TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

AGENDA ITEM REQUEST

AGENDA REQUESTED: December 9, 2009

DATE OF REQUEST: November 20, 2009

NAME & NUMBER OF PERSON TO CONTACT REGARDING CHANGES TO THIS REQUEST, IF NEEDED: Suzanne Vargas, 239-4619.

CAPTION: Docket No. 2009-0725-TML. Consideration for approval to publish and solicit public comment on eight draft TMDLs for indicator bacteria in Greens Bayou Above Tidal and Tributaries (Segments 1016, 1016A, 1016B, 1016C, and 1016D), of the San Jacinto River Basin, in Harris County.
(Ron Stein, Robert Brush)

Division Director, Water Quality Planning Division

Chief Engineer

Texas Commission on Environmental Quality

INTEROFFICE MEMORANDUM

To: Commissioners **Date:** November 20, 2009

Thru: LaDonna Castañuela, Chief Clerk
Mark R. Vickery, P.G., Executive Director

From: Susana M. Hildebrand, P.E., Chief Engineer
Chief Engineer's Office

Subject: Docket No. 2009-0725-TML
Proposal of Eight Draft Total Maximum Daily Loads for Indicator Bacteria in Greens Bayou Above Tidal and Tributaries for Public Comment

Issue Consideration for approval to propose for public comment eight draft TMDLs for indicator bacteria in Greens Bayou Above Tidal and Tributaries (Segments 1016, 1016A, 1016B, 1016C, and 1016D) of the San Jacinto River Basin, in Harris County.

Background and Current Practice Eight draft TMDLs have been prepared as required by Section 303(d) of the Clean Water Act. TMDLs must be submitted to U.S. EPA for approval as certified updates to the State of Texas Water Quality Management Plan (WQMP). The Water Quality Planning Division requests approval from the commission to propose the TMDLs for a formal public review and comment period. After the public comment period, staff will make appropriate changes to the draft TMDLs and respond to public comments. The next step will be to request that the commission consider adoption and certification of the final TMDLs as an update to the State of Texas WQMP. The commission approved TMDLs are then forwarded to U.S. EPA for its final action.

Watershed Information Designated uses for stream segments are defined under the Texas Administrative Code (TAC) [Title 30, Chapter 307: *Texas Surface Water Quality Standards*, Section 7, Site-specific Uses]. The specific uses assigned to the five segments included in this report are contact recreation, aquatic life, general, and fish consumption. This project addresses elevated levels of indicator bacteria related to the contact recreation use in fresh water.

The Greens Bayou Above Tidal watershed (Figure 1) experiences frequent rainfall events, with an annual precipitation total of approximately 50 inches. Summer rainfall is dominated by subtropical convection, winter rainfall by frontal storms, and fall and spring months by combinations of these two. The heavily urbanized Greens Bayou Above Tidal watershed encompasses approximately 140 square miles of land. It drains parts of the cities of Houston and Humble. There are about 200 miles of open streams within the watershed.

Problem Definition *Escherichia coli* (*E. coli*) is the preferred indicator for assessing the contact recreation use in fresh water. The contact recreation use is not supported when the geometric mean of all *E. coli* samples exceeds 126 most probable number (MPN) per 100 milliliter (mL). The contact recreation use is also not supported if individual samples exceed 394 MPN per 100 mL more than 25 percent of the time. Elevated levels of bacteria are widespread and persistent throughout the watershed. Table 1 summarizes historic *E. coli* sampling data throughout the watersheds. Both the geometric mean and single-sample criteria are exceeded at all sampling locations.

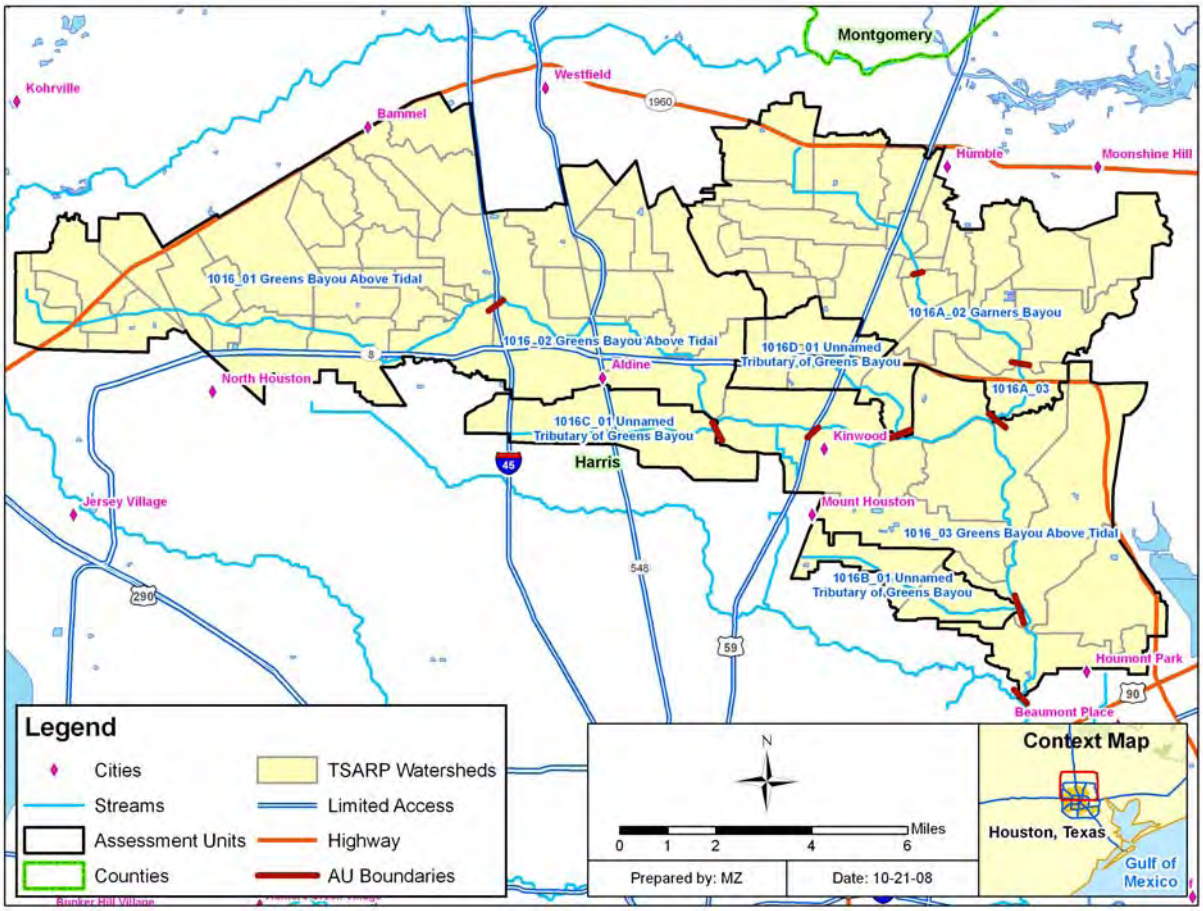

Figure 1. Segments and Watersheds

Table 1. Summary of Historic *E. coli* data (February 1992 – March 2008)

Assessment Unit	Station ID	Geometric Mean Criteria (MPN/100mL)	Geometric Mean Concentration (MPN/100mL)	Single Sample Criteria (MPN/100mL)	Number of Samples	Number of Samples Exceeding Single Sample Criteria	% of Samples Exceeding Single Sample Criteria
1016_03	11369	126	399	394	95	43	45%
	11370	126	379	394	62	26	42%
1016_02	11371	126	1,008	394	81	59	73%
	13778	126	1,355	394	95	78	82%
1016_01	11376	126	435	394	59	28	47%
	17495	126	243	394	59	17	29%
1016A_03	11125	126	732	400	61	35	57%
1016A_02	16589	126	346	394	63	29	46%
1016B_01	16590	126	622	394	62	36	58%
	20024	126	568	394	18	9	50%
1016C_01	11124	126	1,337	394	83	75	90%
1016D_01	16676	126	2,078	394	83	69	83%

Endpoint Identification The endpoint for the TMDLs for freshwater segments is to maintain the geometric mean of concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL.

Source Analysis In response to the listing, the TCEQ initiated an investigation to identify possible point and nonpoint sources of bacteria and to quantify the appropriate reductions necessary to comply with established water quality standards. The most likely contributing sources of impairment to the water bodies include:

- non-compliant discharges from wastewater treatment facilities;
- sanitary sewer overflows;
- storm water runoff;
- illicit discharges;
- on-site sewage facilities;
- domestic pets; and
- direct deposition from waterfowl and wildlife.

Linkage Establishing the potential relationship between instream water quality and the source of pollutant loadings is an important component in developing a TMDL. This component allows for the evaluation of management options that will achieve the desired endpoint.

Load duration curve (LDC) analyses were used to examine the relationship between instream water quality and the source of indicator bacteria loads over the complete range of flow conditions (categorized as highest flows, mid-range flows, and lowest flows). The LDC analysis showed that bacteria concentrations exceeded the geometric mean criterion in all AUs in the highest flow range but met the criterion more frequently at lower flows.

TMDL Calculation TMDLs are the sum of the individual wasteload allocations (WLAs) for sources requiring a discharge permit, load allocations (LAs) for sources that do not require a discharge permit, such as natural background sources, and a margin of safety (MOS). The TMDL equation has historically been written as follows.

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

Where:

WLA = wasteload allocation (permitted source contributions);
LA = load allocation (non-permitted source contributions); and
MOS = margin of safety.

The TMDL defines the total amount of a pollutant that can be assimilated by the receiving water body while still achieving water quality standards. In the TMDL equation, the wasteload allocation is the maximum allowable load from permitted sources and the load allocation is the maximum allowable load for non-permitted sources. The margin of safety is included to account for any uncertainty concerning the relationship between effluent limitations and water quality.

As stated in Title 40 of the Code of Federal Regulations (40 CFR), Section 130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli*, TMDLs are expressed as MPN per day, and represent the maximum one-day load the stream can assimilate while still attaining the surface water quality standards.

The bacteria TMDLs for the 303(d)-listed water quality monitoring stations covered in this report were derived using LDCs. The estimated maximum allowable loads of *E. coli* for each of the assessment units was determined as that corresponding to the flow regime requiring the highest load reduction.

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 a margin of safety.

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the single sample criterion. The explicit margin of safety was used because of the limited amount of data for some of the sampling locations. For contact recreation, this equates to a single sample target of 374 MPN/100mL for *E. coli* and a geometric mean target of 120 MPN/100mL. The net effect of the TMDL with the MOS is that the assimilative capacity, or allowable pollutant loading of each water body, is slightly reduced.

Waste Load Allocations Current TPDES-permitted wastewater treatment facilities (WWTFs) are allocated a daily waste load calculated as their permitted discharge flow rate multiplied by one-half of the instream geometric mean water quality criterion. One-half of the water quality standard (63 MPN/100mL) is used as the target to provide instream and downstream load capacity.

The WLA for each current WWTF (WLA_{WWTF}) is derived from the following equation.

$$WLA_{WWTF} = \text{criterion}/2 * \text{flow} * \text{unit conversion factor (\#/day)}$$

Where:

criterion = 126 MPN/100 mL *E. coli*
flow (10^6 gal/day) = permitted flow
unit conversion factor = 37,854,120 100mL/10^6 gal

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the waste load allocations. For TPDES-regulated municipal and small-construction storm water discharges, water quality-based effluent limits that implement the WLA for storm water may be expressed as best management practices (BMPs) or other similar requirements, rather than as numeric effluent limits (November 22, 2002, memorandum from EPA relating to establishing WLAs for storm water sources at 4). The EPA memo also states that:

"…the Interim Permitting Approach Policy recognizes the need for an iterative approach to control pollutants in storm water discharges...[s]pecifically, the policy anticipates that a suite of BMPs will be used in the initial rounds of permits and that these BMPs will be tailored in subsequent rounds."

Using an iterative, adaptive BMP approach to the maximum extent practicable is appropriate to address the storm water component of this TMDL. The iterative, adaptive approach is reflected in the 2008 permit renewal application of TPDES Permit No. WQ0004685000 for Harris County, Harris County Flood Control District, City of Houston, Texas Department of Transportation's MS4 Storm Water Management Plans. Due to the iterative approach of the permit, BMPs will be reevaluated and revised as necessary.

Load Allocation The load allocation is the sum of loading from all non-permitted sources. The LAs for each stream segment are calculated as the difference between the TMDL, MOS, WLA, and WLA for storm water as follows:

$$LA = TMDL - \Sigma WLA_{WWTF} - \Sigma WLA_{StormWater} - MOS$$

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
$\Sigma WLA_{StormWater}$ = sum of all storm water loads
MOS = margin of safety

TMDL The TMDLs were calculated based on the median flow in the 0-20 flow exceedance percentile range. This percentile corresponds to the range requiring the highest reductions in bacteria.

Future Capacity To account for the probability that new and/or additional flows from WWTFs may occur in any of the segments, a provision for future growth was included in the TMDL calculations by estimating permitted flows to year 2035 using population projections completed by the Houston-Galveston Area Council (H-GAC). The population increases range from 21 percent to 63 percent for each assessment unit. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

Allocations The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are presented in Table 2. In this table the future capacity for WWTFs has been added to the WLAWWTF. The allocations in this table are based on the current criteria for *E. coli* (geometric mean of 126 MPN/100 mL) in freshwater.

Table 2. Final TMDL Allocations

Assessment Unit	TMDL[a] (Billion MPN/day)	WLA_{WWTF} [b] (Billion MPN/day)	$WLA_{STORM\ WATER}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)
1016_01	403	90.2	293	0	20.2
1016_02	1,020	183	789	0	51.2
1016_03	1,780	410	1,050	231	89.0
1016A_02	197	43.5	138	5.69	9.84
1016A_03	419	153	214	31.0	21.0
1016B_01	15.0	0	12.4	1.86	0.751
1016C_01	94.1	1.21	88.2	0	4.70
1016D_01	79.7	33.4	35.8	6.51	3.99

[a] $TMDL = WLA_{WWTF} + WLA_{STORM\ WATER} + LA + MOS$

[b] $WLA_{WWTF} = WLA_{WWTF}$ + Future Growth

In the event that the criteria change due to future revisions in the state's surface water quality standards, the TMDL document provides guidance and equations for recalculating the allocations in Table 2. Note that one-half the current criterion for *E. coli* will be maintained for WWTFs even if criteria change due to future revisions in the state's surface water quality standards. Figure 2 provides an example of the equations that would be used for calculating the TMDL allocations to reflect changes to the contact recreation standards.

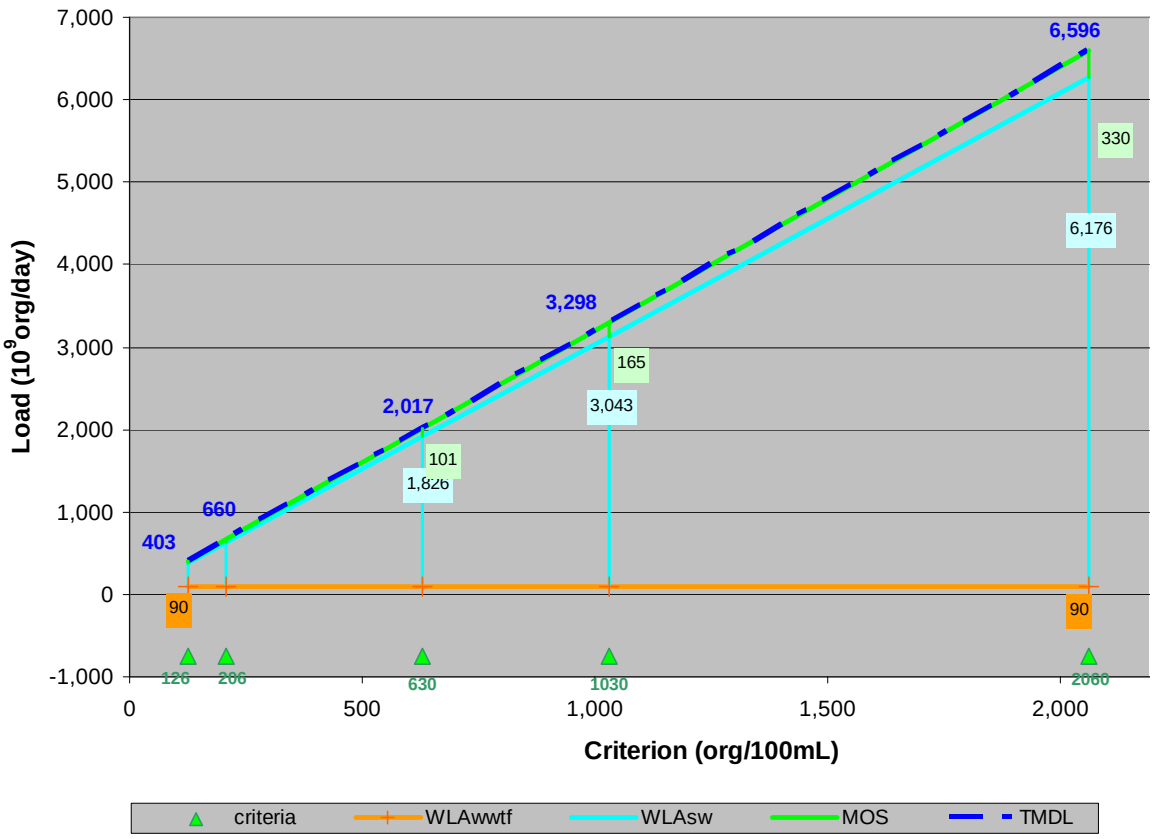

Figure 2. Allocation Loads for AU 1016_01 as a function of WQ Criteria

Equations for Calculating New TMDL and Allocations

TMDL = 3.202*Std
LA = 0
WLAStorm Water = 3.0419*Std - 90.223
WLAWWTF = 63*1.4321 = 90
MOS = 0.05*TMDL

Where:

WLAWWTF = waste load allocation (permitted WWTF)
WLAStorm Water = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

A graph and corresponding set of equations similar to this for each of the eight impaired assessment units covered by the TMDL are in Appendix A of the TMDL document.

Public Participation The TCEQ maintains an inclusive public participation process. From the inception of the source analysis, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

H-GAC is providing coordination for public participation in this project. To provide public involvement in the Greens Bayou Bacteria TMDL and the implementation phase, a public meeting was held on November 5, 2007, at the Aldine Youth Center. The meeting introduced the TMDL process, identified the impaired segments and the reason for the impairment, reviewed historical data, and described potential sources of bacteria within the watershed. In addition, the meeting gave TCEQ the opportunity to solicit input from all interested parties within the study area. An informational open house was held at the Lone Star College Greenspoint Center on November 6, 2008. Information on past and future meetings for the Greens Bayou Bacteria TMDL and related projects in the Houston area can be found on the H-GAC website at <http://www.h-gac.com/community/water/tmdl/metro/default.aspx >.

Implementation In December 2007, stakeholders in the Houston/Harris County area initiated an effort to develop an area-wide implementation plan (I-Plan) to address indicator bacteria sources throughout the greater Houston/Harris County area. The stakeholders have organized a coordinating committee known as the Bacteria Implementation Group (the "BIG") to direct the development of the I-Plan. This effort will include all of the water bodies that have been listed as impaired for contact recreation because of high indicator bacteria concentrations. These water bodies are listed in Table 3. The TCEQ estimates completion of the area-wide I-Plan, which will include the Greens Bayou watershed, in June 2010.

The stakeholder led BIG will develop the I-Plan for *Eight Total Maximum Daily Loads for Indicator Bacteria in Greens Bayou Above Tidal and Tributaries*, along with all other TMDLs for bacteria in the Houston area. Through the BIG, the excellent resources and expertise of the organizations and individuals involved in the group are available to develop the plan. Social and economic factors may be considered by the stakeholders during the development of the I-Plan. An adaptive management strategy will be used to develop a plan which will set priorities, provide flexibility, and be appropriate for all stakeholders.

