# TECHNICAL SUPPORT DOCUMENT: INDICATOR BACTERIA TOTAL MAXIMUM DAILY LOADS FOR EASTERN HOUSTON WATERSHEDS, HOUSTON, TEXAS (1006F_01, 1006H_01, 1007F_01, 1007G_01, 1007H_01, 1007I_01, 1007K_01, 1007M_01, 1007O_01, 1007R_01, 1007R_02, 1007R_03, 1007R_04)

*Prepared for:*

**TEXAS COMMISSION ON ENVIRONMENTAL QUALITY**

TCEQ

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**University of Houston**

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**TEXAS COMMISSION ON ENVIRONMENTAL QUALITY**

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| °F | degrees Fahrenheit |
| ASAE | American Society of Agricultural Engineers |
| C-CAP | Coastal Change Analysis Program |
| CAFO | concentrated animal feeding operation |
| CFR | Code of Federal Regulations |
| cfs | Cubic feet per second |
| cfs | colony-forming unit |
| counts | colony-forming unit |
| CN | curve number |
| dL | deciliter |
| DMR | discharge monitoring report |
| *E. coli* | Escherichia coli |
| 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 allocations |
| LDC | load duration curve |
| mL | milliliter |
| MOS | margin of safety |
| MPN | most probable number |
| MS4 | municipal separate storm sewer discharge |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollution Discharge Elimination System |
| NRCS | National Resources Conservation Service |
| OSSF | onsite sewage facility |
| RMSE | root mean square error |
| SSO | sanitary sewer overflow |
| STATSGO | State Soil Geographic Database |
| SWQS | surface water quality standards |
| TAC | Texas Administrative Code |
| TCEQ | Texas Commission on Environmental Quality |
| TMDL | Total Maximum Daily Loads |
| TPDES | Texas Pollution Discharge Elimination System |
| TSARP | Tropical Storm Allison Recovery Project |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USEPA | U.S. Environmental Protection Agency |
| USGS | U.S. Geological Survey |
| WLA | waste load allocation |
| WQM | water quality monitoring |
| WWTF | wastewater treatment facility |

# SECTION 1
# INTRODUCTION

Twenty-seven segments in the general Houston Metropolitan Area are considered impaired water bodies for contact recreation because they do not meet indicator bacteria (*Escherichia coli* [*E. coli*]) water quality standards. These segments are in a number of watersheds in the San Jacinto River basin, including Greens Bayou Watershed, Halls Bayou Watershed, Hunting Bayou Watershed, Brays Bayou Watershed, Sims Bayou Watershed, and the general Houston Ship Channel Watershed.

For the purpose of total maximum daily load (TMDL) development, the project was subdivided into five subprojects: Greens Bayou Watershed, Halls Bayou Watershed, Brays Bayou Watershed, Sims Bayou Watershed, and Eastern Houston Watersheds. The Eastern Houston Watersheds project includes bacteria-impaired segments in the Houston Ship Channel and Houston Ship Channel/Buffalo Bayou watersheds, which are addressed in this TMDL report.

## 1.1 Watershed Description

There are ten watersheds included in this Eastern Houston TMDL. They are located in central Harris County and are tributaries of Greens Bayou, Sims Bayou, Brays Bayou, and Buffalo Bayou. In addition, Hunting Bayou (a tributary of the Houston Ship Channel) and one of its tributaries are included in this TMDL Study. Combined, the watersheds drain an area of about 63 square miles and encompass the Cities of Houston, South Houston, Pasadena and Jacinto City as well as incorporated areas of Harris County. There are about 120 miles of open streams within the study area.

The watersheds are primarily composed of developed urban land (>90% of the total area) with a mix of residential, commercial, and industrial uses. The only two watersheds that have open space are Big Gulch above Tidal and Spring Gully above Tidal, both with a significant percentage of the drainage area covered by woodlands and wetlands.

### Subwatershed List

This report focuses on the following waterbodies/assessment units that Texas Commission on Environmental Quality (TCEQ) placed in Category 5 [303(d) list] of the 2008 Integrated Report for nonsupport of contact recreation use:

- Big Gulch above Tidal (1006F), Assessment Unit 1006F_01
- Spring Gully above Tidal (1006H), Assessment Unit 1006H_01
- Berry Bayou above Tidal (1007F), Assessment Unit 1007F_01
- Kuhlman Gully above Tidal (1007G), Assessment Unit 1007G_01
- Pine Gully above Tidal (1007H), Assessment Unit 1007H_01
- Plum Creek above Tidal (1007I), Assessment Unit 1007I_01
- Country Club Bayou above Tidal (1007K), Assessment Unit 1007K_01

- Unnamed Tributary of Hunting Bayou (1007M), Assessment Unit 1007M_01
- Unnamed Tributary of Buffalo Bayou (1007O), Assessment Unit 1007O_01
- Hunting Bayou above Tidal (1007R), Assessment Units 1007R_01, 1007R_02, 1007R_03, and 1007R_04

These waterbodies and their surrounding watersheds are hereinafter referred to as the Study Area.

Figure 1-1 is a location map showing the waterbodies addressed in this report and their contributing watersheds. The delineation of each subwatershed is derived from 2005 geographic information system (GIS) data files created for the Tropical Storm Allison Recovery Project (TSARP) provided by HCFCD. Using the TSARP GIS file results in watershed delineations that are slightly different than the historic delineations based on TCEQ GIS files associated with classified segments (Segments 1006 and 1007).

The climate of the region is subtropical humid, with very hot and humid summers and mild winters (Burian and Shepherd 2005). The average daytime temperature in the summer is 34 degrees Celsius (93 degrees Fahrenheit), while the temperature averages between 4 and 16 degrees Celsius (39 to 61 degrees Fahrenheit) 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 approximately 10 square miles which is about 16 percent of the drainage area within the Study Area (Harris County Flood Control District [HCFCD] 2008).

Table 1-1, derived from the 2000 U.S. census, summarizes the population for the cities of Houston, South Houston, Pasadena and Jacinto City as well as for Harris County (U.S. Census Bureau 2000). For comparison purposes, the 2010 estimated population from the Texas Water Development Board was included to show the population growth for the cities and Harris County.

**Table 1-1 City Population and Density**

| Name | 2000 U.S. Census | 2000 Population Density (per square mile) | Texas Water Development Board Projections 2010[a] | 2010 Population Density (per square mile) |
|---|---|---|---|---|
| City of Houston | 1,953,631 | 3,371 | 2,240,974 | 3,867 |
| City of South Houston | 15,833 | 5,174 | 17,307 | 5,655 |
| City of Pasadena | 141,674 | 3,190 | 161,678 | 3,641 |
| Jacinto City | 10,302 | 5,631 | 11,171 | 6,106 |
| Harris County | 3,400,578 | 1,967 | 3,590,782 | 2,077 |

[a] *Texas Water Development Board 2005*

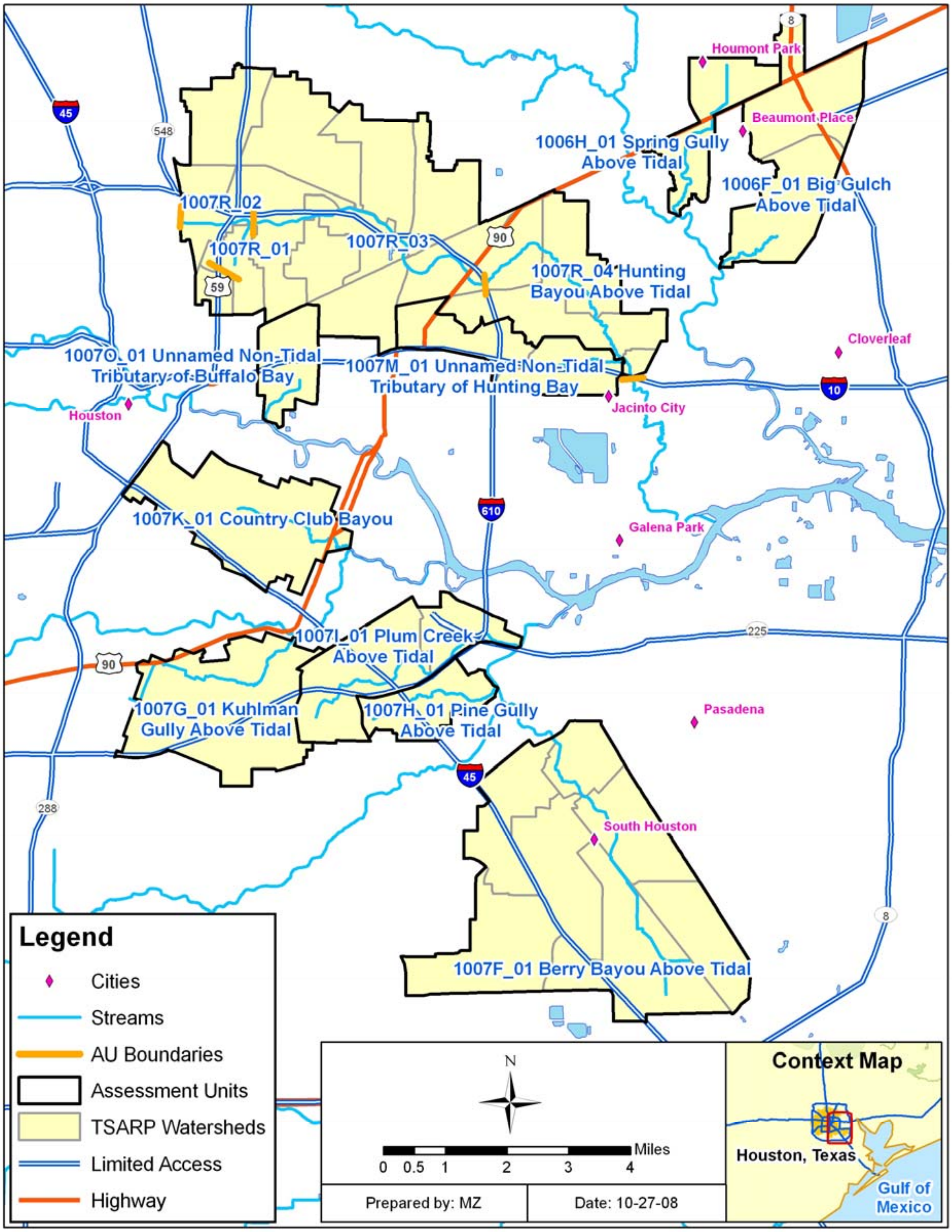


**Figure 1-1 Location Map for Eastern Houston Watersheds**

## 1.2 Summary of Existing Data

The following subsections summarize existing data relevant to soil, land use, and precipitation throughout the watershed as well as the available ambient water quality and stream flow data for the Study Area.

### 1.2.1 Soil and Topography

The State Soil Geographic Database (STATSGO) (National Resources Conservation Service [NRCS] 1994) information was used to characterize soil in the Eastern Houston Watersheds. As can be observed in Figure 1-2, the soil types that dominate the watershed are primarily from the Lake Charles and Clodine soil series. Table 1-2 lists the distribution and attributes of the two soil series found in the Study Area.

**Table 1-2 Characteristics of Soil Types within Eastern Houston Watersheds**

| 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) |
|---|---|---|---|---|---|---|---|---|
| TX007 | Aldine | 7.2% | Fine Sandy Loam | D | Somewhat Poorly Drained | 0.13 | 0.18 | 1.45 |
| TX048 | Bernard | 6.5% | Clay Loam | D | Somewhat Poorly Drained | 0.14 | 0.19 | 1.33 |
| TX100 | Clodine | 14.1% | Loam | D | Poorly Drained | 0.15 | 0.15 | 1.4 |
| TX163 | Edna | 8.2% | Fine Sandy Loam | D | Somewhat Poorly Drained | 0.1 | 0.15 | 1.4 |
| TX238 | Ijam | 0.01% | Clay | D | Somewhat Poorly Drained | 0.11 | 0.16 | 1.4 |
| TX276 | Lake Charles | 64.0% | Clay | D | Somewhat Poorly Drained | 0.12 | 0.17 | 1.33 |

*Source: All data obtained/calculated from STATSGO database*

The topography of the area is characteristic of the Texas Gulf Coastal Plains - flat, grassy, and mostly treeless (U.S. Army Corps of Engineers [USACE], 2005). Elevations in the watersheds vary between 0 and 78 feet, and the slopes between 0.01 percent and 19 percent. The predominant slope is approximately 0.2 percent.

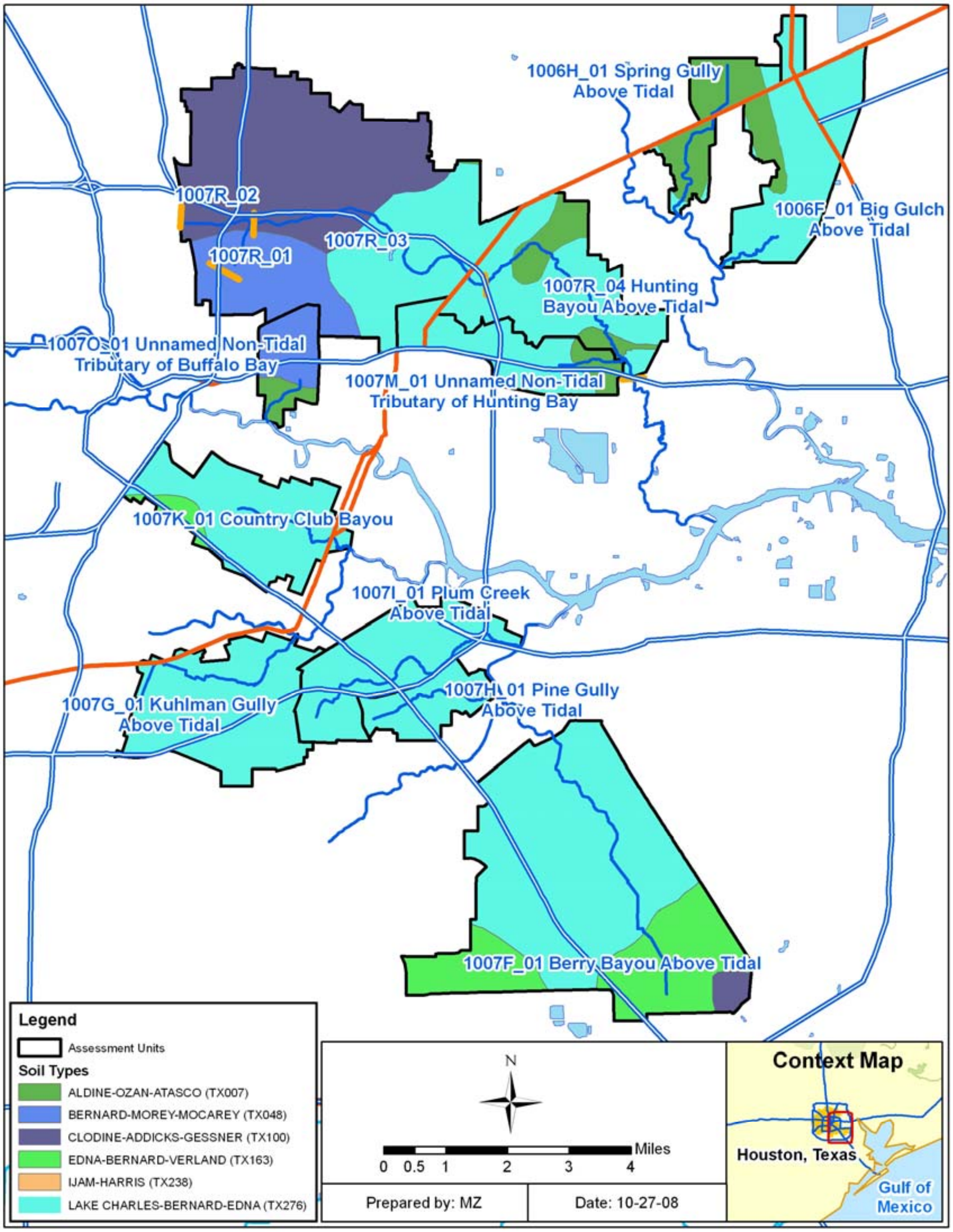


**Figure 1-2 Eastern Houston Watersheds Soil Types**

### 1.2.2 Land Use

Most of the Eastern Houston watershed is highly developed (91% for the combined watersheds), with an overall woodland contribution of 5 percent. Segments 1006F and 1006H are the only ones with urbanized areas lower than 90 percent. In these two watersheds, woodlands and wetlands have a significant contribution. Table 1-3 summarizes the acreages and the corresponding percentages of the land use categories for the contributing watershed associated with each respective assessment unit in the Study Area. The land use/land cover data 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 1-3. The total acreage of each segment in Table 1-3 corresponds to the watershed delineation in Figure 1-1. As mentioned before, the predominant land use category in this watershed is developed land (between 65.6% and 99.8%) followed by woody land (between 0.2% and 16.2%). Open water and bare/transitional land account for less than 1 percent of the subwatersheds.

**Table 1-3 Aggregated Land Use Summaries by Segment**

| Aggregated Landuse Category | Assessment Unit ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1006F_01 | 1006H_01 | 1007F_01 | 1007G_01 | 1007H_01 | 1007I_01 | 1007K_01 | 1007M_01 | 1007O_01 | 1007R[a] |
| **% Developed** | 65.6 | 77.7 | 93.7 | 98.9 | 97.3 | 99.6 | 99.8 | 97.8 | 99.5 | 89.2 |
| **% Cultivated Land** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **% Pasture/Hay** | 0.1 | 0 | 0.9 | 0.1 | 0.2 | 0 | 0 | 0 | 0 | 0.1 |
| **% Grassland/ Herbaceous** | 6.5 | 0.7 | 0.6 | 0 | 0 | 0 | 0 | 0.4 | 0.1 | 0.5 |
| **% Woody Land** | 14.9 | 16.2 | 3.9 | 1 | 2.5 | 0.4 | 0.2 | 1.7 | 0.4 | 7.4 |
| **% Open Water** | 0.1 | 0 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| **%t Wetland** | 12.7 | 5.3 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 2.7 |
| **%Bare/Transitional** | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 |
| | | | | | | | | | | |
| **Acres of Developed** | 2,077 | 984 | 9,287 | 3,320 | 999 | 2,539 | 2,889 | 1,732 | 965 | 12,267 |
| **Acres of Cultivated Land** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Acres of Pasture/Hay** | 2 | 0 | 94 | 4 | 2 | 0 | 0 | 0 | 0 | 8 |
| **Acres of Grassland/ Herbaceous** | 205 | 8 | 58 | 0.3 | 0 | 0.2 | 0 | 7 | 0.6 | 65 |
| **Acres of Woody Land** | 472 | 205 | 385 | 32 | 25 | 9 | 4 | 30 | 4 | 1,010 |
| **Acres of Open Water** | 4 | 0.2 | 31 | 0 | 0.2 | 0.2 | 0 | 0.2 | 0 | 18 |
| **Acres of Wetland** | 403 | 67 | 59 | 0 | 0.2 | 0.4 | 1.0 | 0.7 | 0 | 366 |
| **Bare/Transitional** | 4 | 1 | 2 | 0 | 0.2 | 0 | 0 | 1 | 0.2 | 3 |
| **Watershed Area (acres)** | 3,167 | 1,265 | 9,916 | 3,356 | 1,026 | 2,548 | 2,894 | 1,771 | 970 | 13,737 |

*[a] Assessment Units 1007R_01, 1007R_02, 1007R_03, and 1007R_04*

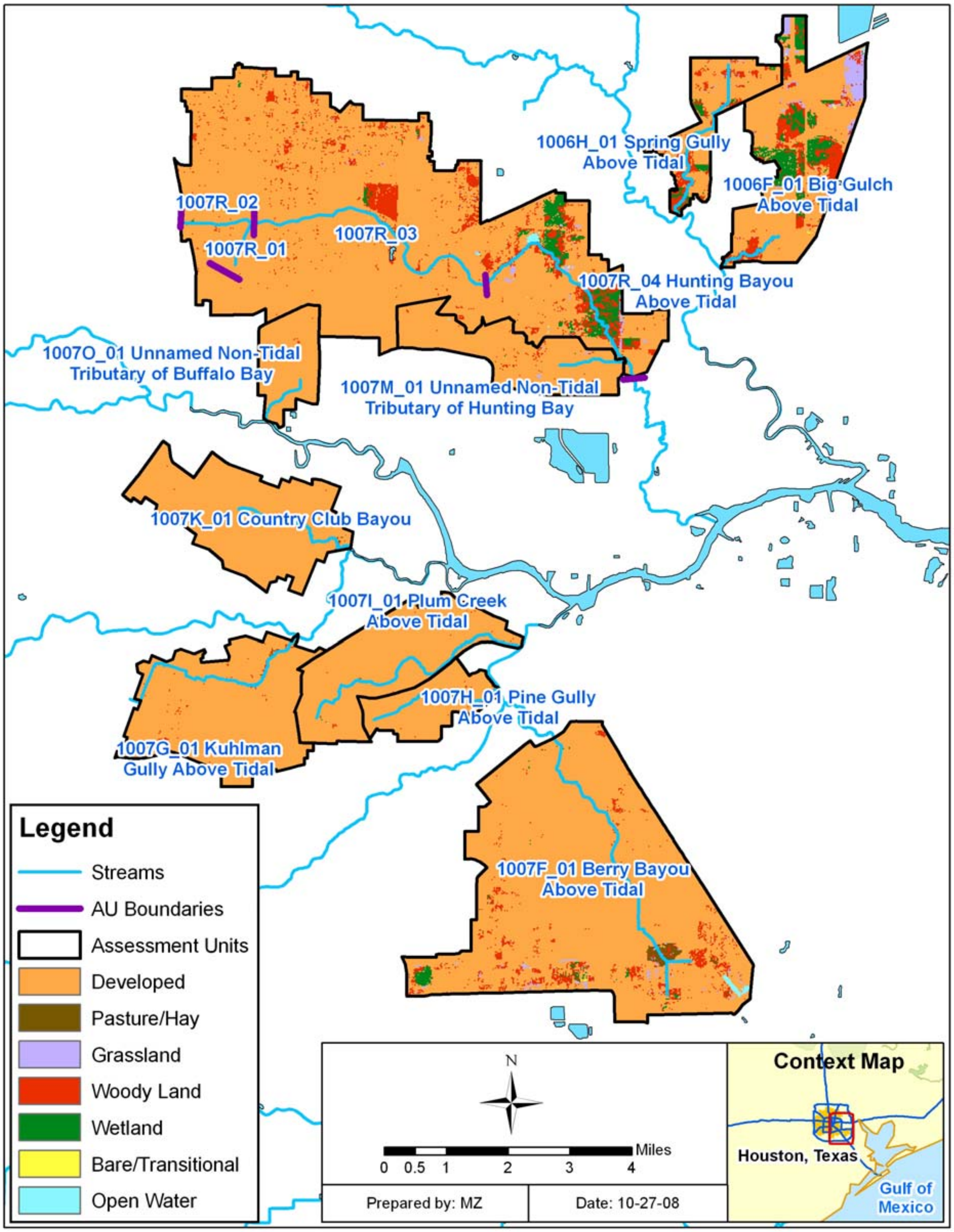


**Figure 1-3 Land Use Map**

### 1.2.3 Precipitation

There are six rain gages located within the watershed (Figure 1-4). The gages are maintained by the Harris County Office of Homeland Security and Emergency Management (HCOEM). Table 1-4 summarizes total annual rainfall for the six gages for a 20-year period. The Study Area has high levels of humidity and receives annual precipitation ranging between 22 and 90 inches per year (Table 1-4). Based on data for the period 1988 to 2007, the watershed average is around 53.2 inches per year. Figure 1-4 shows average annual rainfall across the Study Area. This grid was obtained by kriging data from 148 HCOEM rain gages located across Harris, Fort Bend, and Galveston Counties. Average values by subwatershed are summarized in Table 1-5. These average values were used to support the development of flow duration curves (Section 4).

**Table 1-4 Annual Precipitation Totals at Rainfall Gages in Eastern Houston Watersheds (inches)**

| Assessment Unit | Gauge number | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1007R_04 | 830 | 22.48 | 47.09 | 43.23 | 60.39 | 69.92 | 60.59 | 45.71 | 41.06 | 34.65 | 57.87 |
| 1007R_03 | 840 | NA | NA | NA | NA | NA | NA | NA | 15.55 | 28.78 | 78.23 |
| 1007F_01 | 310 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 1007F_01 | 320 | 22.83 | 50.43 | 38.46 | 56.10 | 63.94 | 56.46 | 59.92 | 40.16 | 27.28 | 59.65 |
| 1007K_01 | 3020 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 1007F_01 | 3030 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Assessment Unit** | **Gauge number** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** |
| 1007R_04 | 830 | 45.24 | 31.61 | 39.49 | 78.62 | 51.42 | 37.56 | 59.49 | 28.15 | 52.80 | 67.20 |
| 1007R_03 | 840 | 42.56 | 39.09 | 44.21 | 58.50 | 54.33 | 48.27 | 76.10 | 52.13 | 68.07 | 80.59 |
| 1007F_01 | 310 | NA | 35.63 | 51.50 | 84.05 | 60.79 | 44.53 | 57.20 | 34.29 | 66.65 | 68.82 |
| 1007F_01 | 320 | 57.13 | 38.43 | 50.87 | 76.81 | 59.13 | 41.57 | 58.74 | 33.82 | 65.59 | 68.90 |
| 1007K_01 | 3020 | NA | NA | 39.72 | 73.54 | 50.67 | NA | 62.05 | 38.78 | 54.68 | 63.07 |
| 1007F_01 | 3030 | NA | NA | 39.84 | NA | 55.28 | 90.75 | 51.89 | NA | 78.46 | 64.53 |

*Average annual rainfall over period of 1988 to 2007 is 49.8 inches.*

**Table 1-5 Annual Average Precipitation in Eastern Houston Watersheds, 1988-2007**

| Segment/ Assessment Unit | Average Annual (Inches) |
|---|---|
| 1006F_01 | 53.0 |
| 1006H_01 | 53.0 |
| 1007F_01 | 53.6 |
| 1007G_01 | 47.1 |
| 1007H_01 | 47.1 |
| 1007I_01 | 47.2 |
| 1007K_01 | 47.1 |
| 1007M_01 | 51.8 |
| 1007O_01 | 50.8 |
| 1007R_01 to 1007R_04 | 51.0 |

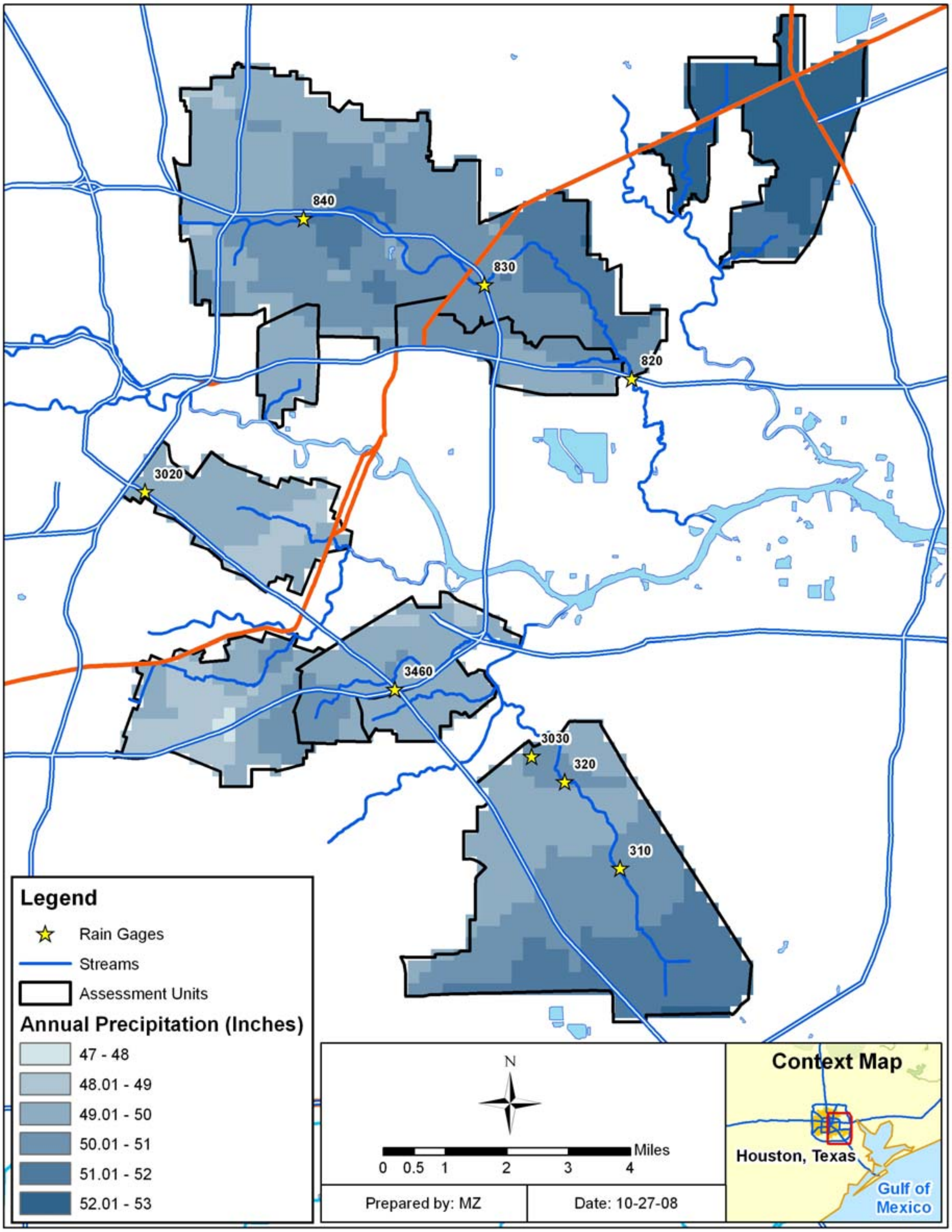


**Figure 1-4 Precipitation Map**

### 1.2.4 Ambient Water Quality

Considerable amounts of ambient water quality data are available to support water quality assessment and development of TMDLs for segments in the Eastern Houston Watersheds. Historical indicator bacteria data for the period 1995 to 2007 was obtained from the TCEQ SWQMIS database, which includes results from the sampling events conducted under this project in 2006. Forty-nine percent of the data correspond to *E. coli* concentrations (1131 samples), while the remaining 51 percent correspond to fecal coliform concentrations (1189 samples). A number of changes have occurred in the past 10 years that warrant refinements in how indicator bacteria data are used to support water quality assessments and TMDL development in Texas. Some key factors that influence which indicator bacteria to use for water quality assessment and TMDL development and the period of record to use include:

- changes in land use and locations of Texas Pollution Discharge Elimination System (TPDES)-permitted facilities;
- changing the indicator bacteria in the 2000 TCEQ surface water quality standards (SWQS) from fecal coliform to *E. coli* for fresh water;
- TCEQ policy and procedures from other TCEQ/U.S. Environmental Protection Agency (USEPA)- approved bacteria TMDLs in Texas;
- refinements in the TCEQ surface water quality monitoring procedures; and
- changes in the TCEQ guidance, *Assessing and Reporting Surface Water Quality in Texas.*

As a result of these evolving factors in the water quality management arena associated with the protection and maintenance of contact recreation use, the historical dataset used to support the TMDLs in this report have been narrowed, wherever possible, to utilize only *E. coli* data for each of the segments of Eastern Houston (available for the period 2001-2007).

Table 1-6 summarizes the historical ambient water quality data for indicator bacteria (1995-2007) for select TCEQ Water Quality Monitoring (WQM) stations in the Eastern Houston Watersheds. Note that data prior to 2001 correspond to fecal coliform concentrations, while data for 2001-2007 are primarily *E. coli* concentrations. Figure 1-5 shows the locations of the WQM locations with indicator bacteria data. The complete ambient water quality dataset for bacteria used to prepare Table 1-6 is provided in Appendix A. Table 1-6 presents the number of indicator bacteria samples, as well as the geometric mean of the concentrations for each indicator, and the number and percentage of single sample exceedances of the Texas SWQS. A more in-depth discussion of the analysis of this dataset is provided in Subsections 2.3 and 2.4.

