**1101**	**1102**	**2425**
Cattle & Calves-All	2,792	4,362	1,745
Beef cows	1,781	2,783	1,113
Milk cows	0	0	0
Horses	210	328	131
Mules, burros, & donkeys	6	9	4
Hogs & Pigs	73	115	46
Goats-all	172	269	108
Sheep & Lambs	31	49	19
Rabbits	10	16	6
Llamas	9	14	5
Bison	1	1	1
Domestic Deer	11	17	7
Chickens	2,680	4,188	1,675
Ducks-Domestic	24	37	15
Geese-Domestic	16	25	10
Ostriches-Domestic	2	3	1
Turkeys-Domestic	11	17	7
Pheasants-Domestic	1	2	1
Pigeons & Squabs- Domestic	2	3	1
Quail-Domestic	18	28	11
Emus	5	8	3
Other poultry**	41	65	26

Notes: As of January 1, 2005, Texas Agricultural Statistics Service and 2002 Agricultural Census, USDA

* Estimates for the Clear Creek watershed segments is calculated by multiplying the total population from the census in/around the Clear Creek watershed by percentage of the total watershed area in square miles.

** Other poultry that did not have a bar on the Census Form

Table 3.6 TMDL Strategies by Segment for Clear Creek

Segment No.	Waterbody Type	Bacteria Data Available	Storm Data Available	Predominant Land Use	Strategy
1101	Tidal	limited	limited	non-urban	MB
1101B	Tidal	limited	limited	non-urban	MB
1102	Non-Tidal	limited	limited	non-urban	MB/LDC
1102A	Non-Tidal	limited	limited	non-urban	MB/LDC
1102B	Non-Tidal	limited	limited	non-urban	MB/LDC
2425C	Tidal	limited	limited	non-urban	MB

CHAPTER 4

QUALITY ASSURANCE PROJECT PLAN AND DATA COLLECTION ACTIVITIES

The goal of this task was to develop a Quality Assurance Project Plan (QAPP) for additional data collection that met the needs for the TMDL. Once the QAPP is approved, sampling would be initiated.

During the previous reporting period (December 2005 through February 2006), an update to the FY05 QAPP for the project was prepared based on the proposed sampling activities for FY06. Revision 0 of the Annual Report of the QAPP was submitted to the TCEQ on February 1, 2006 and comments were received on March 6, 2006. Revision 1 of the annual update (included in Appendix A of the previous quarterly report) that addressed all the comments sent by the TCEQ was submitted for review on March 9, 2006. The QAPP update was approved by TCEQ on April 17, 2006.

Sampling was initiated in the past quarter. There are five elements of the sampling plan discussed in the QAPP update. These include: (i) intensive survey to obtain flow/E. Coli data; (ii) storm water sampling to quantify runoff loads from major tributaries; (iii) sampling of waste water treatment facilities to quantify loads from overflows if any; (iv) in stream sampling to confirm low E. Coli levels at locations within low geomeans; and (v) storm water outfall survey to complete reconnaissance of all the pipes discharging to Clear Creek and its tributaries.

During the past quarter, sampling was undertaken for one dry weather intensive survey, two events for in-stream data gathering, one runoff event as well as sampling baseline water quality from treatment plants during dry weather operations. The samples from these events have been analyzed in the laboratory and the results will be presented in the next quarterly report.

CHAPTER 5

SUMMARY AND FUTURE ACTIVITIES

5.1 SUMMARY

During the third quarter of this TMDL project, an analysis of existing TMDL strategies and models were undertaken. The LDC (load duration curve) and MB (mass balance methods) will be used for the various watershed segments initially. Other methods will be assessed for use once the sampling and data analysis from FY06 are completed.

5.2 PLANNED ACTIVITIES FOR THE FOURTH QUARTER OF THE PROJECT TIME FRAME

During the period June 1, 2006 to August 31, 2006, the project team will focus on the following activities:

- Complete the sampling activities; and
- Continue data gathering and analyses for TMDL allocations.

APPENDIX A

PROJECT SUMMARY

Total Maximum Daily Load for Fecal Pathogens in the Clear Creek Watershed Technical Summary March 30, 2006

Study Area

The Clear Creek Watershed encompasses 200 square miles of land located just southeast of the city of Houston, Texas. The watershed includes all of the area that contributes surface water to segments 1101, 1102, and 2425C and drains into Clear Lake which in turn feeds to Galveston Bay. The Clear Creek watershed contains upland and palustrine forest wetlands, wet and dry prairie-land, and supratidal, subtidal, intertidal and submerged aquatic vegetation marshes. The region has high levels of humidity and receives an annual precipitation ranging between 46 and 52 inches per year. The eastern and central portions of the watershed are primarily urban and residential, with some commercial and industrial uses. The western and southern parts of the watershed are basically rural and agricultural.