Table 3. Watersheds Included in Houston/Harris County Implementation Plan

Watershed	Number of Segments	Number of AUs	Counties
Clear Creek	9	18	Harris, Fort Bend, Galveston, Brazoria
Buffalo & Whiteoak Bayous	18	23	Harris, Waller, Fort Bend
Sims Bayou	2	4	Harris, Fort Bend
Brays Bayou	4	5	Harris, Fort Bend
Halls Bayou	3	4	Harris
Greens Bayou	5	8	Harris
Eastern Houston	10	13	Harris
Lake Houston	9	15	Harris, Montgomery, Liberty, San Jacinto

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For Public Comment, December 2009

Eight Total Maximum Daily Loads for Indicator Bacteria in Greens Bayou Above Tidal and Tributaries

Segments: 1016, 1016A, 1016B, 1016C, and 1016D

Assessment Units: 1016_01, 1016_02, 1016_03, 1016A_02, 1016A_03, 1016B_01, 1016C_01, and 1016D_01

Prepared by the
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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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"Technical Support Document: Indicator Bacteria Total Maximum Daily Loads
for the Greens Bayou Watershed, Houston, Texas
(1016_01, 1016_02, 1016_03, 1016A_02, 1016A_03, 1016B_01, 1016C_01, 1016D_01)"

prepared by University of Houston and Parsons

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List of Acronyms

AU	Assessment Unit
BMP	Best Management Practice
C-CAP	Coastal Change Analysis Program
CFR	Code of Federal Regulations
CFU	Colony-Forming Units
CFS	Cubic Feet per Second
DMR	Discharge Monitoring Report
EC	*Escherichia coli*
EPA	Environmental Protection Agency
FC	Fecal Coliform
FDC	Flow Duration Curve
GIS	Geographic Information System
HCFCD	Harris County Flood Control District
HCOEM	Harris County Office of Homeland Security and Emergency Management
H-GAC	Houston-Galveston Area Council
LA	Load Allocation
LDC	Load Duration Curve
mL	Milliliter
MGD	Million Gallons per Day
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer System
MUD	Municipal Utility District
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	National Resources Conservation Service
OSSF	Onsite Sewage Facility
SSO	Sanitary Sewer Overflow
STATSGO	State Soil Geographic Database
SWPPP	Storm Water Pollution Prevention Plan
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollutant Discharge Elimination System
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WLA	Waste Load Allocation
WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

Eight Total Maximum Daily Loads for Indicator Bacteria in Greens Bayou Above Tidal and Tributaries

Executive Summary

This document describes total maximum daily loads for Greens Bayou Above Tidal and its tributaries, where concentrations of indicator bacteria exceed the criteria used to evaluate attainment of the contact recreation use. The Texas Commission on Environmental Quality (TCEQ) first identified the impairments in the 1996 and 2002 versions of the *Texas Water Quality Inventory and 303(d) List*.

Greens Bayou is located in north central Harris County, about 10 miles north of the central business district of the City of Houston. The Greens Bayou non-tidal watershed drains an area of about 140 square miles and encompasses the cities of Houston and Humble. Most of the watershed is highly developed, but some areas between U.S. Highway 59 and I-10 remain undeveloped (HCFCD, 2008). There are about 200 miles of open streams within the watershed.

As described in the TCEQ's "2004 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data" (TCEQ 2004), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. *Escherichia coli* (*E. coli*) is the preferred indicator bacteria for assessing the contact recreation use in freshwater. Fecal coliform bacteria were the preferred indicator prior to 2000 and may be used when there is insufficient *E. coli* data. For this project *E. coli* data were used for total maximum daily load (TMDL) development. The criteria for assessing attainment of the contact recreation use are expressed as the number ("counts") of indicator bacteria, typically given in most probable number (MPN—for *E. coli*) or colony-forming units (cfu—for fecal coliform) per hundred milliliters (100 mL) of water. These units are considered equivalent. For the *E. coli* indicator, the contact recreation use is not supported when the geometric mean of all *E. coli* samples exceeds 126 MPN per 100 milliliter (mL). The contact recreation use is also not supported if individual samples exceed 394 MPN per 100 mL more than 25 percent of the time.

The historical ambient water quality data for indicator bacteria (1992-2008) for 15 select TCEQ water quality monitoring stations in the Greens Bayou Watershed were examined. Data collected prior to 2001 correspond to fecal coliform concentrations, while data for 2001-2008 are primarily *E. coli* concentrations. All of the stations failed to meet water quality criteria for *E. coli*. The geometric means of *E. coli* exceeded the standard and ranged from 243 MPN/100mL to 2,078 MPN/100mL.

The most probable sources of indicator bacteria within the entire watershed are non-compliant wastewater treatment facility (WWTF) discharges, storm water runoff from permitted storm sewer sources, sanitary sewer overflows, illicit discharges from storm sewers, failing on-site sewer facilities, and runoff from areas not covered by a permit.

A load duration curve (LDC) analysis was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources of indicator bacteria. The TMDL allocations are discussed in the section on TMDL Calculations and are presented in Table 18. The waste load allocation for WWTFs was established as the permitted flow times one-half the geometric mean criterion for the indicator bacteria. Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard. The TMDL calculations in this report will guide determination of the assimilative capacity of each stream under changing conditions, including future growth. Wastewater discharge facilities will be evaluated on a case-by-case basis.

Introduction

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

In simple terms, a TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. 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 the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The 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 addresses impairments to the contact recreation use due to exceeding indicator bacteria criteria in Greens Bayou Above Tidal, Garners Bayou, and three unnamed tributaries of Greens Bayou.

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

units covered by this document were included in the 2008 303(d) list under category 5a indicating that they are a priority for developing a TMDL.

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

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

Upon EPA approval, these TMDLs will become an update to the state's Water Quality Management Plan.

Problem Definition

The TCEQ first identified the impairment to the contact recreation use for Greens Bayou Above Tidal in the *1996 Texas Water Quality Inventory and 303(d) List* (1996 Inventory and List), and Garners Bayou and three unnamed tributaries of Greens Bayou in the *2002 Texas Water Quality Inventory and 303(d) List* (2002 Inventory and List). All of these segments (Table 1) are freshwater bodies located in the northern metropolitan Houston area (Figure 1). In this document, the area that contains all of these segments will be referred to as the TMDL watershed.

Table 1. TMDL Segments, Assessment Units, and First Year on 303(d) List

Segment Number	Segment Name	Type	Assessment Units	First Year Listed
1016	Greens Bayou Above Tidal	Freshwater	1016_01, 1016_02, 1016_03	1996
1016A	Garners Bayou	Freshwater	1016A_02, 1016A_03	2002
1016B	Unnamed Tributary of Greens Bayou	Freshwater	1016B_01	2002
1016C	Unnamed Tributary of Greens Bayou	Freshwater	1016C_01	2002
1016D	Unnamed Tributary of Greens Bayou	Freshwater	1016D_01	2002

The standards for water quality are defined in the *Texas Surface Water Quality Standards* (TCEQ 2000). The specific uses assigned to the five segments included in this report are contact recreation, aquatic life, general, and fish consumption. The criteria for assessing attainment of the contact recreation use are expressed as the number ("counts") of indicator bacteria, typically given in MPN (for *E. coli*) or cfu (for fecal coliform) per hundred milliliters (100 mL) of water. These units are considered equivalent. The number may not exceed certain concentrations in a single sample, nor as a geometric mean of all samples.

As described in the TCEQ's "2004 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data" (TCEQ 2004), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. *E. coli* for freshwater and Enterococci in tidal water are now the preferred indicator bacteria for assessing the contact recreation use. Fecal coliform bacteria may be used when there is insufficient *E. coli* or Enterococci data, since fecal coliform was the preferred indicator prior to 2000. For this project *E. coli* data were used for data analysis and modeling to support TMDL development for Greens Bayou Above Tidal and its tributaries. Fecal coliform data are also presented for some sampling stations.

For the *E. coli* indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all *E. coli* samples exceeds 126 MPN per 100 mL;
- and/or individual samples exceed 394 MPN per 100 mL more than 25 percent of the time.

For the fecal coliform indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all fecal coliform samples exceeds 200 cfu per 100 mL;
- and/or individual samples exceed 400 cfu per 100 mL more than 25 percent of the time.

Ambient Indicator Bacteria Concentrations

Table 2 summarizes the historical ambient water quality data for indicator bacteria (1992-2008) for select TCEQ water quality monitoring stations in the Greens Bayou Watershed. Data in Table 2 collected prior to 2001 correspond to fecal coliform concentrations, while data for 2001-2008 are primarily *E. coli* concentrations.

Watershed Overview

Greens Bayou is located in north central Harris County, about 10 miles north of the central business district of the City of Houston. The Greens Bayou non-tidal watershed drains an area of about 140 square miles and encompasses the cities of Houston and Humble. The non-tidal portion of the bayou flows across northern Harris County generally eastward from its headwaters near Farm-to-Market 1960 for about 23 miles, and then turns at its confluence with Garners Bayou and flows southward for about 7 miles to the confluence with Halls Bayou. The Harris County Flood Control District (HCFCD) has made channel improvements

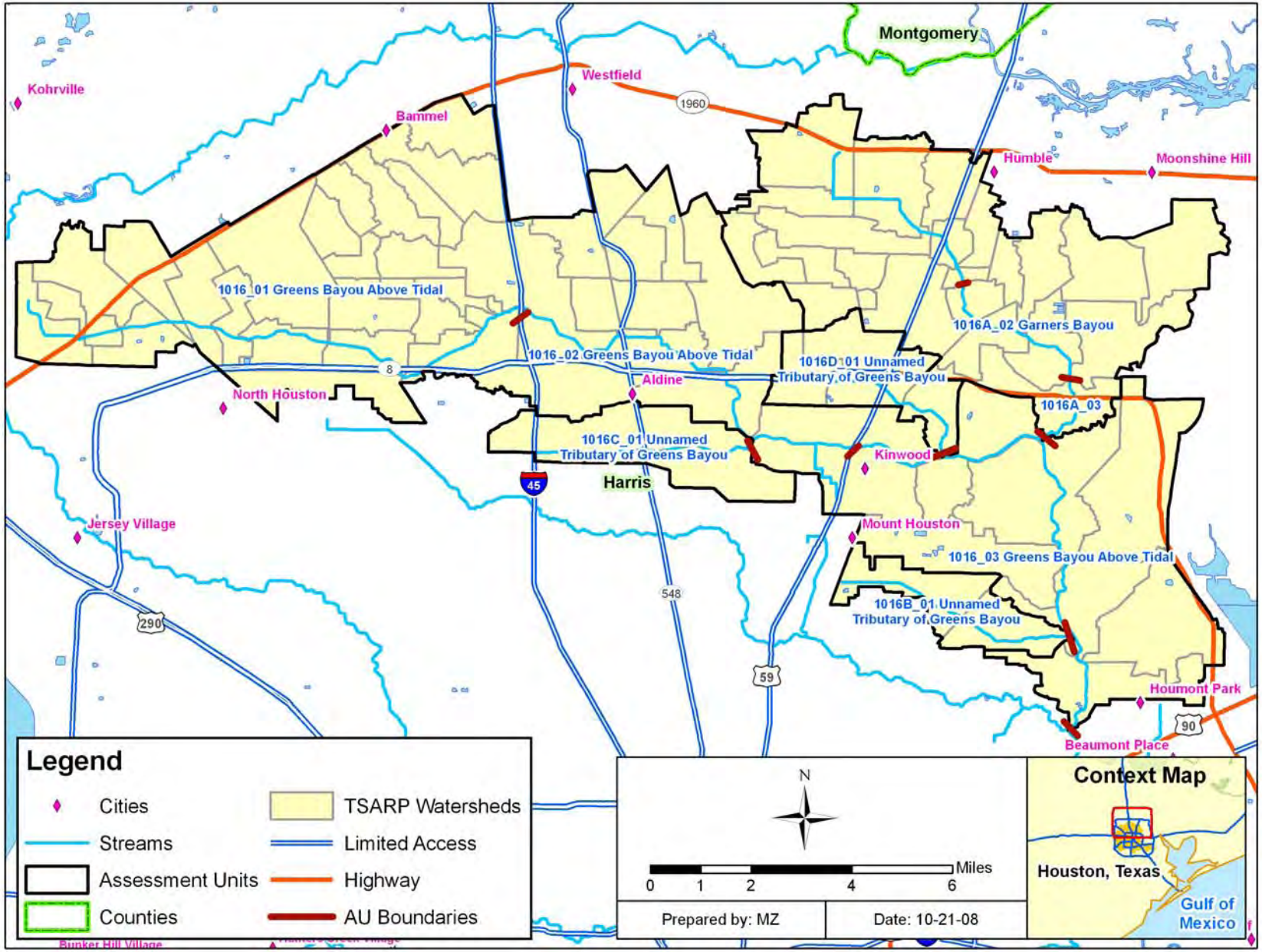

Figure 1. Greens Bayou Above Tidal Watershed

Table 2. Historical Water Quality Data — February 1992 to March 2008

Assessment Unit	Station ID	Indicator Bacteria	Geometric Mean Criteria	Geometric Mean Concentration	Single Sample Criteria	Number of Samples	Number of Samples Exceeding Single Sample Criteria	% of Samples Exceeding
1016_03	11369	EC	126	399	394	95	43	45%
		FC	200	167	400	50	15	30%
	11370	EC	126	379	394	62	26	42%
		FC	200	107	400	49	10	20%
1016_02	11371	EC	126	1,008	394	81	59	73%
		FC	200	423	400	89	45	51%
	11372	FC	200	6	400	8	0	0%
	11373	FC	200	8	400	8	1	13%
	13778	EC	126	1,355	394	95	78	82%
		FC	126	1,111	394	51	35	69%
1016_01	11376	EC	126	435	394	59	28	47%
		FC	200	12	400	9	1	11%
	11378	FC	200	265	400	1	0	0%
	17495	EC	126	243	394	59	17	29%
1016A_03	11125	EC	126	732	400	61	35	57%
		FC	200	553	400	79	38	48%
1016A_02	16589	EC	126	346	394	63	29	46%
		FC	200	1,142	400	63	40	63%
1016B_01	16590	EC	126	622	394	62	36	58%
		FC	200	768	400	78	47	60%
	20024	EC	126	568	394	18	9	50%
1016C_01	11124	EC	126	1,337	394	83	75	90%
		FC	200	1,331	400	75	63	84%
1016D_01	16676	EC	126	2,078	394	83	69	83%
		FC	200	882	400	77	43	56%

EC: *E. coli* in MPN/100mL, FC: Fecal Coliform in cfu/100mL

upstream of U.S. Highway 90 (U.S. Army Corps of Engineers [USACE], 2005). Most of the watershed is highly developed, but some areas between U.S. Highway 59 and I-10 remain undeveloped (HCFCD, 2008). There are about 200 miles of open streams within the watershed.

Table 3 summarizes the acreages and the corresponding percentages of the land use categories for the contributing watershed associated with each respective segment in the Greens Bayou watershed. The land use/land cover data were derived from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center. The specific land use/land cover data files were derived from the Coastal Change Analysis Program (C-CAP), Texas 2005 Land Cover Data (NOAA 2007). The land use categories are displayed in Figure 2. The total acreage of each segment in Table 3 corresponds to the watershed delineation in Figure 2. The predominant land use category in this watershed is developed land (between 44% and 85%) followed by woody land (between 10% and 31%). Open water and bare/transitional land account for less than 2 percent of the subwatersheds.

Table 3. Land Use Summaries

Aggregated Land Use Category	Segment /Assessment Unit ID				
	1016[a]	1016A[b]	1016B_01	1016C_01	1016D_01
Percent Developed	56	52	44	85	63
Percent Cultivated Land	0.0	0.0	0.0	0.0	0.0
Percent Pasture/Hay	3.0	3.2	1.2	1.9	0.4
Percent Grassland/Herbaceous	4.1	2.8	1.1	1.9	3.7
Percent Woody Land	25	31	26	10	23
Percent Open Water	0.3	0.4	0.1	0.0	0.1
Percent Wetland	10.6	9.7	28	1.8	9.0
Percent Bare/Transitional	1.1	0.6	0.1	0.1	0.3
Acres of Developed	32,852	11,284	1,180	3,426	2,256
Acres Cultivated Land	3.0	0.7	0	0	0
Acres Pasture/Hay	1752	698	33	76	13
Acres Grassland/Herbaceous	2381	597	30	79	133
Acres of Woody Land	14,417	6,795	697	387	820
Acres of Open Water	152	91	3.8	0.0	2.4
Acres of Wetland	6,204	2,096	755	73	322
Acres of Bare/Transitional	642	135	2.2	2.0	10.0
Watershed Area (acres)	**58,404**	**21,697**	**2,698**	**4,043**	**3,556**

[a] Assessment Units 1016_01, 1016_02, and 1016_03

[b] Assessment 1016A_02 and 1016A_03

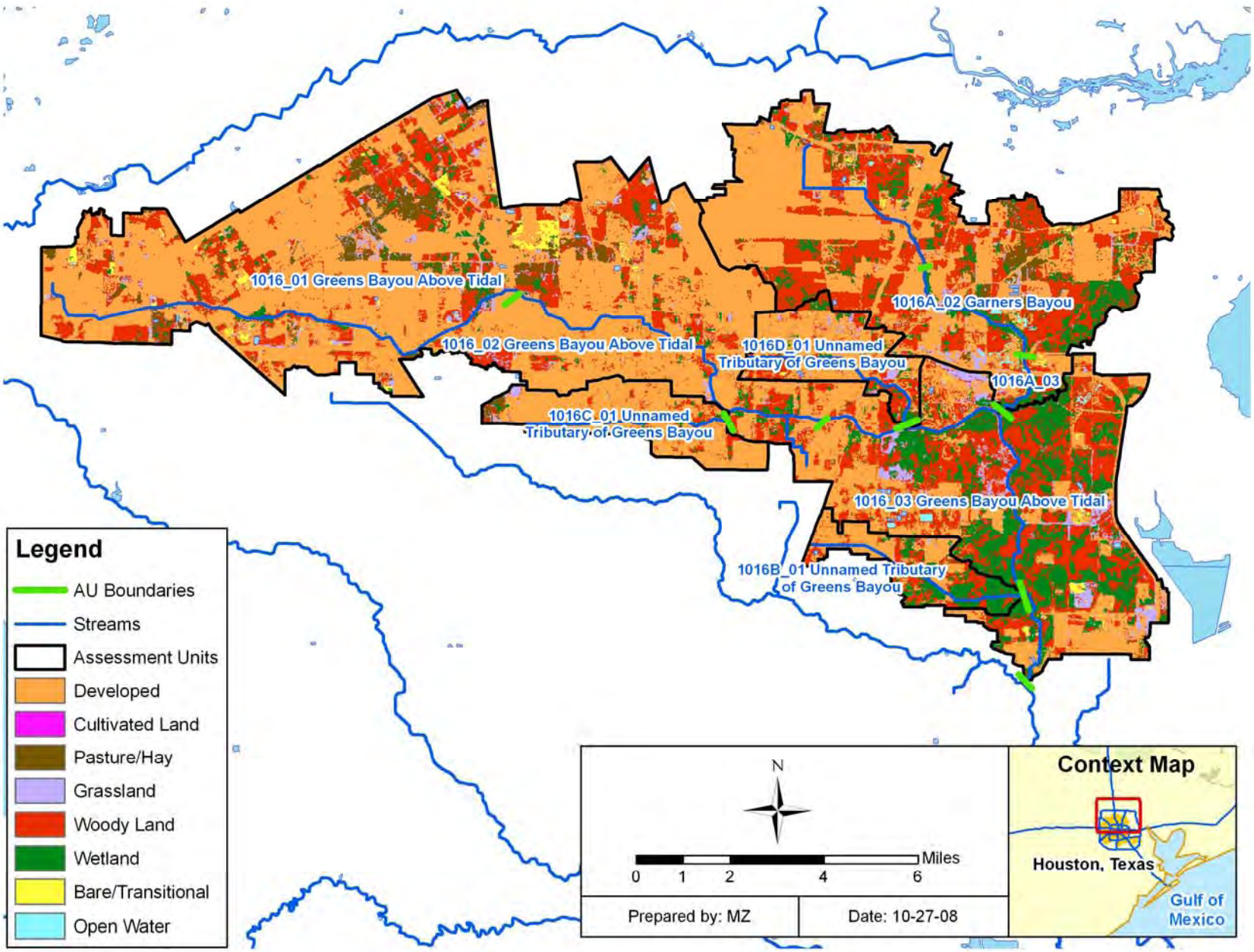

Figure 2. Greens Bayou Above Tidal Watershed Land Use

The climate of the region is subtropical humid, with hot and humid summers and mild winters (U.S. Army Corps of Engineers [USACE] 1985). The average maximum daytime temperature in the summer is 93 degrees Fahrenheit (°F), while the temperature averages between 39 and 61°F during the winter. Summer rainfall is dominated by subtropical convection, winter rainfall by frontal storms, and fall and spring months by combinations of these two (Burian and Shepherd 2005). The 100-year floodplain encompasses about 22 percent of the drainage area of the watershed, approximately 31 square miles (HCFCD 2008).

There are 10 rain gauges located within the watershed (Figure 3). The gauges are maintained by the Harris County Office of Homeland Security and Emergency Management (HCOEM). The Greens Bayou Above Tidal watershed experiences frequent rainfall events, with annual precipitation totals of approximately 50 inches. Monthly rainfall totals are consistent throughout the year. High intensity rainfall often causes localized street flooding and occasional out-of-bank conditions. The watershed is located near the Gulf coast, and is subject to extreme weather between June 1 and November 30 every year, although the chance of tropical weather declines dramatically in October. As a result, an extensive conveyance system for storm water has been developed throughout the area. Figure 3 shows average annual rainfall across the Greens Bayou watershed. This figure was developed by using data from 148 HCOEM rain gauges located across Harris, Fort Bend, and Galveston Counties to estimate rainfall values at unobserved locations throughout the remainder of the watershed. Average values by subwatershed are summarized in Table 4. These average values were used to support the development of flow duration curves.