**Table 1-6 Historical Water Quality Data for TCEQ Stations (May 1995 - Feb 2007)**

| Segment | Station ID | Indicator Bacteria | Geometric Mean Criteria (counts/dL) | Geometric Mean Concentration (counts/dL) | Single Sample Criteria (counts/dL) | Number of Samples | Number of Samples Exceeding Single Sample Criteria | % of Samples Exceeding |
|---|---|---|---|---|---|---|---|---|
| 1006F | 16662 | EC | 126 | 948 | 394 | 83 | 56 | 67% |
| | | FC | 200 | 2,299 | 400 | 67 | 49 | 73% |
| 1006H | 16663 | EC | 126 | 433 | 394 | 80 | 43 | 54% |
| | | FC | 200 | 1,378 | 400 | 66 | 48 | 73% |
| 1007F | 16661 | EC | 126 | 2,379 | 394 | 61 | 59 | 97% |
| | | FC | 200 | 1,360 | 400 | 66 | 48 | 73% |
| 1007G | 16653 | EC | 126 | 1,359 | 394 | 82 | 50 | 61% |
| | | FC | 200 | 1,874 | 400 | 69 | 45 | 65% |
| 1007H | 16659 | EC | 126 | 2,772 | 394 | 79 | 69 | 87% |
| | | FC | 200 | 4,308 | 400 | 67 | 59 | 88% |
| 1007I | 16658 | EC | 126 | 7,553 | 394 | 80 | 74 | 93% |
| | | FC | 200 | 7,829 | 400 | 67 | 64 | 96% |
| 1007K | 16650 | EC | 126 | 6,887 | 394 | 80 | 76 | 95% |
| | | FC | 200 | 10,854 | 400 | 70 | 62 | 89% |
| | 16651 | EC | 126 | 1,889 | 394 | 61 | 43 | 70% |
| | | FC | 200 | 18,786 | 400 | 67 | 60 | 90% |
| 1007M | 16657 | EC | 126 | 578 | 394 | 77 | 45 | 58% |
| | | FC | 200 | 1,727 | 400 | 70 | 52 | 74% |
| 1007O | 16649 | EC | 126 | 2,838 | 394 | 79 | 65 | 82% |
| | | FC | 200 | 5,465 | 400 | 68 | 57 | 84% |
| 1007R | 11128 | EC | 126 | 411 | 394 | 77 | 46 | 60% |
| | | FC | 200 | 1,886 | 400 | 37 | 30 | 81% |
| | 11129 | EC | 126 | 194 | 394 | 61 | 19 | 31% |
| | | FC | 200 | 748 | 400 | 77 | 43 | 56% |
| | 11130 | FC | 200 | 3,373 | 400 | 5 | 5 | 100% |
| | 11131 | FC | 200 | 3,367 | 400 | 44 | 40 | 91% |
| | 15832 | FC | 200 | 3,052 | 400 | 4 | 4 | 100% |
| | 15867 | EC | 126 | 463 | 394 | 61 | 37 | 61% |
| | | FC | 200 | 407 | 400 | 36 | 20 | 56% |
| | 15868 | FC | 200 | 2,469 | 400 | 44 | 37 | 84% |
| | 15869 | EC | 126 | 13,381 | 394 | 61 | 56 | 92% |
| | | FC | 200 | 16,009 | 400 | 73 | 70 | 96% |
| | 15870 | FC | 200 | 5,861 | 400 | 5 | 5 | 100% |
| | 15871 | FC | 200 | 3,137 | 400 | 5 | 5 | 100% |
| | 15872 | FC | 200 | 1,842 | 400 | 6 | 5 | 83% |
| | 15873 | EC | 126 | 787 | 394 | 61 | 37 | 61% |
| | | FC | 200 | 840 | 400 | 30 | 22 | 73% |
| | 15874 | FC | 200 | 1,732 | 400 | 5 | 5 | 100% |
| | 18689 | EC | 126 | 549 | 394 | 18 | 12 | 67% |

*EC: E. coli., FC: Fecal Coliform*

### 1.2.5 Stream Flow Data

Stream flow data are key information when conducting water quality assessments such as TMDLs. The U.S. Geological Survey (USGS) operates flow gages at one location on Hunting Bayou to measure flow and elevations. In addition, there is a gage in Berry Bayou that records water elevations. The period of record and type of data collected are listed in Table 1-7. The location of the gages is shown on Figure 1-5. The historical flow data available from the gage in Hunting Bayou are included in Appendix B.

**Table 1-7 USGS Gages in the Eastern Houston Watersheds**

| USGS Gage Number | Name | Period of Record | Data Type |
|---|---|---|---|
| 8075770 | Hunting Bayou at IH 610 | 5/1/1964 Present | Discharge (cfs) |
| | | 9/5/1996 - Present | Gage Height (ft) |
| 8075650 | Berry Bayou at Forrest Oaks St. | 10/1/1997 - 10/3/2006 | Gage Height (ft) |

During intensive surveys conducted in the summer of 2006, instantaneous flow was measured at nine WQM stations within the Study Area (mainly at the end of each segment, except 1007F): 16662 (assessment unit 1006F_01), 16663 (assessment unit 1006H_01), 16653 (assessment unit 1007G_01), 16659 (assessment unit 1007H_01), 16658 (assessment unit 1007I_01), 16650 (assessment unit 1007K_01), 16657 (assessment unit 1007M_01), 16649 (assessment unit 1007O_01), and 11128 (segment 1007R). The complete set of instantaneous flow data is also provided in Appendix B. A few historical measurements were available from the SWQMIS database to assist in characterizing flows (Appendix B).

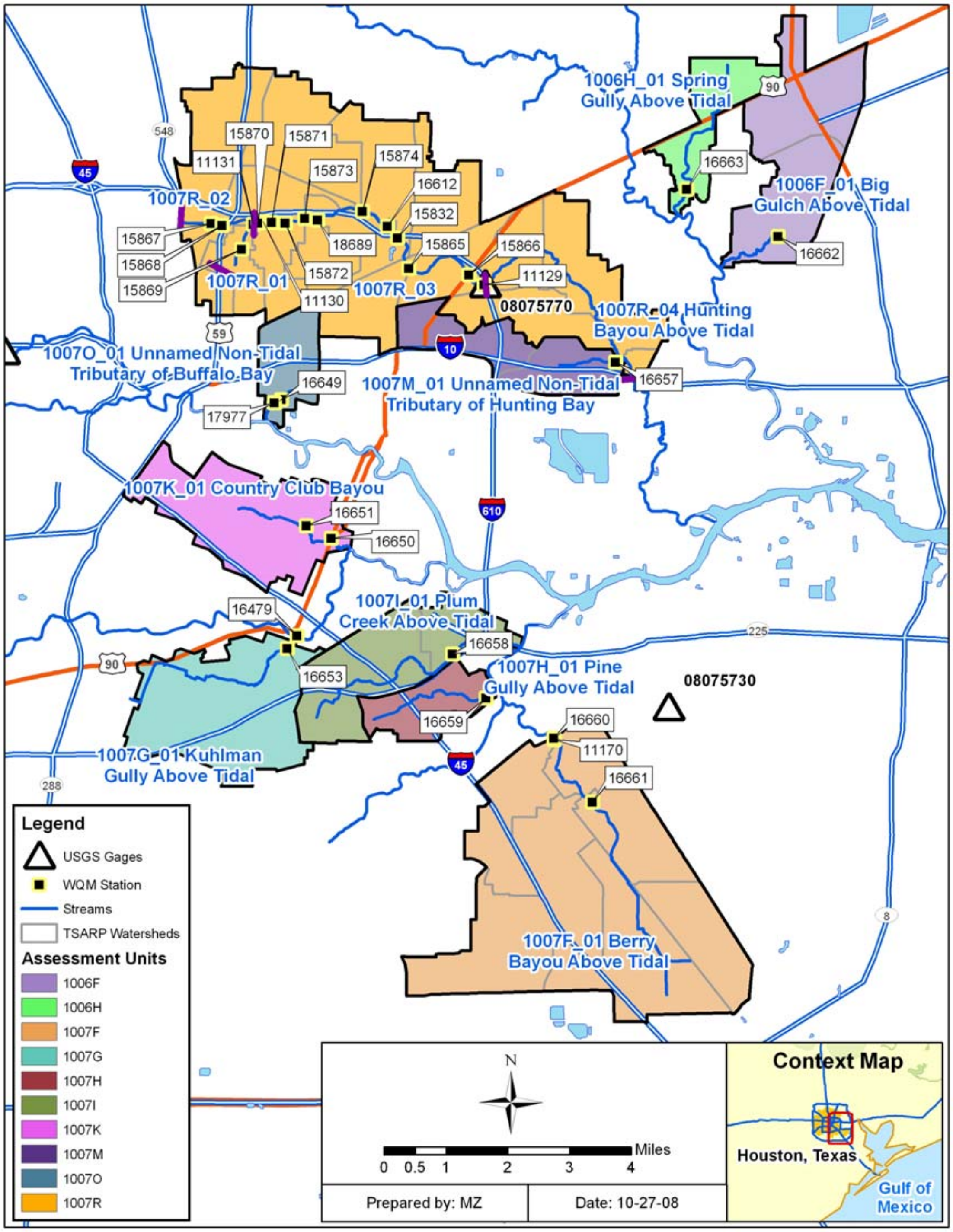


**Figure 1-5 WQM and USGS Station Locations**

## 1.3 Eastern Bayous Seasonality

Seasonal differences in indicator bacteria concentrations were assessed by comparing historical bacteria concentrations collected in the warmer months versus those collected during the cooler months. The monthly average temperatures for Houston obtained from NOAA (Table 1-8) and the following criteria: warm temperatures ranged from 24 – 32°C and cool temperatures ranged from 12 – 18°C were used to divide the data sets into warmer and cooler months. Based on this, November, December, January, and February were cooler months, and May, June, July, August, and September were warmer months.

**Table 1-8 Average Monthly Temperatures for Houston Hobby AP, TX (1971-2000)**

| Month | Daily Max (°C) | Daily Min (°C) | Daily Mean (°C) | Classification |
|---|---|---|---|---|
| Jan | 17.4 | 7.3 | 12.4 | Cool |
| Feb | 19.5 | 9 | 14.3 | Cool |
| Mar | 23.1 | 12.7 | 17.9 | |
| Apr | 26.3 | 15.9 | 21.1 | |
| May | 29.9 | 20.1 | 25 | Warm |
| Jun | 32.8 | 23.1 | 27.9 | Warm |
| Jul | 34.2 | 24.1 | 29.2 | Warm |
| Aug | 34.1 | 24.1 | 29.1 | Warm |
| Sep | 31.8 | 22 | 26.9 | Warm |
| Oct | 27.8 | 16.8 | 22.3 | |
| Nov | 22.5 | 11.9 | 17.2 | Cool |
| Dec | 18.6 | 8.2 | 13.4 | Cool |

*Note: Temperature values from NOAA (degrees Fahrenheit) have been converted to degrees Celsius.*
*http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl*

A t-test was conducted on log transformed data between the warmer months and cooler months for stations with 6 or more samples. Geometric means were also calculated for the warmer and cooler months. Table 1-9 shows that 6 out of 17 stations (35%) exhibited higher geometric means for colder months than for warmer months. However, only at three stations (18%) were fecal coliform levels significantly higher ($p$-value<0.05) during cool months. Overall there was no seasonal significant difference.

**Table 1-9 Seasonal Differences for Fecal Coliform Concentrations**

| Segment | Station ID | Warm Months | | Cool Months | | *p*-value |
|---|---|---|---|---|---|---|
| | | n | Geomean (cfu/100mL) | n | Geomean (cfu/100mL) | |
| 1006F | 16662 | 30 | 3,271 | 22 | 2,192 | 0.460 |
| 1006H | 16663 | 27 | 1,070 | 23 | 1,336 | 0.680 |
| 1007F | 16661 | 31 | 1,356 | 23 | 1,879 | 0.506 |
| 1007G | 16653 | 30 | 2,886 | 21 | 556 | 0.004 |
| 1007H | 16659 | 32 | 1,728 | 14 | 3,732 | 0.291 |
| 1007I | 16658 | 30 | 10,577 | 23 | 5,809 | 0.220 |
| 1007K | 16650 | 31 | 12,659 | 21 | 5,006 | 0.141 |
| | 16651 | 24 | 18,783 | 17 | 1,203 | 0.001 |
| 1007M | 16657 | 32 | 1,188 | 22 | 2,570 | 0.075 |
| 1007O | 16649 | 26 | 8,725 | 19 | 1,935 | 0.017 |
| 1007R | 11128 | 20 | 1,793 | 12 | 2,740 | 0.500 |
| | 11129 | 32 | 1,328 | 22 | 535 | 0.152 |
| | 11130 | 4 | 3,636 | 0 | - | NA |
| | 11131 | 22 | 5,581 | 10 | 1,700 | 0.152 |
| | 15832 | 4 | 3,052 | 0 | - | NA |
| | 15867 | 18 | 462 | 12 | 344 | 0.662 |
| | 15868 | 22 | 5,750 | 8 | 788 | 0.085 |
| | 15869 | 23 | 13,900 | 22 | 8,816 | 0.368 |
| | 15870 | 4 | 7,182 | 0 | - | NA |
| | 15871 | 4 | 3,146 | 0 | - | NA |
| | 15872 | 5 | 1,121 | 0 | - | NA |
| | 15873 | 18 | 653 | 2 | 1,732 | 0.280 |
| | 15874 | 4 | 1,463 | 0 | - | NA |

*n = number of samples*
*NA = not available. Test could not be conducted because station does not have data for cool months.*
*Highlighted rows correspond to stations for which the warm and cold datasets are significantly different at a 95% confidence interval.*
*p-value is based on a t-test conducted at each station using single sample concentrations.*
*All concentrations are in cfu/100mL.*

For *E. coli*, Table 1-10 shows that 31 percent of the stations (5 out of 16) exhibited higher geometric mean concentrations for the colder months than the warmer months. Four of those stations (25%) showed a statistically significant (*p*-value<0.05) higher geometric mean for cooler months than for warmer months.

**Table 1-10 Seasonal Differences for E. coli Concentrations**

| Segment | Station ID | Warm Months | | Cool Months | | *p*-value |
|---|---|---|---|---|---|---|
| | | n | Geomean (MPN/100mL) | n | Geomean (MPN/100mL) | |
| 1006F | 16662 | 45 | 958 | 25 | 1,609 | 0.327 |
| 1006H | 16663 | 42 | 401 | 25 | 429 | 0.841 |
| 1007F | 16661 | 22 | 1,619 | 26 | 4,482 | 0.019 |
| 1007G | 16653 | 42 | 3,847 | 22 | 815 | 0.019 |
| 1007H | 16659 | 38 | 2,984 | 26 | 2,473 | 0.719 |
| 1007I | 16658 | 33 | 7,923 | 23 | 7,541 | 0.919 |
| 1007K | 16650 | 37 | 6,786 | 24 | 5,567 | 0.683 |
| | 16651 | 19 | 5,151 | 22 | 1,614 | 0.145 |
| 1007M | 16657 | 37 | 656 | 26 | 717 | 0.871 |
| 1007O | 16649 | 39 | 4,663 | 24 | 802 | 0.0002 |
| 1007R | 11128 | 39 | 327 | 26 | 692 | 0.190 |
| | 11129 | 20 | 391 | 24 | 198 | 0.244 |
| | 15867 | 22 | 915 | 26 | 264 | 0.009 |
| | 15869 | 19 | 22,689 | 23 | 7,300 | 0.080 |
| | 15873 | 21 | 1,346 | 19 | 1,334 | 0.991 |
| | 18689 | 6 | 617 | 8 | 343 | 0.458 |

*n = number of samples*
*Highlighted rows correspond to stations for which the warm and cold datasets are significantly different at a 95% confidence interval.*
*p-value is based on a t-test conducted at each station using single sample concentrations.*
*All concentrations are in MPN/100mL.*

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.

# SECTION 2
# PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

## 2.1 Pollutant of Concern: Characteristics of Bacterial Indicators

The contact recreation use is assigned to almost every designated water body in the State of Texas, although full support of contact recreation use is not a guarantee the water is completely safe of disease-causing organisms. The evolution of contact recreation criteria currently used by Texas began with criteria first published in 1968 based on general studies done on lakes in the Midwest and New York using fecal coliform bacteria as the indicator of the potential presence of fecal contamination (USEPA 1986). The USEPA-recommended criterion for recreational waters in 1976 included a geometric mean criterion: no more than 200 cfu/100mL based on five samples collected over a 30-day period, and an instantaneous criterion: no more than 10 percent of the individual grab samples could exceed 400 cfu/100mL (USEPA 1986). Shortly thereafter this recommended criterion was adopted by the State of Texas in its SWQS. These criteria, and the studies on which they were based, were heavily criticized by the USEPA in 1986 (USEPA 1986) following an extensive program of epidemiology testing. During that decade, USEPA studies found that fecal coliform was not a good predictor of the risk of disease and recommended new tests and criteria. As a result, USEPA recommended new criteria for swimming areas, using *E. coli* as the new fecal indicator organism, and incorporating the idea of varying criteria with the level of swimming use. TCEQ then revised the WQS in 2000 to establish *E. coli* as the new indicator bacteria for assessment of contact recreation in all freshwater.

Thus in Texas both indicator bacteria - fecal coliform and *E. coli* - can be used to determine support of the contact recreation use in freshwater. However, it is expected that over time since only *E. coli* bacteria are measured through the statewide ambient monitoring program to determine the relative risk of contact recreation, reliance on fecal coliform data will diminish. The presence of *E. coli* indicates that associated pathogens from the waste of warm-blooded species (human or animal) may be reaching a body of water. The standard associated with contact recreation use is designed to ensure that water is safe for swimming, wading by children, or other water sports that involve direct contact with the water, especially with the possibility of ingesting it. High concentrations of certain indicator bacteria in water indicate there may be a risk of becoming ill from recreational activities.

Texas WQSs for contact recreation allow exemptions for waterbodies where elevated bacteria concentrations frequently occur due to sources of pollution that cannot be reasonably controlled by the existing regulations, or where recreation is considered unsafe for other reasons, such as barge or ship traffic (*e.g.,* Houston Ship Channel), unrelated to water quality. This exemption and reclassification to less strict “noncontact recreation” standards have been applied to only a few waterbodies in Texas.

## 2.2 TCEQ Water Quality Standards for Contact Recreation

The TCEQ is responsible for administering provisions of the constitution and laws of the State of Texas to promote judicious use of and protection of the quality of waters in the state. Included in this responsibility is the continuous monitoring and assessment of water quality to evaluate compliance with SWQSs established within Texas Water Code, §26.023 and Title 30 Texas Administrative Code (TAC), §§307.1-307.10. Texas SWQS, 30 TAC 307.4 specify the designated uses and general criteria for all surface waters in the state.

This report focuses on the waterbodies within the Eastern Houston Watersheds identified on the federal Clean Water Act §303(d) list of the 2008 Texas Water Quality Inventory because they do not support contact recreation use. Table 2-1 summarizes the designated uses and the applicable indicator bacteria used to assess the contact recreation use of each waterbody addressed in this report. Table 2-1 also identifies the year each waterbody was placed on the Texas §303(d) List for nonsupport of contact recreation use, the stream length in miles, and other designated uses for each waterbody. The TMDLs in this report only address the contact recreation use. TMDLs are a necessary step in the process to restore contact recreation use for each waterbody.

**Table 2-1 Synopsis of Texas Integrated Report for Waterbodies in Eastern Houston**

| Segment ID | Segment Name | Assessment Unit | Indicator Bacteria | Designated Use* | | | | Year Placed on 303(d) List | Stream Length (miles) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | CR | AL | GU | FC | | |
| 1006F | Big Gulch above Tidal | 1006F_01 | *E. coli* (or FC) | NS | S | NC | NA | 2002 | 1.2 |
| 1006H | Spring Gully above Tidal | 1006H_01 | *E. coli* (or FC) | NS | S | NA | NA | 2002 | 0.5 |
| 1007F | Berry Bayou above Tidal | 1007F_01 | *E. coli* (or FC) | NS | NA | CS | NA | 2002 | 2.0 |
| 1007G | Kuhlman Gully above Tidal | 1007G_01 | *E. coli* (or FC) | NS | S | NA | NA | 2002 | 1.2 |
| 1007H | Pine Gully above Tidal | 1007H_01 | *E. coli* (or FC) | NS | NA | NA | NA | 2002 | 1.0 |
| 1007I | Plum Creek above Tidal | 1007I_01 | *E. coli* (or FC) | NS | NA | NA | NA | 2002 | 3.8 |
| 1007K | Country Club Bayou | 1007K_01 | *E. coli* (or FC) | NS | NS | NA | NA | 2004 | 1.0 |
| 1007M | Unnamed Non-Tidal Tributary of Hunting Bayou | 1007M_01 | *E. coli* (or FC) | NS | S | NA | NA | 2002 | 1.1 |
| 1007O | Unnamed Non-Tidal Tributary of Buffalo Bayou | 1007O_01 | *E. coli* (or FC) | NS | NS | NA | NA | 2002 | 1.0 |
| 1007R | Hunting Bayou above Tidal | 1007R_01 | *E. coli* (or FC) | NS | NS | CS | NA | 2002 | 0.9 |
| | | 1007R_02 | *E. coli* (or FC) | NS | S | NC | NA | 2002 | 1.2 |
| | | 1007R_03 | *E. coli* (or FC) | NS | S | CS | NA | 2002 | 4.8 |
| | | 1007R_04 | *E. coli* (or FC) | NS | S | CS | NA | 2002 | 4.1 |

**CR: Contact recreation; AL: Aquatic Life; GU: General Use; FC: Fish Consumption; NS: Nonsupport; S = Support; NC = No Concern; CS = Concern for Screening Level; NA=not assessed*

The excerpts below from Chapter 307, SWQS (TCEQ 2000) stipulate how water quality data were assessed to determine support of the contact recreation use as well as how the water quality targets are defined for each bacterial indicator. In addition to the specific requirements of §307.7 outlined below, the TMDLs for the Eastern Houston Watersheds will also adhere to §307.5 of the SWQS which defines the antidegradation policy and procedures that apply to authorized wastewater discharges, TMDLs, waste load evaluations, and any other miscellaneous actions, such as those related to man-induced nonpoint sources of pollution, which may impact the water in the state (TCEQ 2000).

**§307.7. Site-specific Uses and Criteria.**

*(a) Uses and numerical criteria are established on a site-specific basis in Appendices A, D, and E of §307.10 of this title (relating to Appendices A - E). Site-specific uses and numerical criteria may also be applied to unclassified waters in accordance with §307.4(h) of this title (relating to General Criteria) and §307.5(c) of this title (relating to Antidegradation). Site-specific criteria apply specifically to substances attributed to waste discharges or the activities of man. Site-specific criteria do not apply to those instances in which surface waters exceed criteria due to natural phenomena. The application of site-specific uses and criteria is described in §307.8 of this title (relating to the Application of Standards) and §307.9 of this title (relating to the Determination of Standards Attainment).*

*(b) Appropriate uses and criteria for site-specific standards are defined as follows.*

*(1) Recreation. Recreational use consists of two categories - contact recreation waters and noncontact recreation waters. Classified segments are designated for contact recreation unless elevated concentrations of indicator bacteria frequently occur due to sources of pollution which cannot be reasonably controlled by existing regulations or contact recreation is considered unsafe for other reasons such as ship or barge traffic. In a classified segment where contact recreation is considered unsafe for reasons unrelated to water quality, a designated use of noncontact recreation may be assigned criteria normally associated with contact recreation. A designation of contact recreation is not a guarantee that the water so designated is completely free of disease-causing organisms. Indicator bacteria, although not generally pathogenic, are indicative of potential contamination by feces of warm blooded animals. The criteria for contact recreation are based on these indicator bacteria, rather than direct measurements of pathogens. Criteria are expressed as the number of "colony forming units" of bacteria per 100 milliliters (mL) of water. Even where the concentration of indicator bacteria is less than the criteria for contact recreation, there is still some risk of contracting waterborne diseases. Additional guidelines on minimum data requirements and procedures for evaluating standards attainment are specified in the latest approved version of the TNRCC Guidance for Screening and Assessing Texas Surface and Finished Drinking Water Quality Data.*

*(A) Freshwater*

*(i) Contact recreation. The geometric mean of E. coli should not exceed 126 per 100 mL. In addition, single samples of E. coli should not exceed 394 per 100 mL. Contact recreation applies to all bodies of freshwater except where specifically designated otherwise in §307.10 of this title (relating to Appendices A - E).*

*(ii) Noncontact recreation. The geometric mean of E. coli should not exceed 605 per 100 mL.*

*(B) Saltwater*

*(i) Contact recreation. The geometric mean of Enterococci should not exceed 35 per 100 mL. In addition, single samples of Enterococci should not exceed 89 per 100 mL. Contact recreation applies to all bodies of saltwater, except where specifically designated otherwise in §307.10 of this title.*

*(ii) Noncontact recreation. The geometric mean of Enterococci should not exceed 168 per 100 mL.*

*(C) Fecal coliform bacteria. Fecal coliform bacteria can be used as an alternative instream indicator of recreational suitability until sufficient data are available for E coli or Enterococci. For segments designated as oyster waters in §307.10 of this title, fecal coliform can continue to be used as an indicator of recreational suitability because fecal coliform is used as the indicator for suitability of oyster water use as described in paragraph (3)(B) of this subsection. Fecal coliform can also continue to be used as a surrogate indicator in effluent limits for wastewater discharges. Fecal coliform criteria are the same for both freshwater and saltwater, as follows.*

*(i) Contact recreation. The geometric mean of fecal coliform should not exceed 200 per 100 mL. In addition, single samples of fecal coliform should not exceed 400 per 100 mL.*

*(ii) Noncontact recreation. Fecal coliform shall not exceed 2,000 per 100 mL as a geometric mean. In addition, single samples of fecal coliform should not exceed 4,000 per 100 mL.*

*(D) Swimming advisory programs. For areas where local jurisdictions or private property owners voluntarily provide public notice or closure based on water quality, the use of any single sample or short-term indicators of recreational suitability are selected at the discretion of the local managers of aquatic recreation. Guidance for single-sample bacterial indicators is available in the EPA document entitled Ambient Water Quality Criteria for Bacteria - 1986. Other short-term indicators to assess water quality suitability for recreation -- such as measures of streamflow, turbidity, or rainfall -- may also be appropriate.*

***§307.10. Appendices A - E.***

*The indicator bacteria for recreation for freshwater is E. coli and for saltwater is Enterococci. Fecal coliform can still be used as an alternative indicator during the transition to the new indicator bacteria, as specified in §307.7 (b). The appropriate bacterial criteria and fecal coliform alternative are listed in the appendix under the Indicator Bacteria column. E. coli criteria of 126 colonies per 100 mL of water are applied as specified in §307.7(b)(1)(A)(i) and (ii) for contact recreation (relating to Site-specific Uses and Criteria). The criteria of 605 colonies per 100 mL of water are applied as specified in §307.7(b)(1)(A)(iii) for noncontact recreation. Enterococci criteria of 35 colonies per 100 mL are applied as specified in §307.7(b)(1)(B)(i) and (ii) for contact recreation, and 168 colonies per 100 mL for noncontact recreation. The indicator bacteria for suitability for oyster waters is fecal coliform. The fecal coliform criteria for oyster waters is 14 colonies per 100 mL as specified in §307.7(b)(3)(B).*

*As an alternative, fecal coliform criteria of 200 per 100 mL are applied as specified in §307.7(b)(1)(C)(i) and (ii). Fecal coliform criteria of 2,000 per 100 mL are applied as specified in §307.7(b)(1)(C)(iii).*

As stipulated in Draft 2006 *Guidance for Assessing and Reporting Surface Water Quality in Texas* (TCEQ 2007), utilization of the geometric mean to determine compliance for any of the bacterial indicators depends on the collection of at least 10 samples over the most recent 10-year period.

Draft 2006 Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ 2007):

- *Ten samples will also be required for listing and delisting water bodies for which the assessment method is based on an average. Larger sample sizes increase the state's confidence that impairments are not missed. Although we will use more than 10 samples, if available, it is not reasonable at this time to require more than 10 samples for a minimum data set, given the monitoring resources and currently available data.*
- *The 2006 assessment period of record for the last five years is December 1, 1999 through November 30, 2004. Samples from these five years are evaluated when available, if necessary, the most recent samples collected in the preceding five years (December 1, 1994 through November 30, 1999) can also be included to meet the requirements for minimum sample number.*

## 2.3 Problem Identification

Pursuant to §303(d) of the federal Clean Water Act, states must establish TMDLs for pollutants contributing to violations of WQSs. Table 2-2 identifies the waterbodies requiring TMDLs identified in Category 5 of the 2008 Texas Water Quality Inventory and §303(d) List (TCEQ 2008). Between 1996 and 2008 the TCEQ WQSs and water quality assessment method were modified and additional water quality data were collected throughout the Eastern Houston Watershed area of impairment were added to the §303(d) list. All the waterbodies listed in Table 2-2 are recognized as Category 5a and, as such, are considered high priority for TMDL development. Table 2-2 lists the TCEQ WQM stations from which ambient water quality data were summarized to support the decision to place these waterbodies on the TCEQ 303(d) list. The locations of these WQM stations are displayed in the map included as Figure 1-5. The waterbodies requiring the TMDLs were first listed in 2002.

**Table 2-2 Water Quality Monitoring Stations Used for 303(d) Listing Decision**

| Assessment Unit | Water Body | Description of Assessment Unit Not Supporting Contact Recreation Use | Monitoring Station IDs | Assessment Year |
|---|---|---|---|---|
| 1006F_01 | Big Gulch above Tidal | Entire Segment | 16662 | 2002 |
| 1006H_01 | Spring Gully above Tidal | Entire Segment | 16663 | 2002 |
| 1007F_01 | Berry Bayou above Tidal | 1.5 miles Upstream from Confluence with Sims Bayou to SH 3 | 16661 | 2002 |
| 1007G_01 | Kuhlman Gully above Tidal | Entire Segment | 16653 | 2002 |
| 1007H_01 | Pine Gully above Tidal | Entire Segment | 16659 | 2002 |
| 1007I_01 | Plum Creek above Tidal | Entire Segment | 16658 | 2002 |
| 1007K_01 | Country Club Bayou above Tidal | Entire Segment | 16650, 16651 | 2004 |
| 1007M_01 | Unnamed Non-Tidal Tributary of Hunting Bayou | Entire Segment | 16657 | 2002 |
| 1007 O_01 | Unnamed Non-Tidal Tributary of Buffalo Bayou | Entire Segment | 16649 | 2002 |
| 1007R_01 | Hunting Bayou above Tidal | From Bain Street to Sayers Street (South Fork) | 15869 | 2002 |
| 1007R_02 | | From just east of Elysian Street to Falls Street (north Fork) | 11131, 15867,15868 | 2002 |
| 1007R_03 | | From Falls Street to Loop 610 (South of US 90A) | 11129, 15873 | 2002 |
| 1007R_04 | | From Loop 610 to IH 10 | 11128 | 2002 |

A number of changes have occurred in the past 10 years that warrant refinements in how indicator bacteria data are used to support water quality assessments and TMDL development in Texas. Some key factors that influence which indicator bacteria to use for water quality assessment and TMDL development and the period of record to use include:

- changes in land use and locations of Texas Pollution Discharge Elimination System (TPDES)-permitted facilities;
- changing the indicator bacteria in the 2000 TCEQ surface water quality standards (SWQS) from fecal coliform to *E. coli* for fresh water;
- TCEQ policy and procedures from other TCEQ/EPA approved bacteria TMDLs in Texas;
- refinements in the TCEQ surface water quality monitoring procedures; and

- changes in the TCEQ guidance, *Assessing and Reporting Surface Water Quality in Texas.*

As a result of these evolving factors in the water quality management arena associated with the protection and maintenance of contact recreation use, only a portion of the historical data set was used to support the TMDLs in this report.

Table 2-3 summarizes the portion of the historical ambient water quality data set from the TCEQ WQM stations in each impaired assessment unit. Only indicator bacteria data from 1996 to September 2006 were used in Table 2-3 for the TMDL development to adhere to TCEQ assessment guidelines and to correspond to the available period of record used to estimate stream flows and existing wastewater treatment plant flows. From data results in Table 2-3, key inferences can be made regarding the temporal and spatial extent of the contact recreation use impairment.