The segments included in the project are Clear Creek Tidal (Segment 1101), Clear Creek Above Tidal (Segment 1102), Chigger Creek (Segment 1101B), Cowert Creek (Segment 1102A), Mary's Creek / North Fork Mary's Creek (Segment 1102B), and Robinson Bayou (Segment 2425). Figure 1 shows the location of the studied segments. The Texas Commission on Environmental Quality (TCEQ) designated the Clear Creek Tidal (Segment 1101) portion of the Clear Creek and Robinson's Bayou (Segment 2425C) as tidally influenced streams. The other segments included in this TMDL study are designated by the TCEQ as freshwater streams, including Chigger Creek (1101B), Clear Creek Above Tidal (Segment 1102), Cowart Creek (1102A), and Mary's Creek/North Fork Mary's Creek (Segment 1102B). The tidal influence within Clear Creek creates a median high tide level of 2.0 feet; this level reaches an average of 3.3 feet above sea level on an annual basis during peak tide.

The population of the Clear Creek watershed in 2000 was estimated to be 182,261 with an overall average population density of 907 persons per square mile (U.S. Census Bureau 2000). Based on census projections, the July 1, 2005 population of the watershed may be estimated at 200,635 with an overall average population density of 998 persons per square mile (U.S. Census Bureau 2000). Approximately 50,000 cats and 44,000 dogs are also estimated to reside in households within the watershed, based on the 2005 census data projection along with national averages of pets per household from the American Veterinary Medical Association (2002). Census data indicate that in 1990 approximately 8 percent of households in the watershed utilized septic tanks for sanitary waste disposal, while approximately 92 percent were connected to a sanitary sewer system. Approximately 260 housing units in the watershed were reportedly not connected to a sanitary sewer system (U.S. Census Bureau 1990).

A 2005 assessment of permitted wastewater treatment plants (WWTPs) discharging within the project watershed showed that there are 36 plants discharging to Clear Creek and its tributaries with a total permitted flow of 576 MGD. Twelve out of the 36 plants have flows greater than 1 MGD (major plants) representing 98% of the total permitted flow discharged to the study segments.

Regulatory Background

The TCEQ adopted the limit of 394 per 100 mL for single samples of *E. coli* and a geometric mean limit of 126 per 100 mL for bodies of water that have been designated for contact recreation uses. Within tidal streams and salt-water bodies, however, the EPA determined that Enterococci concentrations provide the greatest correlation to those of fecal pathogens. The TCEQ adopted a limit of 89 per 100 mL for Enterococci in any single sample and a limit of 35 per 100 mL for the geomean of all samples at any location for Enterococci concentrations within any tidal stream that has been designated for contact recreation uses (TCEQ - Texas Water Quality Standards - adopted July 26, 2000). During the process of switching over to the new standards, the EPA has recommended that the fecal coliform concentrations (400 per 100 mL in any single sample and 200 per 100 mL for the geomean of all samples) be used until at least ten data points have been collected for either of the two new standards that will be used for each segment.

Levels of Indicator Bacteria

Historical Data

Much of the fecal pathogen indicator data from Clear Creek and its tributaries were collected by the Galveston County Health District and the TCEQ Region 12. Additional data collection has been performed by the Houston Health and Human Services, the City of Houston Department of Public Works and Engineering, the City of Pearland, and the Environmental Institute of Houston (EIH).

Figure 2 shows the locations of historical bacteria data and the geometric means of the concentrations for the various indicators. Geometric means ranged from 46 to 628 for fecal coliform, between 40 and 430 for E. coli, and between 17 and 684 for Enterococci. Overall, the geomean water quality standards were excedeed in 31 of the 43 monitoring stations (72%).

Concentrations Measured in 2005

As part of this TMDL study, *E.coli*/Enterococci concentrations in water and sediment were measured at 25 stations located along the main stem and the tributaries of Clear Creek. The observed bacteria concentrations are presented in Figure 3. For water samples, *E. coli* concentrations ranged from 38 to 4,790 MPN/dL, while Enterococci concentrations varied from 39 to 5,460 MPN/dL. The single sample standards were exceeded in 7 of the 16 fresh water stations (43%) and in 7 of the 9 tidal stations (78%). Results from a linear regression analysis of the collected data showed that water concentrations are directly correlated to sediment concentrations (r^2=0.50, α=0.01).