The State Soil Geographic Database (STATSGO) (National Resources Conservation Service [NRCS] 1994) information was used to characterize soil in the Greens Bayou Watershed. The soil types that dominate the watershed are primarily from the Clodine, Aldine, and Wockley soil series (Figure 4). The distribution and attributes of the three soil series found in the Greens Bayou watershed are listed in Table 5. All soil types in the watershed are somewhat poorly drained, thus contributing to high runoff rates. The topography of the area is characteristic of the Texas Gulf Coastal Plains. The streambed has an average slope of about 0.07 percent (3.7 feet per mile). Elevations in the watershed vary from about 123 feet above mean sea level near the headwaters to about 8 feet above mean sea level at the mouth of Greens Bayou (USACE 2005).

Table 4. Average Rainfall for Each Assessment Unit Watershed

Segment/Assessment Unit	Annual Average (Inches)
1016_01, 1016_02, 1016_03	50.3
1016A_02, 1016A_3	49.1
1016B_01	54.6
1016C_01	51.8
1016D_01	49.1

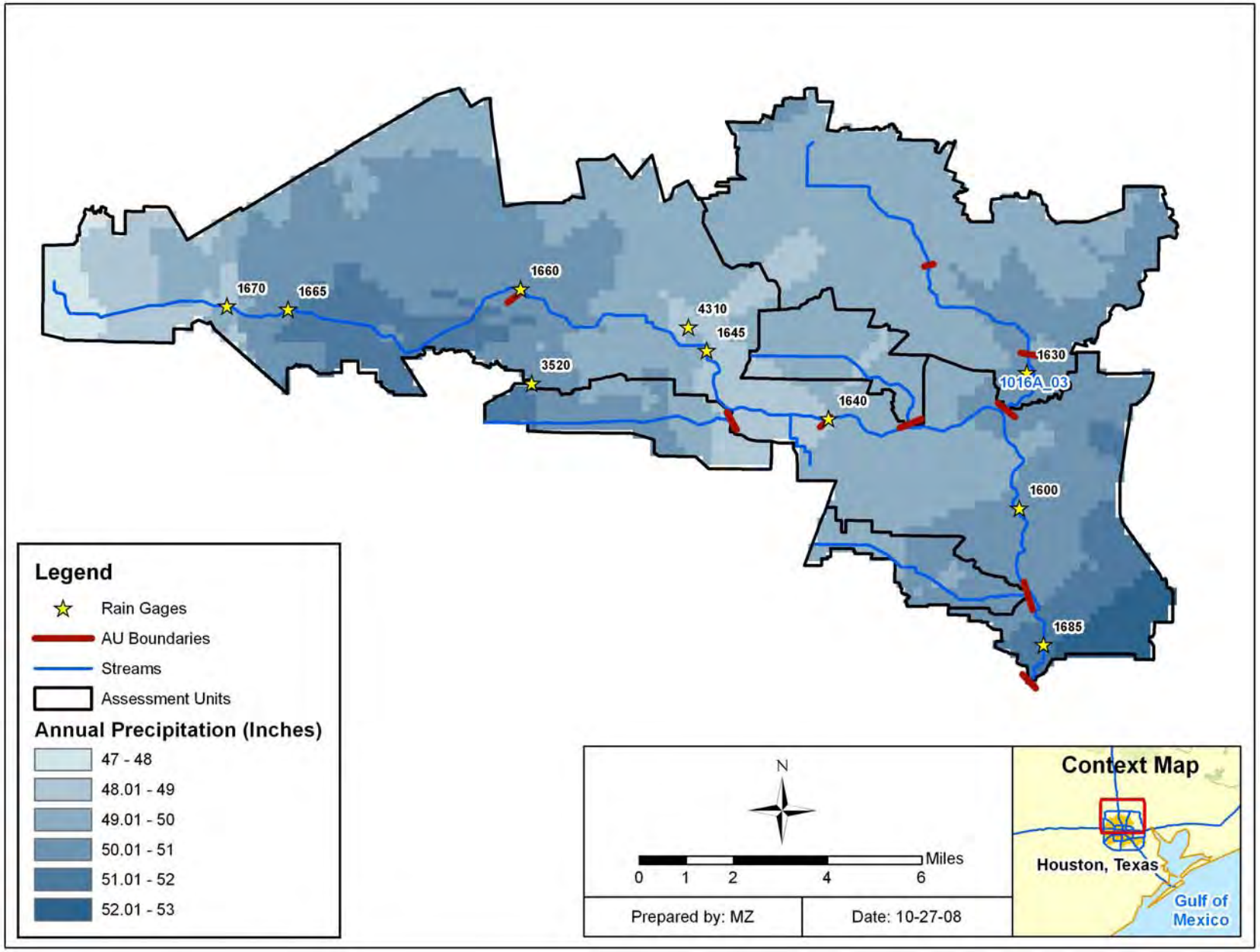

Figure 3. Greens Bayou Above Tidal Watershed Precipitation Map

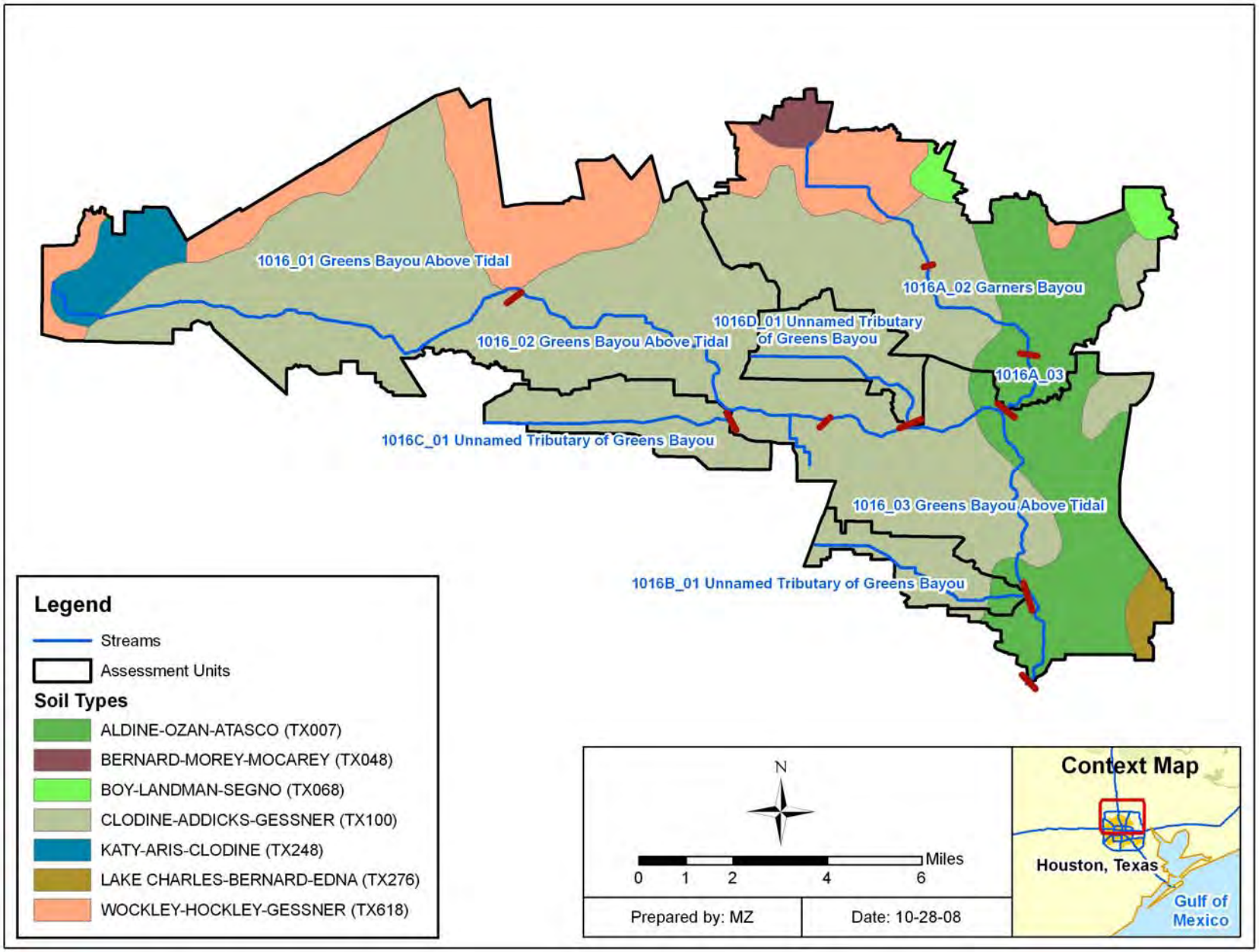

Figure 4. Greens Bayou Above Tidal Watershed Soil Types

Stream flow data is key information when conducting water quality assessments. The U.S. Geological Survey (USGS) operates flow gauges at four locations along Greens Bayou to measure flow and gauge heights. The period of record and type of data collected at these gauges are listed upstream to downstream in Table 6. The locations of these gauge stations are shown on Figure 5. All gauges in the watershed are currently active. The historical flow data available from these gauges are summarized as flow exceedance percentiles in constructing flow duration curves.

Table 5. Characteristics of Soil Types within Greens Bayou Above Tidal Watershed

NRCS Soil Type	Soil Series Name	Percent of Watershed Area	Surface Texture	Hydrologic Group	Soil Drainage Class	Min Water Capacity (in/in)	Max Water Capacity (in/in)	Min Bulk Density (g/cm3)
TX100	Clodine	64.3%	Loam	D	Poorly Drained	0.15	0.15	1.4
TX007	Aldine	16.8%	Fine Sandy Loam	D	Somewhat Poorly Drained	0.13	0.18	1.45
TX618	Wockley	13.3%	Fine Sandy Loam	C	Somewhat Poorly Drained	0.12	0.13	1.45
TX248	Katy	2.6%	Fine Sandy Loam	D	Somewhat Poorly Drained	0.12	0.16	1.4
TX068	Boy	1.2%	Loamy Fine Sand	B	Somewhat Poorly Drained	0.09	0.12	1.5
TX048	Bernard	0.9%	Clay Loam	D	Somewhat Poorly Drained	0.14	0.19	1.33
TX276	Lake Charles	0.9%	Clay	D	Somewhat Poorly Drained	0.12	0.17	1.33

Source: All data obtained/calculated from STATSGO database

Table 6. USGS Gauges in the Greens Bayou Above Tidal Watershed

USGS Gauge Number	Name	Period of Record	Data Type
8075780	Greens Bayou at Cutter Rd	12/6/2003 - Present	Gauge Height (ft)
8075900	Greens Bayou at US HWY 75	8/3/1965 - Present	Discharge (cfs)
		4/17/1997 - Present	Gauge Height (ft)
8076000	Greens Bayou at US 59 North of Houston	10/1/1952 - Present	Discharge (cfs)
		9/28/1952 - Present	Gauge Height (ft)
8076180	Garners Bayou near Humble, Texas	2/25/1986 - Present	Discharge (cfs)
		2/13/1998 - Present	Gauge Height (ft)

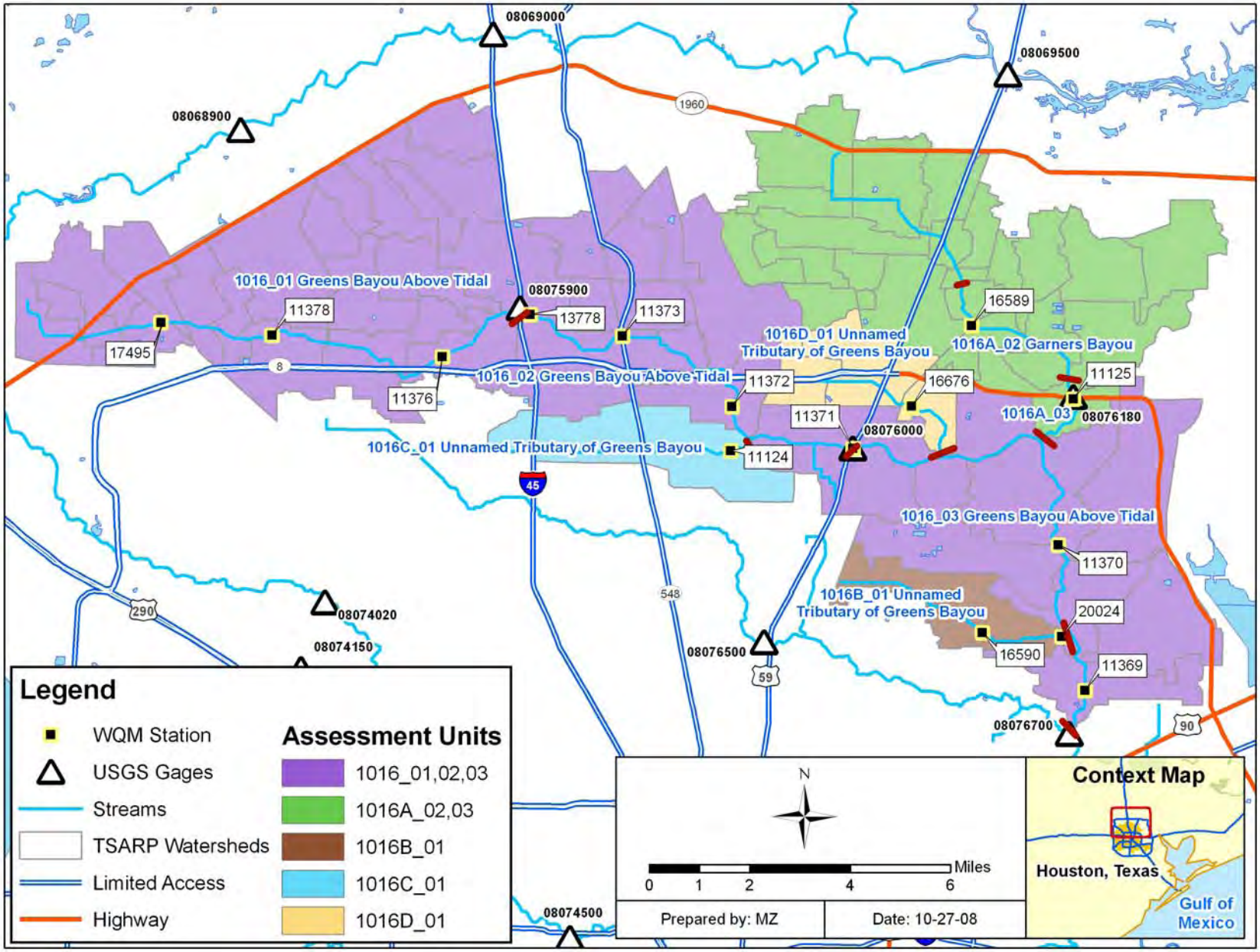

Figure 5. Greens Bayou Above Tidal Watershed Sampling Locations and USGS Gauge Locations

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 endpoint for the TMDLs in this report is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This is the endpoint in Greens Bayou Above Tidal (1016), Garners Bayou (1016A), Unnamed Tributary of Greens Bayou (1016B), Unnamed Tributary of Greens Bayou (1016C), and Unnamed Tributary of Greens Bayou (1016D).

Source Analysis

Pollutants may come from several sources, both point and nonpoint. Pollutants referred to as "point sources" come from sources that are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) and the National Pollutant Discharge Elimination System (NPDES). Waste Water Treatment facilities (WWTFs), and 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. It is usually carried to surface waters by rainfall runoff, and is not regulated by permit under the TPDES or NPDES.

Point Sources

Within the TMDL watershed, Greens Bayou Above Tidal (1016), Garners Bayou (1016A), Unnamed Tributary of Greens Bayou (1016C), and Unnamed Tributary of Greens Bayou (1016D) have NPDES/TPDES-permitted sources. There are no NPDES/TPDES-permitted sources located within Unnamed Tributary of Greens Bayou (1016B). A significant portion of the study area (approximately 84%) is regulated under the TPDES discharge permit for storm water jointly held by Harris County, HCFCD, City of Houston, and Texas Department of Transportation (TPDES Permit No. WQ0004685000). There are no NPDES-permitted confined animal feeding operations or land application sites within the TMDL watershed.

WWTFs

As of October 20, 2008, there were 109 permitted outfalls for WWTFs in the TMDL watershed. The names and permit numbers of the TPDES-permitted facilities that continuously discharge wastewater to surface waters addressed in these TMDLs are listed in Table 7. Facility locations are displayed in Figure 6.

Not all TPDES-permitted facilities that discharge treated wastewater are required to monitor for fecal bacteria. While current criteria for Instream water quality are based on *E. coli* bacteria, permit limits are based on levels of fecal coliform, another measure of fecal

bacteria of which *E. coli* is often the major constituent. Therefore, data on bacteria loads from WWTF outfalls are only available for some of the TPDES permitted dischargers in the Greens Bayou Watershed. Table 8 summarizes data from Discharge Monitoring Reports (DMR) available for 16 TPDES WWTFs (as of October 2008) that monitor their discharge for fecal coliform. The 90th percentile of the monthly average load and the maximum monthly average loads are provided to estimate fecal coliform loads from these 16 TPDES WWTFs. The number of reported monthly exceedances of the geometric mean concentration of 200 cfu/100mL, and the number of reported daily exceedances of the single sample standard of 400 cfu/100mL are shown in Table 8. Seven out of 16 permitted facilities exceeded fecal coliform permit limits during the monitoring time frame.

Sanitary Sewer Overflows

Sanitary sewer overflows (SSO) are permit violations that must be addressed by the responsible TPDES permittee. SSOs most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris, and occur under conditions of high flow in the WWTF system. The TCEQ maintains a database of SSO data collected from wastewater operators in the Greens Bayou Watershed. In 2007, the City of Houston provided the project team a database of SSO data. These data are summarized in Table 9. There were approximately 67 sanitary sewer overflows reported in the Greens Bayou Watershed between February 2001 and December 2003. The reported SSOs averaged 4,477 gallons per event. The locations and magnitudes of the all reported SSOs are displayed in Figure 7 along with the WWTF service area boundaries.

TPDES Regulated Storm Water

When evaluating waste load allocations and load allocations, a distinction must be made between storm water originating from an area under a TPDES regulated discharge permit and storm water originating from areas not under a TPDES regulated discharge permit. Storm water discharges fall into two categories:

1) storm water subject to permitting, which is any storm water originating from a TPDES Phase 1 or Phase 2 permitted-discharge urbanized area; and
2) storm water currently not subject to permitting, which is any storm water originating from any area outside a TPDES Phase 1 or Phase 2 permitted-discharge urbanized area.

Considerable portions of each watershed in the study area are covered under the City of Houston/Harris County discharge permit (TPDES Permit No. WQ0004685000). The jurisdictional boundary of the Houston municipal separate storm sewer system (MS4) permit is derived from Urbanized Area Map Results for Texas which is based on the 2000 U.S. Census and can be found at the EPA Web site: <http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX>.