Big Gulch above Tidal (Assessment Unit 1006F_01): At the only WQM station 16662, more than 25 percent of the samples exceed the *E. coli* and fecal coliform criteria established for this waterbody, and the geometric mean criteria were also exceeded. Given the small size of this subwatershed, it is presumed this station adequately represents water quality conditions throughout the segment and the available data demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Spring Gully above Tidal (Assessment Unit 1006H_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at 16663, the only WQM station. Given the small size of this subwatershed, it is presumed this station adequately represents water quality conditions throughout the segment and the available data demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Berry Bayou above Tidal (Assessment Unit 1007F_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the existing WQM station (16661). Available data, thus, demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Kuhlman Gully above Tidal (Assessment Unit 1007G_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the only WQM station. Available data, thus, demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Pine Gully above Tidal (Assessment Unit 1007H_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at 16659, the only WQM station. Therefore, the available data demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Plum Creek above Tidal (Assessment Unit 1007I_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the existing WQM station, demonstrating persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

**Table 2-3 Water Quality Data for TCEQ WQM Stations from 1996 to September 2006**

| Assessment Unit | Station ID | Indicator Bacteria | Geometric Mean Criteria (counts/dL) | Geometric Mean Concentration (counts/dL) | Single Sample Criteria (counts/dL) | Number of Samples | Number of Samples Exceeding Single Sample Criteria | % of Samples Exceeding |
|---|---|---|---|---|---|---|---|---|
| 1006F_01 | 16662 | EC | 126 | 1,002 | 394 | 78 | 52 | 67% |
| | | FC | 200 | 2,299 | 400 | 67 | 49 | 73% |
| 1006H_01 | 16663 | EC | 126 | 456 | 394 | 75 | 40 | 53% |
| | | FC | 200 | 1,378 | 400 | 66 | 48 | 73% |
| 1007F_01 | 16661 | EC | 126 | 2,192 | 394 | 56 | 54 | 96% |
| | | FC | 200 | 1,360 | 400 | 66 | 48 | 73% |
| 1007G_01 | 16653 | EC | 126 | 1,631 | 394 | 77 | 48 | 62% |
| | | FC | 200 | 1,874 | 400 | 69 | 45 | 65% |
| 1007H_01 | 16659 | EC | 126 | 2,878 | 394 | 74 | 65 | 88% |
| | | FC | 200 | 4,308 | 400 | 67 | 59 | 88% |
| 1007I_01 | 16658 | EC | 126 | 8,252 | 394 | 75 | 70 | 93% |
| | | FC | 200 | 7,829 | 400 | 67 | 64 | 96% |
| 1007K_01 | 16650 | EC | 126 | 7,357 | 394 | 75 | 72 | 96% |
| | | FC | 200 | 10,854 | 400 | 70 | 62 | 89% |
| | 16651 | EC | 126 | 2,639 | 394 | 56 | 43 | 77% |
| | | FC | 200 | 18,786 | 400 | 67 | 60 | 90% |
| 1007M_01 | 16657 | EC | 126 | 602 | 394 | 72 | 43 | 60% |
| | | FC | 200 | 1,727 | 400 | 70 | 52 | 74% |
| 1007O_01 | 16649 | EC | 126 | 2,760 | 394 | 74 | 61 | 82% |
| | | FC | 200 | 5,465 | 400 | 68 | 57 | 84% |
| 1007R_01 | 15869 | EC | 126 | 16,068 | 394 | 56 | 52 | 93% |
| | | FC | 200 | 16,009 | 400 | 73 | 70 | 96% |
| 1007R_02 | 15867 | EC | 126 | 484 | 394 | 56 | 36 | 64% |
| | | FC | 200 | 407 | 400 | 36 | 20 | 56% |
| | 15868 | FC | 200 | 2,469 | 400 | 44 | 37 | 84% |
| | 11131 | FC | 200 | 3,367 | 400 | 44 | 40 | 91% |
| 1007R_03 | 15870 | FC | 200 | 5,861 | 400 | 5 | 5 | 100% |
| | 11130 | FC | 200 | 3,373 | 400 | 5 | 5 | 100% |
| | 15871 | FC | 200 | 3,137 | 400 | 5 | 5 | 100% |
| | 15872 | FC | 200 | 1,842 | 400 | 6 | 5 | 83% |
| | 15873 | EC | 126 | 706 | 394 | 56 | 33 | 59% |
| | | FC | 200 | 840 | 400 | 30 | 22 | 73% |
| | 18689 | EC | 126 | 784 | 394 | 13 | 11 | 85% |
| | 15874 | FC | 200 | 1,732 | 400 | 5 | 5 | 100% |
| | 15832 | FC | 200 | 3,052 | 400 | 4 | 4 | 100% |
| | 11129 | EC | 126 | 222 | 394 | 56 | 18 | 32% |
| | | FC | 200 | 748 | 400 | 77 | 43 | 56% |
| 1007R_04 | 11128 | EC | 126 | 424 | 394 | 72 | 44 | 61% |
| | | FC | 200 | 1,812 | 400 | 36 | 29 | 81% |

*EC: E. coli in MPN/100mL, FC: Fecal Coliform in cfu/100mL*
*Highlight indicates downstream WQM station selected for TMDL development and indicator bacteria selected as water quality target.*

Country Club Bayou above Tidal (Assessment Unit 1007K_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the two WQM stations. Available data, thus, demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Unnamed Non-Tidal Tributary of Hunting Bayou (Assessment Unit 1007M_01): Bacteria samples collected at station 16657 exceeded both the single sample and geometric mean criteria for *E. coli* and fecal coliform. Thus, available data demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Unnamed Non-Tidal Tributary of Buffalo Bayou (Assessment Unit 1007O_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the existing WQM station, demonstrating persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Hunting Bayou above Tidal (Assessment Units 1007R_01, 1007R_02, 1007R_03, and 1007R_04): At all the WQM stations with fecal indicator data (12 total), more than 25 percent of the samples exceeded the single sample criteria for *E. coli* and fecal coliform, and the geometric mean criteria were also exceeded. This indicates conditions of widespread and persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

## 2.4 Water Quality Targets for Contact Recreation

The Code of Federal Regulations (40 CFR §130.7(c)(1)) states that, "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards." The Texas SWQSs (TCEQ 2000) provide numeric and narrative criteria to evaluate attainment of designated uses. The basis for water quality targets for all TMDLs developed in this report will be the numeric criteria for bacterial indicators from the 2000 Texas SWQSs as described in Subsection 2.2 above. *E. coli* is the preferred indicator bacteria for assessing contact recreation use in freshwater but fecal coliform bacteria may also be used since it was the preferred indicator in the past.

Several studies performed by the USEPA show a stronger link between the concentrations of *E. coli* and the concentrations of fecal pathogens than the previous standard, fecal coliform. The USEPA studies found that in freshwater streams, *E. coli* concentrations were the strongest predictor of illness following contact recreation. The TCEQ adopted the limit of 394 MPN/100mL for single samples of *E. coli* and a geometric mean limit of 126 MPN/100mL for waterbodies designated for contact recreation use. During the process of switching to the new standards, the USEPA recommended that fecal coliform concentrations (400 cfu/100mL in any single sample and 200 MPN/100mL for the geomean of all samples) be used until at least 10 data points have been collected for *E. coli* for each segment.

The water quality target for the TMDLs for freshwater segments is to maintain concentrations below the geometric mean criterion of 126 MPN/100mL for *E. coli* or if necessary, 200 cfu/100mL for fecal coliform. Maintaining the geometric mean criterion for each indicator bacteria is expected to be protective of the single sample criterion also, and therefore, will ultimately result in attainment of the contact recreation use. TMDLs will be based on a percent reduction goal required to meet the geometric mean criterion.

The stations highlighted in Table 2-3 correspond to the specific WQM stations where TMDLs will be set for the Eastern Houston Watersheds. The TMDL locations are shown in Figure 2-1. For all the segments in the Study Area, *E. coli* is the selected indicator bacteria.

The water quality target for each waterbody will incorporate an explicit 5 percent margin of safety (MOS). For example, if fecal coliform is utilized to establish the TMDL, then the water quality target would be 380 cfu/100mL, 5 percent lower than the single sample water quality criteria (400 cfu/100mL) and the geometric mean water quality target would be 190 cfu/100mL, 5 percent lower than the criterion value (200 MPN/100mL). For *E. coli*, the single sample water quality target would be 374 MPN/100mL, 5 percent lower than the criterion value (394 MPN/100mL) and the geometric mean water quality target would be 120 MPN, 5 percent lower that the criterion value (126 MPN/100mL).

TMDLs must take into account that no more than 25 percent of the samples may exceed the single sample numeric criterion. However, TMDLs will be based on a percent reduction goal required to meet the geometric mean criteria.

Each water quality target will be used to determine the allowable bacteria load derived by using the actual or estimated flow record multiplied by the instream criteria minus a 5 percent MOS. The line drawn through the allowable load data points is the water quality target that represents the maximum load for any given flow and still satisfies the WQS.

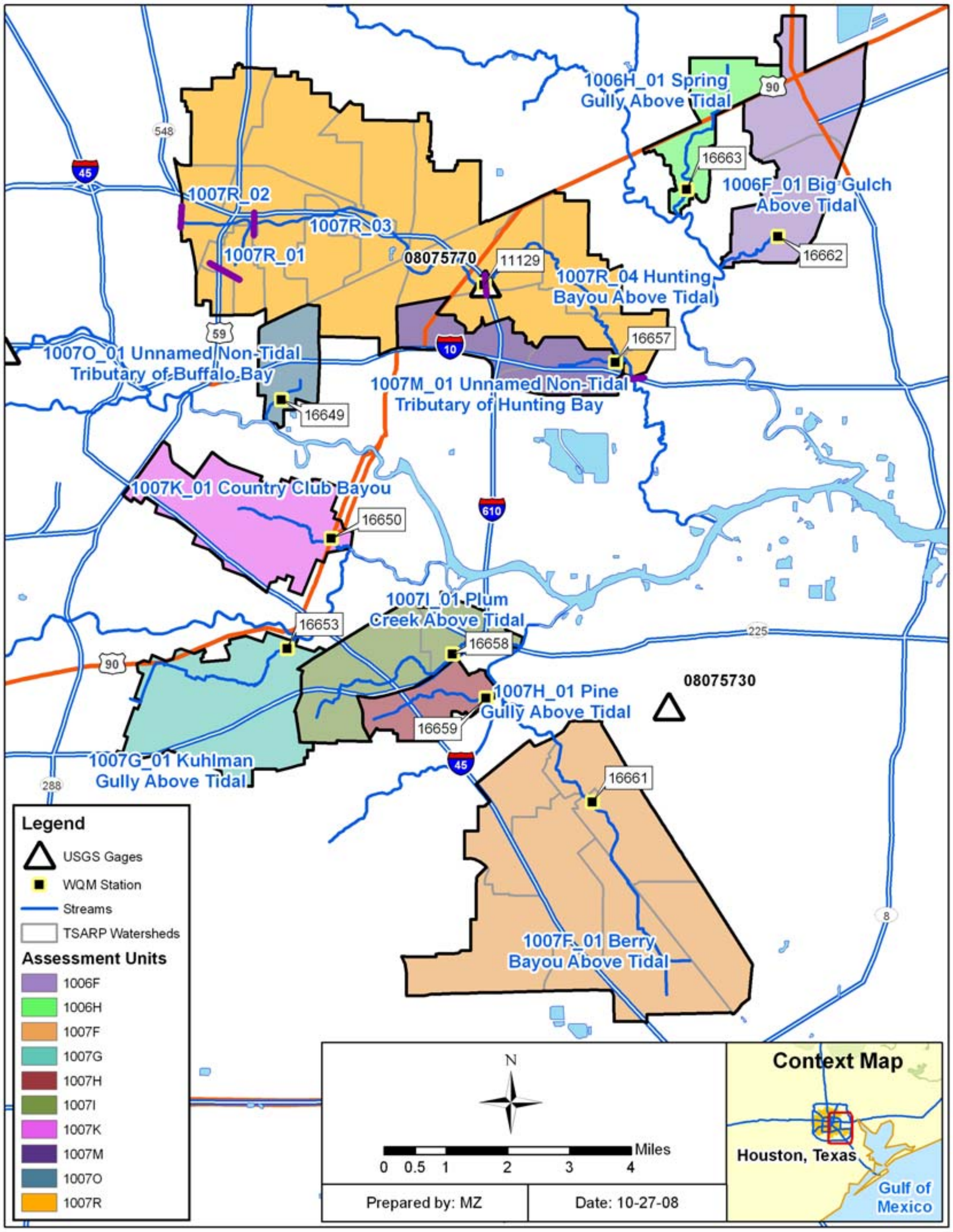


**Figure 2-1 Eastern Bayous TMDL WQM Locations**

# SECTION 3
# POLLUTANT SOURCE ASSESSMENT

To support TMDL development, a pollutant source assessment attempts to characterize known and suspected sources of pollutant loading to impaired waterbodies. Pollutant sources within a watershed are categorized and quantified to the extent that information is available. Fecal bacteria such as *E. coli* originate in the intestines of warm-blooded species (human and animal), and sources of bacteria may be point (permitted) or nonpoint (non-permitted) in nature.

Point sources are permitted through the National Pollution Discharge Elimination System (NPDES) program. Some storm water runoff may be permitted through NPDES as municipal separate storm sewer systems (MS4). Other non-permitted sources of storm water runoff that typically cannot be identified as entering a waterbody through a discrete conveyance at a single location are often referred to as nonpoint sources. For example, non-permitted sources include land activities that contribute bacteria to surface water as a result of rainfall runoff or on-site sewage system facilities. For the TMDLs in this report, all sources of pollutant loading not regulated by a NPDES-permit are considered nonpoint sources. The following discussion describes what is known regarding permitted and non-permitted sources of bacteria in the impaired watersheds.

## 3.1 Point Sources: NPDES/TPDES-Permitted Sources

Under 40 CFR, §122.2, a point source is described as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Under the Texas Water Code, TCEQ has adopted rules and procedures to issue permits to control the quantity and quality of discharges into or adjacent to waters of the state through the TPDES program. NPDES/TPDES-permitted facilities classified as point sources that may contribute bacteria loading to surface waters include:

- TPDES municipal wastewater treatment facilities (WWTF);
- TPDES industrial WWTF;
- TPDES municipal no-discharge WWTF;
- TPDES regulated storm water (construction, industrial and municipal storm sewer systems); and
- TPDES Concentrated Animal Feeding Operation (CAFO).

Continuous point source discharges such as WWTFs, could result in discharge of elevated concentrations of fecal bacteria if the disinfection unit is not properly maintained, is of poor design, or if flow rates exceed the disinfection capacity. Some industrial WWTF may contain fecal bacteria in their effluent. While no-discharge facilities do not discharge wastewater directly to a waterbody, it is possible that collection systems associated with these types of facilities may be a source of bacteria loading to surface waters. Permitted storm water runoff from TPDES regulated discharge areas called municipal separate storm sewer systems can also contain high fecal bacteria concentrations. CAFOs are recognized by USEPA as significant sources of pollution, and may have the potential to cause serious impacts to water quality if not properly managed.

Watersheds in the Study Area, including Big Gulch Above Tidal (1006F_01), Spring Gully Above Tidal (1006H_01), Berry Bayou Above Tidal (1007F_01), and Hunting Bayou Above Tidal (1007R_03 and 1007R_04) have NPDES/TPDES-permitted sources. However, there are no NPDES/TPDES-permitted sources located within Kuhlman Gully Above Tidal (1007G_01), Pine Gully Above Tidal (1007H_01), Plum Creek Above Tidal (1007I_01), Country Club Bayou (1007K_01), Unnamed Non-Tidal Tributary of Hunting Bayou (1007M_01), Unnamed Non-Tidal Tributary of Buffalo Bay (1007O_01), and Hunting Bayou Above Tidal (1007R_01 and 1007R_02). Virtually the entire Study Area (approximately 92%) is regulated under the TPDES storm water discharge permit jointly held by Harris County, HCFCD, City of Houston, and Texas Department of Transportation. There are no NPDES-permitted CAFOs within the Study Area.

### 3.1.1 Permitted Sources: Continuous Point Source Discharges

There are 9 permitted outfalls for WWTFs in the Study Area. 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 3-1. Facility locations are displayed in Figure 3-1. A complete dataset of self-reported flows is included in Appendix C.

Not all TPDES-permitted facilities that discharge treated wastewater are required to monitor for fecal bacteria. In addition, while current instream water quality criteria 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 one of the TPDES permitted dischargers in the Study Area. Table 3-2 summarizes data from Discharge Monitoring Reports (DMR) available for three TPDES WWTFs that monitor their discharge for fecal coliform. The 90$^{th}$ percentile of the monthly average load and the maximum monthly average loads are provided to estimate fecal coliform loads from the TPDES WWTF. The data used to generate Table 3-2 are provided in Appendix D. Table 3-2 also lists the number of reported monthly exceedances of the geometric mean concentration of 200 ccfu/100mL, and the number of reported daily exceedances of the single sample standard of 400 cfu/100mL. As shown in Table 3-2, none of the permitted facilities exceeded fecal coliform permit limits during the monitoring time frame.

**Table 3-1 TPDES-Permitted Facilities in the Study Area**

| Segment | Stream Name | Assessment Unit | TPDES Number | Outfall | NPDES NUMBER | Permitee Name | Facility Name | Facility Type | DTYPE | County | TCEQ Permitted Flow (MGD) | Average Monthly Flow (MGD) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1006F | Big Gulch Above Tidal | 1006F_01 | 10608-002 | 001 | TX0062952 | Royalwood MUD | Royalwood MUD WWTP | Sewerage Systems | D | Harris | 0.26 | 0.12 |
| | | | 14690-001 | 001 | TX0128601 | Normandy Utility Co LP | Normandy Utility Co LP | *NA* | D | Harris | 0.09 | *NA* |
| 1006H | Spring Gully Above Tidal | 1006H_01 | 11923-001 | 001 | TX0075078 | Garlock Sealing Technologies | 1977 Kindred II LP | Sewerage Systems | D | Harris | 0.005 | 0.002 |
| | | | 13503-001 | 001 | TX0105406 | Maxey Road WSC | Maxey Road WWTP | Sewerage Systems | D | Harris | 0.015 | 0.004 |
| 1007F | Berry Bayou Above Tidal | 1007F_01 | 10495-065 | 001 | TX0034886 | City of Houston | Easthaven WWTP | Sewerage Systems | W | Harris | 3 | 1.3 |
| | | | 10287-001 | 001 | TX0057304 | City of South Houston | City of South Houston WWTP | Sewerage Systems | W | Harris | 4 | 2.5 |
| | | | 10495-050 | 001 | TX0063045 | City of Houston | WCID 47 WWTP | Sewerage Systems | W | Harris | 5.76 | 2.9 |
| 1007R | Hunting Bayou Above Tidal | 1007R_03 | 10495-023 | 001 | TX0063029 | City of Houston | Homestead WWTP | Sewerage Systems | W | Harris | 4 | 1.8 |
| | | 1007R_04 | 03987-000 | 001 | TX0119075 | Cooper, Jerry Lynn | Texas Remediation Systems WWTP | Refuse Systems | W | Harris | 0.2 | 0.001 |

*Source: TCE Water Quality Assessment Team. Personal Communication from Charles Marshall to Randy Palachek, May 28, 2008 (TCEQ 2008).*
*MGD = millions of gallons per day*
*NA = data not available*
** flow from both outfalls for 10495-016 cannot exceed 7 MGD*
*Type:*
*C = cooling water*
*D = domestic <1 MGD*
*S = storm water*
*W = domestic >= 1 MGD or industrial process water, including water treatment plant discharge*

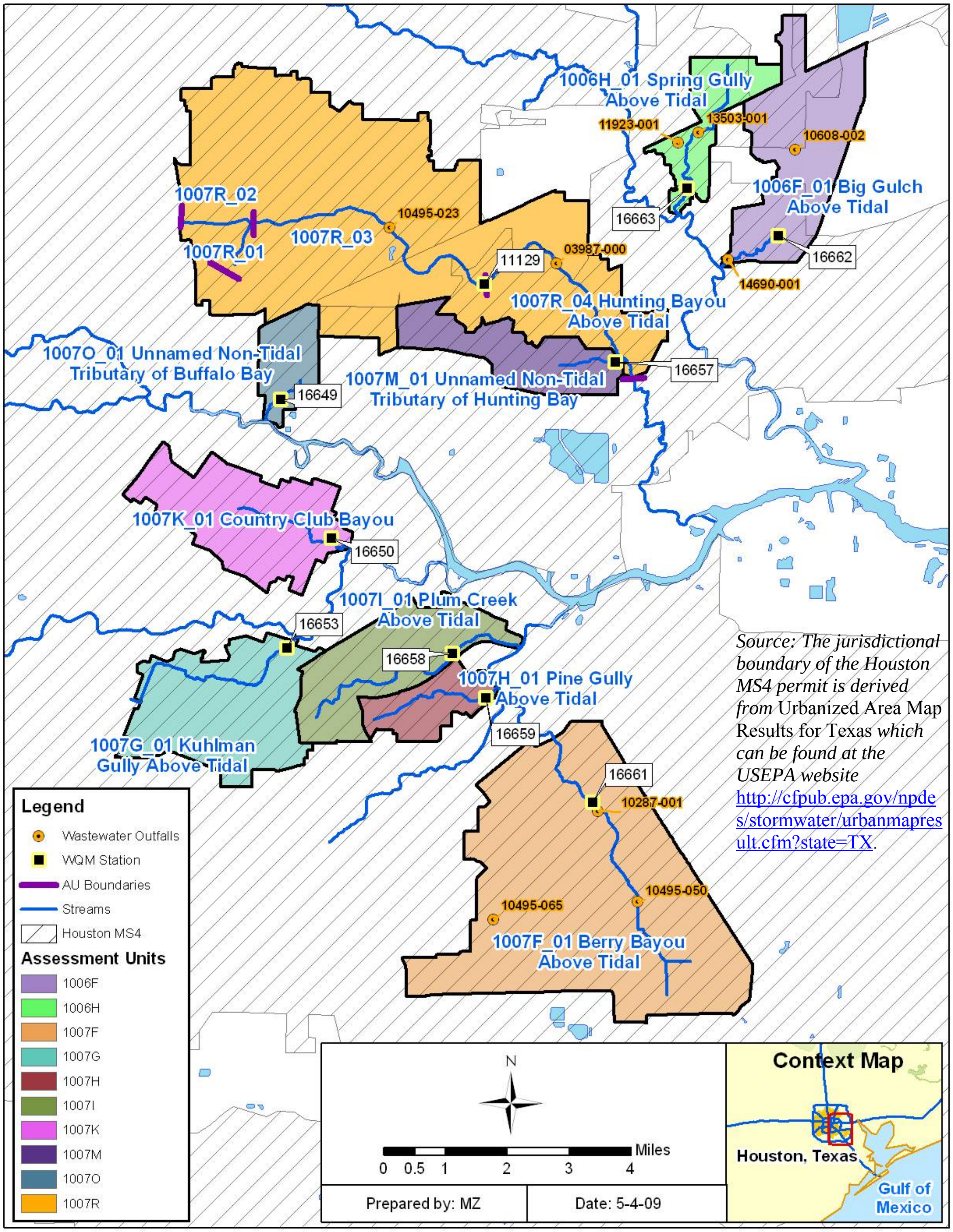


**Figure 3-1 TPDES-Permitted Facilities in the Eastern Houston Watersheds**

**Table 3-2 DMR Data for Permitted Wastewater Discharges (September 1998-June 2006)**

| NPDES Number | TPDES Number | Facility Name | Assessment Unit | Dates Monitored | | # of Records | Number of MCMX Exceedances | Number of MCAV Exceedances | FC Daily Load (cfu) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Start | End | | | | 90 percentile Monthly Average | Maximum Monthly Average |
| TX0075078 | 11923-001 | G & C Investment Co LLP & Garlock Sealing | 1006H_01 | 9/30/1998 | 6/30/2000 | 8 | 0 | 0 | 3.85E+05 | 5.75E+05 |

*Source: TCEQ, 2007*
*Notes: FC = fecal coliform, cfu = colony forming unit, MCMX = measurement: concentration maximum MCAV = measurement: concentration average*

### 3.1.2 Permitted Sources: NPDES No-Discharge Facilities and Sanitary Sewer Overflows

There are no No-Discharge Facilities nor land application sites located within the Study Area.

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 or exceedance of capacity in the sanitary sewer conveyance system. The TCEQ maintains a database of SSO data collected from wastewater operators in the Study Area. In 2007, the City of Houston provided the project team a database summarizing SSO reported. These data are included in Appendix E and summarized in Table 3-3. Analysis of the most current available data, as can be seen from Table 3-3, indicates there were 383 sanitary sewer overflows reported in the Eastern Houston Watersheds between February 2001 and December 2003. The reported SSOs averaged 2,175 gallons per event. The locations and magnitudes of all reported SSOs are displayed in Figure 3-2. The WWTF service area boundaries are also shown in Figure 3-2.

**Table 3-3 Sanitary Sewer Overflow Summary**

| Facility Name | Receiving Water | Facility ID | Number of Occurrences | Date Range | | Amount (Gallons) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | From | To | Min | Max | Total Volume |
| Houston-Sims Bayou [a] | 1007F_01 | 10495-002 | 23 | 01-Mar-01 | 17-Jul-03 | 50 | 59,350 | 106,590 |
| Houston-Sims Bayou [a] | 1007G_01 | 10495-002 | 30 | 04-Mar-01 | 04-Dec-03 | 15 | 7,344 | 32,774 |
| Houston-Sims Bayou [a] | 1007H_01 | 10495-002 | 11 | 27-Feb-01 | 19-Dec-02 | 80 | 8,118 | 35,209 |
| Houston-Sims Bayou [a] | 1007I_01 | 10495-002 | 31 | 07-Mar-01 | 28-Sep-03 | 0 | 9,000 | 62,985 |
| Houston-Sims Bayou [a] | 1007K_01 | 10495-002 | 57 | 23-Feb-01 | 29-Nov-03 | 30 | 26,432 | 158,286 |
| Houston-Homestead | 1007R_03 | 10495-023 | 13 | 19-Feb-01 | 22-Nov-03 | 24 | 13,320 | 15,597 |
| Houston-WCID 047 | 1007F_01 | 10495-050 | 20 | 23-Feb-01 | 11-Nov-03 | 44 | 10,700 | 50,367 |
| Houston-Easthaven | 1007F_01 | 10495-065 | 11 | 09-Apr-01 | 22-Sep-03 | 40 | 9,657 | 29,939 |
| Houston-Northeast [b] | 1007M_01 | 10495-077 | 10 | 23-Feb-01 | 04-Jan-03 | 46 | 4,690 | 17,823 |
| Houston-Northeast [b] | 1007R_04 | 10495-077 | 20 | 25-Mar-01 | 21-Sep-03 | 50 | 13,080 | 51,987 |
| Houston-Southeast | 1007F_01 | 10495-079 | 2 | 02-Feb-02 | 27-Sep-02 | 4,320 | 8,445 | 12,765 |
| Houston-69th Street [c] | 1007K_01 | 10495-090 | 30 | 27-Feb-01 | 25-Nov-03 | 20 | 17,148 | 56,802 |
| Houston-69th Street [c] | 1007M_01 | 10495-090 | 3 | 29-Jul-01 | 06-Jan-03 | 1,000 | 6,000 | 8,316 |
| Houston-69th Street [c] | 1007O_01 | 10495-090 | 11 | 22-Mar-01 | 28-Aug-03 | 40 | 2,931 | 12,198 |
| Houston-69th Street [c] | 1007R_03 | 10495-090 | 111 | 13-Feb-01 | 20-Nov-03 | 15 | 43,605 | 181,423 |

[a] *The service area for Houston-Sims Bayou (10495-002) covers part of 1007F_01, 1007G_01, 1007H_01, 1007I_01, and 1007K_01*
[b] *The service area for Houston-Northeast (10495-077) covers part of 1007M_01, 1007R_04*
[c] *The service area for Houston-69th Street (10495-090) covers part of 1007K_01, 1007M_01, 1007O_01, 1007R_03*

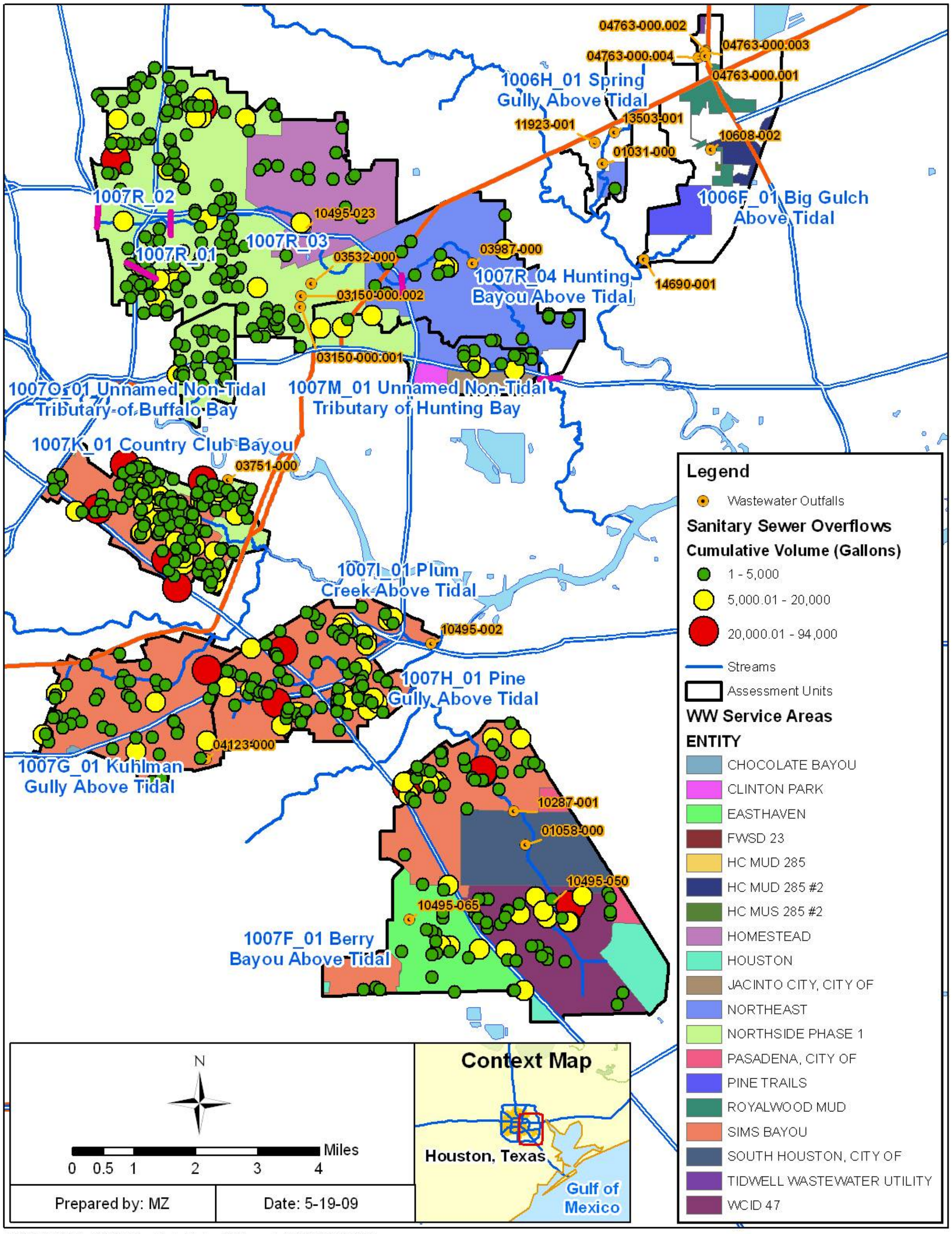


**Figure 3-2 Sanitary Sewer Overflow Locations**

### 3.1.3 Permitted Sources: TPDES Regulated Storm Water

In 1990, the USEPA developed rules establishing Phase I of the NPDES Storm Water Program, designed to prevent harmful nonpoint sources of pollutants from being washed by storm water runoff into municipal separate storm sewer systems and then discharged into local waterbodies (USEPA 2005). Phase I of the program required medium and large permitted dischargers (those generally serving populations of 100,000 or greater) to implement a storm water management program as a means to control polluted discharges. Approved storm water management programs for medium and large permitted discharges are required to address a variety of water quality-related issues, including roadway runoff management, municipal-owned operations, and hazardous waste treatment.

Phase II of the rule extends coverage of the NPDES Storm Water program to certain small MS4s. Small MS4s are defined as any MS4 that is not a medium or large MS4 covered by Phase I of the NPDES Storm Water Program. Phase II requires operators of regulated small MS4s to obtain NPDES permits and develop a storm water management program. Programs are designed to reduce discharges of pollutants to the "maximum extent practicable," protect water quality, and satisfy appropriate water quality requirements of the Clean Water Act. Small MS4 storm water programs must address the following minimum control measures:

- Public Education and Outreach;
- Public Participation/Involvement;
- Illicit Discharge Detection and Elimination;
- Construction Site Runoff Control;
- Post- Construction Runoff Control; and
- Pollution Prevention/Good Housekeeping.

When evaluating pollutant loads originating from storm water runoff, a critical distinction must be made between storm water originating from an area under an NPDES/TPDES regulated discharge permit and storm water originating from areas not under an NPDES/TPDES regulated discharge permit. To characterize pollutant loads from storm water runoff, it is necessary to segregate storm water into two categories: 1) permitted storm water, which is storm water originating from an NPDES/TPDES-permitted Phase 1 or Phase 2 urbanized area; and 2) non-permitted storm water, which is storm water originating from any area outside an NPDES/TPDES-permitted Phase 1 or Phase 2 urbanized area. Considerable portions of each watershed in the Study Area are covered under the City of Houston/Harris County MS4 permit (TPDES Permit No. WQ0004685000). The jurisdictional boundary of the Houston 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 USEPA website http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX. Figure 3-1 displays the portion of the watershed that contributes bacteria loads to the receiving waters from areas of permitted and non-permitted storm water.

Under the City of Houston/Harris County permitted discharge permit, Harris County, HCFCD, City of Houston, and Texas Department of Transportation are designated as co-permittees. Table 3-4 lists the percentage of area within each watershed covered under the Houston MS4 permit.

**Table 3-4 Percentage of Permitted Storm Water in Each Watershed**

| Assessment Unit | Stream Name | TPDES Number | Total Area (acres) | Area under MS4 Permit (Acres) | Percent of Assessment Unit under MS4 Jurisdiction |
|---|---|---|---|---|---|
| 1006F_01 | Big Gulch above Tidal | WQ0004685000 | 3,167 | 1,827 | 58% |
| 1006H_01 | Spring Gully above Tidal | WQ0004685000 | 1,265 | 1,123 | 89% |
| 1007F_01 | Berry Bayou above Tidal | WQ0004685000 | 9,916 | 9,916 | 100% |
| 1007G_01 | Kuhlman Gully above Tidal | WQ0004685000 | 3,356 | 3,356 | 100% |
| 1007H_01 | Pine Gully above Tidal | WQ0004685000 | 1,026 | 1,026 | 100% |
| 1007I_01 | Plum Creek above Tidal | WQ0004685000 | 2,548 | 2,548 | 100% |
| 1007K_01 | Country Club Bayou | WQ0004685000 | 2,894 | 2,894 | 100% |
| 1007M_01 | Unnamed Non-Tidal Tributary of Hunting Bay | WQ0004685000 | 1,771 | 1,771 | 100% |
| 1007O_01 | Unnamed Non-Tidal Tributary of Buffalo Bay | WQ0004685000 | 970 | 970 | 100% |
| 1007R_01 | Hunting Bayou above Tidal | WQ0004685000 | 788 | 788 | 100% |
| 1007R_02 | | WQ0004685000 | 717 | 717 | 100% |
| 1007R_03 | | WQ0004685000 | 9,111 | 7,939 | 87% |
| 1007R_04 | | WQ0004685000 | 3,121 | 2,428 | 78% |
| 1007R (total) | | WQ0004685000 | 13,737 | 11,872 | 86% |

### 3.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. Dry-weather and illicit discharges are regulated under WWTF permits, and where applicable, under the provisions of an MS4. 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).