Trends in Bacteria Data

Indicator bacteria concentration profiles along Clear creek and its major tributaries are shown in Figure 4. For the main stem, both Enterococci and *E. coli* geomeans exhibited a decreasing trend from upstream to downstream, however, only the Enterococci trend is statistically significant

(α=0.05). Marys Creek and Cowart Creek showed increasing trends. It is noted that the geomean data at almost all stations in Marys Creek were below the water quality standard, but Station 16473 near the mouth exceeded the geomean standard of 126 MPN/dL. In contrast, all three stations in Cowart Creek were above the standard. Finally, the first three stations along Chigger Creek exhibited increases while the geomean at the furthest downstream station 16472 decreased from the upstream geomean concentrations.

An analysis of temporal EC trends for 45 stations showed that concentrations at 78% of the stations (35) seem to be decreasing over time, but only 8 of them showed a significant trend at the 95% confidence level. Similarly, 13 out of 39 locations (40%) showed decreasing Enterococci concentrations over time, with only 3 of them showing a statistically significant trend.

On-going Activities

The project team is currently preparing for a significant sampling effort to be completed by August 31, 2006. The goal of this sampling effort is to provide sufficient data for the development of Load Duration Curves (LDC) and Mass Balances (MB) to support development of total maximum daily loads (TMDLs) for Indicator Bacteria. Sampling is also aimed at quantifying major contributors of indicator bacteria to the study segments to aid in load allocations. In addition, the project team is preparing a database of all the watershed parameters that will be needed for the development of LDCs and MB.