Table 7. WWTF Dischargers in the TMDL Watershed

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES NUMBER	Facility Name	DTYPE	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
1016	Greens Bayou Above Tidal	1016_01	14446-001	TX0095265	1920 Interpark	N/A	0.012	N/A
		1016_01	11238-002	TX0026344	Harris Co. MUD 005	D	0.9	0.49
		1016_01	11201-001	TX0027324	Emerald Forest UD	W	1.5	0.46
		1016_01	11026-002	TX0033243	Harris Co. WCID #109	W	3	1.42
		1016_01	10495-115	TX0054798	Houston-Northborough MUD	W	2	0.57
		1016_01	10905-001	TX0058424	North Forest MUD	D	0.3	0.13
		1016_01	04084-001	TX0063878	CSA Limited	D	0.004	0.0022
		1016_01	04084-002	TX0063878	CSA Limited	D	0.008	0.0022
		1016_01	11863-001	TX0072893	Harris Co. MUD 150	W	3	0.95
		1016_01	11884-001	TX0073407	NW Harris Co. MUD 006	D	0.475	0.17
		1016_01	11904-001	TX0074136	Harris Co. MUD 033	W	3	0.83
		1016_01	11907-002	TX0075132	Mills Road MUD	D	0.9	0.33
		1016_01	02596-001	TX0076155	Reliant Energy-Greensp	W	0.02	0.0025
		1016_01	12000-001	TX0077062	Moulding Specialists	D	0.005	0.0074
		1016_01	12065-001	TX0078824	Harris Co. MUD 086	D	0.95	0.22
		1016_01	12127-001	TX0079529	Harris Co. MUD 180	D	0.95	0.31
		1016_01	12144-001	TX0079821	NW Harris Co. MUD 021	W	1.5	0.55
		1016_01	12218-001	TX0083429	CMH Parks	D	0.122	0.083
		1016_01	12237-001	TX0083712	Harris Co. MUD 189	D	1.25	0.52
		1016_01	10495-133	TX0084875	Houston-HC MUD #203	W	3	0.54
		1016_01	12294-001	TX0085413	Harris Co. MUD 200	W	1.44	0.76
		1016_01	04853-001	TX0088897	R&A Harris South	W	0.006	0.00011

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES NUMBER	Facility Name	DTYPE	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
		1016_01	12527-001	TX0090069	Movimex Co.	D	0.01	0.00061
		1016_01	14447-001	TX0090476	Harris Co. MUD #191	D	0.71	0.19
		1016_01	12631-001	TX0091901	Harris Co. MUD 202	D	0.725	0.078
		1016_01	12655-001	TX0092312	NW Harris Co. MUD 024	D	0.5	0.084
		1016_01	12934-001	TX0097047	Rankin Rd West MUD	D	0.3	0.14
		1016_01	13564-001	TX0097225	Harris Co. MUD #304	D	0.65	0.17
		1016_01	04483-001	TX0102008	Centerpoint Energy Houston	W	0.015	0.0026
		1016_01	11351-001	TX0111767	Harris Co. MUD 011	D	0.5	0.23
		1016_01	10495-126	TX0113131	Hou-Willowbrook Reg.	W	2	0.75
		1016_02	14882-001	NA	AMC Facilities LP	D	0.025	NA
		1016_02	10495-101	TX0020478	Houston-Imperial Valley	W	4	1.44
		1016_02	10785-001	TX0021199	Sequoia Id	D	0.2	0.081
		1016_02	11414-002	TX0033189	Sasson, Eli	D	0.099	0.048
		1016_02	10495-078	TX0034916	Houston-Intercont Air	W	8	1.14
		1016_02	10495-100	TX0055310	Houston-Northgate UD	W	3.71	2.03
		1016_02	11597-001	TX0058076	North Belt UD	D	1.5	0.17
		1016_02	11678-001	TX0064424	Yazdcorp Funds V LLC	D	0.05	0.031
		1016_02	11791-001	TX0071382	Sunbelt FWSD	W	1.225	0.22
		1016_02	04018-001	TX0078638	Dresser Industries	W	0.07	0.032
		1016_02	12070-001	TX0078808	Aldine ISD	D	0.063	0.026
		1016_02	12149-001	TX0081388	MLR Management	D	0.01	0.0027
		1016_02	12206-001	TX0083381	North Green MUD	D	0.6	0.25
		1016_02	03420-001	TX0084093	VAM USA	W	0.02	0.0058

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES NUMBER	Facility Name	DTYPE	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
		1016_02	02453-001	TX0084298	Smith International	W	0.15	0.064
		1016_02	12320-001	TX0085901	Component Structures	D	0.002	NA
		1016_02	12484-001	TX0089281	Boring Specialties	D	0.005	0.0022
		1016_02	12617-001	TX0091651	Goodwin, Sandra	D	0.035	0.0014
		1016_02	12754-001	TX0093475	Greens Parkway MUD	D	0.98	0.047
		1016_02	12765-001	TX0093556	United Structures	D	0.008	0.0033
		1016_02	13066-001	TX0097276	Hoajey, Ltd.	D	0.009	0.00011
		1016_02	03402-001	TX0103616	GSE Lining Technology	W	0.016	0.00095
		1016_02	14302-001	TX0124460	RJR Realty, Ltd	D	0.003	NA
		1016_02	14621-001	TX0127957	Rankin Park Mainten & Util	D	0.05	NA
		1016_02	14784-001	TX0129445	Skymark Development	D	0.45	NA
		1016_02	14891-001	TX0131555	Lochinvar Golf Club	0	0.005	NA
		1016_03	14513-001	TX0126594	Christian Tabernacle	D	0.019	NA
		1016_03	14633-001	TX0128066	South Central Water Company	D	0.45	NA
		1016_03	11061-001	TX0020800	Greenwood Utility District	D	0.95	0.42
		1016_03	10495-150	TX0025291	Houston-WCID #76	D	0.7	0.42
		1016_03	11158-001	TX0032085	Champ's Water Co.	D	0.028	0.011
		1016_03	14874-001	TX0067539	BCWK Inc.	D	0.1	NA
		1016_03	11818-001	TX0071897	Harris Co. MUD 148	D	0.5	0.15
		1016_03	11818-003	TX0071897	Harris Co. MUD 148	D	0.95	0.15
		1016_03	14557-001	TX0087840	Mumtaz Builders	D	0.008	NA
		1016_03	12626-001	TX0091847	Thurber	D	0.019	0.0086
		1016_03	12692-001	TX0092711	Karbalai, Rita	D	0.05	0.019
		1016_03	13955-001	TX0094935	Murhaj, Kobra	D	0.025	0.0093

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES NUMBER	Facility Name	DTYPE	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
		1016_03	13559-001	TX0095761	Hinojosa Rene	D	0.015	0.0098
		1016_03	10495-148	TX0101460	Hou-Tidwell Timbers	D	0.488	0.13
		1016_03	13483-001	TX0104965	Harris Co. MUD	W	1	0.17
		1016_03	14320-001	TX0124702	Tidwell Wu, LLC	D	0.4	NA
		1016_03	14897-001	TX0125326	Holy Trinity Episcopal School	D	0.075	0.0012
		1016_03	14608-001	TX0127825	Greens Bayou Assembly Of God	D	0.035	NA
		1016_03	14625-001	TX0127981	Marhaba Partners Limited Part	D	0.75	NA
		1016_03	14625-002	TX0127990	Marhaba Partners Limited Part	D	0.45	NA
		1016_03	14703-001	TX0128694	FRM/MRA Holdings #1	D	0.98	NA
1016A	Garners Bayou	1016A_02	10763-003	TX0073989	Humble-Timberwood	W	0.65	NA
		1016A_02	11161-001	TX0020320	Clark, Harold	D	0.099	0.047
		1016A_02	11302-001	TX0025623	El Dorado UD	D	0.45	0.22
		1016A_02	10763-002	TX0034401	Humble-South	W	6.5	2.17
		1016A_02	14405-001	TX0079570	International Airport Sq Inves	D	0.012	0.00056
		1016A_02	12418-001	TX0088111	Panalpina Inc.	D	0.007	0.00085
		1016A_02	12571-001	TX0090506	Champ's Water Co	D	0.1	0.059
		1016A_02	02685-001	TX0094196	Tiampo, Jamie	W	0.077	NA
		1016A_02	13870-001	TX0119067	Aquasource Developm	D	0.099	0.014
		1016A_02	13037-002	TX0127124	Harris Co. MUD 278	D	2.7	NA
		1016A_03	11533-001	TX0058963	Harris Co. MUD 109	W	9	3.80
		1016A_03	11901-001	TX0074021	Trail Of The Lakes MUD	W	1.75	0.40
		1016A_03	11919-001	TX0074268	Harris Co. MUD 049	D	0.2	0.083
		1016A_03	11919-002	TX0074446	Harris Co. MUD 049	D	1.5	0.059
		1016A_03	13037-001	TX0097071	Harris Co. MUD 278	D	0.4	0.13

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES NUMBER	Facility Name	DTYPE	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
		1016A_03	13561-001	TX0107301	Harris Co. Detention Center	D	0.5	0.25
		1016A_03	14289-001	TX0124346	Austofield Partners #1	D	0.375	0.060
		1016A_03	14419-001	TX0125661	Land Tejas Park Lakes	W	1	0.035
		1016A_03	14527-001	TX0126756	Pine Development Ltd	D	0.64	NA
		1016A_03	14812-001	TX0129666	Land Tejas Park Lakes 1023	W	1	NA
1016C	Unnamed Tributary of Greens Bayou	1016C_01	10694-001	TX0027707	Southwest Utilities	D	0.1	0.077
		1016C_01	11739-001	TX0069582	Champ's Water Co.	D	0.025	0.0072
		1016C_01	13882-001	TX0070769	C&P Utilities	D	0.15	0.097
		1016C_01	12450-001	TX0088650	Darlene Ann Young	D	0.065	0.0073
		1016C_01	02761-001	TX0092037	West Road WSC	W	0.013	0.0048
		1016C_01	14307-001	TX0124508	Metal Building Components	D	0.02	NA
1016D	Unnamed Tributary of Greens Bayou	1016D_01	11200-001	TX0031461	Douglas Utility Co.	D	0.38	0.27
		1016D_01	14066-001	TX0033430	Houston Airport Hospitality	D	0.125	0.052
		1016D_01	11794-001	TX0071251	Hydrill Co.	D	0.05	0.0087
		1016D_01	12766-001	TX0093548	QBN Corp.	D	0.019	0.0019
		1016D_01	10495-122	TX0103721	Houston-Northbelt	W	5	1.63

Source: TCEQ Water Quality Assessment Team, May 2008.

DTYPE: C = Cooling Water; D = Domestic <1 MGD; S = Storm water; W = domestic >=1 MGD or industrial process water, including water treatment plant discharge

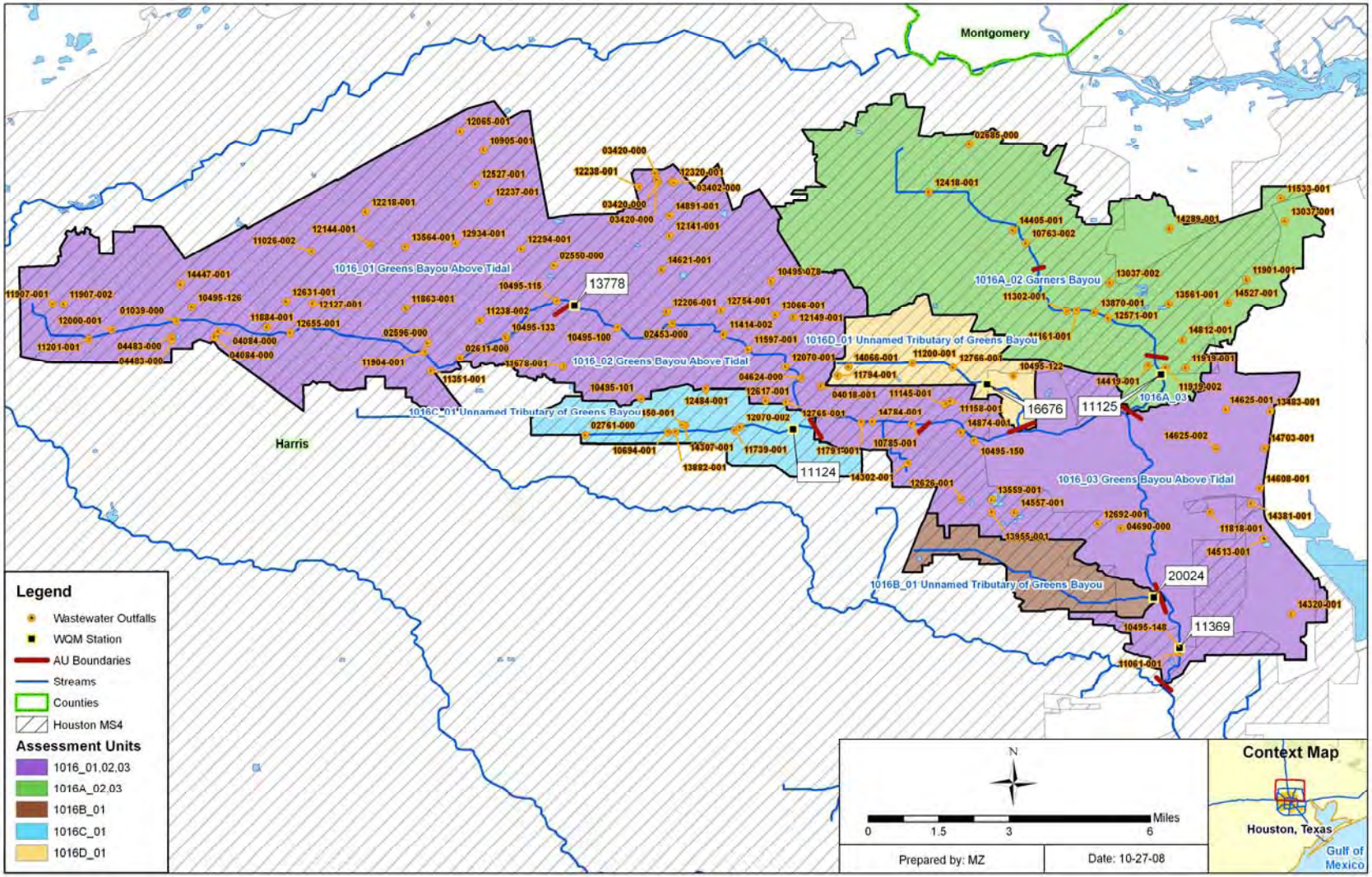

Figure 6. TPDES-Permitted Facilities in the TMDL Watershed

Table 8. Discharge Monitoring Report Data for Permitted Wastewater Discharges (December 1998-September 2007)

TPDES Number	Facility Name	Segment	Dates Monitored		# of Records	Number of MCMX Exceedances	Number of MCAV Exceedances	FC Daily Load (Billion cfu)	
			Start	End				90 percentile Monthly Average	Maximum Monthly Average
11061-001	Greenwood Utility District	1016	03/31/1998	12/31/2000	12	0	0	0.429	0.486
10495-150	Houston-WCID #76	1016	12/31/1998	12/31/1999	5	0	0	0.102	0.149
11302-001	El Dorado UD	1016A	03/31/1998	09/30/2000	11	0	0	0.0531	0.0973
11238-002	Harris Co. MUD 005	1016	09/30/1998	06/30/2007	64	2	0	1.7	4.94
11200-001	Douglas Utility Co.	1016D	03/31/1998	03/31/2000	9	1	0	1.59	2.17
11026-002	Harris Co. WCID #109	1016	02/29/2000	06/30/2007	89	15	0	12.3	18.4
10763-002	Humble-South	1016A	01/31/1998	06/30/2007	110	11	0	16.9	66.8
11818-001	Harris Co. MUD 148	1016	01/31/1998	09/30/1999	10	1	0	0.521	0.874
11907-002	Mills Road MUD	1016	01/31/1998	10/31/1999	22	2	0	0.166	5.31
12206-001	North Green MUD	1016	01/31/1998	07/31/2002	15	1	0	1.5	10
12218-001	CMB Parks	1016	09/30/1998	09/30/1999	5	0	0	0.0624	0.0719
12631-001	Harris Co. MUD 202	1016	09/30/1998	03/31/2000	7	0	0	0.049	0.0933
12692-001	Karbalai, Rita	1016	09/30/1998	06/30/2000	7	0	0	0.000786	0.000818
12754-001	Greens Parkway MUD	1016	01/31/1998	03/31/2000	9	0	0	0.00111	0.00132
13037-001	Harris Co. MUD 278	1016A	06/30/1998	12/31/1999	6	0	0	0.14	0.276
10495-148	Hou--Tidwell Timbers	1016	12/31/1998	09/30/1999	4	0	0	0.0222	0.0252

Source: TCEQ, 2007

Notes: FC = Fecal Coliform, cfu = Colony Forming Unit, MCMX = Measurement: Concentration Maximum, MCAV = Measurement: Concentration Average

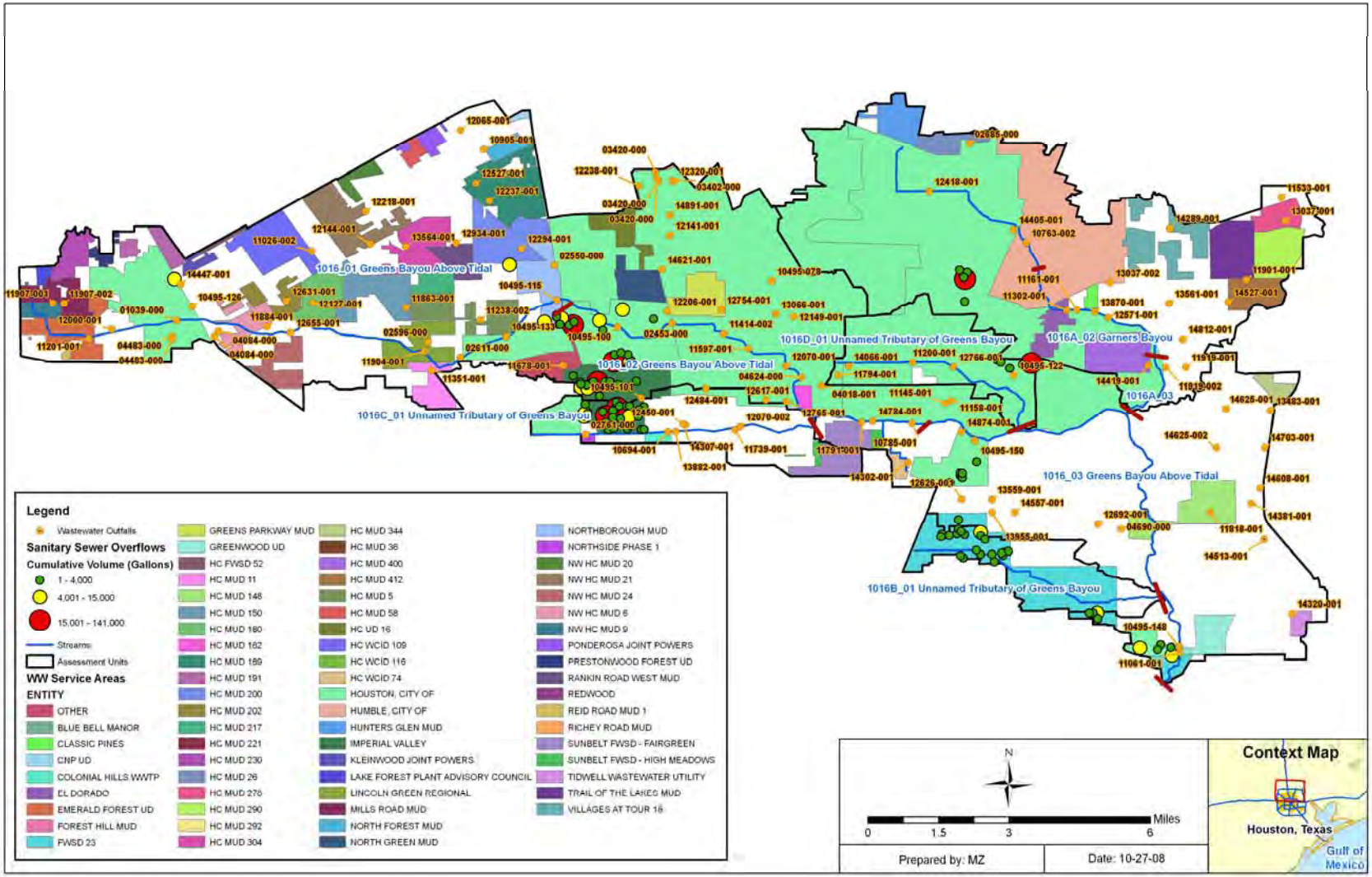

Figure 7. Sanitary Sewer Overflows in the TMDL Watershed

Under the City of Houston/Harris County permit for storm water discharge, Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation are designated as co-permittees. Figure 6 displays the portion of the watershed that contributes indicator bacteria loads to the receiving waters from permitted and non-permitted storm water. Table 10 lists the percentage of each watershed covered under the Houston MS4 permit. The TMDLs calculated for this project were based on the median flow of the highest range for flow exceedance (see the "Load Duration Curve Analysis" section), which coincides with storm water-influenced high flow events.

Table 9. Sanitary Sewer Overflow Summary for the TMDL Watershed

Facility ID	Receiving Water	Number of Occurrences	Date Range		Amount (Gallons)		
			From	To	Min	Max	Total Volume
10495-016	1016	4	1/13/2002	6/4/2002	116	7036	12,947
10495-016	1016B	9	2/25/2001	10/3/2003	100	2184	5126
10495-100	1016	10	2/16/2001	6/3/2003	148	69,825	113,492
10495-101	1016	8	3/22/2001	11/18/2003	39	23,172	35,689
10495-101	1016C	16	3/12/2001	10/24/2003	35	41,595	48,628
10495-115	1016	4	4/7/2001	2/5/2003	288	8015	19,207
10495-122	1016A	3	2/26/2001	6/24/2003	52	10,675	12,143
10495-122	1016D	4	10/11/2001	5/9/2003	26	27,044	30,963
10495-126	1016	1	6/29/2001	6/30/2001	-	5196	5196
10495-148	1016	4	2/7/2003	9/17/2003	82	8740	13,553
10495-150	1016	4	1/27/2002	12/2/2003	200	2360	3010

Table 10. Percent of MS4 Jurisdiction in the TMDL Watershed

Segment	Stream Name	TPDES Number	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Watershed under MS4 Jurisdiction
1016_01	Greens Bayou Above Tidal	WQ0004685000	23,826	23,849	100%
1016_02		WQ0004685000	15,607	15,611	100%
1016_03		WQ0004685000	18,970	6,747	36%
1016A_02	Garners Bayou	WQ0004685000	15,406	14,795	96%
1016A_03		WQ0004685000	6,241	4,109	66%
1016B_01	Unnamed Tributary of Greens Bayou	WQ0004685000	2,691	2,347	87%
1016C_01	Unnamed Tributary of Greens Bayou	WQ0004685000	4,029	4,039	100%
1016D_01	Unnamed Tributary of Greens Bayou	WQ0004685000	3,560	3,010	85%

Illicit Discharges

Bacteria loads from storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in EPA's Phase II storm water regulations as "any discharge to a municipal separate storm sewer that is not composed entirely of storm water, except discharges pursuant to an NPDES permit and discharges resulting from fire-fighting activities" (NEIWPCC 2003). Dry weather discharges may also include allowable discharges such as runoff from lawn watering in addition to illicit discharges. Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC 2003) include:

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (e.g., used motor oil) that have been dumped illegally into a storm drain catch basin;
- a shop floor drain that is connected to the storm sewer; and
- a cross-connection between the municipal sewer and storm sewer systems.