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,
- 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 were at times very high (similar to the levels found in raw sewage). An outfall inventory survey has not been completed for Brays 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 Brays Bayou watershed.

### 3.1.5 Concentrated Animal Feeding Operations

There are no CAFOs located within the Study Area.

## 3.2 Non-permitted Sources: Storm Water, On-site Sewage Facilities, and Direct Deposition

Non-permitted sources (nonpoint sources) include those sources that cannot be identified as entering the waterbody at a specific location. Bacteria originate from rural, suburban, and urban areas. The following section describes possible major non-permitted sources contributing indicator bacteria loading within the Study Area.

Nonpoint sources of bacteria can emanate from wildlife, various agricultural activities, and domesticated animals, land application fields, urban runoff, failing on-site sewage facilities (OSSF), and domestic pets. Bacteria associated with urban runoff can emanate from humans, wildlife, livestock, and domestic pets. Based on the ability of warm-blooded animals to harbor and shed human pathogens, the current USEPA policy establishes the position that it is inappropriate to conclude that livestock and wildlife sources present no risk to human health from waterborne pathogens. Consequently, states and authorized tribes should not use broad exemptions from the bacteriological criteria for waters designated for primary contact recreation based on the presumption that high levels of bacteria resulting from non-human fecal contamination present no risk to human health (USEPA 2002). Water quality data collected from streams draining urban communities often show existing concentrations of fecal coliform bacteria at levels greater than a state's instantaneous standards. A study under USEPA's National Urban Runoff Project indicates that the average fecal coliform concentration from 14 watersheds in different areas within the United States was approximately 15,000 /dL in storm water runoff (USEPA 1983). Non-permitted storm water can be a significant source of fecal bacteria.

### 3.2.1 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 the potential for bacteria contributions from wildlife by watershed. 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 waterbody. 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, 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.

### 3.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

There are a number of non-permitted agricultural activities that 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 not found in these watersheds and therefore are not considered as a contributor of bacteria loads.

### 3.2.3 Failing On-site Sewage Facilities

On-site sewage facilities 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 also 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, which is part of Region 4, were chronically malfunctioning. Most studies estimate 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. Table 3-5 lists the OSSF totals based on the 1990 U.S. census and the number of OSSF permits obtained by authorized county or city agents between 1992 -2007. Permits are obtained to install or replace systems. However, some permits are obtained when an older failing system needs repair (Houston-Galveston Area Council [H-GAC] 2005). It is assumed that more OSSFs were installed in Harris County prior to 1992 than listed in Table 3-5.

**Table 3-5 Numbers of OSSF Permits Issued by Authorized County or City Agent**

| Year | Harris |
|---|---|
| **1990 Census Totals** | 44,120 |
| **1992** | 243 |
| **1993** | 651 |
| **1994** | 881 |
| **1995** | 1,035 |
| **1996** | 1,327 |
| **1997** | 1,393 |
| **1998** | 1,301 |
| **1999** | 1,606 |
| **2000** | 1,422 |
| **2001** | 1,388 |
| **2002** | 1,397 |
| **2003** | 1,424 |
| **2004** | 1,174 |
| **2005** | 1,080 |
| **2006** | 1,039 |
| **2007*** | 498 |
| **Total** | **61,979** |

*Note: Data obtained from TCEQ On-Site Activity Reporting System*
** only data up to 8/8/2007 were available*

To estimate the potential magnitude of fecal bacteria loading from OSSFs, the number of OSSFs was estimated for each watershed. The estimate of OSSFs was derived by using data from the 1990 U.S. census (U.S. Census Bureau 2000) and a GIS shapefile obtained from H-GAC showing all areas where wastewater service currently exists. Figure 3-4 displays unsewered areas 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 unsewered area were then totaled by TMDL watershed. This approach gives an estimate of OSSFs in the watershed. Table 3-6 shows the estimated number of OSSFs calculated using this GIS method.

Harris County provided a GIS shapefile showing the locations of potential OSSF violations from 2006-2007. Data are shown for areas not covered by wastewater service in Figure 3-3.

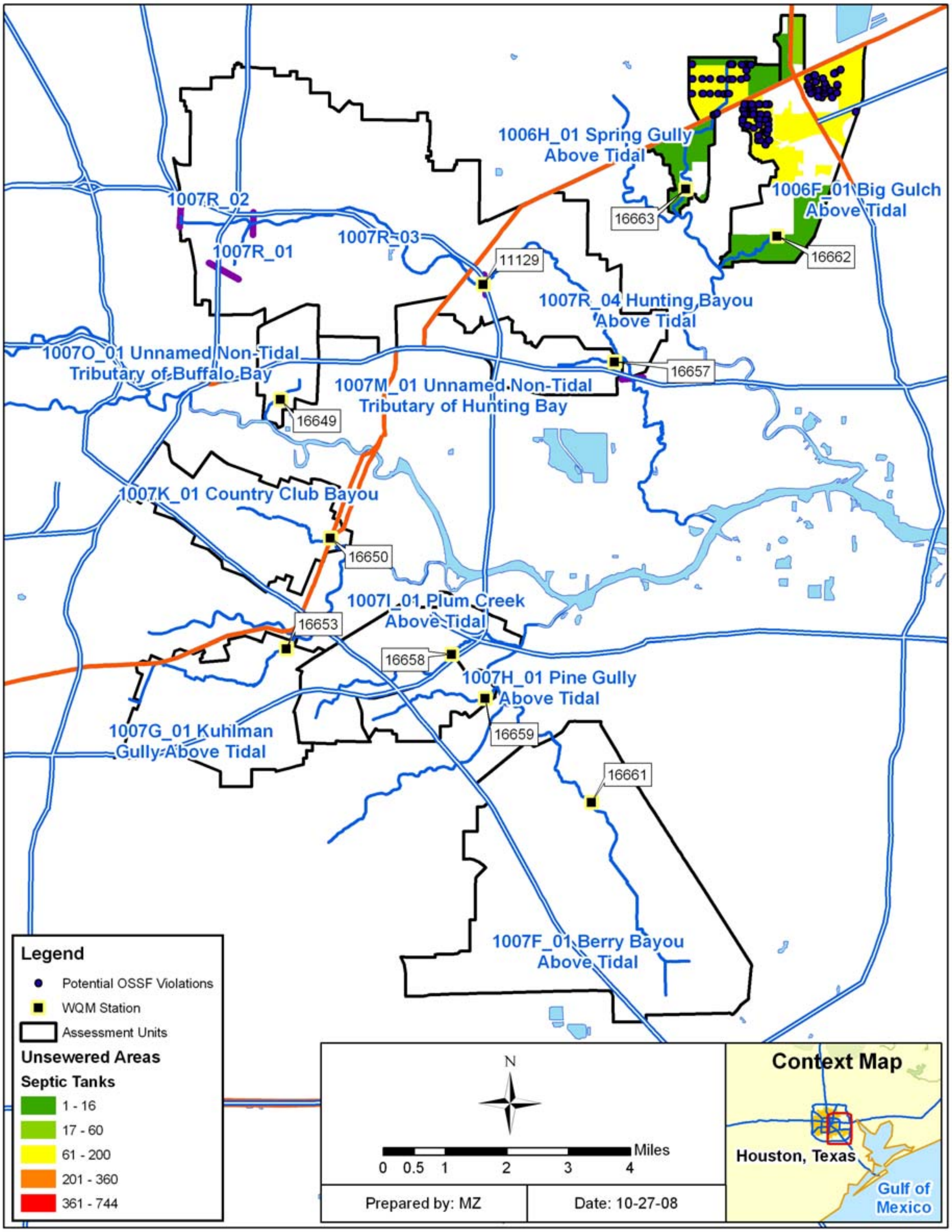


**Figure 3-3 Unsewered Areas and Subdivisions with OSSF**

For the purpose of estimating fecal coliform loading in watersheds, the OSSF failure rate of 12 percent from the Reed, Stowe & Yanke, LLC (2001) report for Texas Region 4 was used. Using this 12 percent failure rate, calculations were made to characterize fecal coliform loads in each watershed. Fecal coliform loads were estimated using the following equation (USEPA 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 of 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 100mL 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 below in Table 3-6. Based on these data, the estimated fecal coliform loading from OSSFs in the Study Area was found to be negligible.

**Table 3-6 Estimated Number of OSSFs per Watershed and Fecal Coliform* Load**

| Segment | Stream Name | OSSF Estimate using 1990 Census method | # of Failing Septic Tanks[a] | Potential Violation Database[b] | Estimated Loads from Septic Tanks (x$10^9$ counts/day)[c] |
|---|---|---|---|---|---|
| 1006F | Big Gulch Above Tidal | 403 | 48 | 102 | 358 |
| 1006H | Spring Gully Above Tidal | 197 | 24 | 34 | 175 |
| 1007F | Berry Bayou Above Tidal | 0 | 0 | 0 | 0 |
| 1007G | Kuhlman Gully Above Tidal | 0 | 0 | 0 | 0 |
| 1007H | Pine Gully Above Tidal | 0 | 0 | 0 | 0 |
| 1007I | Plum Creek Above Tidal | 0 | 0 | 0 | 0 |
| 1007K | Country Club Bayou | 0 | 0 | 0 | 0 |
| 1007M | Unnamed Non-Tidal Tributary of Hunting Bay | 0 | 0 | 0 | 0 |
| 1007O | Unnamed Non-Tidal Tributary of Buffalo Bay | 0 | 0 | 0 | 0 |
| 1007R | Hunting Bayou Above Tidal | 0 | 0 | 0 | 0 |

*[a] A 12% failure rate was multiplied by the number of OSSFs estimated 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.*

### 3.2.4 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 2004). 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 3-7 summarizes the estimated number of dogs and cats for the watersheds of the Study Area.

**Table 3-7 Estimated Numbers of Pets**

| Segment | Stream Name | Dogs | Cats |
|---|---|---|---|
| 1006F | Big Gulch Above Tidal | 2,096 | 2,385 |
| 1006H | Spring Gully Above Tidal | 2,493 | 2,837 |
| 1007F | Berry Bayou Above Tidal | 11,737 | 13,356 |
| 1007G | Kuhlman Gully Above Tidal | 7,300 | 8,307 |
| 1007H | Pine Gully Above Tidal | 4,177 | 4,753 |
| 1007I | Plum Creek Above Tidal | 8,192 | 9,322 |
| 1007K | Country Club Bayou | 8,348 | 9,499 |
| 1007M | Unnamed Non-Tidal Tributary of Hunting Bay | 631 | 718 |
| 1007O | Unnamed Non-Tidal Tributary of Buffalo Bay | 2,663 | 3,031 |
| 1007R | Hunting Bayou Above Tidal | 10,495 | 11,942 |

Table 3-8 provides an estimate of the fecal coliform load from pets. These estimates are based on estimated fecal coliform production rates of $5.4 \times 10^8$ per day for cats and $3.3 \times 10^9$ per day for dogs (Schueler 2000). Only a small portion of these loads is expected to reach waterbodies, through wash-off of land surfaces and conveyance in runoff.

**Table 3-8 Estimated Fecal Coliform Daily Production by Pets (x $10^9$)**

| Segment | Stream Name | Dogs | Cats | Total |
|---|---|---|---|---|
| 1006F | Big Gulch Above Tidal | 6,918 | 1,288 | 8,206 |
| 1006H | Spring Gully Above Tidal | 8,226 | 1,532 | 9,758 |
| 1007F | Berry Bayou Above Tidal | 38,734 | 7,212 | 45,946 |
| 1007G | Kuhlman Gully Above Tidal | 24,090 | 4,486 | 28,575 |
| 1007H | Pine Gully Above Tidal | 13,783 | 2,566 | 16,349 |
| 1007I | Plum Creek Above Tidal | 27,033 | 5,034 | 32,067 |
| 1007K | Country Club Bayou | 27,548 | 5,130 | 32,678 |
| 1007M | Unnamed Non-Tidal Tributary of Hunting Bay | 2,083 | 388 | 2,471 |
| 1007O | Unnamed Non-Tidal Tributary of Buffalo Bay | 8,789 | 1,637 | 10,426 |
| 1007R | Hunting Bayou Above Tidal | 34,633 | 6,449 | 41,082 |

### 3.2.5 Bacteria Re-growth and Die-off

Bacteria are living organisms that grow and die. Certain enteric bacteria can regrow in organic materials if appropriate conditions prevail (*e.g.,* warm temperature). It is shown in the general literature that fecal organisms can regrow from improperly treated effluent during their transport in pipe networks, and they can regrow 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 regrowth is less well understood. Both processes (regrowth and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body.

# SECTION 4
# TECHNICAL APPROACH AND METHODS

The objective of a TMDL is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed so appropriate control measures can be implemented and the standard for contact recreation achieved. A TMDL is expressed as the sum of three elements as described in the following mathematical equation:

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

The wasteload allocation (WLA) is the portion of the TMDL allocated to existing and future permitted (point) sources. The load allocation (LA) is the portion of the TMDL allocated to non-permitted (nonpoint) sources, including natural background sources. The MOS is intended to ensure that standard for contact recreation will be met. Thus, the allowable pollutant load that can be allocated to point and nonpoint sources can then be defined as the TMDL minus the MOS.

40 CFR, §130.2(1), states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli* bacteria, TMDLs are expressed as numbers per day and represent the maximum one day load the stream can assimilate while still attaining the standard for contact recreation. For the Eastern Watersheds, to quantify allowable pollutant loads, percent reduction goals to achieve standard for contact recreation, and specific TMDL allocations for point and nonpoint sources using the load duration curve (LDC) method as described in this section.

## 4.1 Using Load Duration Curves to Develop TMDLs

The TMDL calculations for streams presented in this report are derived from LDCs. LDCs facilitate rapid development of TMDLs, and as a TMDL development tool, are effective at identifying whether impairments are associated with point or nonpoint sources. The technical approach for using LDCs for TMDL development includes the four following steps described in Subsections 4.2 through 4.4 below:

- preparing flow duration curves (FDC) for gaged and ungaged WQM stations;
- estimating existing bacteria loading in the receiving water using ambient water quality data;
- using LDCs to identify the critical condition that will dictate loading reductions necessary to attain the contact recreation standard; and
- interpreting LDCs to derive TMDL elements – WLA, LA, MOS, and percent reduction goal.

Historically, in developing WLAs for pollutants from point sources, it was customary to designate a critical low flow condition (*e.g.,* 7Q2) at which the maximum permissible loading was calculated. As water quality management efforts expanded in scope to quantitatively address nonpoint sources of pollution and types of pollutants, it became clear that this single critical low flow condition was inadequate to ensure adequate water quality across a range of flow conditions. Use of the LDC obviates the need to determine a design storm or selected flow recurrence interval with which to characterize the appropriate flow level for the assessment of critical conditions. For waterbodies impacted by both point and nonpoint sources, the "nonpoint source critical condition" would typically occur during high flows, when rainfall runoff would contribute the bulk of the pollutant load, while the "point source critical condition" would typically occur during low flows, when WWTF effluents would dominate the base flow of the impaired water.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by the water quality 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.

Strengths of using the LDC method for TMDL development include:

- LDCs facilitate rapid development of TMDLs, and as a TMDL development tool, are effective at identifying whether impairments are associated with point or nonpoint sources despite the reality of data limitations.
- Since TMDLs and WQS apply under all flow conditions LDC is an effective tool for displaying allowable loads over the complete range of flow conditions. It provides flexibility in expressing a TMDL as a continuous function of flow or a discrete value derived from a specific flow.
- LDC presents pollutant loads on a "daily" basis which is a requirement in presenting and allocating TMDLs.
- LDC has been used as the technical basis for the development of hundreds of EPA-approved TMDLs around the nation.

## 4.2 Development of Flow Duration Curves

Flow duration curves serve as the foundation of LDCs and are graphical representations of the flow characteristics of a stream at a given site. FDCs utilize the historical hydrologic record from stream gages to forecast future recurrence frequencies. While many WQM stations throughout Texas do not have long term flow data, there are various methods that can be used to estimate flow frequencies at ungaged stations or gaged stations missing flow data. The most basic method to estimate flows at an ungaged site involves 1) identifying an upstream or downstream flow gage; 2) calculating the contributing drainage areas of the ungaged sites and the flow gage; and 3) calculating daily flows at the ungaged site by using the flow from an acceptable nearby gaged site multiplied by the drainage area ratio. In developing the FDC presented in this report, a more complex approach was used that also considers watershed differences in rainfall, land use, WWTF discharges, and the hydrologic properties of soil that govern runoff and retention. More than one upstream flow gage may also be considered. A more detailed explanation of the methods for estimating flow at ungaged WQM stations is provided in Appendix F. Flow duration curves are a type of cumulative distribution function. The flow duration curve represents the fraction of flow observations that exceed a given flow at the site of interest. The observed flow values are first ranked from highest to lowest then, for each observation, the percentage of observations exceeding that flow is calculated. The flow value is read from the y-axis, which is typically on a logarithmic scale since the high flows would otherwise overwhelm the low flows. The flow exceedance frequency is read from the x-axis, which is numbered from 0 to 100 percent, and may or may not be logarithmic. The lowest measured flow occurs at an exceedance frequency of 100 percent indicating that flow has equaled or exceeded this value 100 percent of the time, while the highest measured flow is found at an exceedance frequency of 0 percent. The median flow occurs at a flow exceedance frequency of 50 percent.

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 5-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 gaging stations operated by the USGS are utilized. The only USGS gage on the Study Area is located in Hunting Bayou at IH 610 (08075770). Thus, it was necessary to complete flow projections to establish estimated flows for each of the remaining freshwater segments in the Study Area using data from neighboring gages. USGS gages 08076000 (Greens Bayou near Houston, TX), 08075730 (Vince Bayou at Pasadena, TX) and 08075770 (Hunting Bayou at IH 610, Houston, TX) were chosen for that effect. The period of record for flow data used from the stations was 1996 through 2006.

A typical semi-log flow duration curve exhibits a sigmoidal shape, bending upward near a flow exceedance frequency value of 0 percent and downward at a frequency near 100 percent, often with a relatively constant slope in between. For sites that on occasion exhibit no flow, the curve will intersect the abscissa at a frequency less than 100 percent. As the number of observations at a site increases, the line of the FDC tends to appear smoother. However, at extreme low and high flow values, flow duration curves may exhibit a “stair step” effect due to the USGS flow data rounding conventions near the limits of quantitation.

FDCs 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 Eastern Houston Watersheds is outlined in Table 4-1.

**Table 4-1 Hydrologic Classification Scheme**

| Assessment Units | Flow Exceedance Percentile | Hydrologic Condition Class |
|---|---|---|
| 1006F_01,1006H_01, 1007G_01, 1007H_01, 1007I_01, 1007K_01, 1007M_01, 1007O_01, 1007R_01 to 04 | 0-20 | Highest flows |
| | 20-80 | Mid-range flows |
| | 80-100 | Lowest flows |
| 1007F_01 | 0-20 | Highest flows |
| | 20-60 | Mid-range flows |
| | 60-100 | Lowest flows |

The low flow category was derived by calculating the percentage of bayou flows contributed by WWTFs using the long-term average reported flows. Since the flows from WWTFs represent less than the 15th percentile of the stream flows, "low flows" were assumed to be exceeded between 80 and 100 percent of the time. The only exception is Berry Bayou above Tidal (1007F_01), for which flows from WWTFs correspond to the 65th flow exceedance percentile and thus low flows were assumed to be exceeded between 60 and 100 percent of the time. 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.

Figures 4-1 through 4-10 present the FDCs developed for the downstream WQM station used for calculating the TMDLs of each 303(d) listed freshwater stream using either USGS data (Hunting Bayou at IH 610, which encompasses 1007R_01 to 1007R_03) or the flow projection method outlined above and further described in Appendix F. The flow exceedance percentiles for each WQM station described below and presented in the figures are provided in Appendix G.

Figure 4-1 represents the FDC for Big Gulch Above Tidal, assessment unit 1006F_01 at WQM station 16662. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08076000 (Greens Bayou near Houston, TX). Because WWTF discharges occur in this water quality segment, average monthly WWTF flows obtained from DMRs were added to the projected flow. No DMR data were available for TX0128601. Therefore, half of the permitted flow for these facilities was added to the projected flow.

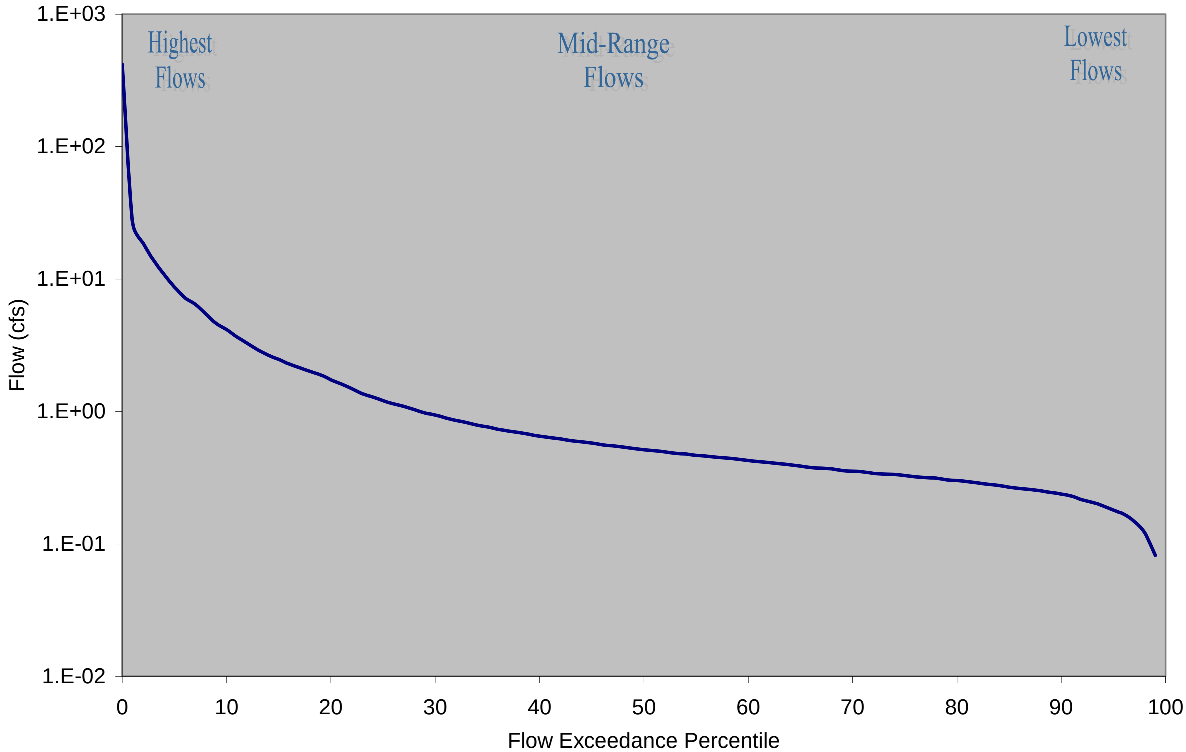


**Figure 4-1 Flow Duration Curve for Big Gulch Above Tidal (1006F_01)**

Figure 4-2 represents the FDC for Spring Gully Above Tidal, assessment unit 1006H_01 at WQM station 16663 . Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08076000 (Greens Bayou nr Houston, TX). Because WWTF discharges occur in this water quality segment, average monthly WWTF flows obtained from DMRs were added to the projected flow.

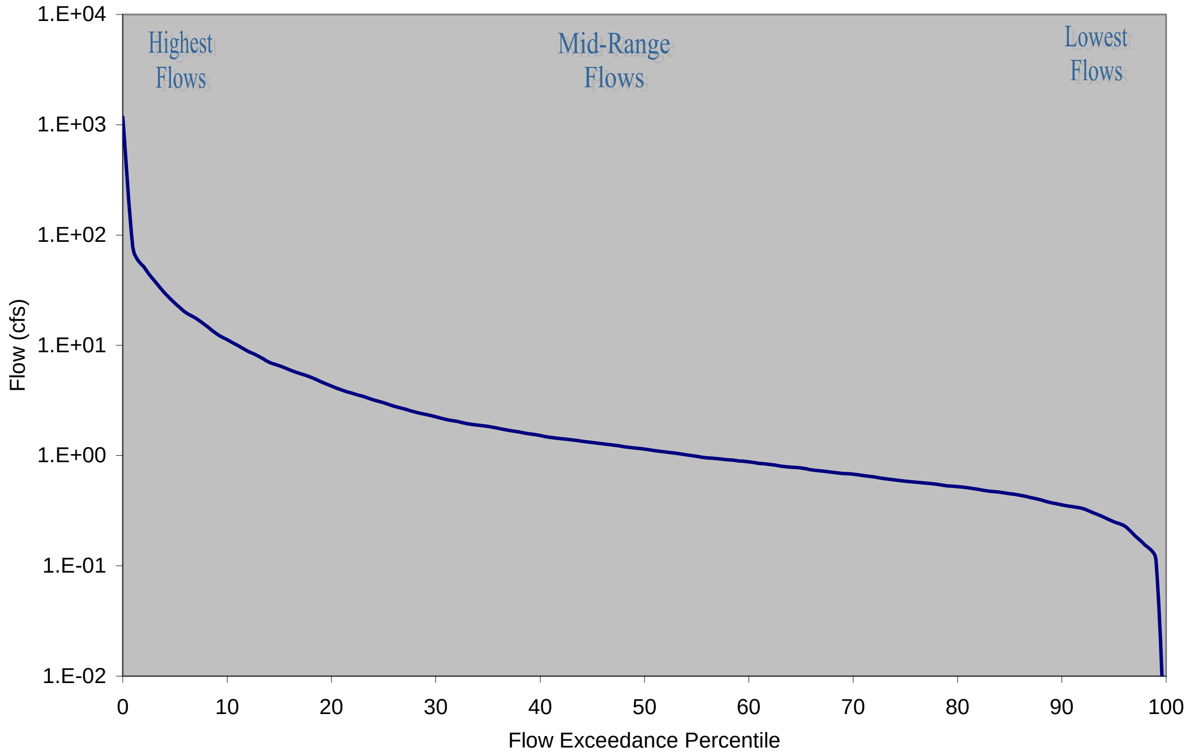


**Figure 4-2 Flow Duration Curve for Spring Gully Above Tidal (1006H_01)**

Figure 4-3 represents the FDC for Berry Bayou Above Tidal, assessment unit 1007F_01 at WQM station 16661 . Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX). Because WWTF discharges occur in this water quality segment, average monthly WWTF flows obtained from DMRs were added to the projected flow.

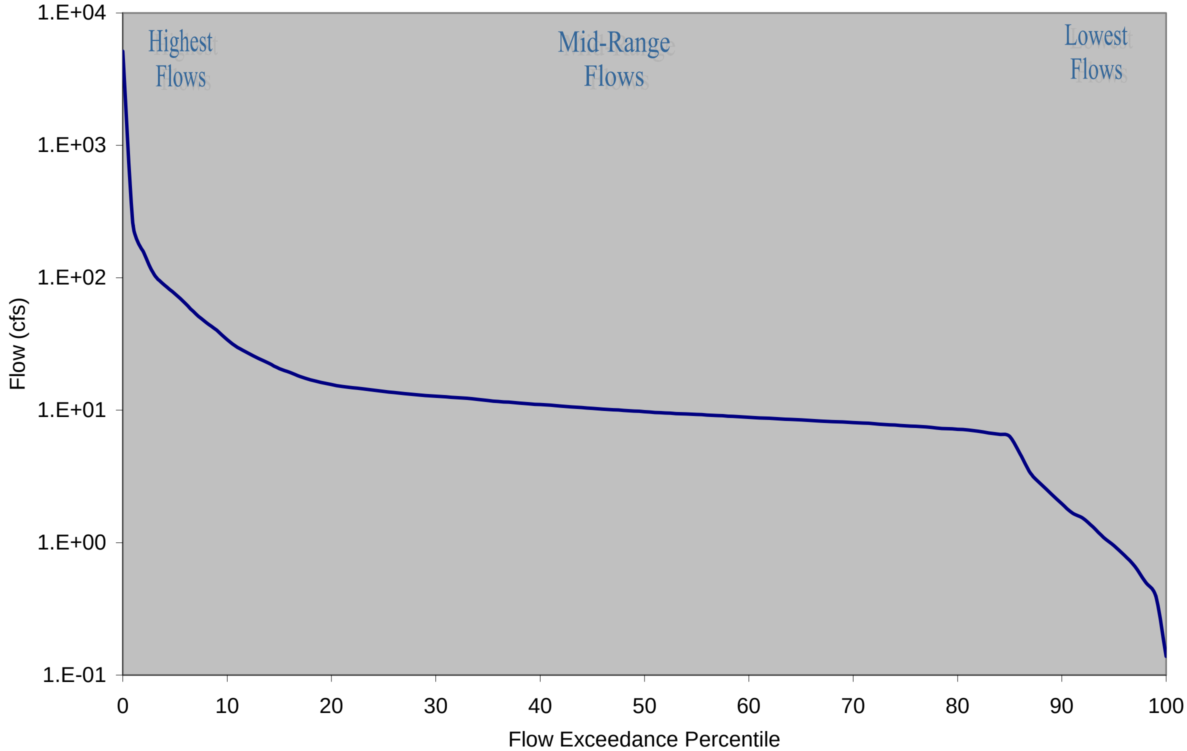


**Figure 4-3 Flow Duration Curve for Berry Bayou Above Tidal (1007F_01)**

Figure 4-4 represents the FDC for Kuhlman Gully Above Tidal, assessment unit 1007G_01 at WQM station 16653. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX).

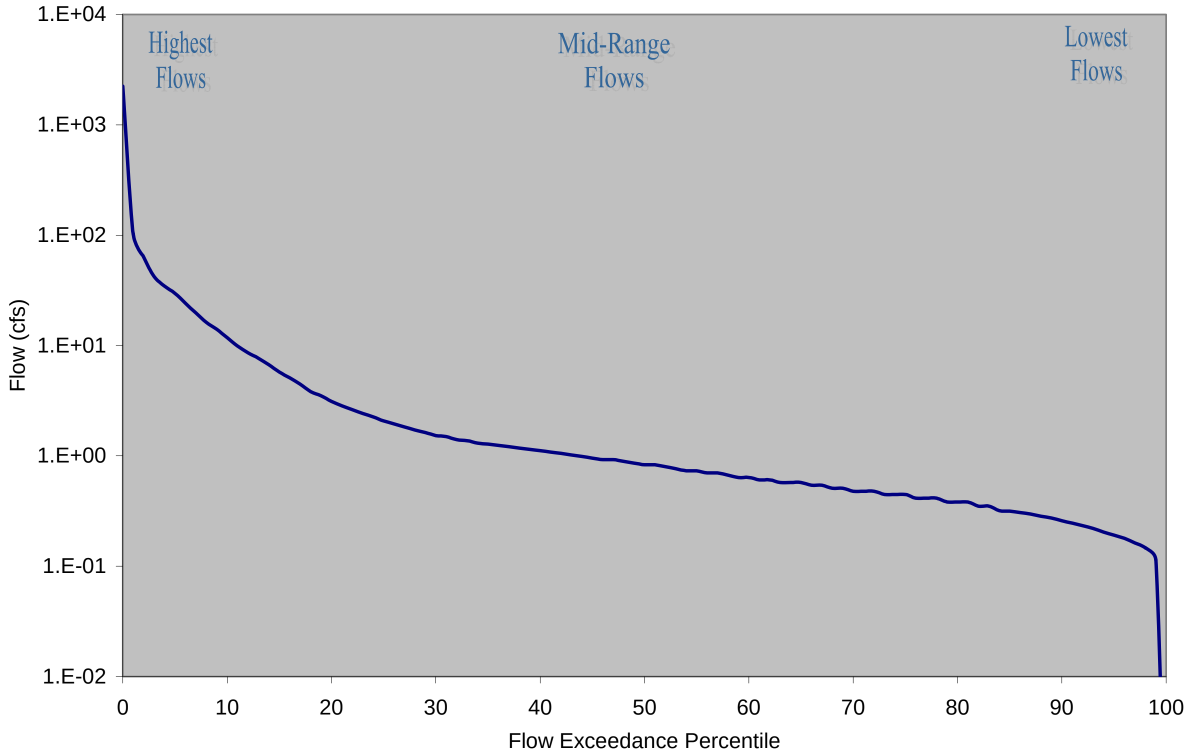


**Figure 4-4 Flow Duration Curve for Kuhlman Gully Above Tidal (1007G_01)**

Figure 4-5 represents the FDC for Pine Gully Above Tidal, assessment unit 1007H_01 at WQM station 16659. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX).