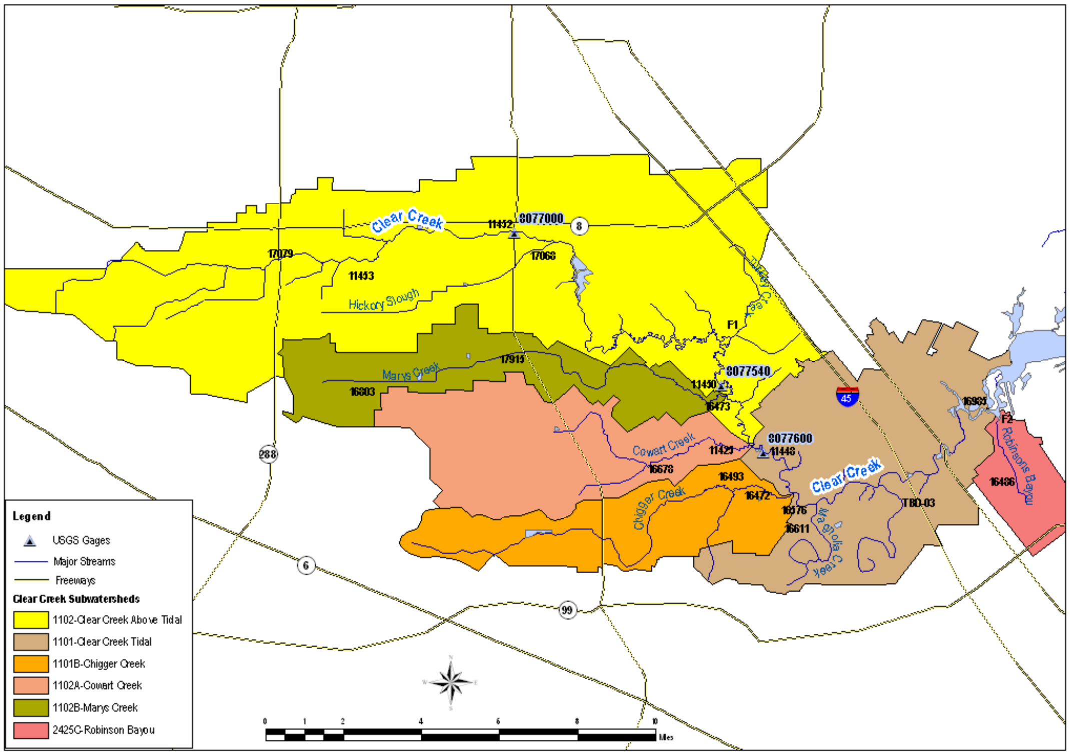


Figure 1. Project Watershed

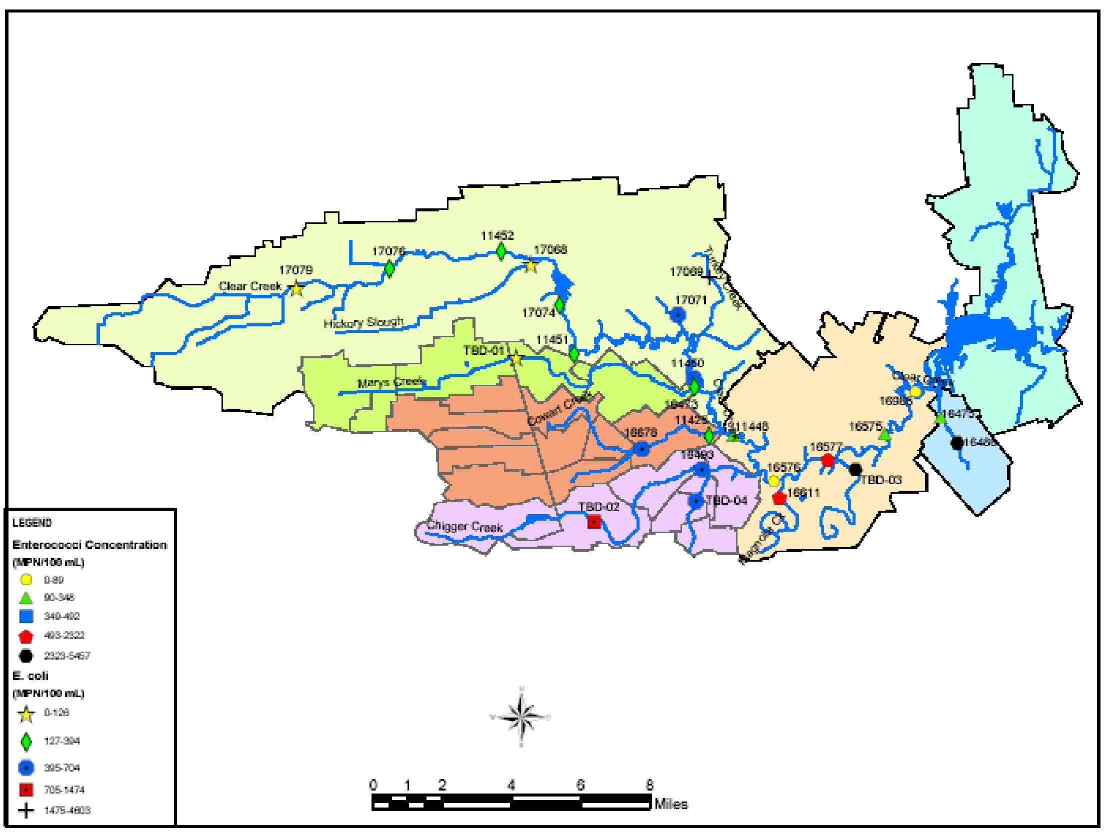


Figure 2. Historical Fecal Indicator Concentrations in the Project Watershed