Indirect illicit discharges:

- an old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line; and
- a failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer

Various investigations have been conducted in localized areas of Houston. Data from neighboring watersheds (Buffalo and Whiteoak Bayous) demonstrate that illicit discharges are a source of significant indicator bacteria load. While the dry weather flows from the storm sewer network in Buffalo and Whiteoak Bayous were small relative to the other dry weather flows, the *E. coli* concentrations measured during these events were at times high (similar to the levels found in raw sewage). An outfall inventory survey has not been completed for Greens Bayou, and dry weather discharges from the storm sewer network have not been sampled. Therefore, there is insufficient data to adequately quantify the magnitude of indicator bacteria loads from illicit discharges in the Greens Bayou watershed.

Nonpoint Sources

Nonpoint source (NPS) loading enters the impaired segment through distributed, non-specific locations, and is not regulated. Nonpoint sources of indicator bacteria can emanate from wildlife, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

Wildlife and Unmanaged Animal Contributions

Fecal coliform and *E. coli* bacteria are common inhabitants of the intestines of all warm blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife is naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. Typical of coastal watersheds, there is a significant population of avian species that frequent the watershed—and the riparian corridors—in particular. However, for Greens Bayou currently there are insufficient data available to estimate populations and spatial distribution of wildlife and avian species by watershed. Consequently, it is difficult to assess the magnitude of bacteria contributions from wildlife species as a general category.

Non-Permitted Agricultural Activities and Domesticated Animals

A number of agricultural activities that do not require permits can also be sources of fecal bacteria loading. Given the fact that the Greens Bayou Watershed is highly urbanized, livestock and other domesticated animals are either not found in these watersheds or exist in small numbers. Therefore livestock and other domesticated animals are not considered as a significant contributor of bacteria loads.

Failing On-site Sewage Facilities

On-site sewage facilities (OSSFs) can be a source of bacteria loading to streams and rivers. Bacteria loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface ponding or through groundwater. Fecal coliform-contaminated groundwater can be discharged to creeks through springs and seeps.

Over time, most OSSFs operating at full capacity will fail. OSSF failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1995 American Housing Survey conducted by the U.S. Census Bureau estimates that, nationwide, 10 percent of occupied homes with OSSFs experience malfunctions during the year (U.S. Census Bureau 1995). A statewide study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12 percent of the OSSFs in Harris County were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against contamination is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSSFs per square mile (6.25 septic systems per 100 acres) can be considered to have potential contamination problems (Canter and Knox 1985).

Only permitted OSSF systems are recorded by authorized county or city agents; therefore, it is difficult to estimate the exact number of OSSFs in use in the study area. The estimate of OSSFs was derived by using data from the latest available census data—the 1990 U.S. Census (U.S. Census Bureau 2000)—and a geographic information system (GIS) shape file obtained from the Houston-Galveston Area Council (H-GAC) showing all areas where

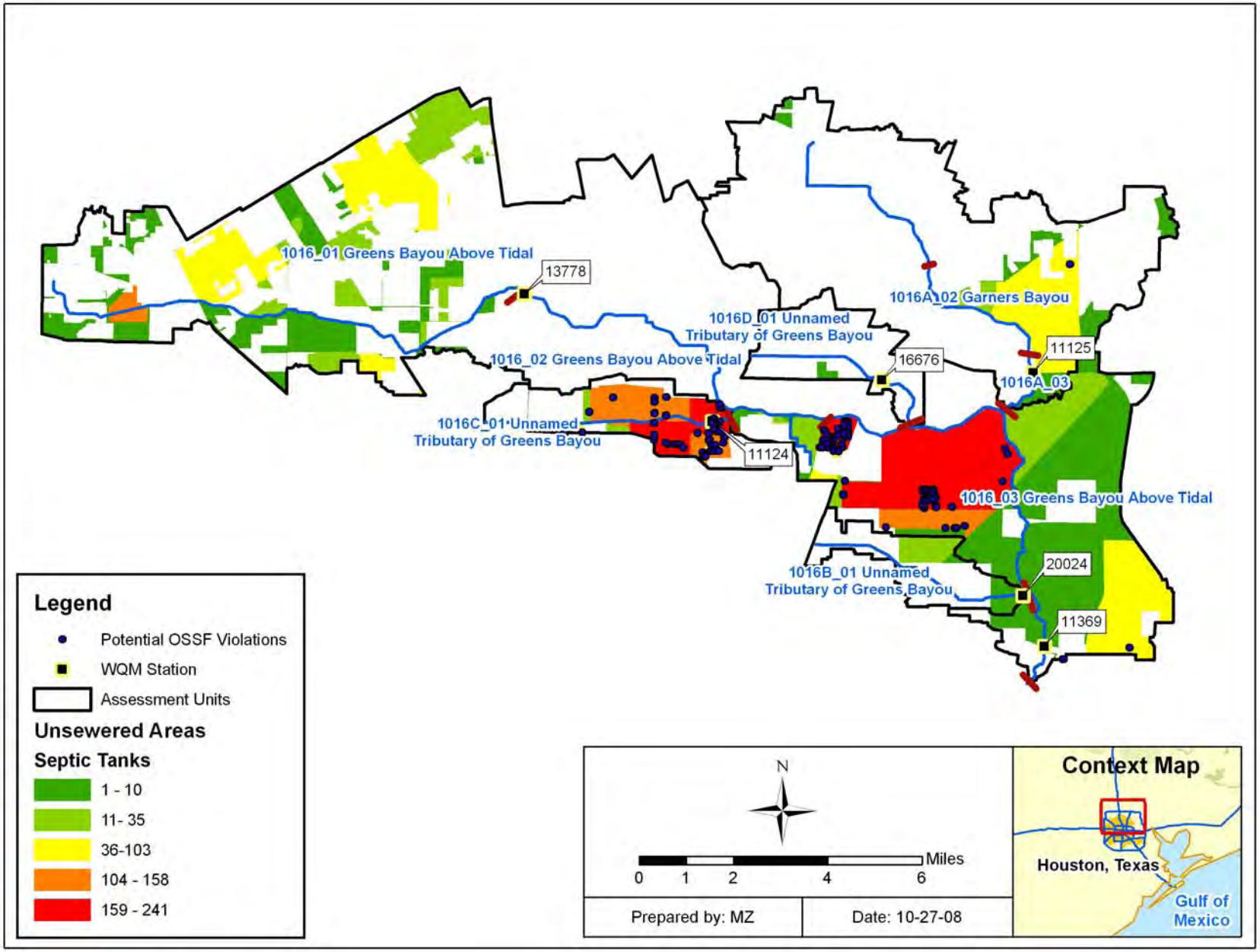

Figure 8. Areas without Sewers and Subdivisions with OSSFs in the TMDL Watershed

wastewater service currently exists. Figure 8 displays areas without public sewers that did not fall under the wastewater service areas. OSSFs were calculated using spatial GIS queries for areas not covered by wastewater service areas. OSSFs were assigned proportionally based on the percentage of the area falling outside a wastewater service area within each watershed. Finally, the OSSFs for each area without sewers were then totaled by TMDL watershed. This approach gives an estimate of OSSFs in the watershed. Table 11 shows the estimated number of OSSFs calculated using this GIS method.

A statewide study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12 percent of the OSSFs in Harris County were chronically malfunctioning. Using this 12 percent failure rate, calculations were made to characterize fecal coliform loads in each watershed. Estimates of fecal coliform loads were developed because there is little *E. coli* data available. Fecal coliform loads were estimated using the following equation (EPA 2001):

$$\#\frac{counts}{day} = \left(\# Failing_systems\right) \times \left(\frac{10^6 counts}{100ml}\right) \times \left(\frac{70gal}{personday}\right) \times \left(\#\frac{person}{household}\right) \times \left(3785.2\frac{ml}{gal}\right)$$

The average number of people per household was calculated to be 2.79 for Harris County (U.S. Census Bureau 2000). Approximately 70 gallons of wastewater were estimated to be produced on average per person per day (Metcalf and Eddy 1991). The fecal coliform concentration in septic tank effluent was estimated to be 10^6 per 100 mL of effluent based on reported concentrations from a number of published reports (Metcalf and Eddy 1991; Canter and Knox 1985; Cogger and Carlile 1984). Using this information, the estimated load from potential violation septic systems within the watersheds was summarized in Table 11. Based on these data, it was determined that the estimated fecal coliform loading from OSSFs in the TMDL watershed is negligible overall, but may be important locally.

Domestic Pets

Based on the urban nature of this project and the availability of relevant data, dogs and cats are the only pets considered in calculating loads for domestic pets. Fecal matter from dogs and cats is transported to streams by runoff from urban and suburban areas and can be a potential source of bacteria loading. On average nationally, there are 0.58 dogs per household and 0.66 cats per household (American Veterinary Medical Association 2002). Using the U.S. Census data at the block level (U.S. Census Bureau 2000), dog and cat populations can be estimated for each watershed. Table 12 summarizes the estimated number of dogs and cats for the watersheds of the TMDL watershed.

Table 13 provides an estimate of the fecal coliform load from domestic dogs and cats. These estimates are based on estimated fecal coliform production rates of 5.4×10^8 per day for cats and 3.3×10^9 per day for dogs (Schueler 2000). Only a small portion of these loads is expected to reach water bodies, through wash-off from land surfaces and conveyance in runoff. This would likely have only a temporary and localized impact on the overall bacteria loading of the watershed.

Table 11. Estimated Number of OSSFs and Fecal Coliform Load in the TMDL Watershed

Segment	Stream Name	OSSF Estimate using 1990 Census method	# of Failing Septic Tanks[a]	Potential Violation Database[b]	Estimated Loads from Septic Tanks (Billion cfu/day)[c]
1016_01 to 1016_03	Greens Bayou Above Tidal	1,710	205	110	1,517
1016A_02 and 1016A_03	Garners Bayou	128	15	1	114
1016B	Unnamed Tributary of Greens Bayou	26	3	0	23
1016C	Unnamed Tributary of Greens Bayou	1,027	123	54	911
1016D	Unnamed Tributary of Greens Bayou	2	0.2	0	2

[a] A 12% failure rate was multiplied by the number of OSSFs derived from the 1990 census.

[b] The Potential Violation Database was obtained from Harris County (2006-2007)

[c] Load estimate was based on literature values for fecal coliform concentrations since no *E. coli* concentration values were available. This calculation was based on the number of failing septic tanks.

Table 12. Estimated Numbers of Pets in the TMDL Watershed

Segment	Stream Name	Dogs	Cats
1016_01 to 1016_03	Greens Bayou Above Tidal	53,218	60,559
1016A_02 and 1016A_03	Garners Bayou	9,875	11,237
1016B	Unnamed Tributary of Greens Bayou	3,515	4,000
1016C	Unnamed Tributary of Greens Bayou	10,275	11,692
1016D	Unnamed Tributary of Greens Bayou	3,915	4,455

Table 13. Estimated Fecal Coliform Daily Production by Pets (in Billions)

Segment	Stream Name	Dogs	Cats	Total
1016_01 to 1016_03	Greens Bayou Above Tidal	175,619	32,702	208,321
1016A_02 and 1016A_03	Garners Bayou	32,586	6,068	38,654
1016B	Unnamed Tributary of Greens Bayou	11,601	2,160	13,761
1016C	Unnamed Tributary of Greens Bayou	33,907	6,314	40,221
1016D	Unnamed Tributary of Greens Bayou	12,920	2,405	15,325

Bacteria Re-growth and Die-off

Bacteria are living organisms that grow and die. Certain enteric bacteria can re-grow in organic materials if appropriate conditions prevail (*e.g.,* warm temperature). Fecal organisms can re-grow from improperly treated effluent during their transport in pipe networks, and they can re-grow in organic rich materials such as compost and sludges. While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both processes (re-growth and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL area.

Linkage Analysis

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

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

Bacteria contributions from permitted and non-permitted storm water sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of low concentration in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations reduce because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Load duration curve (LDC) analyses were used to examine the relationship between instream water quality and the source of indicator bacteria loads.

Load Duration Curve Analysis

LDCs are similar in appearance to flow duration curves; however, the y-axis is expressed in terms of a bacteria load in MPN/day. The curve represents the single sample criterion for *E. coli* (394 MPN/100 mL), expressed in terms of a load through multiplication by the flows historically observed at this site. Using the single sample criterion to generate the LDC is necessary to display the allowable pollutant load in relation to the existing loads which are represented by existing ambient water quality samples. The basic steps to generate an LDC involve:

- preparing flow duration curves (FDC) for gauged and un-gauged sampling locations;
- estimating existing bacteria loading in the receiving water using ambient water quality data;
- using LDCs to identify the critical condition that will define loading reductions necessary to attain the contact recreation standard; and
- interpreting LDCs to derive TMDL elements—waste load allocation, load allocation, margin of safety, and overall percent reduction goals.

The result of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve.

Equation 1

TMDL (MPN/day) = criterion * flow in cubic feet per second (cfs) * unit conversion factor

Where:

criterion = 394 MPN/100 mL (*E. coli*)

unit conversion factor = 24,465,755 100 mL/ft^3 * seconds/day

The flow exceedance frequency (x-value of each point) is obtained by determining the percent of historical observations that equal or exceed the measured or estimated flow. While the number of observations required to develop a flow duration curve is not rigorously specified, a flow duration curve is usually based on more than five years of observations, and encompasses inter-annual and seasonal variation. Ideally, the drought of record and flood of record are included in the observations. For this purpose, the long-term flow gauging stations operated by the USGS are used. Estimation of flows within the TMDL watershed is necessary because there is a lack of long-term flow data. Therefore, USGS gauge station 08076000 (Greens Bayou near Houston, Texas), which is located inside the watershed, was chosen to conduct flow projections to establish estimated flows for each of these freshwater segments. The period of record for flow data used from this station was 1996 through 2006.

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of flow and LDCs. The hydrologic classification scheme utilized for the Greens Bayou Above Tidal watershed is outlined in Table 14.

The low flow category was derived by calculating the percentage of bayou flows contributed by WWTFs using the long-term average reported flows. These percentages varied by assessment unit, resulting in different ranges for the low-flow (and corresponding mid-range flow) categories. Some instantaneous flow measurements were available from the intensive surveys collected for this project. These were not combined with the daily average flows or used in calculating flow percentiles but were matched to bacteria grab measurements collected at the same site and time. When available, these instantaneous flow measurements were used in lieu of the daily average flow to calculate instantaneous bacteria loads.

Table 14. Hydrologic Classification Scheme

Assessment Unit	Hydrologic Condition Class		
	Highest Flows	Mid-range Flows	Lowest Flows
1016_01 to 1016_03	0-20	20-80	80-100
1016A_02 and 1016A_03	0-20	20-60	60-100
1016B_01	0-20	20-80	80-100
1016C_01	0-20	20-80	80-100
1016D_01	0-20	20-50	50-100

Historical observations of bacteria concentration are paired with flow data and are plotted on the LDC. The indicator bacteria load (or the y-value of each point) is calculated by multiplying the indicator bacteria concentration (counts or counts/100mL) by the instantaneous flow in cubic feet per second (cfs) at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads that exceed the water quality criterion fall above the line that represents the criterion on the graph for each water body.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by the single-sample criterion. Using LDCs, a TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition. LDCs do not simulate the fate of contaminants; rather, they calculate allowable loading for a given flow. Since LDCs do not link the loading to specific sources, processes affecting the fate of bacteria are not included.

Load Duration Curve Results

Greens Bayou Above Tidal

The LDC for Greens Bayou Above Tidal, assessment units 1016_01 and 1016_02 (Figure 9) is based on *E. coli* bacteria measurements at sampling location 11371 (Greens Bayou at US 59). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under high and mid-range flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions. Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during generally dry conditions. The geometric mean of existing *E. coli* data within each flow range is shown by yellow dots on this LDC and the ones that follow.

The LDC for Greens Bayou Above Tidal assessment unit 1016_03 (Figure 10) is based on *E. coli* bacteria measurements at sampling location 11369 (Greens Bayou at Tidwell Road). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under high flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions.

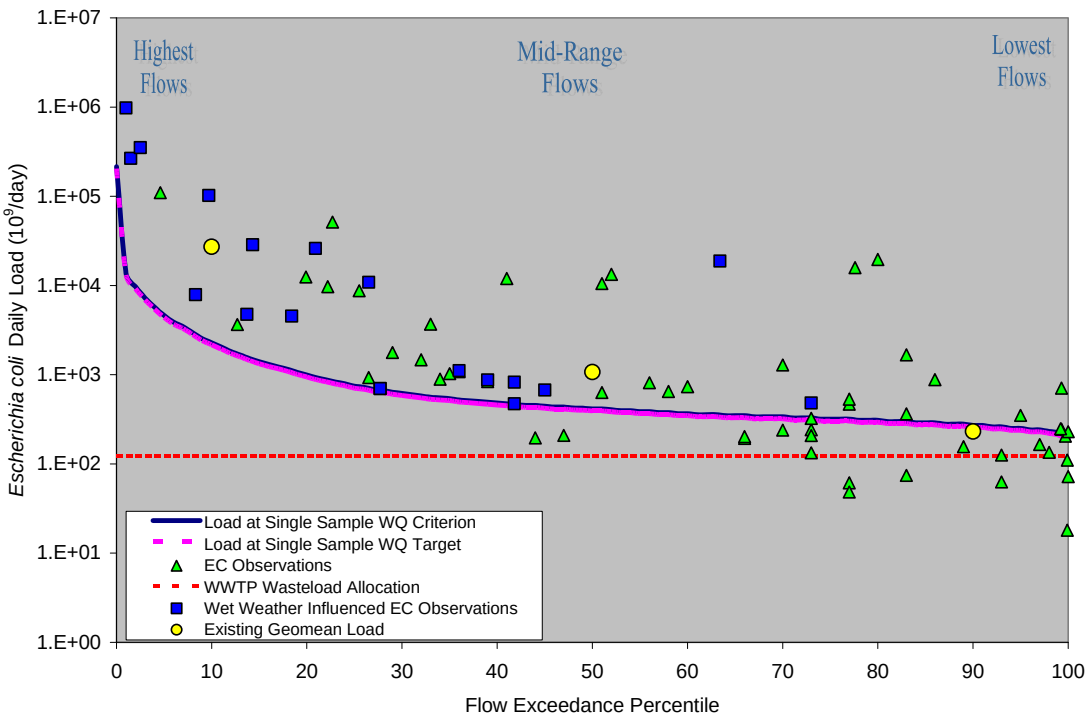

Figure 9. Load Duration Curve for Greens Bayou Above Tidal (1016_01, 1016_02)

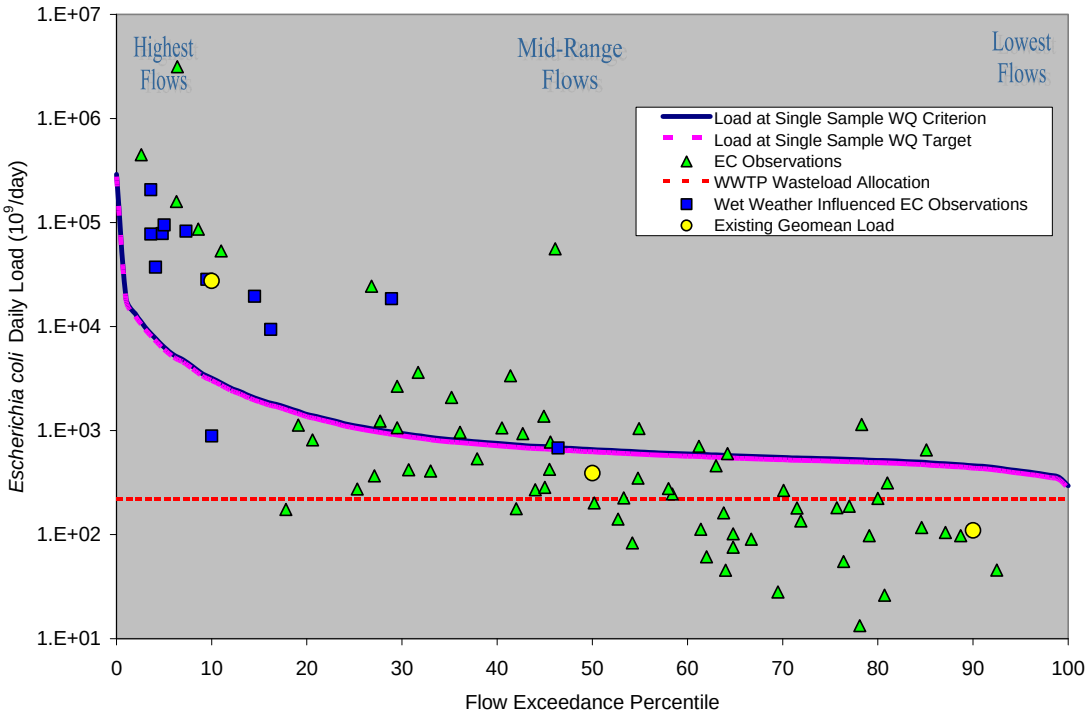

Figure 10. Load Duration Curve for Greens Bayou Above Tidal (1016_03)

Garners Bayou Above Tidal

The LDC for Garners Bayou Above Tidal, assessment units 1016A_02 and 1016A_03 (Figure 11) is based on *E. coli* bacteria measurements at sampling location 11125 (Garners Bayou at SH Loop 8). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under high and mid-range flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions.