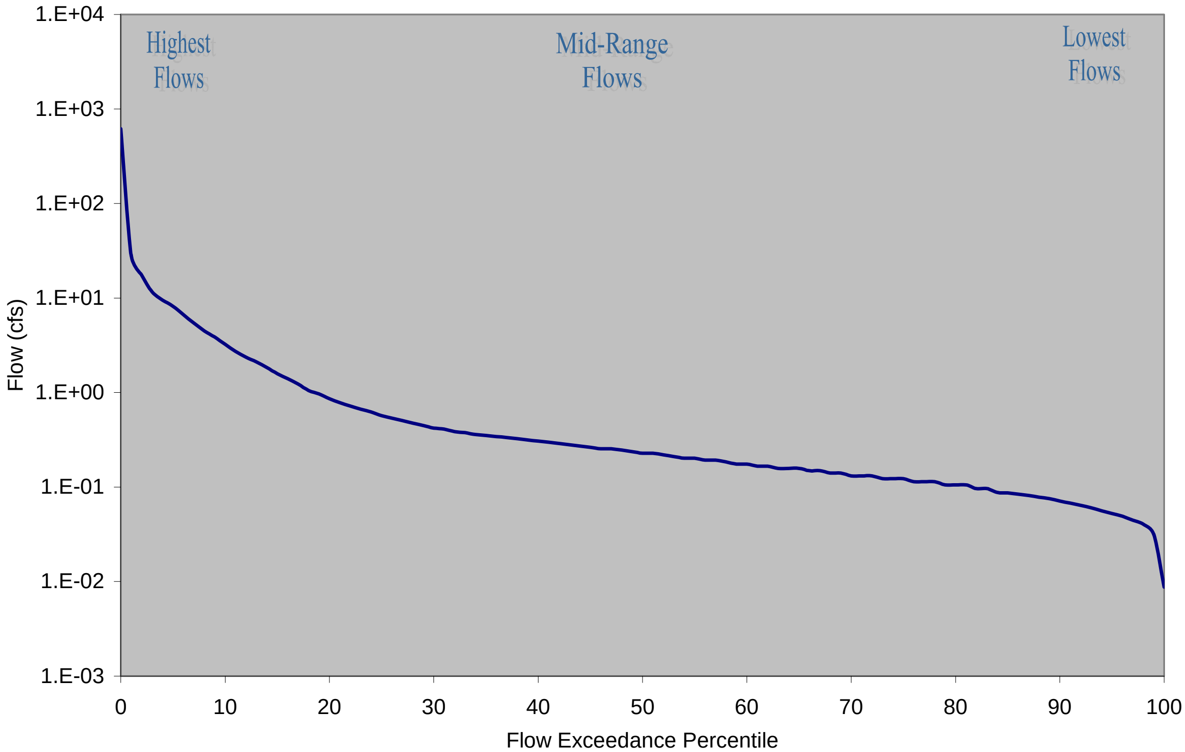


**Figure 4-5 Flow Duration Curve for Pine Gully Above Tidal (1007H_01)**

Figure 4-6 represents the FDC for Plum Creek Above Tidal, assessment unit 1007I_01 at WQM station 16658. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX).

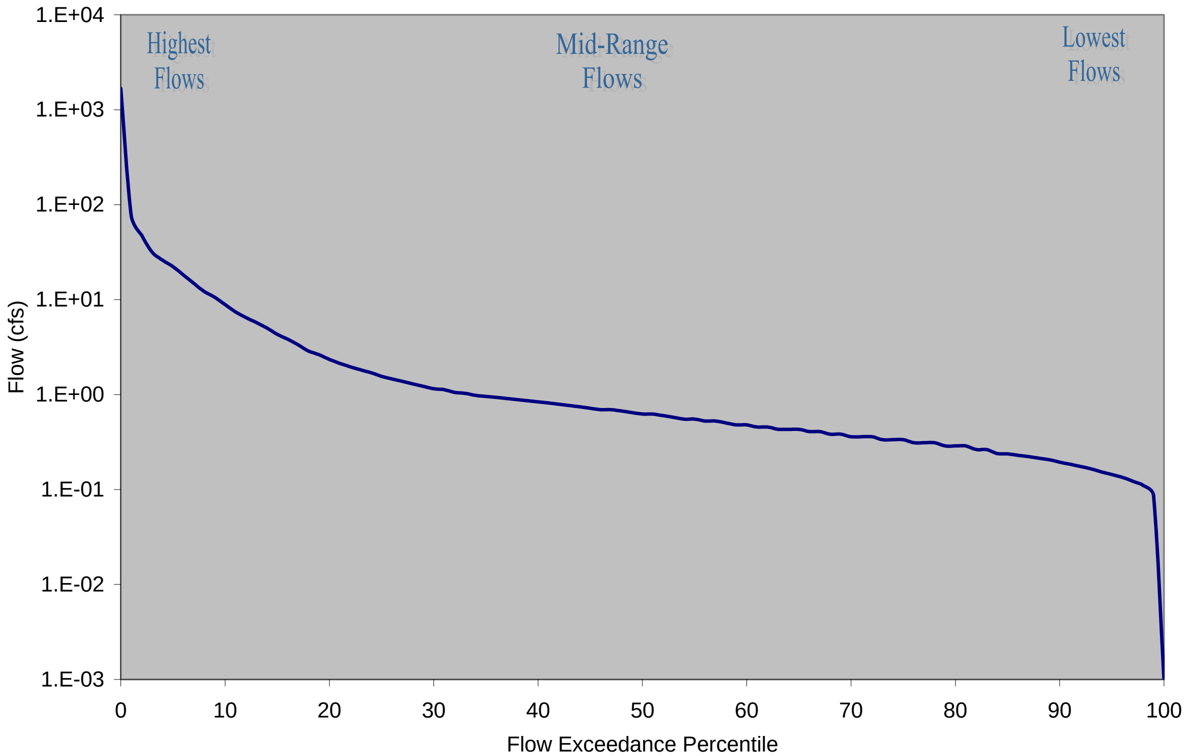


**Figure 4-6 Flow Duration Curve for Plum Creek Above Tidal (1007I_01)**

Figure 4-7 represents the FDC for Country Club Bayou, assessment unit 1007K_01 at WQM station 16650. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075770 (Hunting Bayou at IH 610, Houston, TX).

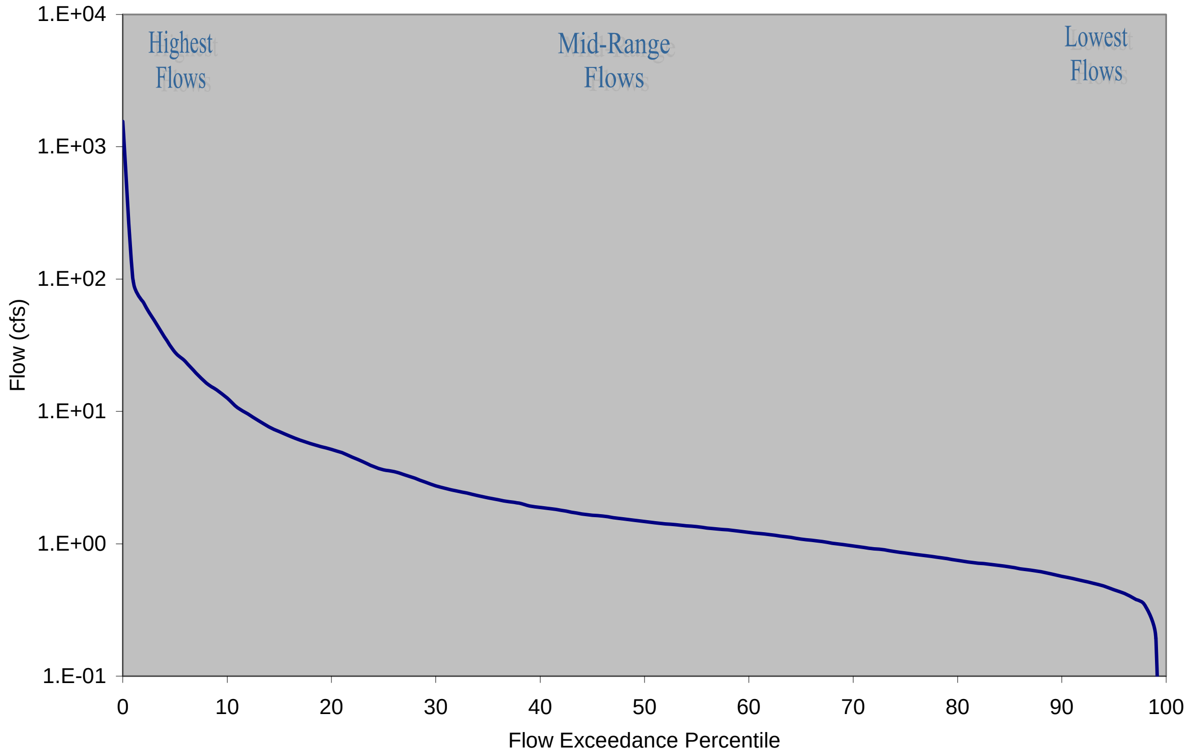


**Figure 4-7 Flow Duration Curve for Country Club Bayou (1007K_01)**

Figure 4-8 represents the FDC for Unnamed Non-Tidal Tributary of Hunting Bayou, assessment unit1007M_01 at WQM station 16657. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX).

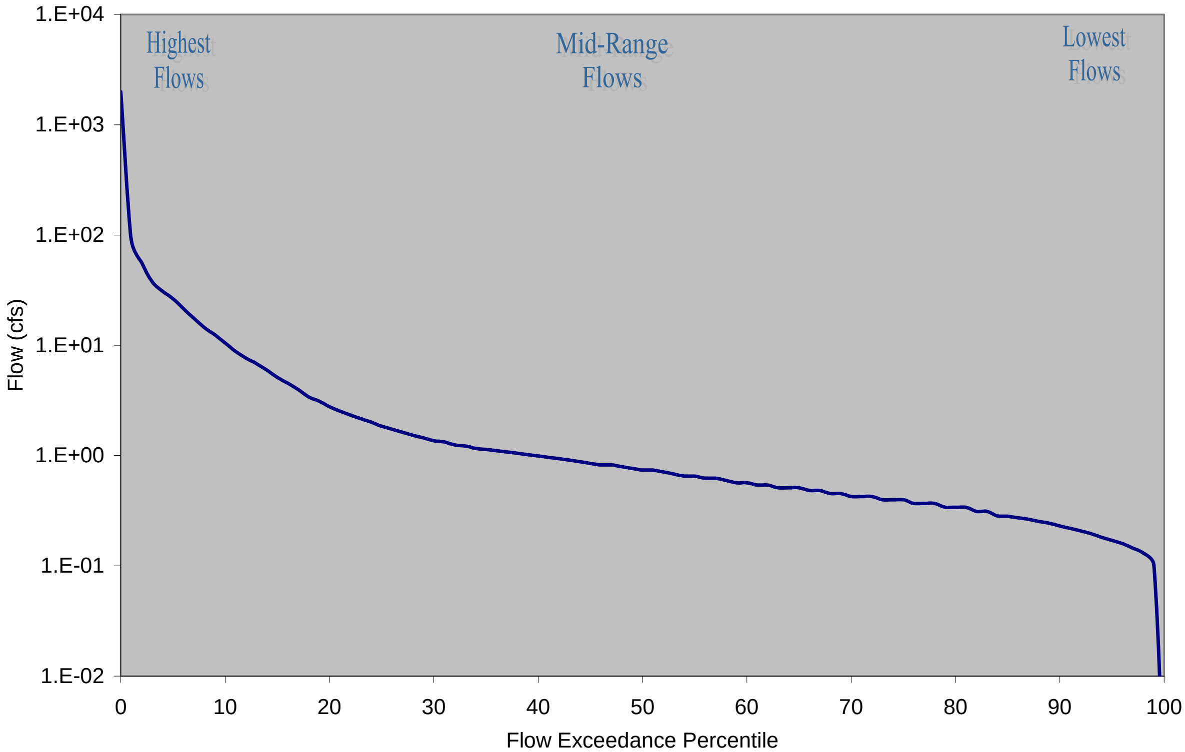


**Figure 4-8 Flow Duration Curve for Unnamed Non-Tidal Tributary of Hunting Bayou (1007M_01)**

Figure 4-9 represents the FDC for Unnamed Non-Tidal Tributary of Buffalo Bayou, assessment unit1007O_01 at WQM station 16649. Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075730 (Vince Bayou at Pasadena, TX).

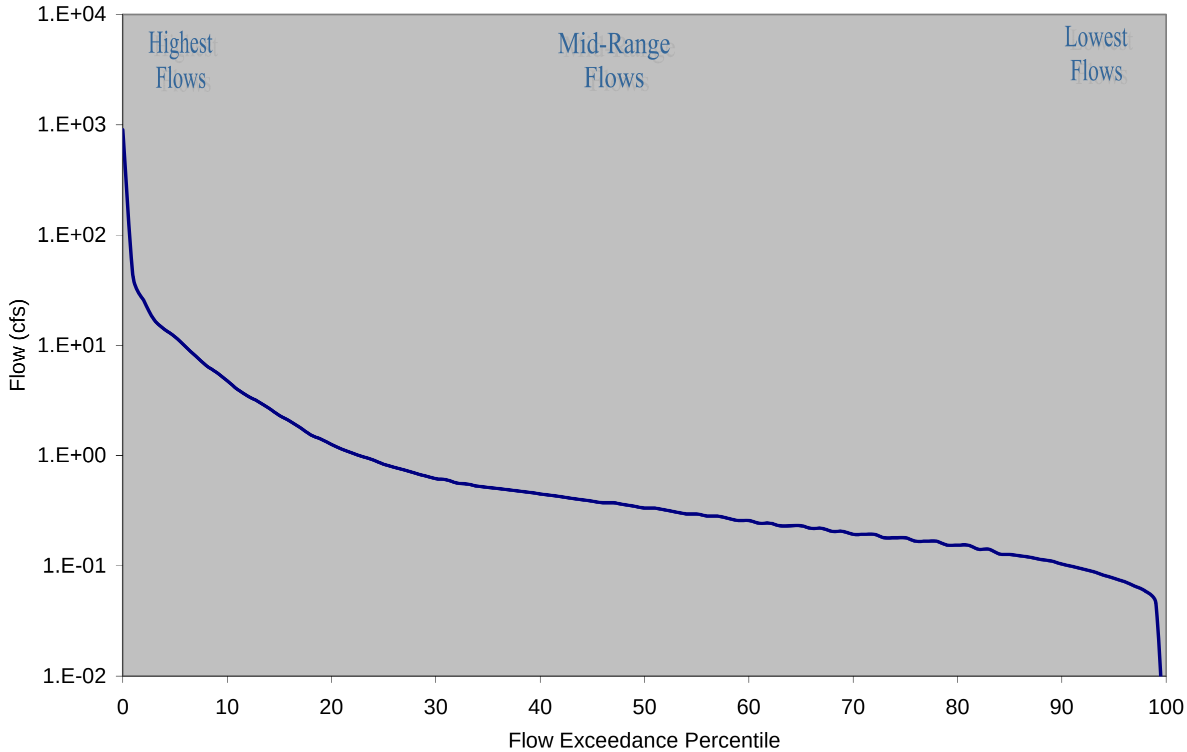


**Figure 4-9 Flow Duration Curve for Unnamed Non-Tidal Tributary of Buffalo Bayou (1007O_01)**

Figure 4-10 represents the FDC for Hunting Bayou above Tidal, assessment units 1007R_01 to 1007R_03. The curve was developed using data from USGS gage station 08075770 (Hunting Bayou at IH 610, Houston, TX), which is located at the downstream end of Assessment Unit 1007R_03 (WQM station 11129).

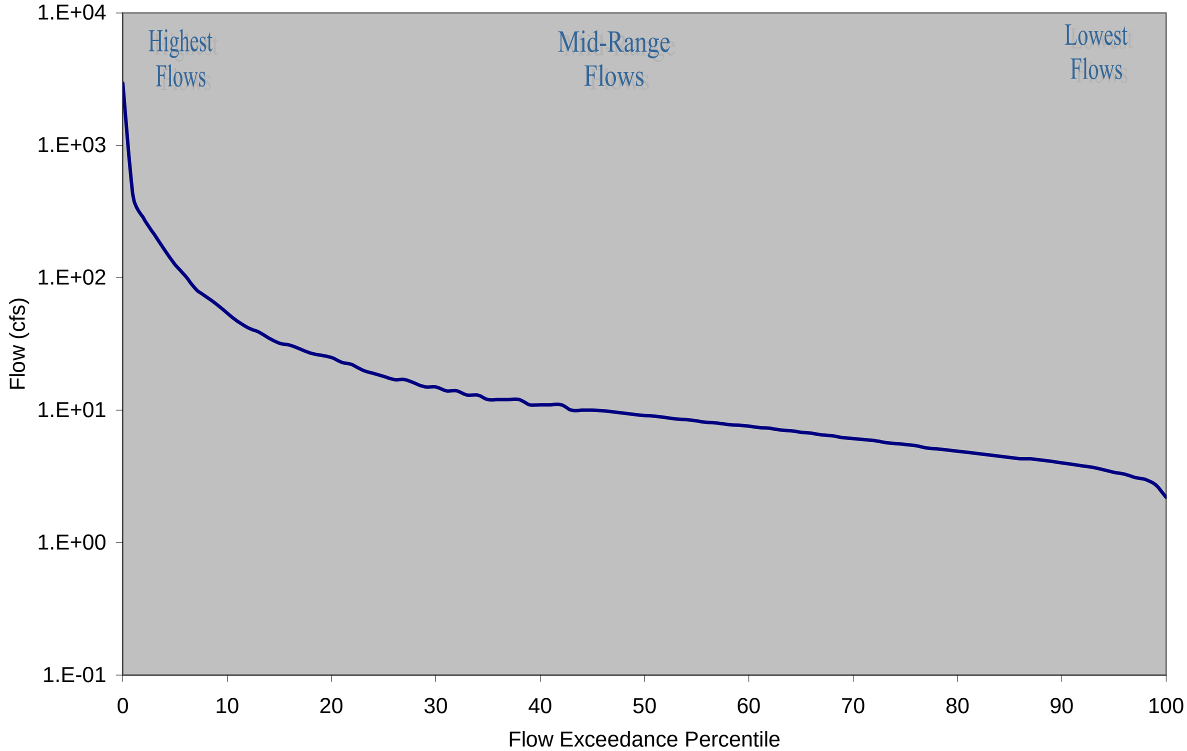


**Figure 4-10 Flow Duration Curve for Hunting Bayou Above Tidal (1007R_01 to 100R_03)**

Figure 4-11 represents the FDC for Hunting Bayou above Tidal, assessment unit 1007R_04 at WQM station 11128 Daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08075770 (Hunting Bayou at IH 610, Houston, TX). Average monthly WWTF flows obtained from DMRs were added to the projected flow.

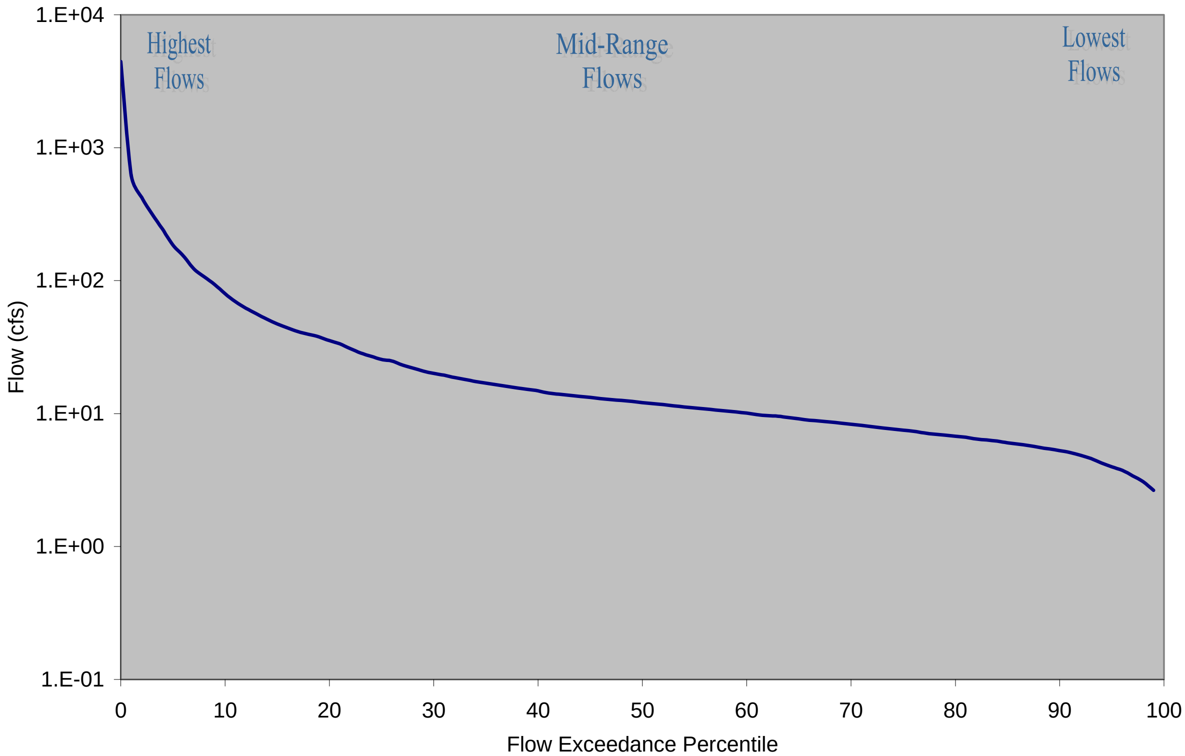


**Figure 4-11 Flow Duration Curve for Hunting Bayou Above Tidal (1007R_04)**

## 4.3 Estimating Current Point and Nonpoint Loading and Identifying Critical Conditions from Load Duration Curves

Another key step in the use of LDCs for TMDL development is the estimation of existing bacteria loading from point and nonpoint sources and the display of this loading in relation to the TMDL. In Texas, WWTFs that discharge treated sanitary wastewater must meet the criteria for indicator bacteria at the point of discharge. However, for TMDL analysis it is necessary to understand the relative contribution of WWTFs to the overall pollutant load and its general compliance with required effluent limits. The monthly bacteria load for continuous point source dischargers is estimated by multiplying the monthly average flow rates by the monthly geometric mean bacteria concentration, with a volumetric conversion factor. Where available, fecal coliform data for this calculation were extracted from each point source's discharge monitoring reports from 1996 through 2006. The current pollutant loading from each permitted point source discharge is calculated using the equation below:

*Point Source Loading = monthly average flow rates (mgd) * geometric mean of corresponding fecal coliform concentration * unit conversion factor*

*Where:*

*unit conversion factor = 37,854,120 dL/million gallons (mg)*

It is difficult to estimate current nonpoint loading due to lack of specific water quality and flow information that would assist in estimating the relative proportion of non-specific sources within the watershed. Therefore, existing instream loads were used as a conservative surrogate for nonpoint loading. Existing instream loads were calculated using measured bacteria concentrations from WQM stations multiplied by the flow rate (estimated or instantaneous) under various flow conditions.

## 4.4 Development of Bacteria TMDLs Using Load Duration Curves

The final step in the TMDL calculation process involves a group of additional computations derived from the preparation of LDCs. These computations are necessary to derive a percent reduction goal (one method of presenting how much bacteria loading must be reduced to meet the water quality criterion in an impaired watershed).

**Step 1: Generate Bacteria LDCs.** LDCs are similar in appearance to flow duration curves; however, the y-axis is expressed in terms of a bacteria load in counts/day. The curve represents the instantaneous water quality criterion for *E. coli* (394 MPN/100mL), expressed in terms of a load through multiplication by the continuum of flows historically observed at this site. Using the single sample water quality 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 generating an LDC involve:

- obtaining daily flow data for the WQM station of interest from the USGS;
- sorting the flow data and calculating flow exceedance percentiles for the time period and season of interest;
- obtaining the water quality data;
- matching the water quality observations with the flow data from the same date;
- displaying a curve on a plot that represents the allowable load multiply the actual or estimated flow by the SWQS for each respective indicator;
- multiplying the flow by the water quality parameter concentration to calculate daily loads; then
- plotting the flow exceedance percentiles and daily load observations in a load duration plot.

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

*TMDL (counts/day) = criterion * flow (cfs) * unit conversion factor*

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

*unit conversion factor = 24,465,755 dL/ft3 * seconds/day*

The flow exceedance frequency (x-value of each point) is obtained by looking up the historical exceedance frequency of the measured or estimated flow; in other words, the percent of historical observations that equal or exceed the measured or estimated flow. 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 ((MPN/100mL) by the instantaneous flow (cfs) at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads representing exceedance of water quality criterion fall above the water quality criterion line.

Figure 4-12 provides a schematic representation of where permitted and non-permitted sources of pollution occur throughout the entire hydrograph for a typical stream. This figure shows that runoff typically contributes pollutant loads during high flow to mid-ranged flow conditions. However, flows do not always correspond directly to runoff events. For instance, high flows may occur in dry weather and runoff influence may be observed with low or moderate flows.

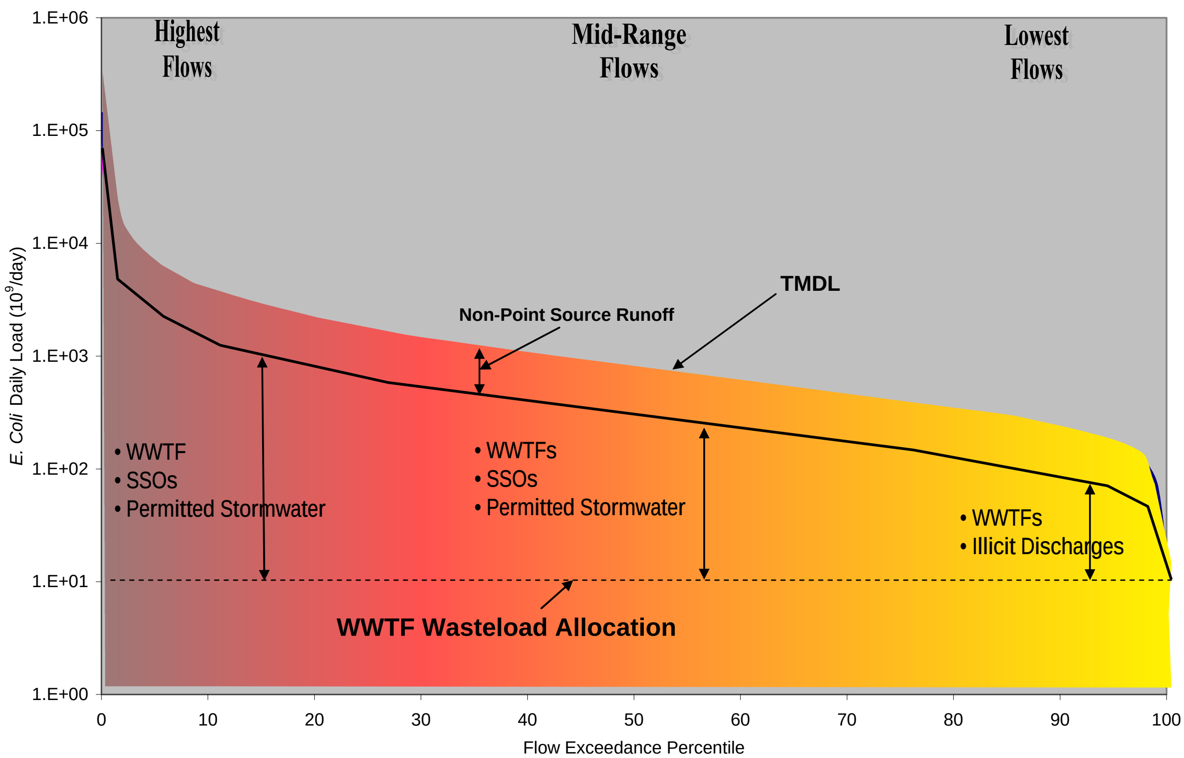


**Figure 4-12 LDC Schematic Diagram – Interpreting Sources and Loads**

To determine if a bacteria sample was influenced by runoff, rainfall data from the rain gage closest to a WQM station were evaluated. The potential maximum retention after runoff begins (S) was calculated to determine how much rainfall would be needed to produce runoff for each watershed. S is calculated using the formula below:

$$S = \frac{1000}{CN} - 10$$

*Where: S = potential maximum retention after runoff begins (inches)*

*CN =average curve number for the watershed*

Three-day rainfall totals were then calculated for each rain gage. These data were matched to the date the bacteria sample was collected. A bacteria sample was then considered a wet weather sample if the three-day rainfall total was greater than or equal to *S*. These bacteria samples were then plotted in the LDCs using a different symbol from those samples that were not considered wet weather influenced.

**Step 2: Develop LDCs with MOS.** The MOS may be defined explicitly or implicitly. A LDC depicting slightly lower estimates than the TMDL is typically developed to incorporate an MOS into the TMDL calculations. A typical explicit approach would reserve some fraction of the TMDL (*e.g.,* 5%) as the MOS. In an implicit MOS approach, conservative assumptions used in developing the TMDL are relied upon to provide an MOS to assure that standard for contact recreation is attained.

For the TMDLs in this report, an explicit MOS of 5 percent of the TMDL value (5% of the instantaneous water quality criterion, which is equivalent to 5% of the load) has been selected to slightly reduce assimilative capacity in the watershed. The MOS at any given percent flow exceedance, therefore, is defined as the difference in loading between the TMDL and the TMDL with MOS.

**Step 3: Calculate WLA.** As previously stated, the pollutant load allocation for permitted (point) sources is defined by the WLA. A point source can be either a wastewater (continuous) or storm water permitted discharge. Storm water point sources are typically associated with urban and industrialized areas, and recent USEPA guidance includes NPDES-permitted storm water discharges as point source discharges and, therefore, part of the WLA.

The LDC approach recognizes that the assimilative capacity of a waterbody depends on the flow, and that maximum allowable loading will vary with flow condition. TMDLs can be expressed in terms of maximum allowable concentrations, or as different maximum loads allowable under different flow conditions, rather than single maximum load values. This concentration-based approach meets the requirements of 40 CFR, 130.2(i) for expressing TMDLs “in terms of mass per time, toxicity, or other appropriate measures” and is consistent with USEPA’s Protocol for Developing Pathogen TMDLs (USEPA 2001).

**WLA for WWTF.** WLAs may be set to zero for watersheds with no existing or planned continuous permitted point sources. For watersheds with permitted point sources, WLAs may be derived from TPDES permit limits. A WLA may be calculated for each active TPDES wastewater discharger using a mass balance approach as shown in the equation below. The permitted average flow rate used for each point source discharge and the water quality criterion concentration are used to estimate the WLA for each wastewater facility. Through TPDES permits, WLAs for WWTFs are constant across all flow conditions and ensure that WQS will be attained (USEPA 2007). All WLA values for each TPDES wastewater discharger are then summed to represent the total WLA for the watershed.

*WLA = criterion/2 * flow * unit conversion factor (#/day)*

*Where: criterion = 126 MPN/100mL (E. coli)*

*flow (mgd) = permitted flow*

*unit conversion factor = 37,854,120-dL/ mgd*

**WLA for NPDES/TPDES Storm Water.** Given the lack of data and the complexity of quantifying bacteria concentrations or loads associated with wet weather events, calculating the

WLA for permitted storm water (MS4) discharges must be derived in a manner similar to that used for all other non-permitted nonpoint sources. In other words it must be derived from the overall LA or the area under the TMDL curve and above the WLA established for WWTFs. Rather than one discrete value, which is practical for WWTF discharges, the WLA calculations for permitted storm water discharges must be expressed as different maximum loads allowable under different flow conditions. Therefore, the percentage of a watershed under MS4 jurisdiction is used to estimate the load that should be allocated as the permitted storm water load. For example, the coverage area of the City of Houston/Harris County permitted MS4 discharge in segment 1006I_01 is estimated to be 376 acres or 83 percent of the watershed. Therefore, 83 percent of the LA calculated at any flow condition will be designated as the $WLA_{Storm\ water}$ for the City of Houston as part of the TMDL for segment 1006I_01.

**Step 4: Calculate LA.** LAs for non-permitted sources (nonpoint sources) can be calculated under different flow conditions as the water quality target load minus the sum of WLA for WWTFs (if any) and permitted storm water (or MS4). The LA is represented by the area under the LDC but above the WLA. The LA at any particular flow exceedance is calculated as shown in the equation below.

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

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
$\Sigma WLA_{STORM\ WATER}$ = sum of all WWTF loads
$\Sigma WLA_{MS4}$ = sum of all STORM WATER loads
MOS = margin of safety

**Step 5: Estimate WLA Load Reduction.** The WLA load reduction for TPDES-permitted WWTFs was not calculated since it was assumed that continuous dischargers are adequately regulated under existing permits and, therefore, no WLA reduction would be required. However, for permitted storm water the load reduction will be the same as the percent reduction goal established for the LA (nonpoint sources).

**Step 6: Estimate LA Load Reduction.** A percent reduction goal is derived for each WQM station on each segment for the geometric mean criterion. After existing loading estimates are computed for the indicator bacteria, nonpoint load reduction estimates for each sampling location are calculated by using the difference between estimated existing loading and the allowable load expressed by the LDC (TMDL-MOS). Existing loads were determined by using the median flow of each of the three flow regimes multiplied by the geometric mean concentration of the historical bacteria data within a given regime. For example, for the 0-$20^{th}$ percentile flow range, the flow corresponding to the $10^{th}$ percentile was used. The geometric mean of the indicator bacteria samples within the 0-$20^{th}$ flow percentile range was then multiplied by the flow corresponding to the $10^{th}$ exceedance percentile to determine the existing load. Overall, percent reduction goals were also calculated for the most-downstream station of each segment. The highest reduction determined for each segment is then applied as the percent reduction goal. In this case, all indicator bacteria data from flow exceedance percentiles of 0 through 100 were used to calculate the geometric mean and the percent reduction goal was derived using the following formula:

*Percent Reduction Goal = (Geometric Mean of Indicator Bacteria Data – Water Quality Target)* 100*

Figures 4-13 through 4-23 present the LDCs developed for the downstream WQM station used for calculating the TMDLs of each 303(d) listed waterbody.