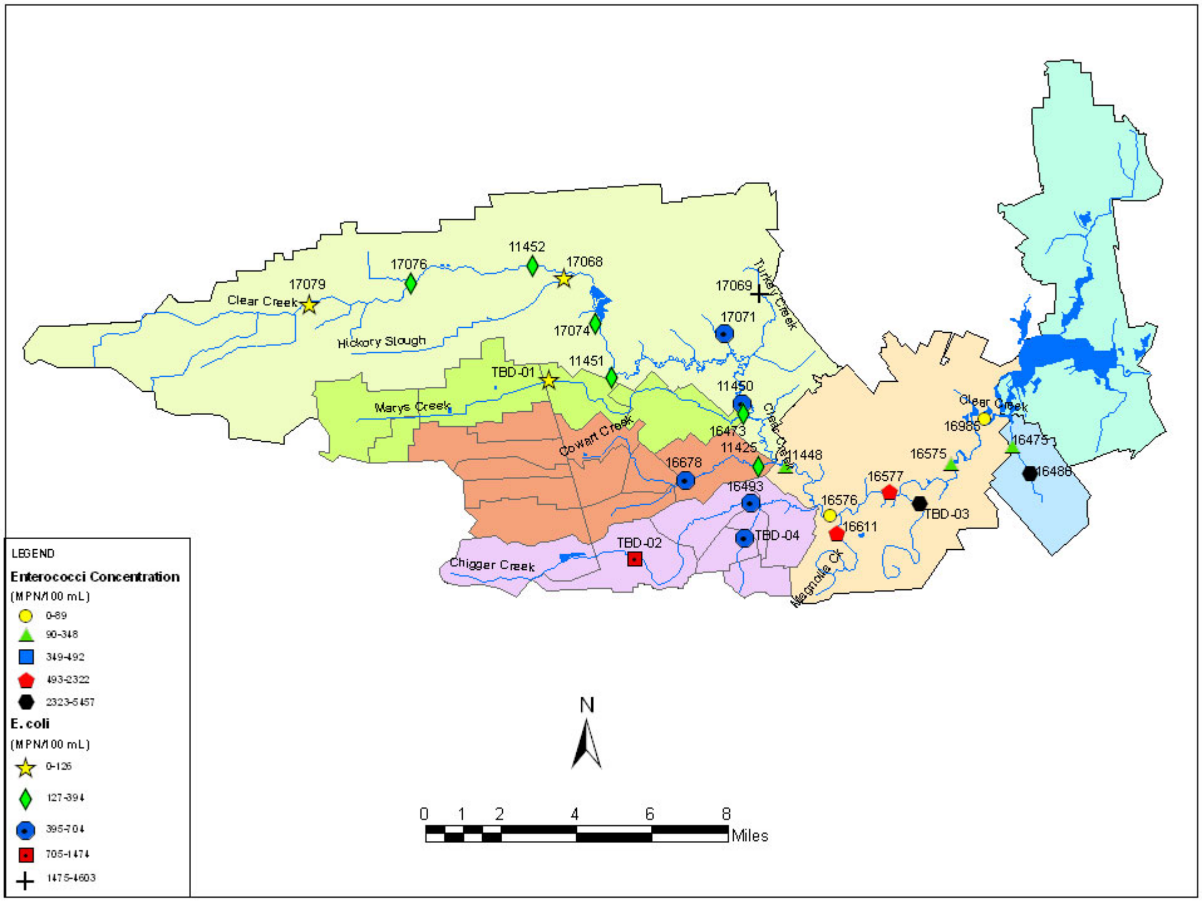
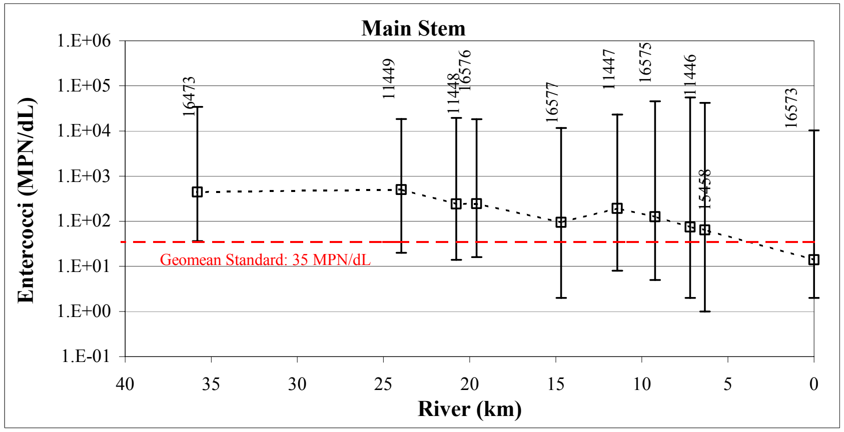
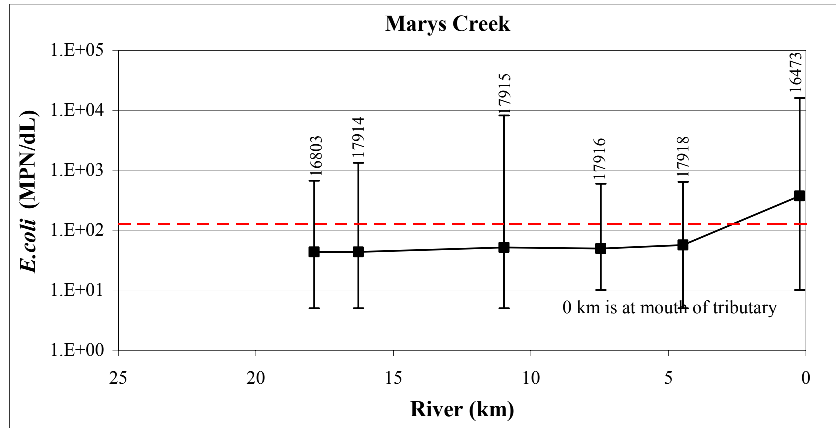
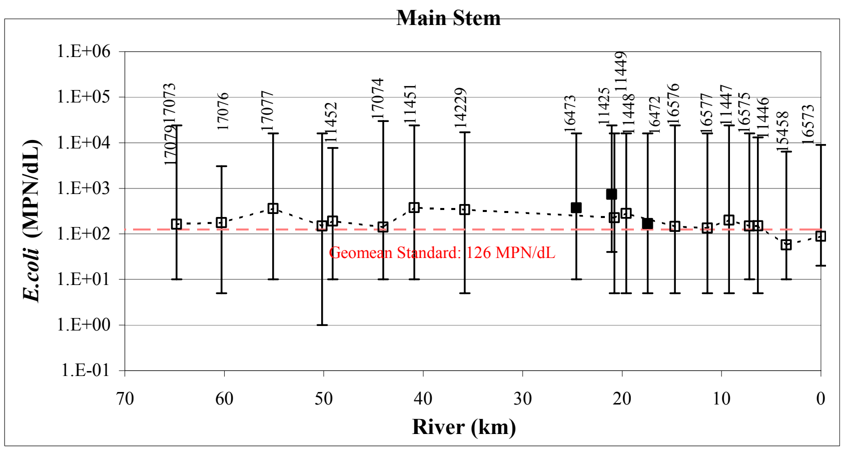
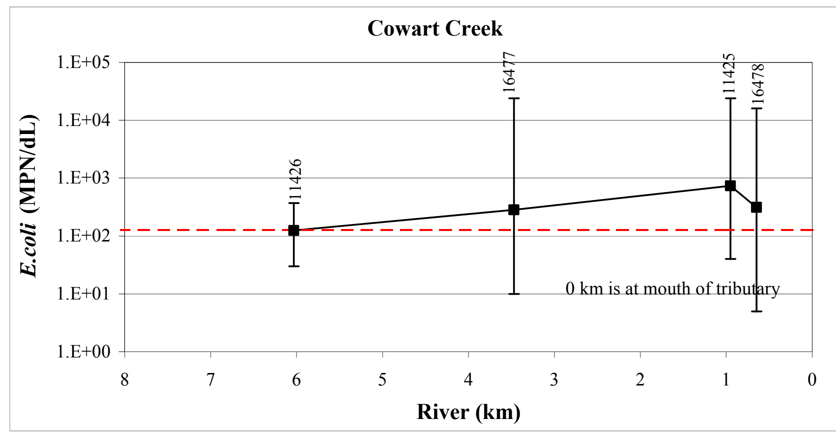