Unnamed Tributaries of Greens Bayou

The LDC for Unnamed Tributary of Greens Bayou assessment unit 1016B_01 (Figure 12) is based on *E. coli* bacteria measurements at sampling location 20024 (Unnamed Tributary of Greens Bayou). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under high and mid range flow conditions. Wet weather influenced *E. coli* observations are found under high flow conditions.

The LDC for Unnamed Tributary of Greens Bayou assessment unit 1016C_01 (Figure 13) is based on *E. coli* bacteria measurements at sampling location 11124 (Unnamed Tributary of Greens Bayou). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions.

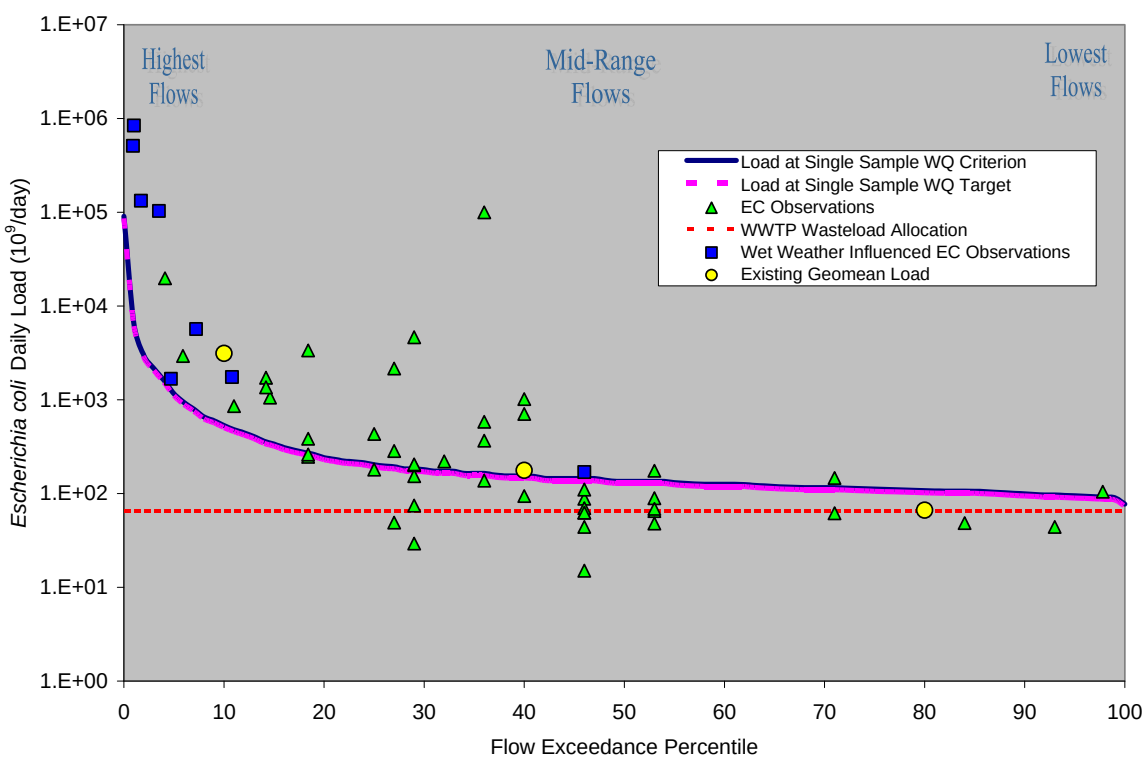

Figure 11. Load Duration Curve for Garners Bayou Above Tidal (1016A_02, 1016A_03)

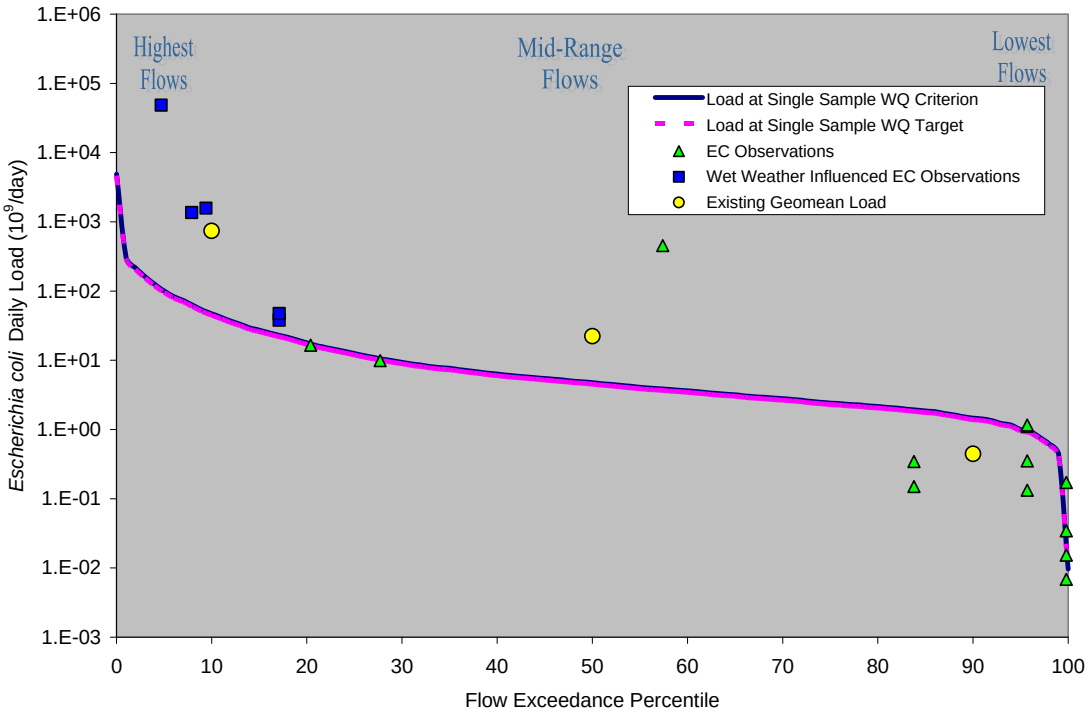

Figure 12. Load Duration Curve for Unnamed Tributary of Greens Bayou (1016B_01)

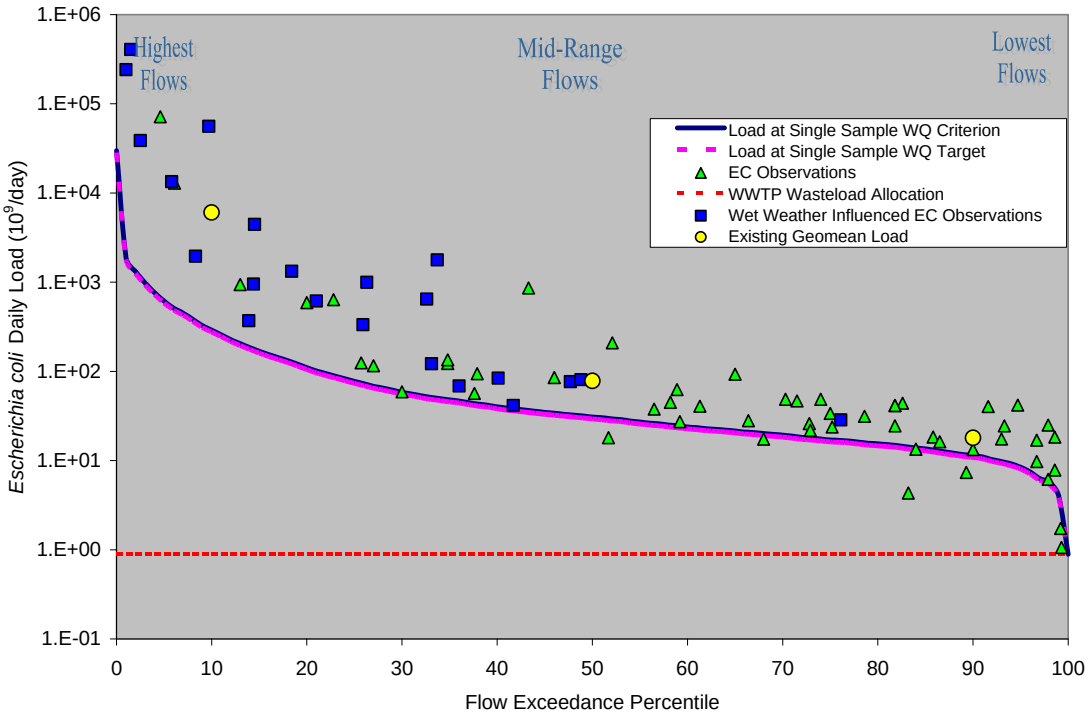

Figure 13. Load Duration Curve for Unnamed Tributary of Greens Bayou (1016C_01)

The LDC for Unnamed Tributary of Greens Bayou assessment unit 1016D_01 (Figure 14) is based on *E. coli* bacteria measurements at sampling location 16676 (Unnamed Tributary of Greens Bayou). Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during generally dry conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions. In the last part of the curve, where permitted WWTF flow makes up nearly all of the base flow, the allowable load becomes equal to the WLA_{WWTF}.

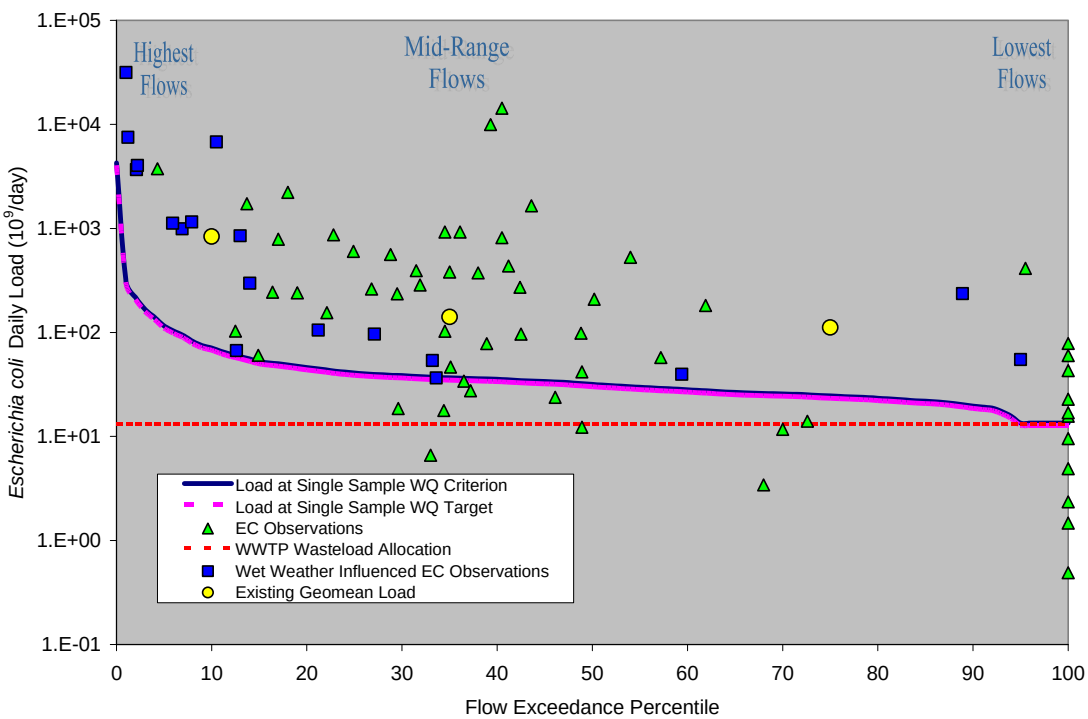

Figure 14. Load Duration Curve for Unnamed Tributary of Greens Bayou (1016D_01)

Margin of Safety

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

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water

quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the single sample criterion. The explicit margin of safety was used because of the limited amount of data for some of the sampling locations. For contact recreation, this equates to a single sample target of 374 MPN/100mL for *E. coli* and a geometric mean target of 120 MPN/100mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced. The TMDLs covered by this report incorporate an explicit MOS in each LDC by using 95 percent of the single sample criterion.

Pollutant Load Allocation

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

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

Where:

WLA = waste load allocation (permitted or point source contributions)
LA = load allocation (non-permitted or nonpoint source contributions)
MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli*, TMDLs are expressed as MPN/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

The bacteria TMDLs for the 303(d)-listed water quality monitoring stations covered in this report were derived using LDCs. The estimated maximum allowable loads of *E. coli* for each of the assessment units was determined as that corresponding to the flow regime requiring the highest load reduction.

Waste Load Allocation

TPDES-permitted facilities are allocated a daily waste load (WLA_{WWTF}) calculated as their permitted discharge flow rate multiplied by one-half of the instream geometric mean water quality criterion. One-half of the water quality criterion is used as the target to provide instream and downstream load capacity, and to provide consistency with other TMDLs developed in the Houston area. This is expressed in the following equation:

$$WLA_{WWTF} = \text{criterion}/2 * \text{flow} * \text{unit conversion factor (\#/day)}$$

Where:

criterion = 126 MPN/100 mL *E. coli*
flow (10^6 gal/day) = permitted flow
unit conversion factor = 37,854,120 100mL/10^6 gal

Table 15 summarizes the WLA for the TPDES-permitted facilities within the study area. The facilities are required to meet instream criteria at their points of discharge. When multiple TPDES facilities occur within a watershed, loads from individual WWTFs are summed and the total load for continuous point sources is included as part of the WLA_{WWTF} component of the TMDL calculation for the corresponding segment. When no TPDES WWTFs discharge into the contributing watershed of a water quality monitoring station, the WLA_{WWTF} is zero. Compliance is achieved when the discharge limits are met. Disinfection is used by facilities to meet the discharge limit. Individual WLA_{WWTF} values for new or amended TPDES-permitted WWTF dischargers added in the Greens Bayou watershed will be assigned from the future capacity allocation based on the discharge concentration of water quality standard for indicator bacteria (63 MPN/100mL) and will be subject to the effluent limitations. Any additional flow for these facilities is accounted for in the development of the future capacity allocation.

Storm water discharges from MS4 areas are considered permitted point sources. Therefore, the WLA calculations must also include an allocation for permitted storm water discharges. A simplified approach for estimating the WLA for MS4 areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of storm water loading. The LDC method was used to determine WLAs for these TMDLs. The percentage of each watershed that is under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be allocated as the permitted storm water contribution in the $WLA_{StormWater}$ component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from storm water runoff and the portion allocated to $WLA_{StormWater}$.

The TCEQ intends to implement the individual WLAs through the permitting process as either monitoring requirements or effluent limitations. However, there may be a more economical or technically feasible means of improving water quality and circumstances may warrant changes in individual WLAs after this TMDL is completed. Therefore, the individual WLAs, as well as the WLAs for storm water, are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of an update to the state's Water Quality Management Plan Update. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The executive director or commission may establish interim effluent limits and/or monitoring-only requirements at a permit amendment or permit renewal. These interim limits will allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet the TCEQ and EPA approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits will not contain interim effluent limits because compliance schedules are not allowed for a new permit.

Table 15. Waste Load Allocations for TPDES-Permitted Facilities

Receiving Water	Assess-mint Unit	TPDES Number	NPDES NUMBER	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
Greens Bayou Above Tidal (1016)	1016_01	04853-001	TX0088897	R & A Harris South	0.006	0.0143
		02596-001	TX0076155	Reliant Energy-Greensp	0.02	0.0477
		04084-001	TX0063878	CSA Limited	0.004	0.00954
		04084-002	TX0063878	CSA Limited	0.008	0.0191
		04483-001	TX0102008	Centerpoint Energy Houston	0.015	0.0358
		10495-115	TX0054798	Houston-Northborough MUD	2	4.77
		10495-126	TX0113131	Hou-Willowbrook Reg.	2	4.77
		10495-133	TX0084875	Houston-HCMUD #203	3	7.15
		10905-001	TX0058424	North Forest MUD	0.3	0.715
		11026-002	TX0033243	Harris Co. WCID #109	3	7.15
		11201-001	TX0027324	Emerald Forest UD	1.5	3.58
		11238-002	TX0026344	Harris Co. MUD 005	0.9	2.15
		11351-001	TX0111767	Harris Co. MUD 011	0.5	1.19
		11863-001	TX0072893	Harris Co. MUD 150	3	7.15
		11884-001	TX0073407	NW Harris Co. MUD 006	0.475	1.13
		11904-001	TX0074136	Harris Co. MUD 033	3	7.15
		11907-002	TX0075132	Mills Road MUD	0.9	2.15
		12000-001	TX0077062	Moulding Specialists	0.005	0.0119
		12065-001	TX0078824	Harris Co. MUD 086	0.95	2.27
		12127-001	TX0079529	Harris Co. MUD 180	0.95	2.27
		12144-001	TX0079821	NW Harris Co. MUD 021	1.5	3.58
		12218-001	TX0083429	CMH Parks	0.122	0.291
		12237-001	TX0083712	Harris Co. MUD 189	1.25	2.98
		12294-001	TX0085413	Harris Co. MUD 200	1.44	3.43
		12527-001	TX0090069	Movimex Co.	0.01	0.0238
		12631-001	TX0091901	Harris Co. MUD 202	0.725	1.73
		12655-001	TX0092312	NW Harris Co. MUD 024	0.5	1.19

Receiving Water	Assess-mint Unit	TPDES Number	NPDES NUMBER	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
		12934-001	TX0097047	Rankin Rd West MUD	0.3	0.715
		13564-001	TX0097225	Harris Co. MUD #304	0.65	1.55
		14446-001	TX0095265	1920 Interpark	0.012	0.0286
		14447-001	TX0090476	Harris Co. MUD #191	0.71	1.69
Greens Bayou Above Tidal (1016)	1016_02	02453-001	TX0084298	Smith International	0.15	0.358
		03402-001	TX0103616	GSE Lining Technology	0.016	0.0382
		03420-001	TX0084093	VAM USA	0.02	0.0477
		04018-001	TX0078638	Dresser Industries	0.07	0.167
		10495-078	TX0034916	Houston-Intercont Air	8	19.1
		10495-100	TX0055310	Houston-Northgate UD	3.71	8.85
		10495-101	TX0020478	Houston-Imperial Valley	4	9.54
		10785-001	TX0021199	Sequoia Id	0.2	0.477
		11414-002	TX0033189	Sasson, Eli	0.099	0.236
		11597-001	TX0058076	North Belt UD	1.5	3.58
		11678-001	TX0064424	Yazdcorp Funds V LLC	0.05	0.119
		11791-001	TX0071382	Sunbelt FWSD	1.225	2.92
		12070-001	TX0078808	Aldine ISD	0.063	0.15
		12149-001	TX0081388	MLR Management	0.01	0.0238
		12206-001	TX0083381	North Green MUD	0.6	1.43
		12320-001	TX0085901	Component Structures	0.002	0.00477
		12484-001	TX0089281	Boring Specialties	0.005	0.0119
		12617-001	TX0091651	Goodwin, Sandra	0.035	0.0835
		12754-001	TX0093475	Greens Parkway MUD	0.98	2.34
		12765-001	TX0093556	United Structures	0.008	0.0191
		13066-001	TX0097276	Hoajey, Ltd.	0.009	0.0215
		14302-001	TX0124460	RJR Realty, Ltd	0.003	0.00715
		14621-001	TX0127957	Rankin Park Mainten & Util	0.05	0.119
		14784-001	TX0129445	Skymark Development	0.45	1.07

Receiving Water	Assess-mint Unit	TPDES Number	NPDES NUMBER	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
		14882-001	NA	AMC Facilities LP	0.025	0.0596
		14891-001	TX0131555	Lochinvar Golf Club	0.005	0.0119
Greens Bayou Above Tidal (1016)	1016_03	10495-148	TX0101460	Hou-Tidwell Timbers	0.488	1.16
		10495-150	TX0025291	Houston-WCID #76	0.7	1.67
		11061-001	TX0020800	Greenwood Utility District	0.95	2.27
		11158-001	TX0032085	Champ's Water Co.	0.028	0.0668
		11818-001	TX0071897	Harris Co. MUD 148	0.5	1.19
		11818-003	TX0071897	Harris Co. MUD 148	0.95	2.27
		12626-001	TX0091847	Thurber	0.019	0.0453
		12692-001	TX0092711	Karbalai, Rita	0.05	0.119
		13483-001	TX0104965	Harris Co. MUD	1	2.38
		13559-001	TX0095761	Hinojosa Rene	0.015	0.0358
		13955-001	TX0094935	Murhaj, Kobra	0.025	0.0596
		14320-001	TX0124702	Tidwell Wu, LLC	0.4	0.954
		14897-001	TX0125326	Holy Trinity Episcopal School	0.075	0.179
		14513-001	TX0126594	Christian Tabernacle	0.019	0.0453
		14557-001	TX0087840	Mumtaz Builders	0.008	0.0191
		14608-001	TX0127825	Greens Bayou Assembly Of God	0.035	0.0835
		14625-001	TX0127981	Marhaba Partners Limited Part	0.75	1.79
		14625-002	TX0127990	Marhaba Partners Limited Part	0.45	1.07
		14633-001	TX0128066	South Central Water Company	0.45	1.07
		14703-001	TX0128694	FRM/MRA Holdings #1	0.98	2.34
		14874-001	TX0067539	BCWK Inc.	0.1	0.238
Garners Bayou (1016A)	1016A_02	10763-003	TX0073989	Humble-Timberwood	0.65	1.55
		11161-001	TX0020320	Clark, Harold	0.099	0.236
		11302-001	TX0025623	El Dorado UD	0.45	1.07
		10763-002	TX0034401	Humble-South	6.5	15.5