Figure 4-13 represents the LDC for Big Gulch Above Tidal, assessment unit 1006F_01 and is based on *E. coli* bacteria measurements at sampling location 16662 (Big Gulch At Wallisville Rd). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions. The geometric mean criterion is exceeded under high and mid range flow conditions. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions. The last part of the curve, where the loads at WQ target are lower than the WWTF wasteload allocation, is assumed to be equal to the WLA-WWTF. This explains the difference of shape between the LDC and FDC at very low flows (above 98th percentile).

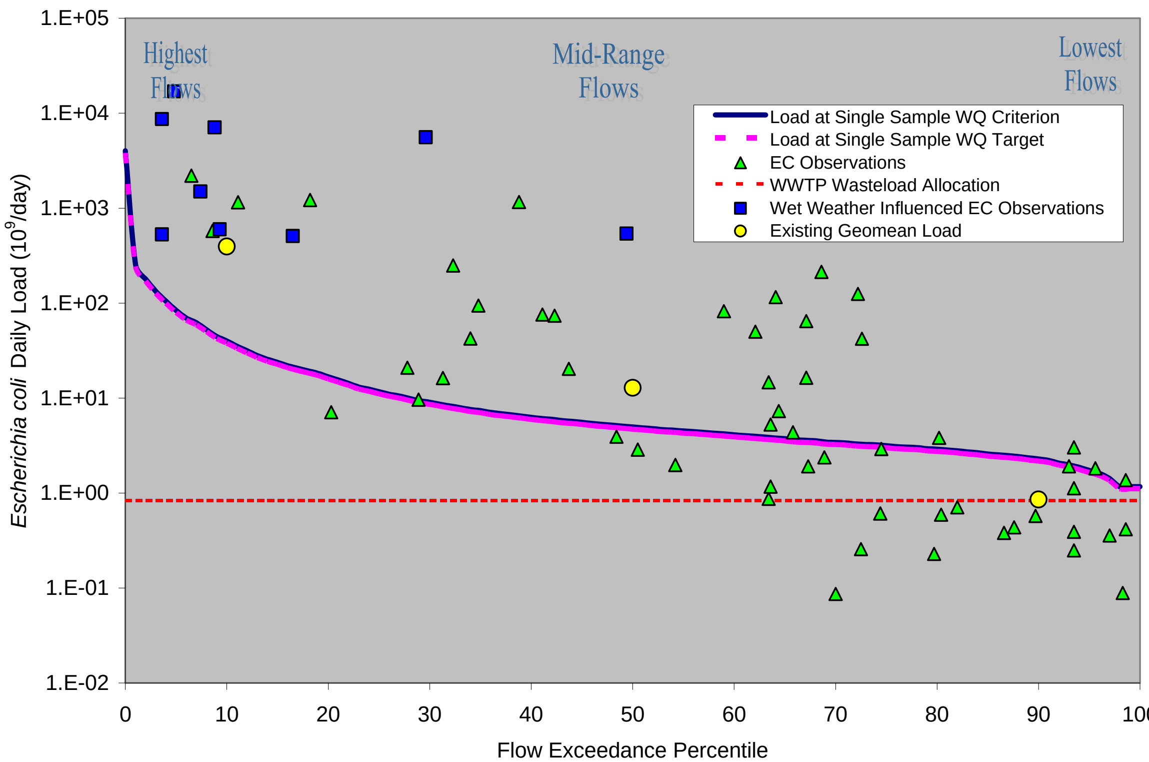


**Figure 4-13 Load Duration Curve for Big Gulch Above Tidal (1006F_01)**

Figure 4-14 represents the LDC for Spring Gully Above Tidal, assessment unit 1006H_01 and is based on *E. coli* bacteria measurements at sampling location 16663 (Spring Gully At Barnesworth Dr). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions, while the geometric mean criterion is exceeded under high flow conditions only. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions.

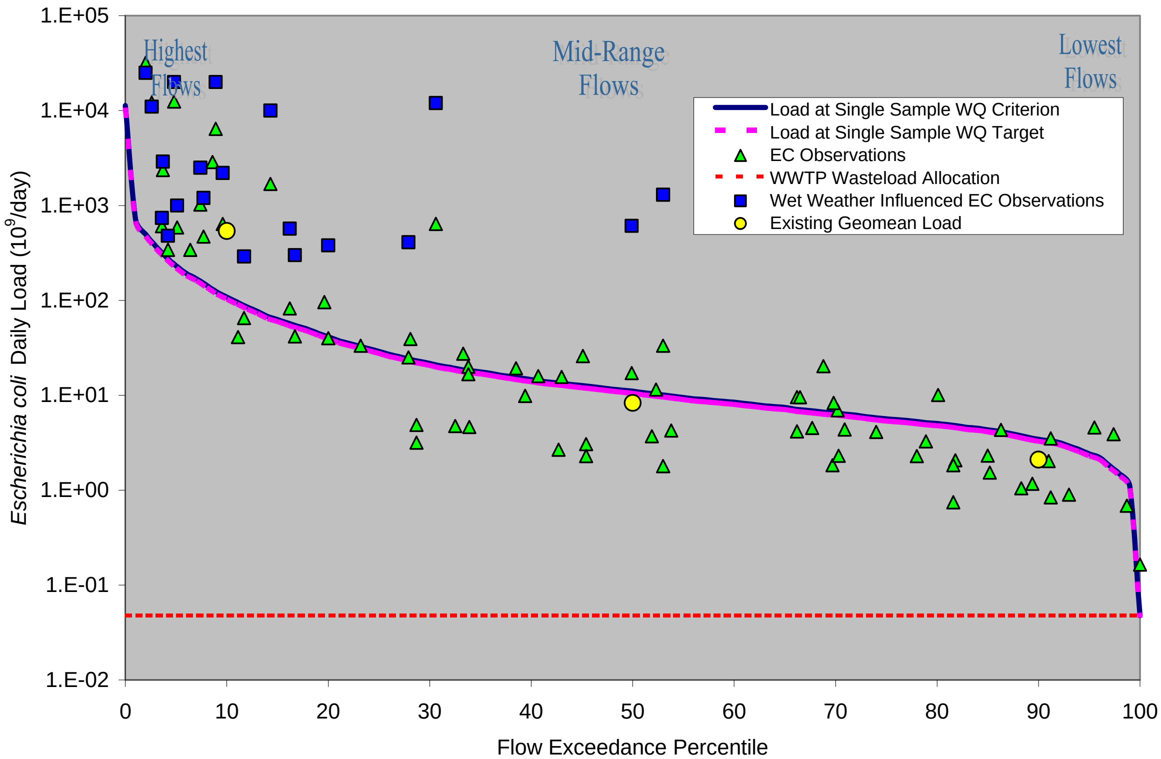


**Figure 4-14 Load Duration Curve for Spring Gully Above Tidal (1006H_01)**

Figure 4-15 represents the LDC for Berry Bayou Above Tidal, assessment unit 1007F_01 and is based on *E. coli* bacteria measurements at sampling location 16661 (Berry Bayou At South Richey). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions. The last part of the curve, where the loads at WQ target are lower than the WWTF wasteload allocation, is assumed to be equal to the WLA-WWTF. This explains the difference of shape between the LDC and FDC at very low flows (above $88^{th}$ percentile).

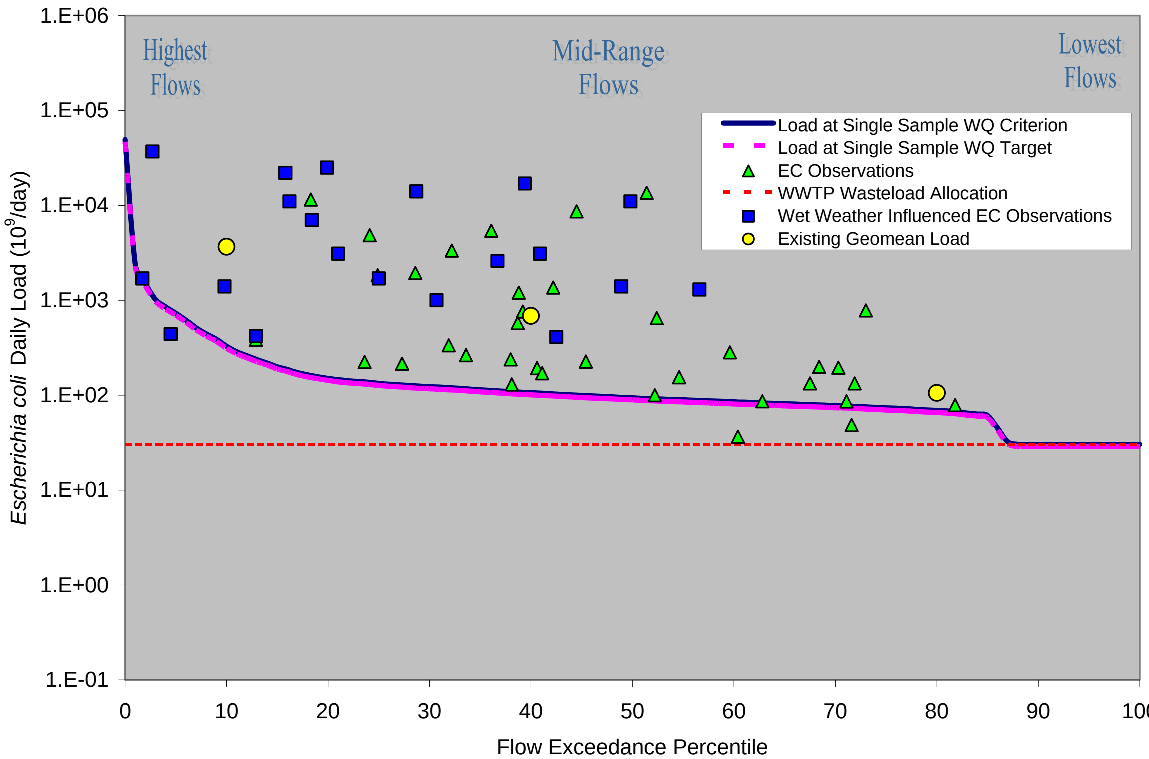


**Figure 4-15 Load Duration Curve for Berry Bayou Above Tidal (1007F_01)**

Figure 4-16 represents the LDC for Kuhlman Gully Above Tidal, assessment unit 1007G_01 and is based on *E. coli* bacteria measurements at sampling location 16653 (Kuhlman Gully At Brock St). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions.

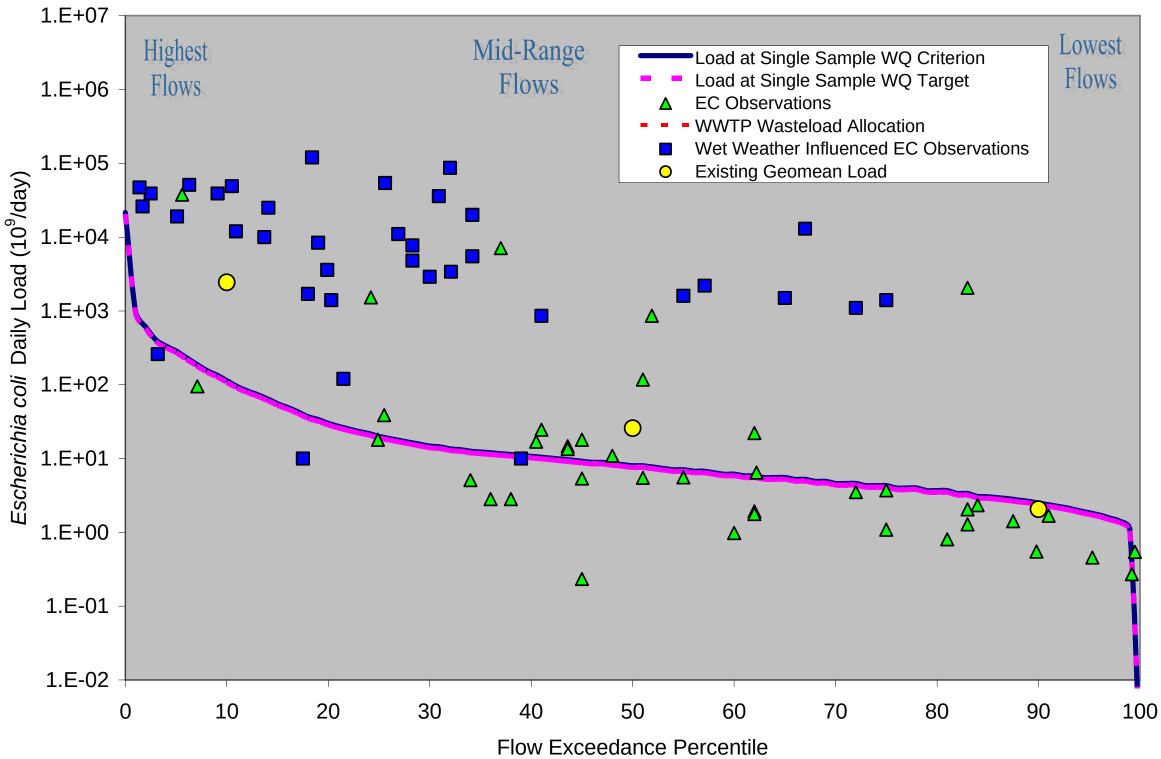


**Figure 4-16 Load Duration Curve for Kuhlman Gully Above Tidal (1007G_01)**

Figure 4-17 represents the LDC for Pine Gully Above Tidal, assessment unit 1007H_01 and is based on *E. coli* bacteria measurements at sampling location 16659 (Pine Gully At Old Galveston Rd). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion and the geometric mean criterion under all flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions.

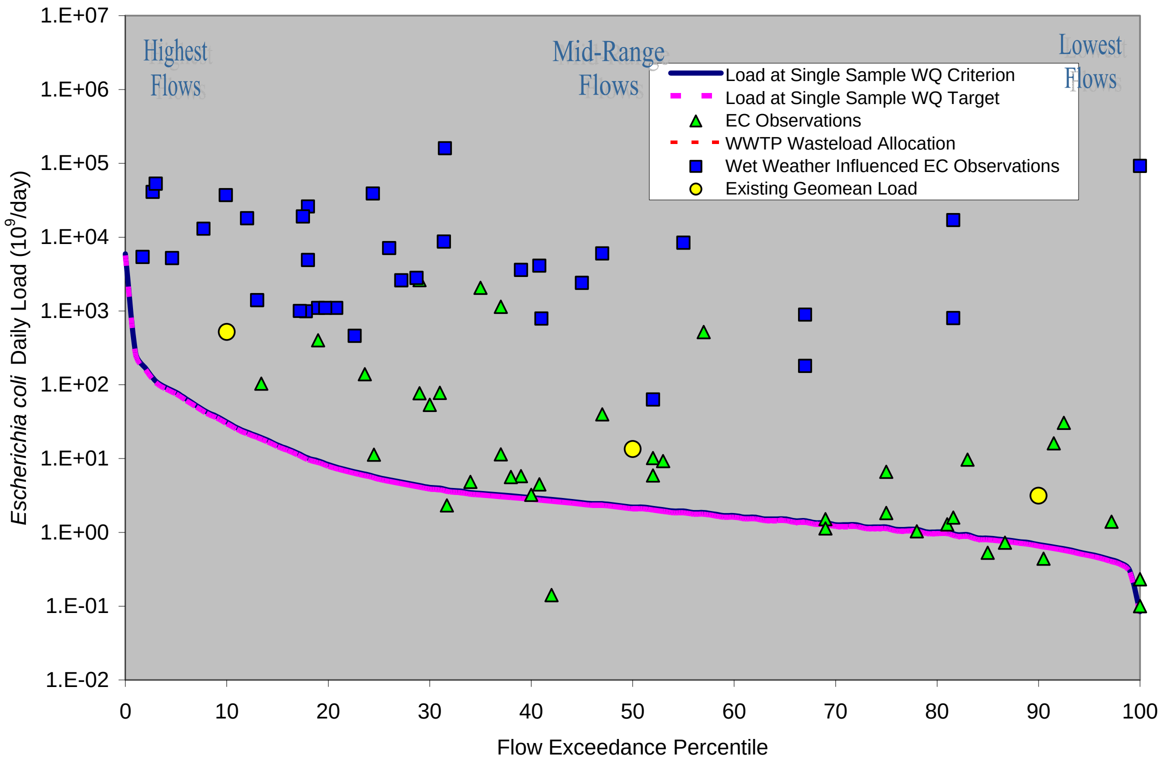


**Figure 4-17 Load Duration Curve for Pine Gully Above Tidal (1007H_01)**

Figure 4-18 represents the LDC for Plum Creek Above Tidal, assessment unit 1007I_01 and is based on *E. coli* bacteria measurements at sampling location 16658 (Plum Creek At Old Galveston Rd). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions

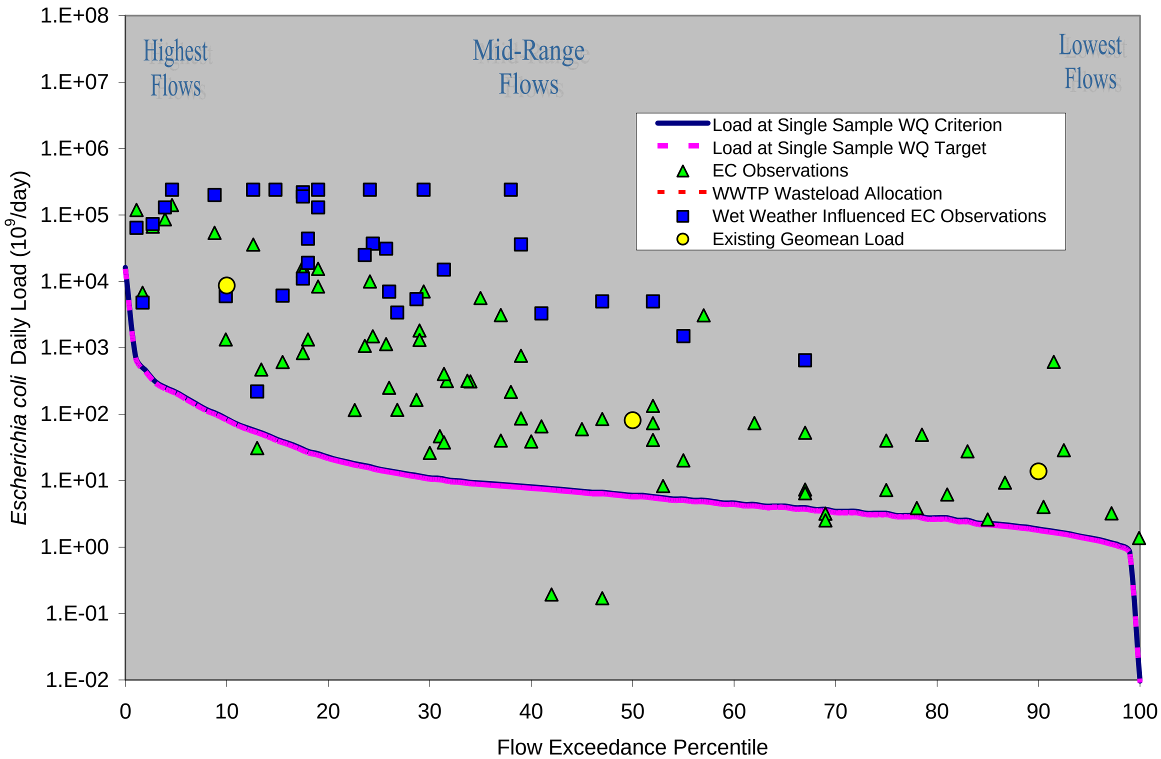


**Figure 4-18 Load Duration Curve for Plum Creek Above Tidal (1007I_01)**

Figure 4-19 represents the LDC for Country Club Bayou, assessment unit 1007K_01 and is based on *E. coli* bacteria measurements at sampling location 16650 (Country Club Bayou At Wayside). The LDC indicates that *E. coli* levels exceed both the instantaneous water quality criterion and the geometric mean criterion under all flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions.

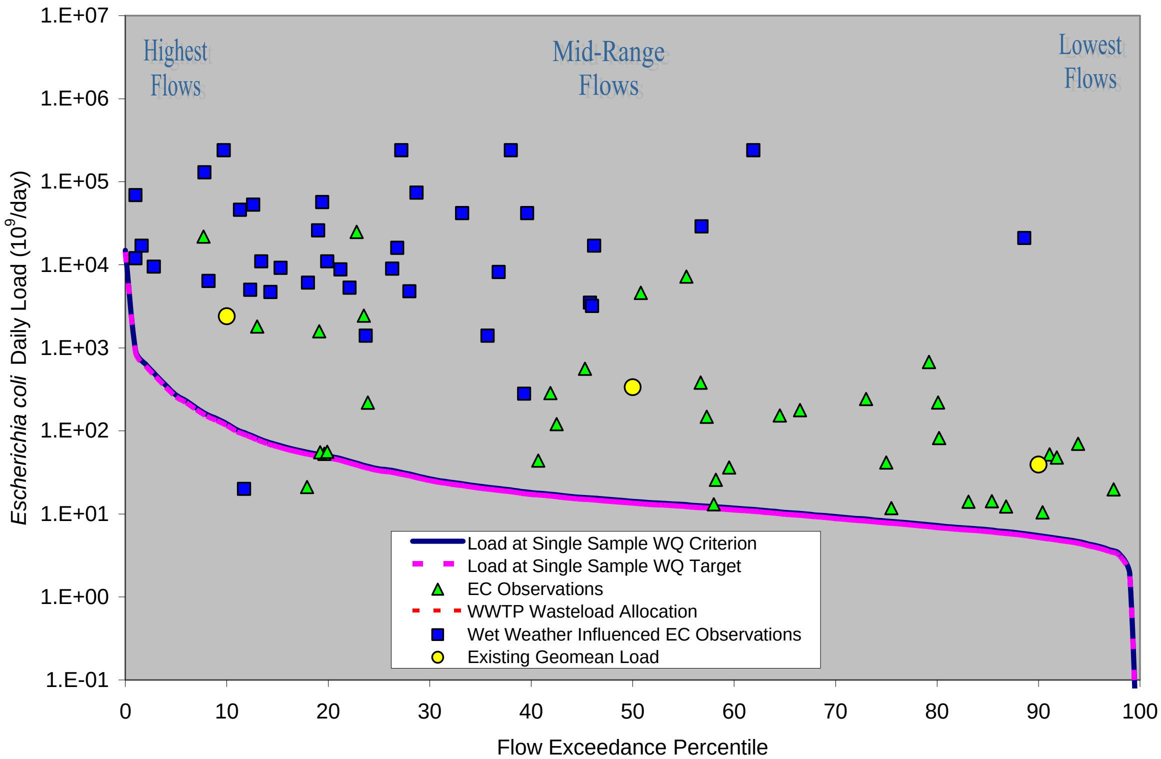


**Figure 4-19 Load Duration Curve for Country Club Bayou (1007K_01)**

Figure 4-20 represents the LDC for Unnamed Non-Tidal Tributary of Hunting Bay, assessment unit 1007M_01 and is based on *E. coli* bacteria measurements at sampling location 16657 (Trib Hunting Bayou At Ralston). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions. The *E. coli* geometric mean water quality criterion was exceeded under high and mid-range flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions.

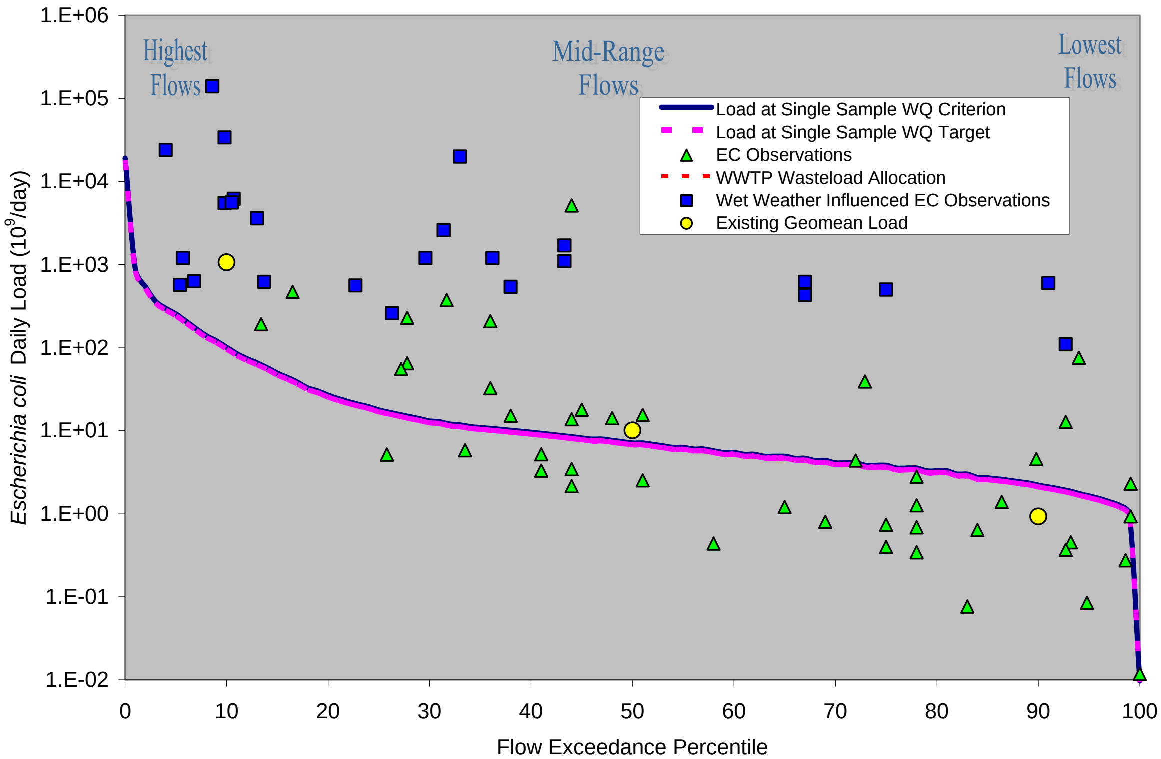


**Figure 4-20 Load Duration Curve for Unnamed Non-Tidal Tributary of Hunting Bay (1007M_01)**

Figure 4-21 represents the LDC for Unnamed Non-Tidal Tributary of Buffalo Bay, assessment unit 1007O_01 and is based on *E. coli* bacteria measurements at sampling location 16649 (Trib Of Buffalo Bayou Clinton). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions.

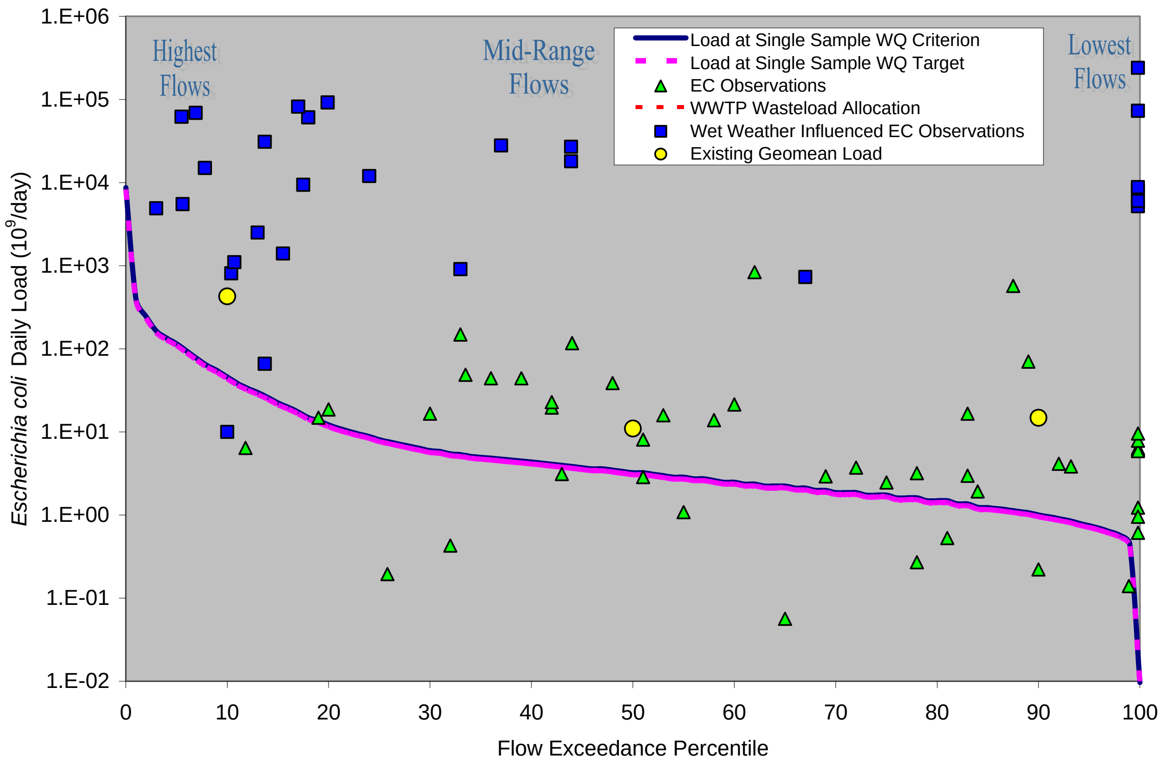


**Figure 4-21 Load Duration Curve for Unnamed Non-Tidal Tributary of Buffalo Bay (1007O_01)**

Figure 4-22 represents the LDC for Hunting Bayou Above Tidal, assessment units 1007R_01, 1007R_02, and 1007R_03 and is based on *E. coli* bacteria measurements at sampling location 11129 (Hunting Bayou immediately downstream of IH 610). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under mid-range and high flow conditions, while the geometric mean criterion was exceeded under high flows only. Wet weather influenced *E. coli* observations are found under mid-range and high flow conditions

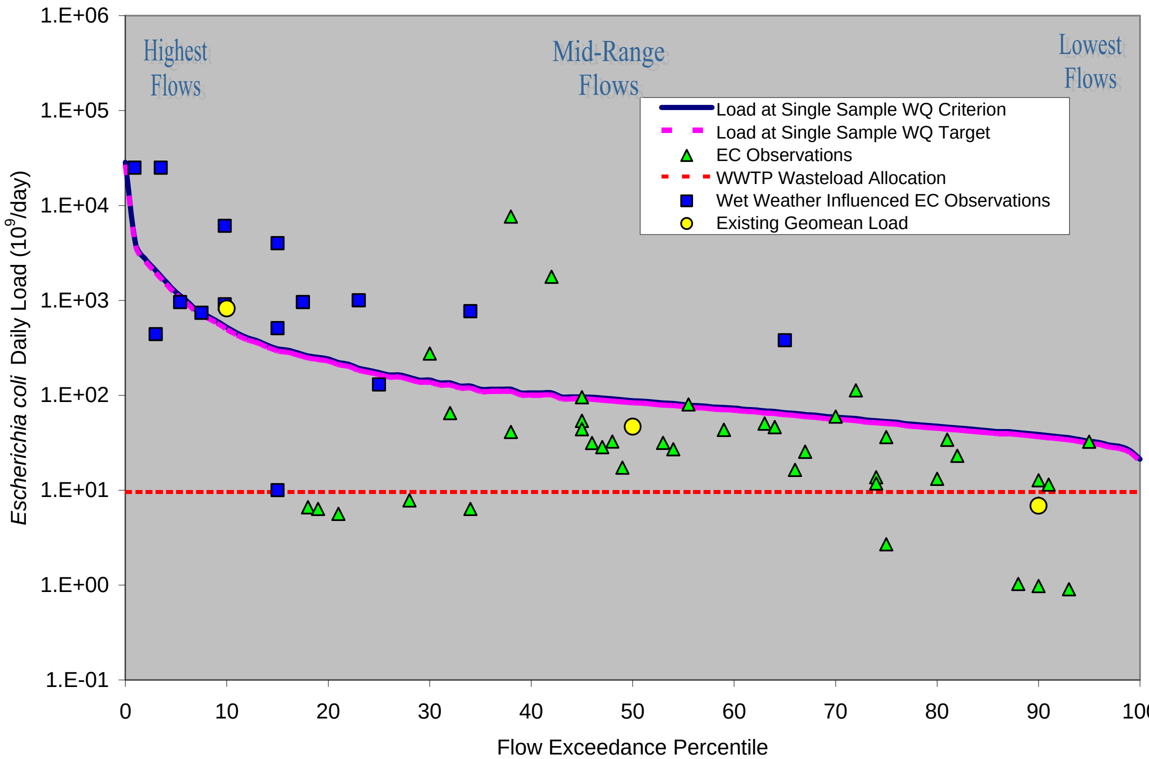


**Figure 4-22 Load Duration Curve for Hunting Bayou Above Tidal (1007R_01 to 1007R_03)**

Figure 4-23 represents the LDC for Hunting Bayou Above Tidal, assessment unit 1007R_04, and is based on *E. coli* bacteria measurements at sampling location 11128 (Hunting Bayou downstream of IH 10). The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under all flow conditions. The *E. coli* geometric mean water quality criterion was exceeded under high flow conditions only. Wet weather influenced *E. coli* observations are found under mid-range and high flow conditions.