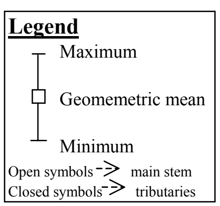
Figure 3. Indicator Bacteria Concentrations in Ambient Water (Summer 2005)











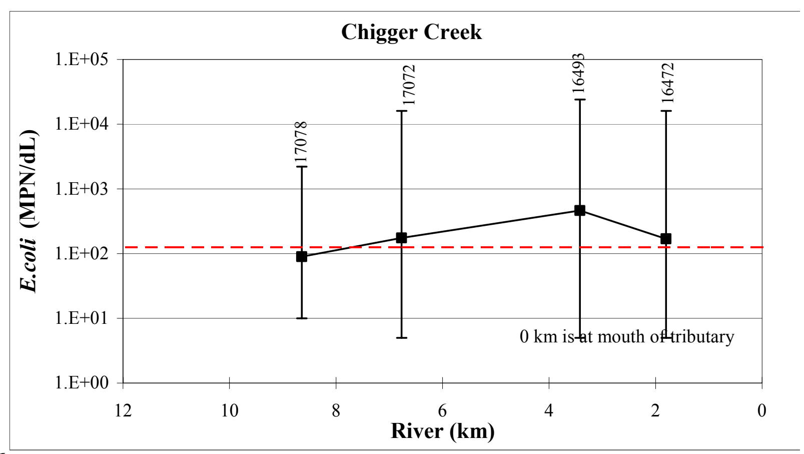


Figure 4. Longitudinal Profiles