Receiving Water	Assess-mint Unit	TPDES Number	NPDES NUMBER	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
		14405-001	TX0079570	International Airport Sq Inves	0.012	0.0286
		12418-001	TX0088111	Panalpina Inc.	0.007	0.0167
		12571-001	TX0090506	Champ's Water Co	0.1	0.238
		02685-001	TX0094196	Tiampo, Jamie	0.077	0.184
		13870-001	TX0119067	Aquasource Developm	0.099	0.236
		13037-002	TX0127124	Harris Co. MUD 278	2.7	6.44
Garners Bayou (1016A)	1016A_03	11533-001	TX0058963	Harris Co. MUD 109	9	21.5
		11901-001	TX0074021	Trail Of The Lakes MUD	1.75	4.17
		11919-001	TX0074268	Harris Co. MUD 049	0.2	0.477
		11919-002	TX0074446	Harris Co. MUD 049	1.5	3.58
Garners Bayou (1016A)	1016A_03	13037-001	TX0097071	Harris Co. MUD 278	0.4	0.954
		13561-001	TX0107301	Harris Co. -Detention Center	0.5	1.19
		14289-001	TX0124346	Austofield Partners #1	0.375	0.894
		14419-001	TX0125661	Land Tejas Park Lakes	1	2.38
		14527-001	TX0126756	Pine Development Ltd	0.64	1.53
		14812-001	TX0129666	Land Tejas Park Lakes 1023	1	2.38
Unnamed Tributary of Greens Bayou (1016C)	1016C_01	10694-001	TX0027707	Southwest Utilities	0.1	0.238
		11739-001	TX0069582	Champ's Water Co.	0.025	0.0596
		13882-001	TX0070769	C&P Utilities	0.15	0.358
		12450-001	TX0088650	Darlene Ann Young	0.065	0.155
		02761-001	TX0092037	West Road WSC	0.013	0.031
		14307-001	TX0124508	Metal Building Components	0.02	0.0477
Unnamed Tributary of Greens Bayou (1016D)	1016D_01	11200-001	TX0031461	Douglas Utility Co.	0.38	0.906
		14066-001	TX0033430	Houston Airport Hospitality	0.125	0.298
		11794-001	TX0071251	Hydrill Co.	0.05	0.119
		12766-001	TX0093548	QBN Corp.	0.019	0.0453
		10495-122	TX0103721	Houston-Northbelt	5	11.9

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the waste load allocations. For NPDES/ TPDES-regulated municipal and small-construction storm water discharges, water quality-based effluent limits that implement the WLA for storm water may be expressed as best management practices (BMPs) or other similar requirements, rather than as numeric effluent limits (November 22, 2002, memorandum from EPA relating to establishing WLAs for storm water sources). The EPA memo also states that:

> "...the Interim Permitting Approach Policy recognizes the need for an iterative approach to control pollutants in storm water discharges...[s]pecifically, the policy anticipates that a suite of BMPs will be used in the initial rounds of permits and that these BMPs will be tailored in subsequent rounds."

Using this iterative adaptive BMP approach to the maximum extent practicable is appropriate to address the storm water component of this TMDL. The iterative adaptive approach is reflected in the 2008 renewal of TPDES Permit No. WQ0004685000.

This TMDL is, by definition, the total of the sum of the waste load allocation, the sum of the load allocation, and the margin of safety. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the TMDL document; instead, changes will be made through updates to the TCEQ's Water Quality Management Plan. Any future changes to effluent limitations will be addressed through the permitting process and by updating the Water Quality Management Plan (WQMP).

Load Allocation

The load allocation is the sum of loading from all nonpoint sources. The LAs for each stream segment are calculated as the difference between the TMDL, MOS, WLA, and WLA for storm water as follows:

$$LA = TMDL - \Sigma WLA_{WWTF} - \Sigma WLA_{StormWater} - MOS$$

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
$\Sigma WLA_{StormWater}$ = sum of all storm water loads
MOS = margin of safety

The LA totals allocated for each AU can be found in Tables 17 and 18.

Allowance for Future Growth

Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of

streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard. Wastewater discharge facilities will be evaluated on a case-by-case basis. The LDC and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including future growth.

To account for the probability that new additional flows from WWTF may occur in any of the segments, a provision for future growth was included in the TMDL calculations by estimating permitted flows to year 2035 using population projections completed by H-GAC (H-GAC 2007). Table 16 shows the population increases in each of the eight TMDL assessment units based on the population projections from the H-GAC report. The population increases range from 21 percent to 63 percent. The permitted flows were increased by the expected population growth per assessment unit between 2005 and 2035 to determine the estimated future flows. Future WWTF flows were calculated by multiplying the permitted flow by the increase in population estimated for each assessment unit. The future WWTF flows for each assessment unit were added to the flows from runoff to calculate the TMDL. The allocation for future population growth is the difference between the WWTF loads calculated using estimated future flows and permitted flows.

Table 16. Population Projection per Subwatershed

Stream Name	Assessment Unit	2005 Population	2035 Population	Population Increase
Greens Bayou Above Tidal	1016_01	122,837	156,222	27%
	1016_02	48,239	87,338	81%
	1016_03	27,189	56,546	108%
Garners Bayou	1016A_02	20,226	54,531	170%
	1016A_03	3,048	6,614	117%
Unnamed Tributary of Greens Bayou	1016B_01	7,626	10,860	42%
	1016C_01	20,839	28,288	36%
	1016D_01	4,556	11,437	151%

Additional dischargers represent additional flow that is not accounted for in the current allocations. Changes in MS4 jurisdiction or additional development associated with population increases in the watershed can be accommodated by shifting allotments between the waste load allocation and the load allocation. This can be done without the need to reserve future capacity in waste load allocations for storm water. In un-urbanized areas, growth can be accommodated by shifting loads between the load allocation and the waste load allocation (for storm water). In urbanized areas currently regulated by an MS4 permit, development and/or re-development of land in urbanized areas must implement the control

measures/programs outlined in an approved Storm Water Pollution Prevention Plan (SWPPP).

Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in both the NPDES permit and the SWPPP. Currently, the iterative adaptive management BMP approach is expected to be used to address storm water discharges. This approach encourages the implementation of controls (i.e. structural or non-structural), implementation of mechanisms to evaluate the performance of the controls, and finally allowance to make adjustments (i.e., more stringent controls or specific BMPs) as necessary to protect water quality.

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

TMDL Calculations

The final TMDLs for the eight assessment units included in this project are summarized in Table 17. The TMDLs were calculated based on the median flow in the 0-20 percentile range for flow exceedance. The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are presented in Table 18. In Table 18, the future capacity for WWTF has been added to the WLA_{WWTF}. The allocations are based on the current criteria for *E. coli* in freshwater. The technical support document (University of Houston and Parsons 2009) contains additional detail on the calculation of the TMDLs.

In the event that the criteria change due to future revisions in the state's surface water quality standards, Appendix A provides guidance for recalculating the allocations in Table 18. Figures A-1 through A-8 of Appendix A were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of hypothetical water quality criteria for *E. coli*. The equations provided, along with Figures A-1 through A-8, allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*. However, one-half the current criterion for *E. coli* will be maintained for WWTFs even if criteria change due to future revisions in the state's surface water quality standards.

The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a first step in describing the water quality problem. This tool:

- Is easily developed and explained to stakeholders;
- Uses the available water quality and flow data.

Table 17. *E. coli* TMDL Summary Calculations for Greens Bayou Assessment Units

Assessment Unit	Sampling Location	Stream Name	TMDL[a] (Billion MPN/day)	WLA_{WWTF}[b] (Billion MPN/day)	$WLA_{STORM\ WATER}$[f] (Billion MPN/day)	LA[g] (Billion MPN/day)	MOS[h] (Billion MPN/day)	Future Growth[i] (Billion MPN/day)
1016_01	11371	Greens Bayou Above Tidal	403	70.9	293	0	20.2	19.3
1016_02			1,020	123[c]	789	0	51.2	60.7
1016_03	11369		1,780	219[d]	1,050	231	89.0	190
1016A_02	11125	Garners Bayou	197	25.5	138	5.69	9.84	18.0
1016A_03			419	64.5[e]	214	31.0	21.0	88.9
1016B_01	20024	Unnamed Tributary of Greens Bayou	15.0	0	12.4	1.86	0.751	0
1016C_01	11124	Unnamed Tributary of Greens Bayou	94.1	0.89	88.2	0	4.70	0.320
1016D_01	16676	Unnamed Tributary of Greens Bayou	79.7	13.3	35.8	6.51	3.99	20.1

[a] Maximum allowable load for the flow range requiring the highest percent reduction; TMDL= WLA_{WWTF} + $WLA_{STORM\ WATER}$ + LA + MOS + Future Growth

[b] Sum of loads from the WWTF discharging to the segment Individual loads are calculated as permitted flow * 126/2 (*E. coli*) MPN/100mL*conversion factor

[c] The WLA_{WWTF} for 1016_02 includes all the facilities discharging upstream of station 11371 and, thus, it includes WWTF that discharge to 1016_01

[d] The WLA_{WWTF} for 1016_03 includes all the facilities discharging upstream of station 11369 and, thus, it includes WWTF that discharge to all other assessment units

[e] The WLA_{WWTF} for 1016A_03 includes all the facilities discharging upstream of station 11125 and, thus, it includes WWTF that discharge to 1016A__02

[f] $WLA_{STORM\ WATER}$ = (TMDL – MOS –WLA_{WWTF})*(percent of drainage area covered by storm water permits)

[g] LA = TMDL – MOS –WLA_{WWTF} –$WLA_{STORM\ WATER}$-Future growth

[h] MOS = TMDL x 0.05

[i] Projected increase in WWTF permitted flows*126/2*conversion factor

Also, the LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed.

The U.S. EPA supports the use of this approach to characterize pollutant sources. The Texas Bacterial Task Force also identifies this method as a tool for TMDL development. In addition many other states are using this method to develop TMDLs.

The weaknesses of this method include the limited information it provides regarding the magnitude or specific origin of the various sources. Only limited information is gathered regarding point and nonpoint sources in the watershed. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

Table 18. Final TMDL Allocations

Assessment Unit	TMDL [a] (Billion MPN/day)	WLA_{WWTF} [b] (Billion MPN/day)	$WLA_{STORM\ WATER}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)
1016_01	403	90.2	293	0	20.2
1016_02	1,020	183	789	0	51.2
1016_03	1,780	410	1,050	231	89.0
1016A_02	197	43.5	138	5.69	9.84
1016A_03	419	153	214	31.0	21.0
1016B_01	15.0	0	12.4	1.86	0.751
1016C_01	94.1	1.21	88.2	0	4.70
1016D_01	79.7	33.4	35.8	6.51	3.99

[a] $TMDL = WLA_{WWTF} + WLA_{STORM\ WATER} + LA + MOS$

[b] $WLA_{WWTF} = WLA_{WWTF}$ + Future Growth

Seasonal Variation

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Seasonal variation was accounted for in these TMDLs by using more than 5 years of water quality data and by using the longest period of USGS flow records when developing flow exceedance percentiles.

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing historical bacteria concentrations collected in the warmer months against those collected during the cooler months. Overall this analysis of fecal coliform and *E. coli* data demonstrates that there is no significant difference in indicator bacteria between cool and warm weather seasons.

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the source analysis, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

H-GAC is providing coordination for public participation in this project. To provide public involvement in the Greens Bayou Bacteria TMDL and the implementation phase, a public meeting was held on November 5, 2007, at the Aldine Youth Center. The meeting introduced the TMDL process, identified the impaired segments and the reason for the impairment, reviewed historical data, and described potential sources of bacteria within the watershed. In addition, the meeting gave TCEQ the opportunity to solicit input from all interested parties within the study area. An informational open house was held at the Lone Star College Greenspoint Center on November 6, 2008. Information on past and future meetings for the Greens Bayou Bacteria TMDL and related projects in the Houston area can be found on the H-GAC Web site at <http://www.h-gac.com/community/water/tmdl/metro/default.aspx >.

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 within one 24-hour period and still meet applicable water quality standards; and
2) **an Implementation Plan (I-Plan)**, which is a detailed description and schedule of the 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 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.

In December 2007, stakeholders in the Houston/Harris County area initiated an effort to develop an area-wide I-Plan to address indicator bacteria sources throughout the greater Houston/Harris County area. The effort, known as the Bacteria Implementation Group (BIG), is being lead by the Houston-Galveston Area Council with funding from the TCEQ. This effort will include all of the water bodies that have been listed as impaired for contact recreation because of high indicator bacteria concentrations (Table 19). The area-wide I-Plan, which will include the Greens Bayou watershed, is expected to be completed in June 2010.

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. Additionally, if

further research results in revisions to the surface water quality standards, an adaptive management approach affords the TCEQ and stakeholders the opportunity to adjust the implementation in a corresponding manner.

The stakeholder led BIG will develop the I-Plan for *Eight Total Maximum Daily Loads for Indicator Bacteria in Greens Bayou Above Tidal and Tributaries* along with all other TMDLs for bacteria in the Houston area. Through the BIG, the excellent resources and expertise of the organizations and individuals involved in the group are available to develop the plan. An adaptive management strategy will be used to develop a plan to set priorities, provide flexibility, and will be appropriate for all stakeholders. Social and economic factors may be considered by the stakeholders during the development of the I-Plan.

Table 19. Watersheds Included in Houston/Harris County Implementation Plan

Watershed	Number of Segments	Number of AUs	Counties
Clear Creek	9	18	Harris, Fort Bend, Galveston, Brazoria
Buffalo & Whiteoak Bayous	18	23	Harris, Waller, Fort Bend
Sims Bayou	2	4	Harris, Fort Bend
Brays Bayou	4	5	Harris, Fort Bend
Halls Bayou	3	4	Harris
Greens Bayou	5	8	Harris
Eastern Houston	10	13	Harris
Lake Houston	9	15	Harris, Montgomery, Liberty, San Jacinto, Grimes, Walker, Waller

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 of the TMDL

Together, a TMDL and I-Plan direct the correction of water quality conditions not meeting water quality standards 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.

An I-Plan specifically identifies the actions that will be taken to achieve the pollutant loading goals of the TMDL.

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.

The TMDL report 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 for storm water. The I-Plan developed by stakeholders and approved by the state will direct implementation efforts to certain sources contributing to the impaired water quality.

In determining source reductions, the I-Plan may consider factors such as:

- cost and/or feasibility;
- 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 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 waste load reduction or load reduction is required by the TMDL, high uncertainty with the TMDL analysis exists, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

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

The TCEQ's Water Quality Management Plan (WQMP) directs the state's 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 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 after the I-Plan is adopted by the commission. Based on 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, which are a substitute for effluent limitations in TPDES MS4 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, the 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 Storm Water Management Program or Pollution Prevention Plan, or implement other specific revisions affecting storm water dischargers in accordance with an adopted I-Plan.

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Appendix A – Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

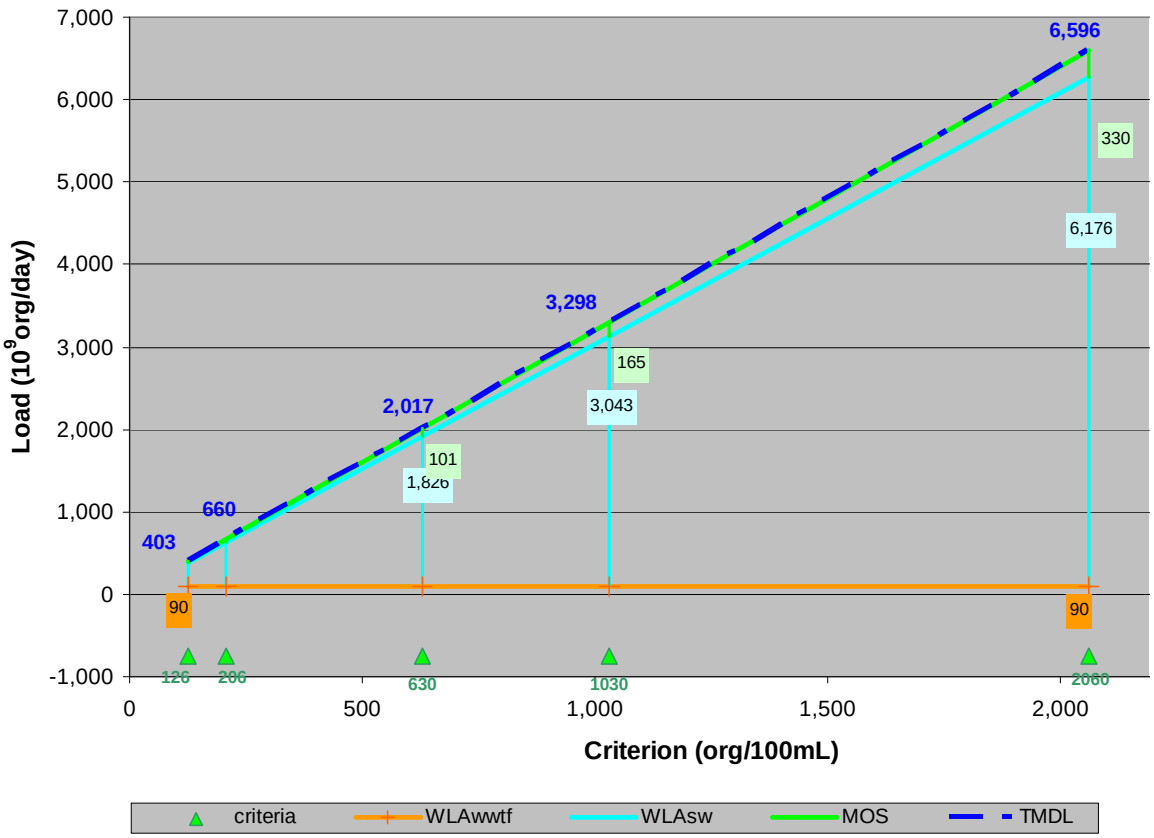

Figure A-1. Allocation Loads for AU 1016_01 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 3.202*Std$$
$$LA = 0$$
$$WLA_{Storm\ Water} = 3.0419*Std - 90.223$$
$$WLA_{WWTF} = 63*1.4321 = 90$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

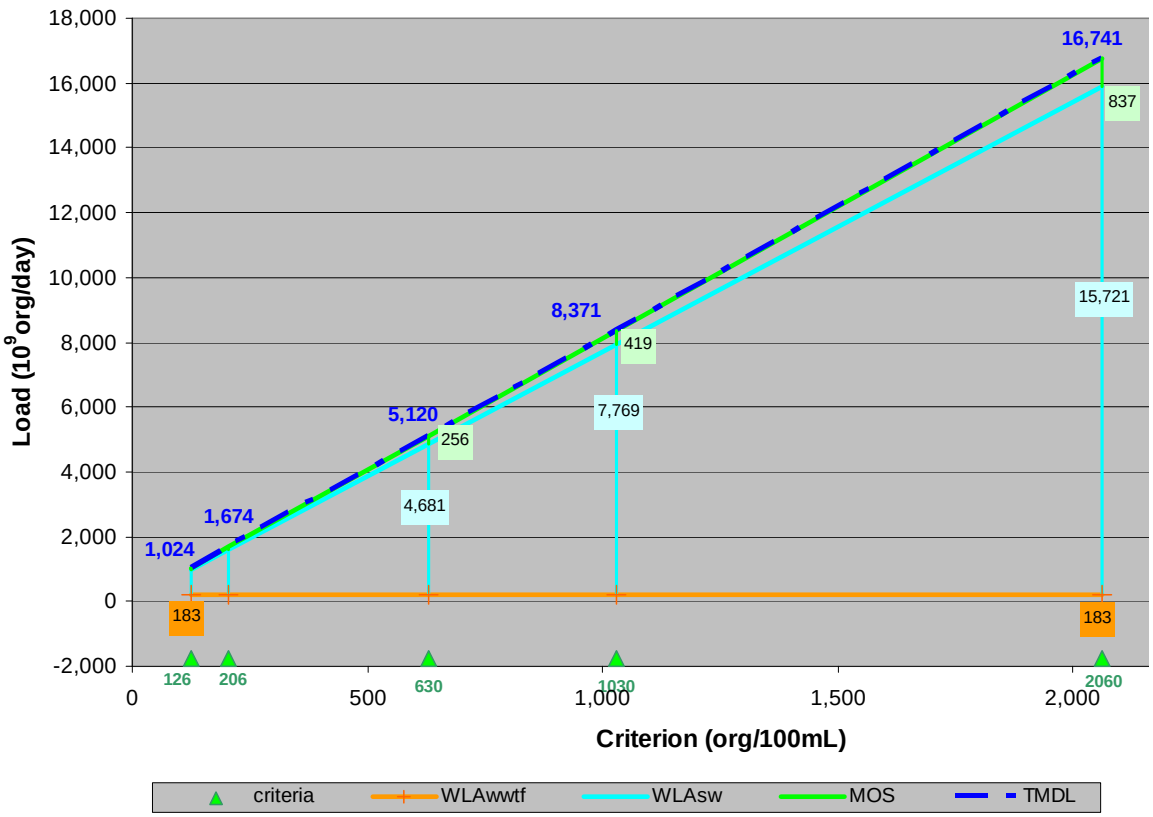

Figure A-2. Allocation Loads for AU 1016_02 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 8.1268*Std$$
$$LA = 0$$
$$WLA_{Storm\ Water} = 7.7204*Std - 183.3$$
$$WLA_{WWTF} = 63*2.9098 = 183$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