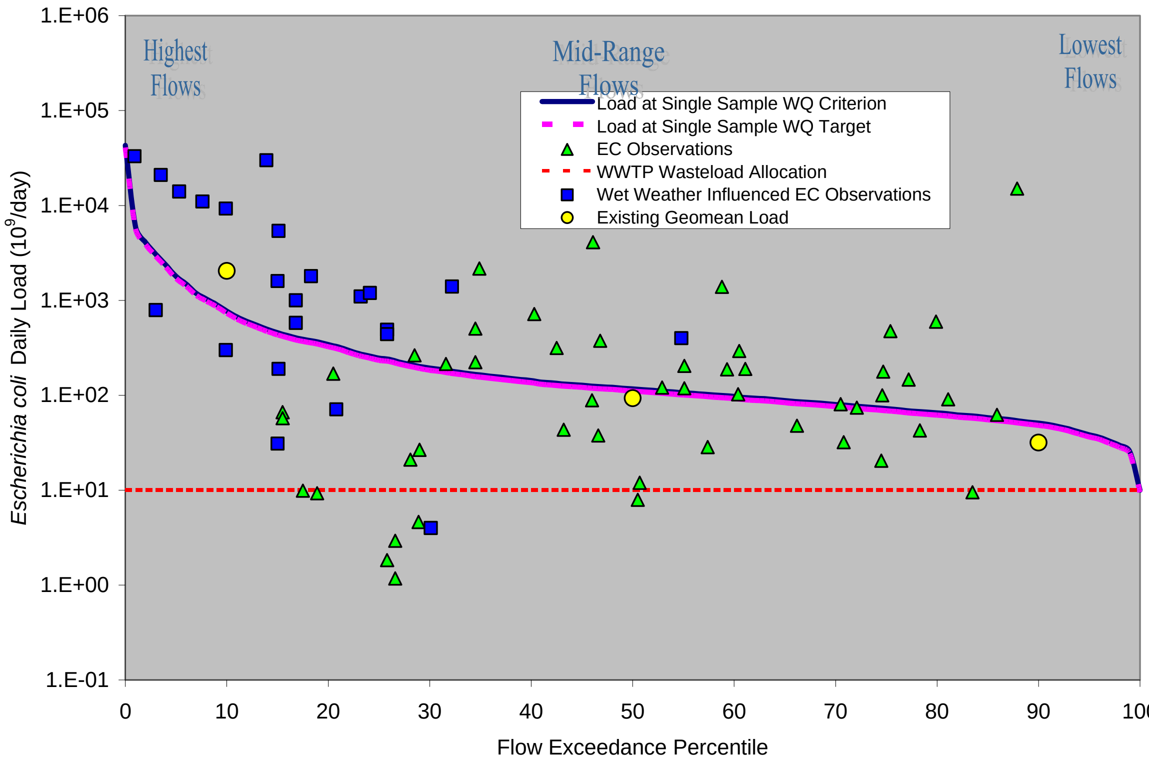


**Figure 4-23 Load Duration Curve for Hunting Bayou Above Tidal (1007R_04)**

## 4.5 Estimated Loading and Critical Conditions

USEPA regulations at 40 CFR 130.7(c) (1) require TMDLs to take into account critical conditions for stream flow, loading, and all applicable water quality standards. To accomplish this, available instream WQM data were evaluated with respect to stream flows and the magnitude of water quality criteria exceedance. TMDLs are derived for indicator bacteria in 303(d) listed water bodies at specific WQM stations based on LDCs.

To calculate the bacteria load at the criterion for freshwater segments, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*24,465,755 dL/ft3 * seconds/day*) and the criterion specific to each indicator bacteria. This calculation produces the maximum bacteria load in the stream without exceeding the instantaneous standard over the range of flow conditions. In the case of *E. coli*, the allowable geometric mean concentrations defined in the SWQS are the TMDL. *E. coli* is plotted versus flow exceedance percentiles as a LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a bacteria load.

To estimate existing loading, bacteria observations from 2000 to 2006 are paired with the flows measured or estimated in that segment on the same date. Pollutant loads are then calculated by multiplying the measured bacteria concentration by the flow rate and a unit conversion factor of *24,465,755 dL/ft3 * seconds/day*. The associated flow exceedance percentile is then matched with the measured flow from the tables provided in Appendix G. The observed bacteria loads are then added to the LDC plot as points. These points represent individual ambient water quality samples of bacteria. Points above the LDC indicate the bacteria instantaneous standard was exceeded at the time of sampling. Conversely, points under the LDC indicate the sample met the criterion.

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

Table 4-2 presents the percent reduction goals necessary to achieve the contact recreation standard for select indicator bacteria for each 303(d) listed stream in the Study Area, as derived from the LDCs. Percent reduction goals for each 303(d)-listed stream in the Study Area are based on data analysis using the geometric mean criterion since it is anticipated that achieving the geometric mean over an extended period of time will likely ensure that the single sample criterion will also be achieved. Because the geometric mean criterion is considered more stringent, the TMDL for each of these sampling locations is determined by selecting the highest percent reduction goal calculated for the geometric mean criterion.

The sampling location requiring the highest percent reduction based on the geometric mean criterion was chosen for each stream. The most-downstream stations were found to require the highest percent reductions for all the segments within the Study Area. The TMDL percent reduction goals are based on the geometric mean criterion for *E. coli*.

The highest percent reductions for each stream are found in Table 4-2. The pollutant load allocations and percent reduction goals for each flow regime are summarized in Section 5.6. The highest percent reduction goals for each segment were all but one found to occur in the flow regime with the highest flows (0-20$^{th}$ percentile). The only exception is assessment unit 1007O_01, for which the highest reduction occurs at the lowest flows. The percent reduction goals under the highest flow conditions range from 81 to 100 percent. However, the overall percent reduction goals range from 46 to 99 percent.

**Table 4-2 TMDL percent Reductions Required to Meet Contact Recreation Standards in the Eastern Houston Watersheds**

| Assessment Unit | Sampling Location | Stream Name | Indicator Bacteria Species | Highest Reduction | | Overall Reduction |
|---|---|---|---|---|---|---|
| | | | | Percent Reduction | Corresponding Flow Regime | |
| 1006F_01 | 16662 | Big Gulch Above Tidal | *E. coli* | 97% | Highest flows | 88% |
| 1006H_01 | 16663 | Spring Gully Above Tidal | *E. coli* | 94% | Highest flows | 74% |
| 1007F_01 | 16661 | Berry Bayou Above Tidal | *E. coli* | 96% | Highest flows | 95% |
| 1007G_01 | 16653 | Kuhlman Gully Above Tidal | *E. coli* | 99% | Highest flows | 93% |
| 1007H_01 | 16659 | Pine Gully Above Tidal | *E. coli* | 98% | Highest flows | 96% |
| 1007I_01 | 16658 | Plum Creek Above Tidal | *E. coli* | 100% | Highest flows | 99% |
| 1007K_01 | 16650 | Country Club Bayou | *E. coli* | 99% | Highest flows | 98% |
| 1007M_01 | 16657 | Unnamed Non-Tidal Tributary of Hunting Bay | *E. coli* | 97% | Highest flows | 80% |
| 1007O_01 | 16649 | Unnamed Non-Tidal Tributary of Buffalo Bay | *E. coli* | 98% | Lowest flows | 96% |
| 1007R_01 to 1007R_03 | 11129 | Hunting Bayou Above Tidal | *E. coli* | 81% | Highest flows | 46% |
| 1007R_04 | 11128 | | *E. coli* | 87% | Highest flows | 72% |

# SECTION 5
# TMDL CALCULATIONS

## 5.1 Wasteload Allocation

TPDES-permitted facilities are allocated a daily wasteload calculated as their permitted discharge flow rate multiplied by one half of the instream geometric mean water quality criterion. In other words, the facilities are required to meet instream criteria at their points of discharge. Table 5-1 summarizes the WLA for the TPDES-permitted facilities within the Study Area. The WWTFs will not be subject to all listed indicator bacteria. The WLA for each facility ($WLA_{WWTF}$) is derived from the following equation:

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

*Where:*

*criterion = 126 MPN/100mL for E. coli*

*flow ($10^6$ gal/day) = permitted flow*

*unit conversion factor = 37,854,120-$10^6$gal/day*

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 there are no TPDES WWTFs discharging into the contributing watershed of a WQM station, then WWTF WLA is zero. Compliance with the $WLA_{WWTF}$ will be achieved by adhering to the indicator bacteria discharge limits and disinfection requirements of TPDES permits.

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. Given the limited amount of data available and the complexities associated with simulating rainfall runoff and the variability of storm water loading, a simplified approach for estimating the $WLA_{MS4}$ areas was used in the development of these TMDLs. For the LDC method, the percentage of each watershed under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be dedicated as the permitted storm water contribution in the $WLA_{STORM\ WATER}$ component of the TMDL. The difference between the total storm water runoff load and the portion allocated to $WLA_{STORM\ WATER}$ constitutes the LA component of the TMDL (direct nonpoint runoff).

**Table 5-1 Wasteload Allocations for TPDES-Permitted Facilities**

| Stream Name | Assessment Unit | TPDES Number | NPDES Number | Facility Name | 2008 Permitted Flow (MGD) | *E. Coli* (counts/day) |
|---|---|---|---|---|---|---|
| Big Gulch Above Tidal | 1006F_01 | 10608-002 | TX0062952 | Royalwood MUD | 0.26 | 6.20E+08 |
| | | 14690-001 | TX0128601 | Normandy Utility Co LP | 0.09 | 2.15E+08 |
| Spring Gully Above Tidal | 1006H_01 | 11923-001 | TX0075078 | G & C Investment Co LLP & Garlock Sealing | 0.005 | 1.19E+07 |
| | | 13503-001 | TX0105406 | Maxey Road WSC | 0.015 | 3.58E+07 |
| Berry Bayou Above Tidal | 1007F_01 | 10495-065 | TX0034886 | City of Houston - Easthaven | 3 | 7.15E+09 |
| | | 10287-001 | TX0057304 | City of South Houston | 4 | 9.54E+09 |
| | | 10495-050 | TX0063045 | City of Houston - WCID 047 | 5.76 | 1.37E+10 |
| Hunting Bayou Above Tidal | 1007R_03 | 10495-023 | TX0063029 | City of Houston - Homestead | 4 | 9.54E+09 |
| | 1007R_04 | 03987-000 | TX0119075 | Cooper, Jerry Lynn | 0.2 | 4.77E+08 |

## 5.2 Load Allocation

As discussed in Section 3, non-permitted sources of bacteria loading to the receiving streams of each waterbody emanate from a number of different sources. The data analyses demonstrate that exceedances at the WQM stations are in part caused by nonpoint source loading. The LAs for each stream segment are calculated as the difference between the TMDL, MOS, WLA, and WLA for storm water as follows:

$$LA = TMDL - \sum WLA_{WWTF} - \sum WLA_{STORM\ WATER} - MOS$$

Where:

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

## 5.3 Allocations for Future Growth

Compliance with each TMDL 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. It is assumed the assimilative capacity of streams increases as the amount of flow increases. Increases in flow may allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation criterion. The addition of any future wastewater discharge facilities will be evaluated on a case-by-case basis.

Table 5-2 shows the population increases in each of the eleven TMDL assessment units based on the population projections from the H-GAC report. The population increases range from 7 percent to 62 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 5-2 Population Projection per Subwatershed**

| Stream Name | Assessment Unit | 2005 | 2035 | Increase |
|---|---|---|---|---|
| Big Gulch Above Tidal | 1006F_01 | 10,167 | 15,545 | 53% |
| Spring Gully Above Tidal | 1006H_01 | 2,850 | 4,536 | 59% |
| Berry Bayou Above Tidal | 1007F_01 | 68,390 | 89,140 | 30% |
| Kuhlman Gully Above Tidal | 1007G_01 | 24,146 | 34,936 | 45% |
| Pine Gully Above Tidal | 1007H_01 | 11,574 | 12,596 | 9% |
| Plum Creek Above Tidal | 1007I_01 | 30,046 | 38,680 | 29% |

| Stream Name | Assessment Unit | 2005 | 2035 | Increase |
|---|---|---|---|---|
| Country Club Bayou | 1007K_01 | 28,911 | 39,732 | 37% |
| Unnamed Non-Tidal Tributary of Hunting Bay | 1007M_01 | 5,834 | 9,441 | 62% |
| Unnamed Non-Tidal Tributary of Buffalo Bay | 1007O_01 | 5,864 | 7,350 | 25% |
| Hunting Bayou Above Tidal | 1007R_01 | 5,134 | 5,468 | 7% |
| Hunting Bayou Above Tidal | 1007R_02 | 4,061 | 5,541 | 36% |
| Hunting Bayou Above Tidal | 1007R_03 | 45,918 | 62,092 | 35% |
| Hunting Bayou Above Tidal | 1007R_04 | 8,673 | 13,773 | 59% |

## 5.4 Margin of Safety

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs include an MOS. The MOS is a conservative measure incorporated into the TMDL equation that accounts for the uncertainty associated with calculating the allowable pollutant loading to ensure geometric mean criterion are attained. USEPA guidance allows for use of implicit or explicit expressions of the MOS, or both. When conservative assumptions are used in development of the TMDL, or conservative factors are used in the calculations, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for uncertainty, then the MOS is considered explicit.

These TMDLs incorporate an explicit MOS by setting a more stringent target for indicator bacteria loads 5 percent lower than the single sample criterion. The explicit MOS 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 *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 waterbody is slightly reduced. The TMDLs for the streams in this report incorporate an explicit MOS in each LDC by using 95 percent of the single sample criterion.

## 5.5 Seasonal Variability

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.

## 5.6 TMDL Calculations

The bacteria TMDLs for the 303(d)-listed WQM stations covered in this report were derived using LDCs. A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS, which attempts to account for uncertainty concerning the relationship between effluent limitations and water quality.

This definition can be expressed by the following equation:

$$\boldsymbol{TMDL = \Sigma\, WLA + \Sigma\, LA + MOS}$$

Tables 5-3 through 5-13 summarize the pollutant load allocations and percent reduction goals, for the median flow exceedance percentile of each of the three hydrologic classification categories. The percent reduction goals provided in the tables are derived from calculations using the geometric mean criterion not the single sample criterion. The estimated maximum allowable load of *E. coli* for each freshwater segment was determined as that corresponding to the regime requiring the highest load reduction (Tables 5-3 to 5-13).

**Table 5.3 *E. coli* TMDL Calculations for Big Gulch Above Tidal (1006F_01)**

| Station 16662 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 4.1 | 0.51 | 0.24 |
| **Existing Load (10^9 org/day)** | 3.96E+02 | 1.29E+01 | 8.57E-01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 1.28E+01 | 1.59E+00 | 7.32E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 6.39E-01 | 7.93E-02 | 3.66E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 1.21E+01 | 1.51E+00 | 6.96E-01 |
| **Load Reduction (10^9 org/day)** | 3.84E+02 | 1.14E+01 | 1.61E-01 |
| **Load Reduction** | **96.9%** | 88.3% | 18.8% |
| **Overall Load Reduction** | 88% | | |
| **TMDL ($Q_{future}$*WQS) (10^9 org/day)** | 1.49E+01 | | |

**Table 5.4 *E. coli* TMDL Calculations for Spring Gully Above Tidal (1006H_01)**

| Station 16663 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 11.2 | 1.15 | 0.36 |
| **Existing Load (10^9 org/day)** | 5.38E+02 | 8.31E+00 | 2.10E+00 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 3.46E+01 | 3.53E+00 | 1.10E+00 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.73E+00 | 1.77E-01 | 5.50E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 3.29E+01 | 3.35E+00 | 1.05E+00 |
| **Load Reduction (10^9 org/day)** | 5.05E+02 | 4.96E+00 | 1.05E+00 |
| **Load Reduction** | **93.9%** | 59.6% | 50.2% |
| **Overall Load Reduction** | 74% | | |
| **TMDL ($Q_{future}$*WQS) (10^9 org/day)** | 3.48E+01 | | |

**Table 5.5 *E. coli* TMDL Calculations for Berry Bayou Above Tidal (1007F_01)**

| Station 16661 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-60%** | **60%-100%** |
| **Median Flow, Q (cfs)** | 34.1 | 11.03 | 7.17 |
| **Existing Load (10^9 org/day)** | 3.67E+03 | 6.87E+02 | 1.06E+02 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 1.05E+02 | 3.40E+01 | 2.21E+01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 5.25E+00 | 1.70E+00 | 1.11E+00 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 9.98E+01 | 3.23E+01 | 2.10E+01 |
| **Load Reduction (10^9 org/day)** | 3.57E+03 | 6.54E+02 | 8.49E+01 |
| **Load Reduction** | **97.3%** | 95.3% | 80.2% |
| **Overall Load Reduction** | 95% | | |
| **TMDL ($Q_{future}$*WQS) (10^9 org/day)** | 1.62E+02 | | |

**Table 5.6 *E. coli* TMDL Calculations for Kuhlman Gully Above Tidal (1007G_01)**

| Station 16653 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 11.8 | 0.83 | 0.26 |
| **Existing Load (10^9 org/day)** | 2.44E+03 | 2.58E+01 | 2.06E+00 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 3.63E+01 | 2.55E+00 | 7.95E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.82E+00 | 1.28E-01 | 3.98E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 3.45E+01 | 2.42E+00 | 7.55E-01 |
| **Load Reduction (10^9 org/day)** | 2.40E+03 | 2.33E+01 | 1.30E+00 |
| **Load Reduction** | **98.6%** | 90.6% | 63.3% |
| **Overall Load Reduction** | 93% | | |
| **TMDL (Q*WQS) (10^9 org/day)** | 3.63E+01 | | |

**Table 5.7 *E. coli* TMDL Calculations for Pine Gully Above Tidal (1007H_01)**

| Station 16659 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 3.2 | 0.23 | 0.07 |
| **Existing Load (10^9 org/day)** | 5.20E+02 | 1.35E+01 | 3.14E+00 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 1.00E+01 | 7.02E-01 | 2.19E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 5.00E-01 | 3.51E-02 | 1.09E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 9.50E+00 | 6.67E-01 | 2.08E-01 |
| **Load Reduction (10^9 org/day)** | 5.11E+02 | 1.28E+01 | 2.93E+00 |
| **Load Reduction** | **98.2%** | 95.0% | 93.4% |
| **Overall Load Reduction** | 96% | | |
| **TMDL (Q*WQS) (10^9 org/day)** | 1.00E+01 | | |

**Table 5.8 *E. coli* TMDL Calculations for Plum Creek Above Tidal (1007I_01)**

| Station 16658 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 8.9 | 0.62 | 0.19 |
| **Existing Load (10^9 org/day)** | 8.67E+03 | 8.12E+01 | 1.38E+01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 2.73E+01 | 1.92E+00 | 5.98E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.37E+00 | 9.61E-02 | 2.99E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 2.60E+01 | 1.83E+00 | 5.69E-01 |
| **Load Reduction (10^9 org/day)** | 8.65E+03 | 7.93E+01 | 1.33E+01 |
| **Load Reduction** | **99.7%** | 97.8% | 95.9% |
| **Overall Load Reduction** | 99% | | |
| **TMDL (Q*WQS) (10^9 org/day)** | 2.73E+01 | | |

**Table 5.9 E. coli TMDL Calculations for Country Club Bayou (1007K_01)**

| Station 16650 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 12.6 | 1.47 | 0.57 |
| **Existing Load (10^9 org/day)** | 2.40E+03 | 2.76E+02 | 3.93E+01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 3.89E+01 | 4.54E+00 | 1.75E+00 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.95E+00 | 2.27E-01 | 8.76E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 3.70E+01 | 4.32E+00 | 1.66E+00 |
| **Load Reduction (10^9 org/day)** | 2.37E+03 | 2.72E+02 | 3.76E+01 |
| **Load Reduction** | **98.5%** | 98.4% | 95.8% |
| **Overall Load Reduction** | 98.4% | | |
| **TMDL (Q*WQS) (10^9 org/day)** | 3.89E+01 | | |

**Table 5.10 *E. coli* TMDL Calculations for Unnamed Non-Tidal Tributary of Hunting Bay (1007M_01)**

| Station 16657 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 10.5 | 0.74 | 0.23 |
| **Existing Load (10^9 org/day)** | 1.07E+03 | 1.01E+01 | 9.26E-01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 3.23E+01 | 2.27E+00 | 7.08E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.62E+00 | 1.14E-01 | 3.54E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 3.07E+01 | 2.16E+00 | 6.72E-01 |
| **Load Reduction (10^9 org/day)** | 1.04E+03 | 7.93E+00 | 2.54E-01 |
| **Load Reduction** | **97.1%** | 78.6% | 27.4% |
| **Overall Load Reduction** | 80% | | |
| **TMDL ($Q_{future}$*WQS) (10^9 org/day)** | 3.23E+01 | | |

**Table 5.11 *E. coli* TMDL Calculations for Unnamed Non-Tidal Tributary of Buffalo Bay (1007O_01)**

| Station 16649 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 4.7 | 0.33 | 0.10 |
| **Existing Load (10^9 org/day)** | 4.27E+02 | 1.10E+01 | 1.48E+01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 1.46E+01 | 1.03E+00 | 3.20E-01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 7.32E-01 | 5.14E-02 | 1.60E-02 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 1.39E+01 | 9.77E-01 | 3.04E-01 |
| **Load Reduction (10^9 org/day)** | 4.13E+02 | 9.99E+00 | 1.45E+01 |
| **Load Reduction** | 96.7% | 91.1% | **97.9%** |
| **Overall Load Reduction** | 95.7% | | |
| **TMDL ($Q_{future}$*WQS) (10^9 org/day)** | | | 3.20E-01 |

**Table 5.12 *E. coli* TMDL Calculations for Hunting Bayou Above Tidal (1007R_01 to 1007R_03)**

| Station 11129 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 54.0 | 9.1 | 4.0 |
| **Existing Load (10^9 org/day)** | 8.23E+02 | 4.68E+01 | 6.86E+00 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 1.66E+02 | 2.81E+01 | 1.23E+01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 8.32E+00 | 1.40E+00 | 6.17E-01 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 1.58E+02 | 2.66E+01 | 1.17E+01 |
| **Load Reduction (10^9 org/day)** | 6.65E+02 | 2.01E+01 | 0.00E+00 |
| **Load Reduction** | **80.8%** | 43.0% | 0.0% |
| **Overall Load Reduction** | 46% | | |
| **TMDL[a] ($Q_{future}$*WQS) (10^9 org/day)** | 1.92E+02 | | |

[a] *Total drainage areas for 1007R_01, 1007R_02, and 1007R_03*

**Table 5.13 *E. coli* TMDL Calculations for Hunting Bayou Above Tidal (1007R_04)**

| Station 11128 | | | |
|---|---|---|---|
| **Flow Regime** | **0%-20%** | **20%-80%** | **80%-100%** |
| **Median Flow, Q (cfs)** | 79.8 | 12.09 | 5.27 |
| **Existing Load (10^9 org/day)** | 1.74E+03 | 8.69E+01 | 3.18E+01 |
| **Load Capacity at Current Flow (Q*126 org/dL) (10^9 org/day)** | 2.46E+02 | 3.73E+01 | 1.63E+01 |
| **MOS (Load Capacity*0.05) (10^9 org/day)** | 1.23E+01 | 1.86E+00 | 8.13E-01 |
| **Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)** | 2.34E+02 | 3.54E+01 | 1.54E+01 |
| **Load Reduction (10^9 org/day)** | 1.51E+03 | 5.14E+01 | 1.63E+01 |
| **Load Reduction** | **86.6%** | 59.2% | 51.4% |
| **Overall Load Reduction** | 72% | | |
| **TMDL[a] ($Q_{future}$*WQS) (10^9 org/day)** | 2.73E+02 | | |

[a] *Total area draining to Hunting Bayou Above Tidal (1007R all assessment units)*

Because Hunting Bayou above Tidal at WQM station 11129 encompasses three assessment units, the calculated TMDL for AU 1007R_03 (Table 5-12) was proportioned using two ratios: (i) assessment unit length to total stream length to proportion WLA, MS4 and LA, and (ii) ratio of WWTF flows discharging to each assessment unit to the total WWTF in the watershed draining to station 11129 to proportion WLA-WWTF and Future Growth for AUs 1007R_01 and 1007R_02. Ratios are summarized in Table 5-14.

**Table 5-14 Ratios for Proportioning of Hunting Bayou at 11129 TMDL by Assessment Unit**

| Length of Segment (mi) | Assessment Unit | Length of AU (mi) | AU/Segment Length Ratio[a] | Total Estimated Future WWTF Permitted Flow for Segment (cfs) | Estimated Future WWTF Permitted Flow (cfs) | AU/Segment Flow Ratio[b] |
|---|---|---|---|---|---|---|
| 6.9 | 1107R_01 | 0.9 | 0.13 | 7.8 | 0 | 0 |
| | 1107R_02 | 1.2 | 0.17 | | 0 | 0 |

[a] *To proportion WLA-MS4 and LA*
[b] *To proportion WLA-WWTF and future growth*

Once the LA, WLA, and Future Growth for each assessment unit were calculated using the above listed ratios and the percent of the drainage areas within an MS4 (Table 3-4), they were added. The sums were then divided by 0.95 (to account for the 5% MOS) to obtain the proportioned TMDLs.

The final TMDLs for the thirteen assessment units included in this project are summarized in Table 5-15. The TMDLs were calculated based on the median flow range, which corresponds to the range requiring the highest percent reductions as shown in Table 4-2.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are presented in Table 5-16. In this table the future capacity for WWTF has been added to the $WLA_{WWTF}$.

TMDL values and allocations in Table 5-16 are derived from calculations using the existing water quality criterion for *E. coli* and a critical flow condition (median flow of the hydrologic range requiring the greatest pollutant load reduction). However, designated uses and water quality criteria for these water bodies are subject to change through the TCEQ standards revision process. Figures 5-1 through 5-13 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 5-1 through 5-13 allow calculating new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*.

**Table 5-15 *E. coli* TMDL Summary Calculations for Eastern Houston Watershed Assessment Units**

| Assessment Unit | Sampling Location | Stream Name | Indicator Bacteria Species | TMDL[a] (MPN/day) | $WLA_{WWTF}$[b] (MPN/day) | $WLA_{MS4}$[c] (MPN/day) | LA[d] (MPN/day) | MOS[e] (MPN/day) | Future Growth[f] (MPN/day) |
|---|---|---|---|---|---|---|---|---|---|
| 1006F_01 | 16662 | Big Gulch above Tidal | *E. coli* | 1.49E+10 | 8.35E+08 | 7.33E+09 | 5.53E+09 | 7.44E+08 | 4.41E+08 |
| 1006H_01 | 16663 | Spring Gully above Tidal | *E. coli* | 3.48E+10 | 4.77E+07 | 2.90E+10 | 3.96E+09 | 1.74E+09 | 2.82E+07 |
| 1007F_01 | 16661 | Berry Bayou above Tidal | *E. coli* | 1.62E+11 | 3.04E+10 | 1.15E+11 | 0 | 8.12E+09 | 9.23E+09 |
| 1007G_01 | 16653 | Kuhlman Gully above Tidal | *E. coli* | 3.63E+10 | NA[g] | 3.45E+10 | 0 | 1.82E+09 | 0[h] |
| 1007H_01 | 16659 | Pine Gully above Tidal | *E. coli* | 1.00E+10 | NA[g] | 9.50E+09 | 0 | 5.00E+08 | 0[h] |
| 1007I_01 | 16658 | Plum Creek above Tidal | *E. coli* | 2.73E+10 | NA[g] | 2.60E+10 | 0 | 1.37E+09 | 0[h] |
| 1007K_01 | 16650 | Country Club Bayou | *E. coli* | 3.89E+10 | NA[g] | 3.70E+10 | 0 | 1.95E+09 | 0[h] |
| 1007M_01 | 16657 | Unnamed Non-Tidal Tributary of Hunting Bay | *E. coli* | 3.23E+10 | NA[g] | 3.07E+10 | 0 | 1.62E+09 | 0[j] |
| 1007O_01 | 16649 | Unnamed Non-Tidal Tributary of Buffalo Bay | *E. coli* | 3.20E+08 | NA[g] | 3.04E+08 | 0 | 1.60E+07 | 0[i] |
| 1007R_01 | 11129 | Hunting Bayou above Tidal | *E. coli* | 2.33E+10 | NA[g] | 2.21E+10 | 0 | 1.17E+09 | 0[j] |
| 1007R_02 | | | *E. coli* | 3.11E+10 | NA[g] | 2.95E+10 | 0 | 1.55E+09 | 0[j] |
| 1007R_03 | | | *E. coli* | 1.92E+11 | 9.54E+09 | 1.46E+11 | 2.38E+10 | 9.61E+09 | 3.36E+09 |
| 1007R_04 | 11128 | | *E. coli* | 2.73E+11 | 1.00E+10[k] | 2.12E+11 | 3.44E+10 | 1.37E+10 | 3.64E+09 |

[a] *Sum of WWTF with projected permitted flows for 2035, storm water runoff, and tributary loads discharging directly to the water quality segment that result in attainment of the geometric mean criterion.*
[b] *Sum of loads from the WWTF discharging upstream of the TMDL station. Individual loads are calculated as permitted flow * 126/2 (E. coli)MPN/100mL*conversion factor (Table 5-1).*
[c] *$WLA_{\text{STORM WATER}}$ = (TMDL – MOS – $WLA_{WWTF}$)*(percent of drainage area covered by Storm Water permits).*
[d] *LA = TMDL – MOS – $WLA_{WWTF}$ – $WLA_{\text{STORM WATER}}$ -Future growth*
[e] *MOS = TMDL x 0.05*
[f] *Projected increase in WWTF permitted flows*126/2*conversion factor*
[g] *NA= Allocation not applicable at this time. New WWTF must comply with the allocation for future growth*
[h] *Watershed is included in the service area for City of Houston-Sims Bayou WWTF and, thus, growth is addressed in the Sims Bayou TMDLs*
[i] *Watershed is included in the service area for City of Houston-69th Street WWTF and, thus, growth is to be addressed in another TMDL*
[j] *Future growth is addressed in other assessment units for the segment*
[k] *The WLAWWTF for 1007R_04 includes all the facilities discharging upstream of station 11128. Thus, this allocation includes WWTF that discharge to other AUs. Individual allocations are provided in Table 5-1*

## Table 5-16 Final TMDL Allocations

| Assessment Unit | TMDL (MPN/day) | $WLA_{WWTF}$ (MPN/day)[a] | $WLA_{STORM}$ WATER (MPN/day) | LA (MPN/day) | MOS (MPN/day) |
|---|---|---|---|---|---|
| 1006F_01 | 1.49E+10 | 1.28E+09 | 7.33E+09 | 5.53E+09 | 7.44E+08 |
| 1006H_01 | 3.48E+10 | 7.59E+07 | 2.90E+10 | 3.96E+09 | 1.74E+09 |
| 1007F_01 | 1.62E+11 | 3.97E+10 | 1.15E+11 | 0 | 8.12E+09 |
| 1007G_01 | 3.63E+10 | 0 | 3.45E+10 | 0 | 1.82E+09 |
| 1007H_01 | 1.00E+10 | 0 | 9.50E+09 | 0 | 5.00E+08 |
| 1007I_01 | 2.73E+10 | 0 | 2.60E+10 | 0 | 1.37E+09 |
| 1007K_01 | 3.89E+10 | 0 | 3.70E+10 | 0 | 1.95E+09 |
| 1007M_01 | 3.23E+10 | 0 | 3.07E+10 | 0 | 1.62E+09 |
| 1007O_01 | 3.20E+08 | 0 | 3.04E+08 | 0 | 1.60E+07 |
| 1007R_01 | 2.33E+10 | 0 | 2.21E+10 | 0 | 1.17E+09 |
| 1007R_02 | 3.11E+10 | 0 | 2.95E+10 | 0 | 1.55E+09 |
| 1007R_03 | 1.92E+11 | 1.29E+10 | 1.46E+11 | 2.38E+10 | 9.61E+09 |
| 1007R_04 | 2.73E+11 | 1.37E+10 | 2.12E+11 | 3.44E+10 | 1.37E+10 |

[a] $WLA_{WWTF} = WLA_{WWTF\ (Table\ 5\text{-}15)} + Future\ Growth_{(Table\ 5\text{-}15)}$