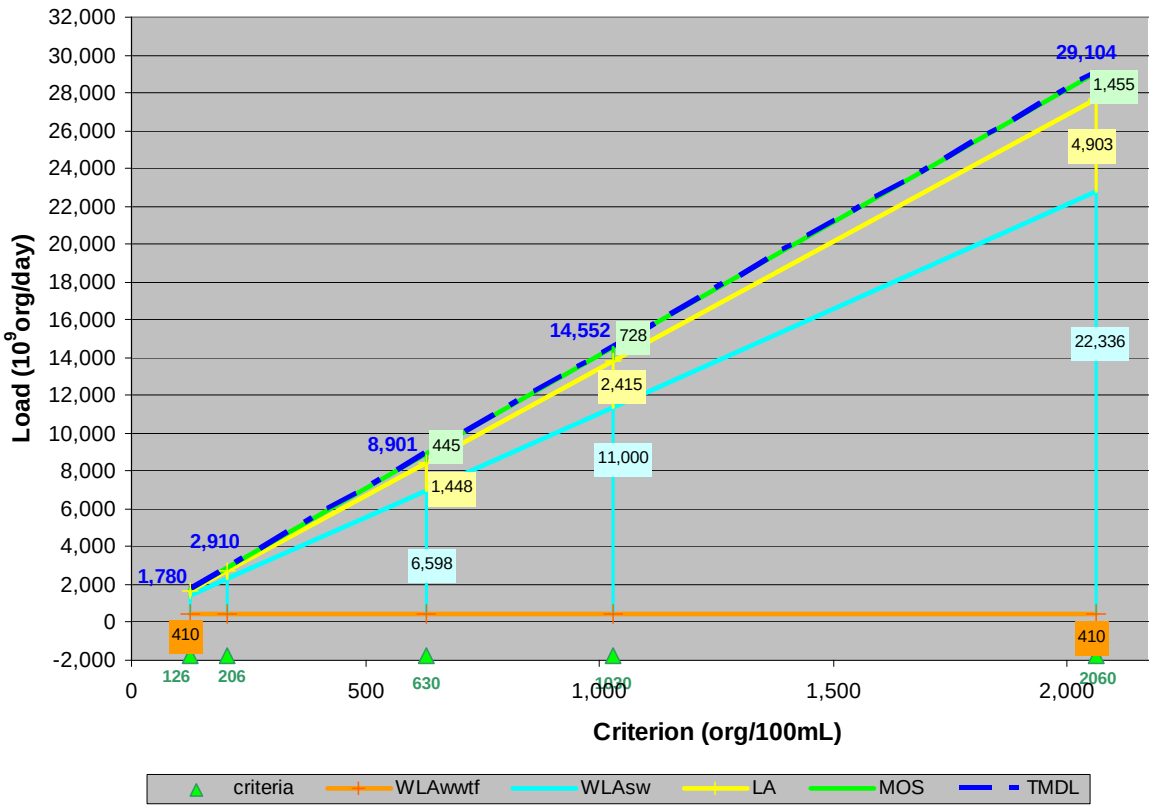

Figure A-3. Allocation Loads for AU 1016_03 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 14.128*Std$$
$$LA = 2.416*Std - 73.764$$
$$WLA_{Storm\ Water} = 11.006*Std - 336.04$$
$$WLA_{WWTF} = 63*6.505 = 410$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

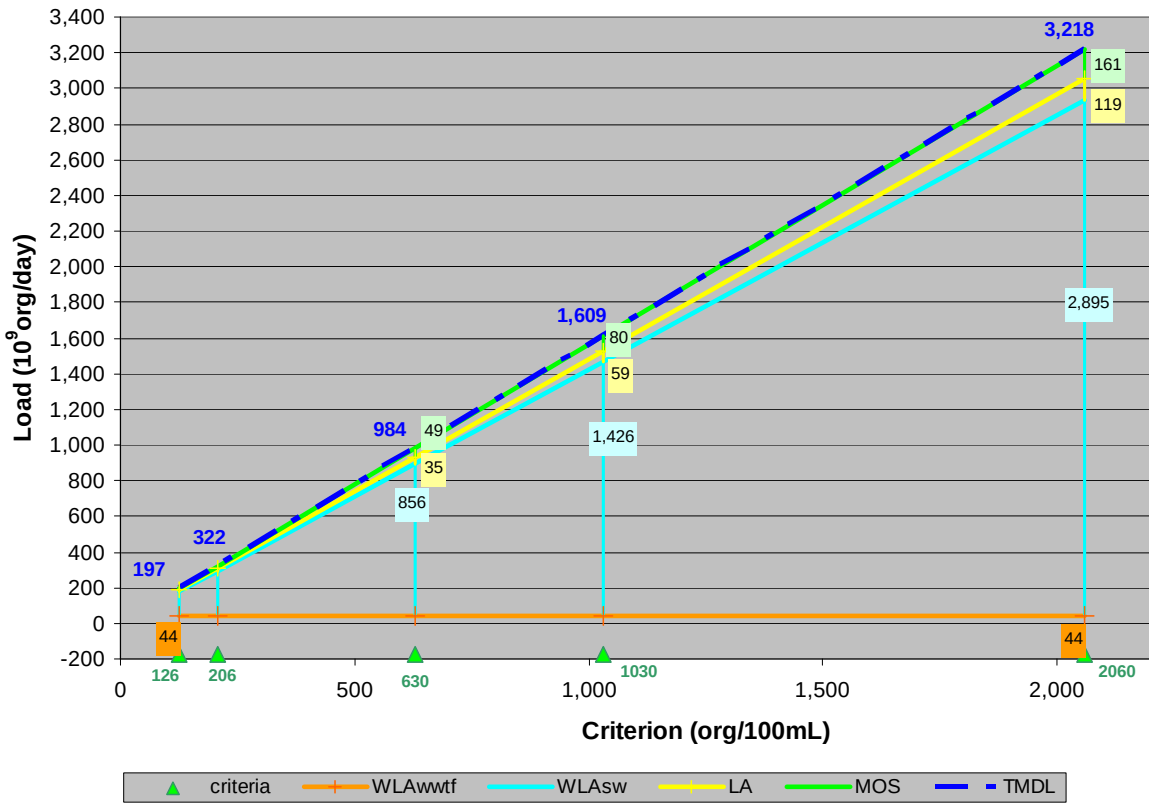

Figure A-4. Allocation Loads for AU 1016A_02 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 1.5624*Std$$
$$LA = 0.0588*Std - 1.7258$$
$$WLA_{Storm\ Water} = 1.4254*Std - 41.819$$
$$WLA_{WWTF} = 63*0.6912 = 44$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

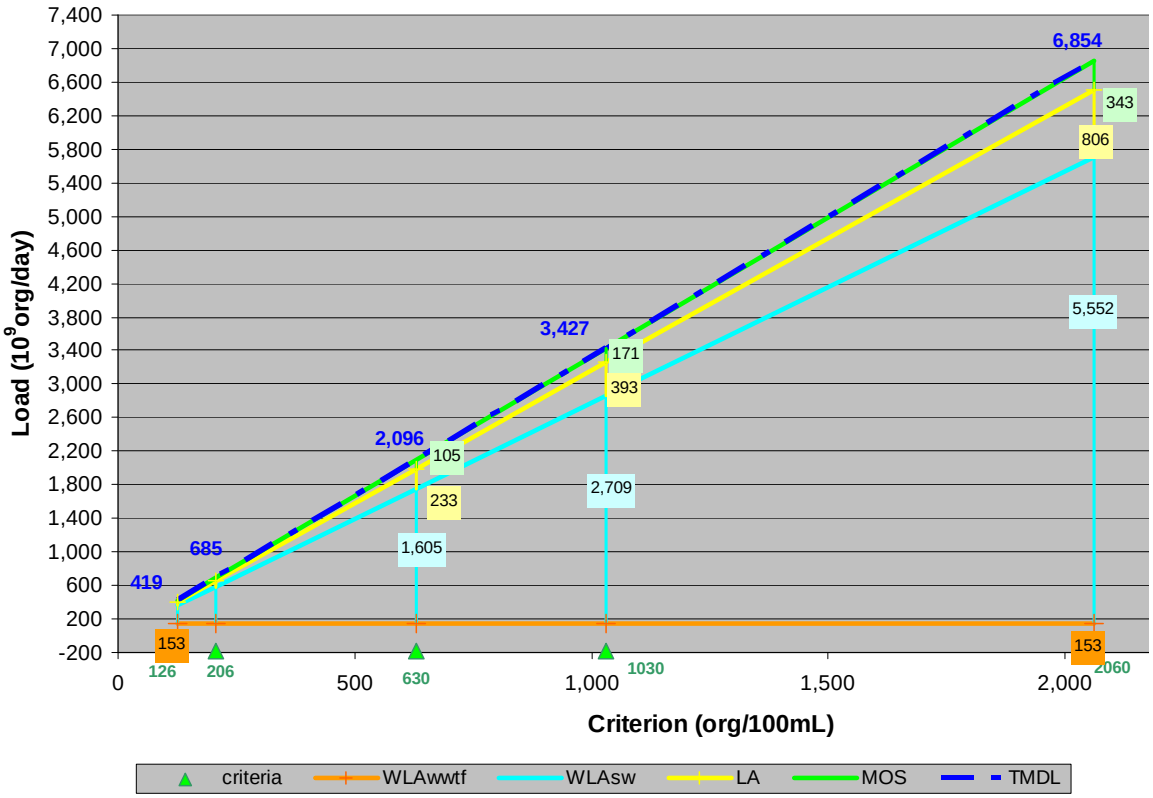

Figure A-5. Allocation Loads for AU 1016A_03 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 3.327*Std$$
$$LA = 0.4005*Std - 19.442$$
$$WLA_{Storm\ Water} = 2.7602*Std - 134$$
$$WLA_{WWTF} = 63*2.4356 = 153$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

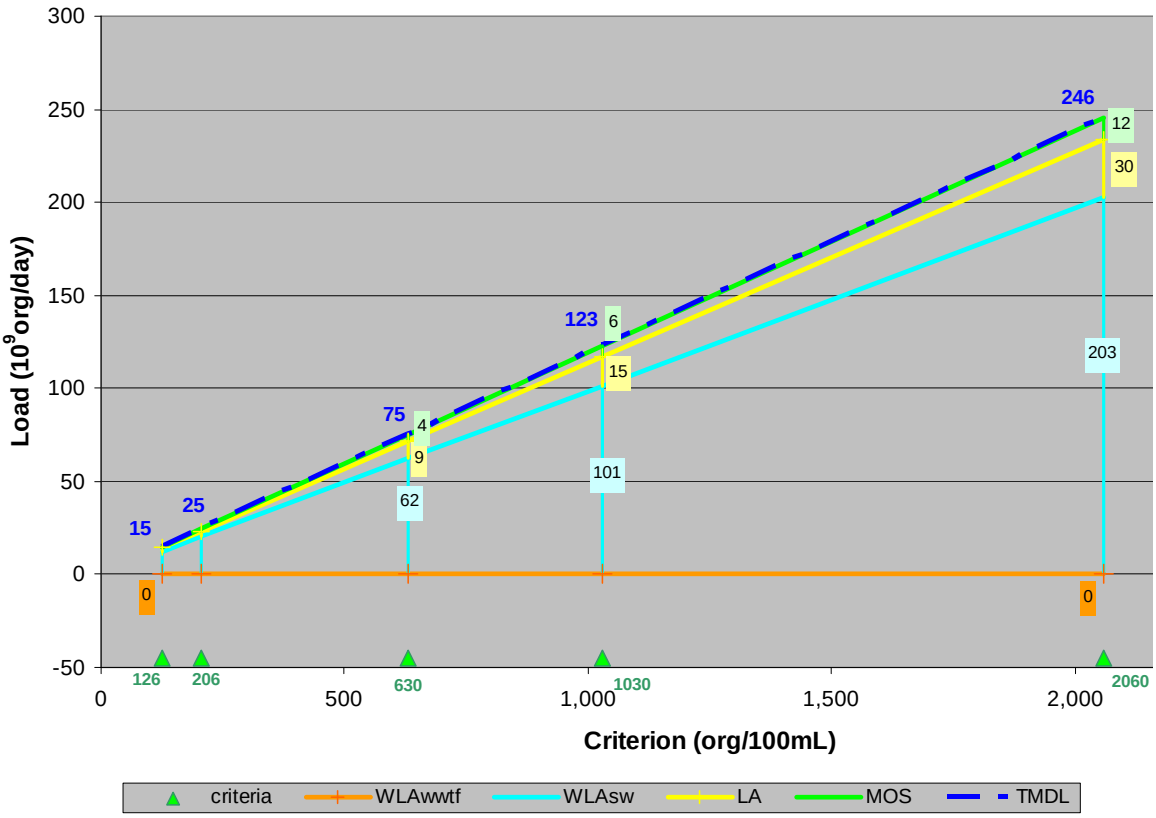

Figure A-6. Allocation Loads for AU 1016B_01 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 0.1192*Std$$
$$LA = 0.0147*Std$$
$$WLA_{Storm\ Water} = 0.0985*Std$$
$$WLA_{WWTF} = 0$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

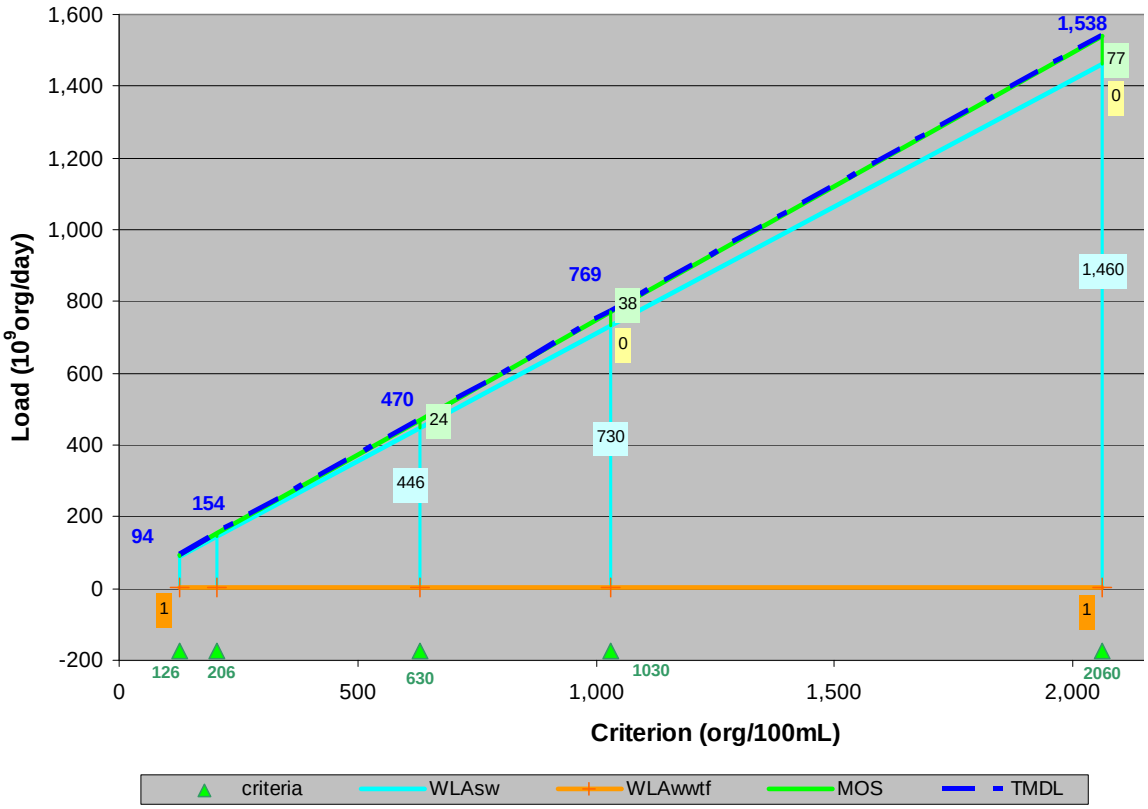

Figure A-7. Allocation Loads for AU 1016C_01 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 0.7468*Std$$
$$LA = 0$$
$$WLA_{Storm\ Water} = 0.7095*Std - 1.2091$$
$$WLA_{WWTF} = 63*0.0192 = 1$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety

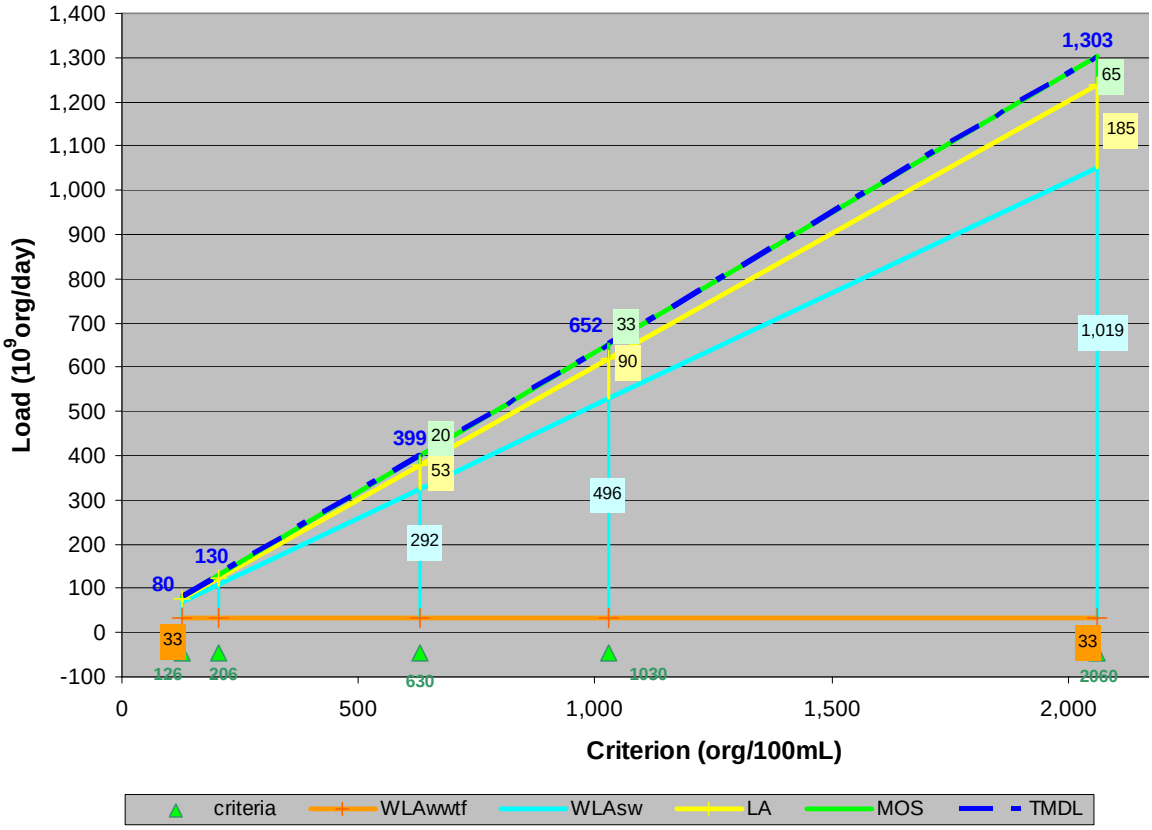

Figure A-8. Allocation Loads for AU 1016D_01 as a Function of Water Quality Criteria

Equations for Calculating New TMDL and Allocations

$$TMDL = 0.6325*Std$$
$$LA = 0.0924*Std - 5.1275$$
$$WLA_{Storm\ Water} = 0.5086*Std - 28.236$$
$$WLA_{WWTF} = 63*0.5296 = 33$$
$$MOS = 0.05*TMDL$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard
MOS = Margin of Safety