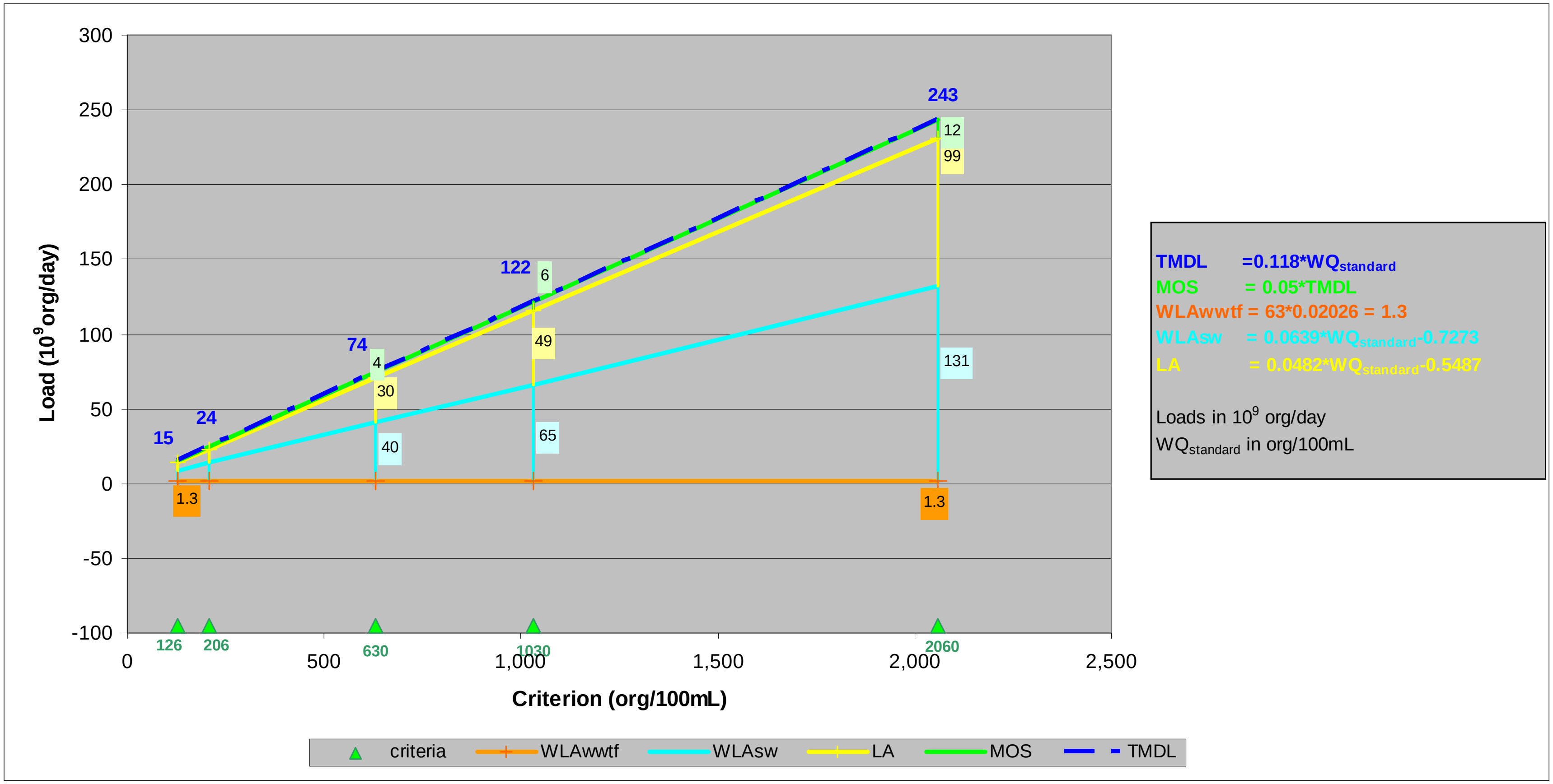


**Figure 5-1 Allocation Loads for AU 1006F_01 as a Function of WQ Criteria**

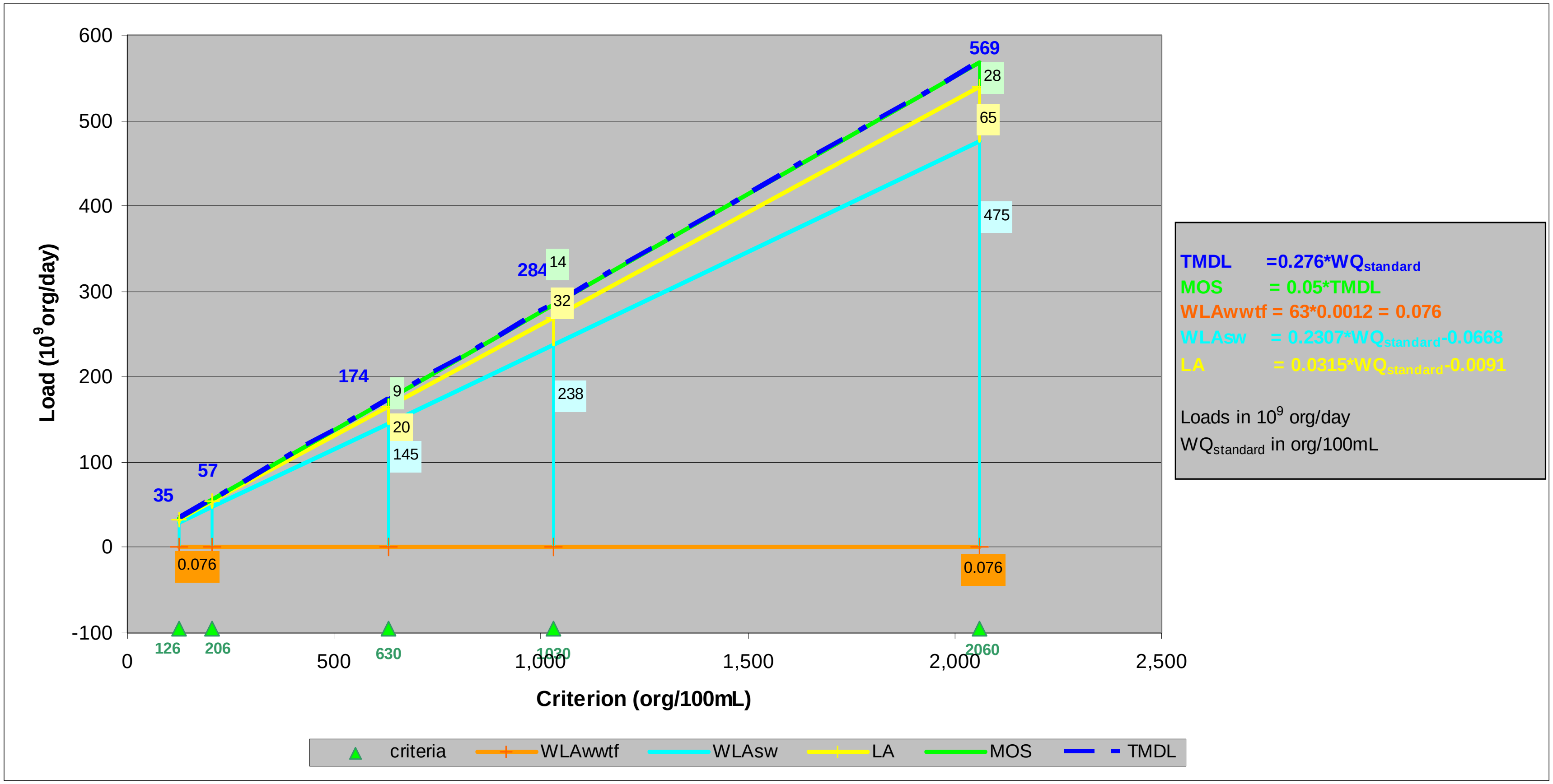


**Figure 5-2 Allocation Loads for AU 1006H_01 as a Function of WQ Criteria**

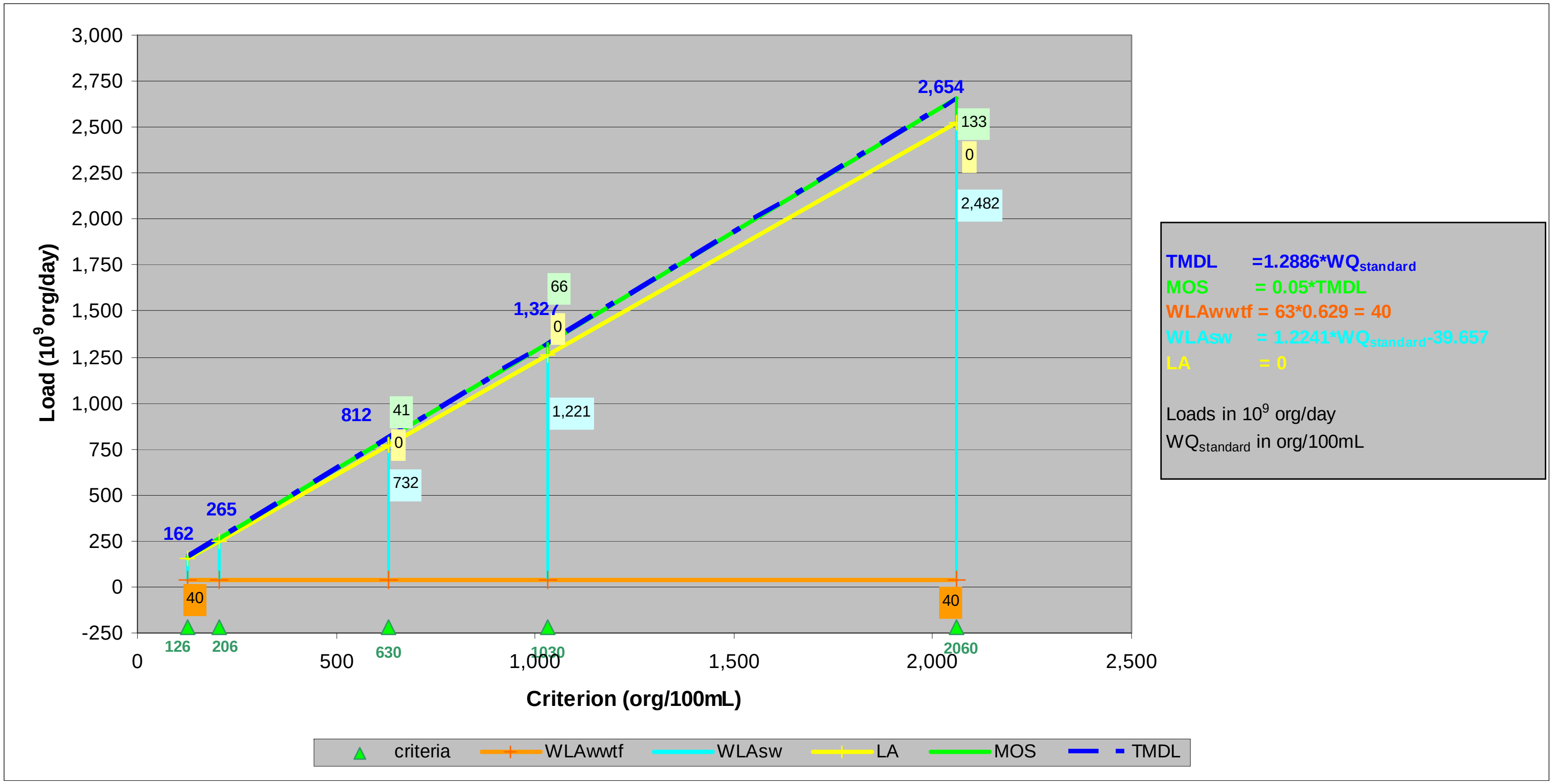


**Figure 5-3 Allocation Loads for AU 1007F_01 as a Function of WQ Criteria**

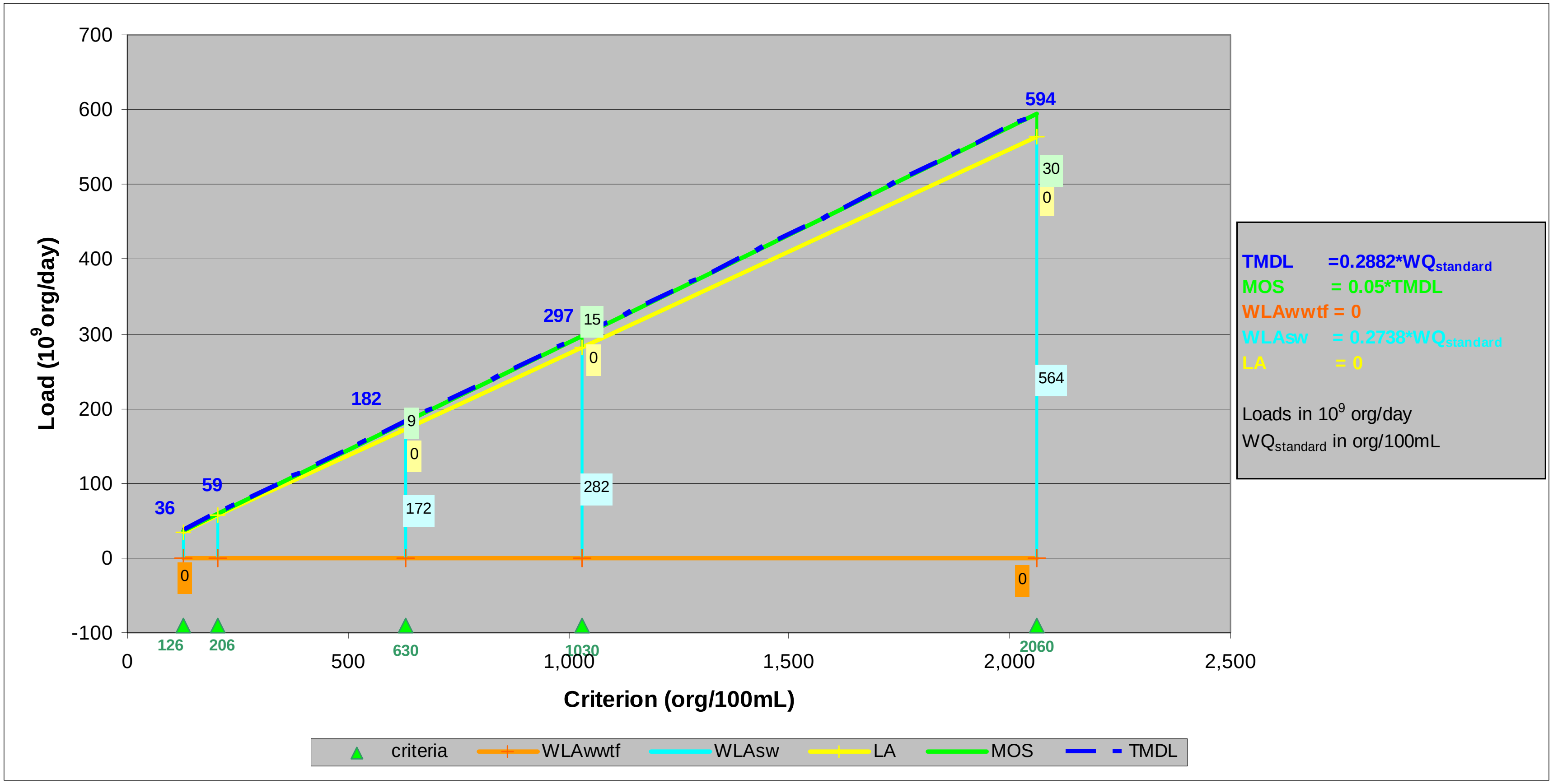


**Figure 5-4 Allocation Loads for AU 1007G_01 as a Function of WQ Criteria**

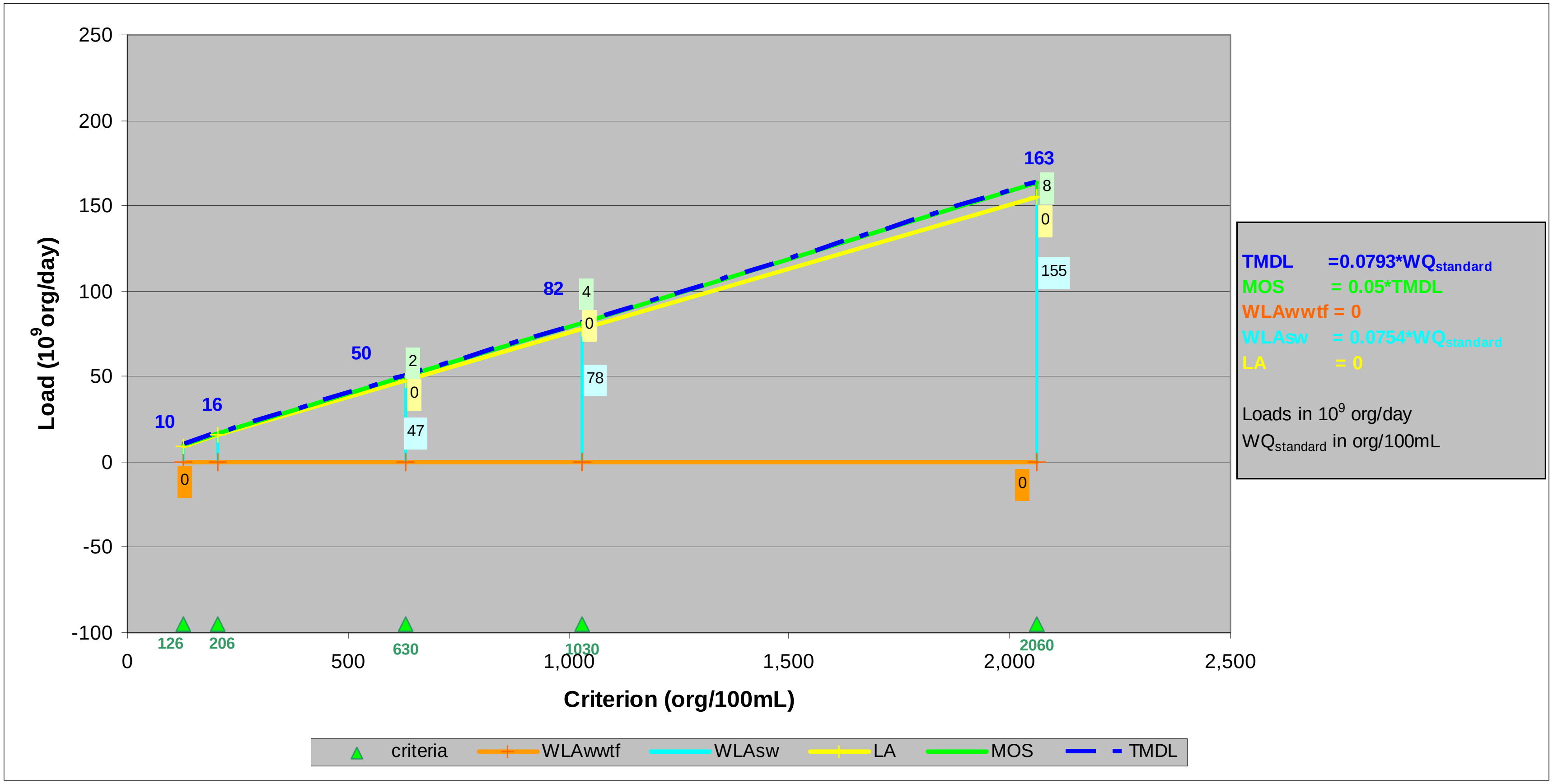


**Figure 5-5 Allocation Loads for AU 1007H_01 as a Function of WQ Criteria**

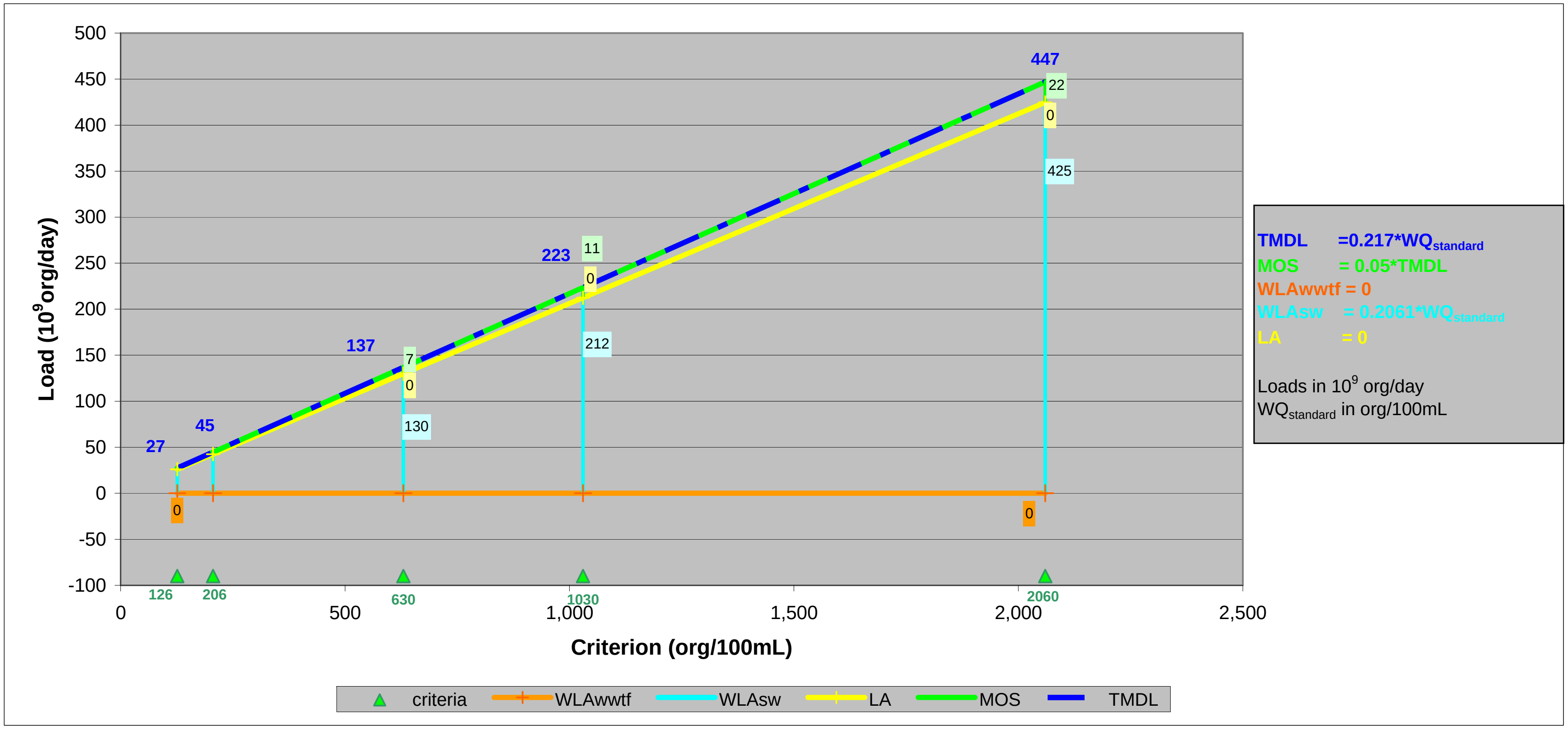


**Figure 5-6 Allocation Loads for AU 1007I_01 as a Function of WQ Criteria**

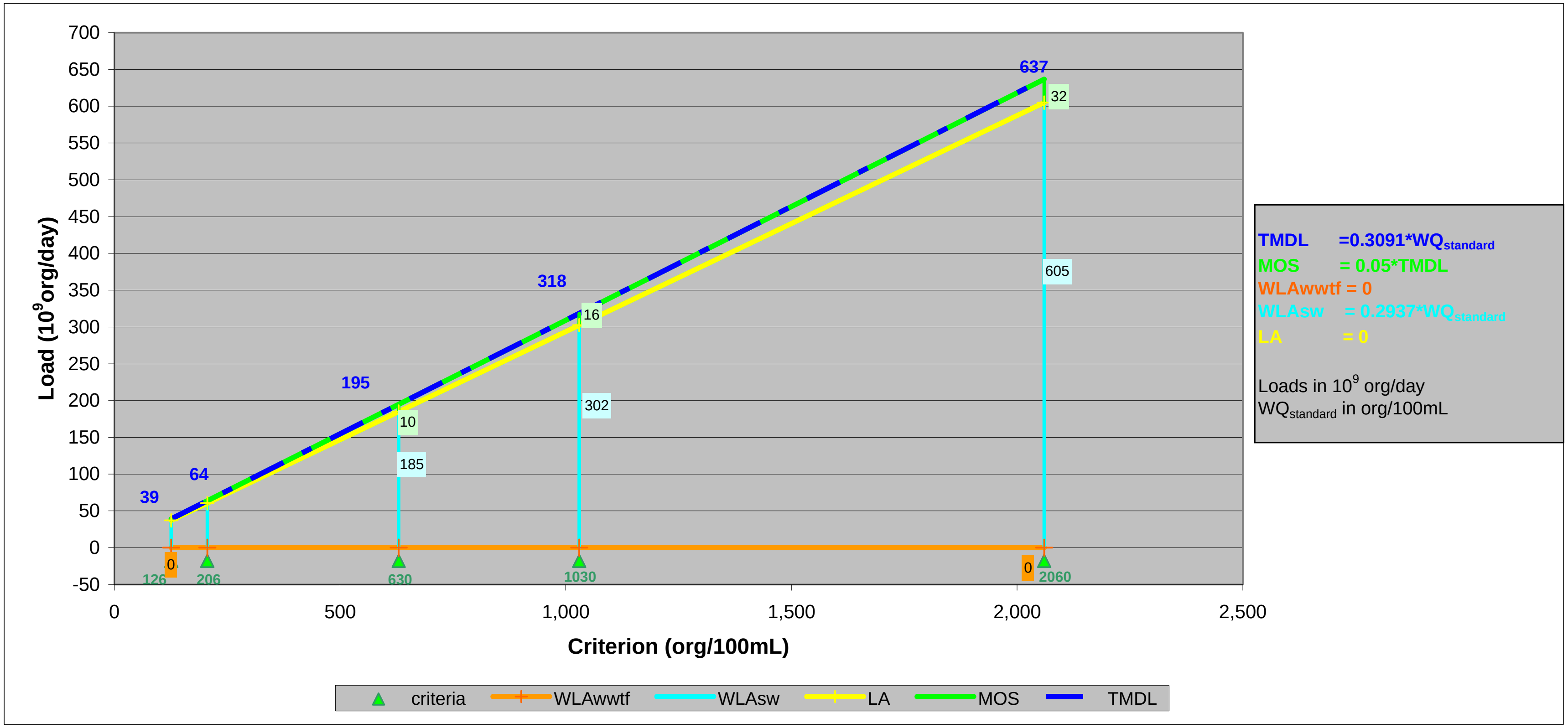


**Figure 5-7 Allocation Loads for AU 1007K_01 as a Function of WQ Criteria**

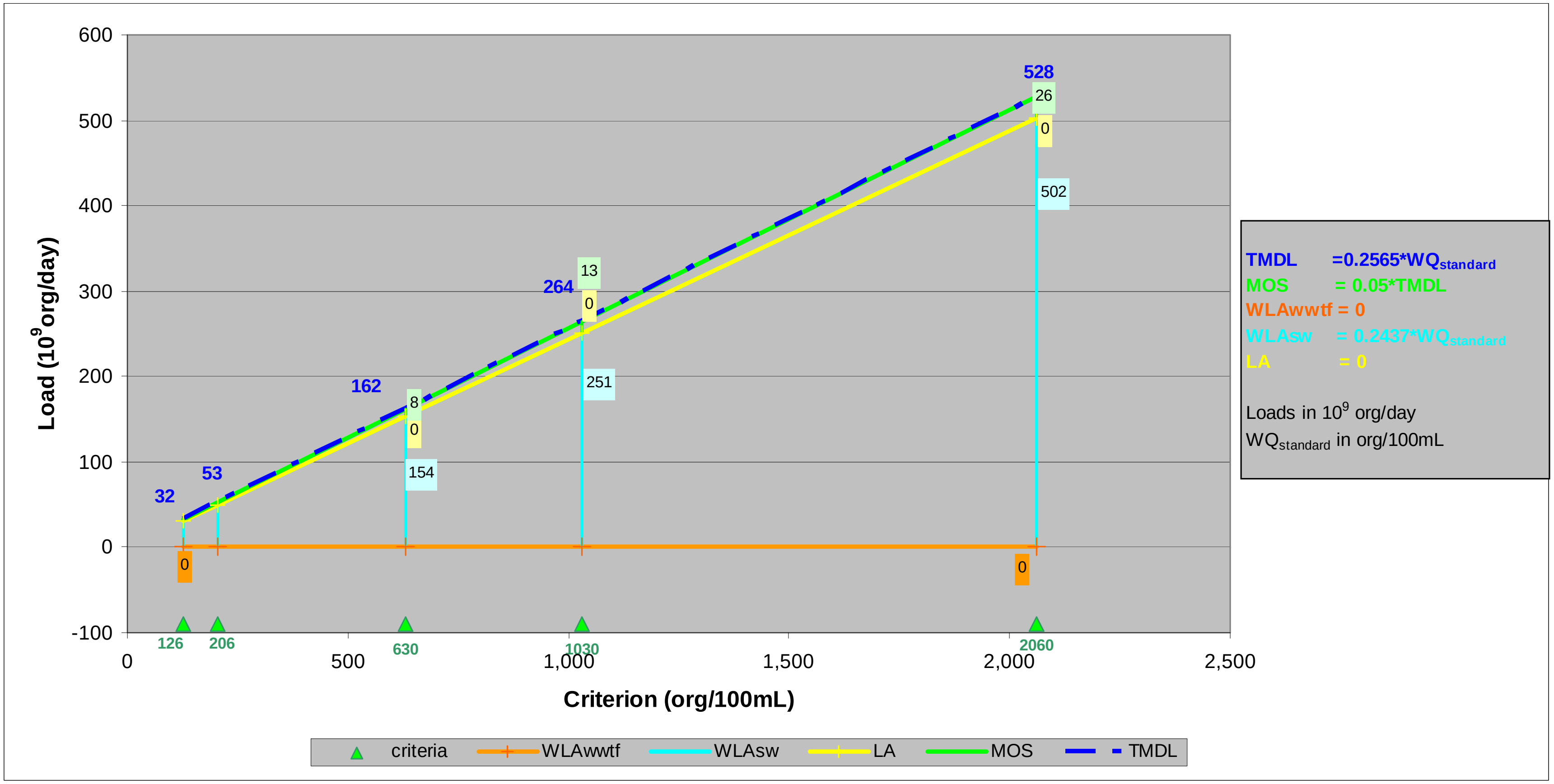


**Figure 5-8 Allocation Loads for AU 1007M_01 as a Function of WQ Criteria**

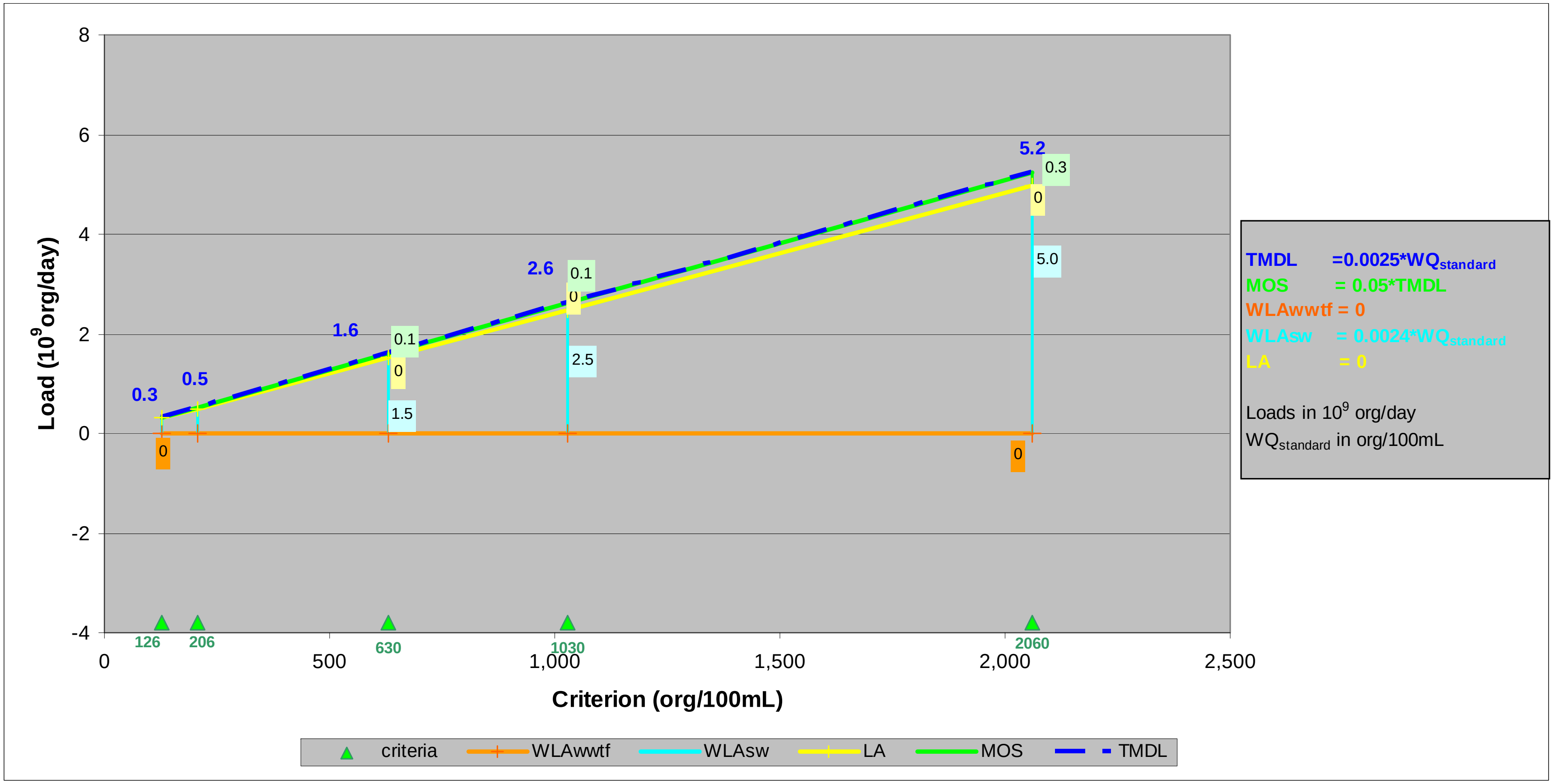


**Figure 5-9 Allocation Loads for AU 1007O_01 as a Function of WQ Criteria**

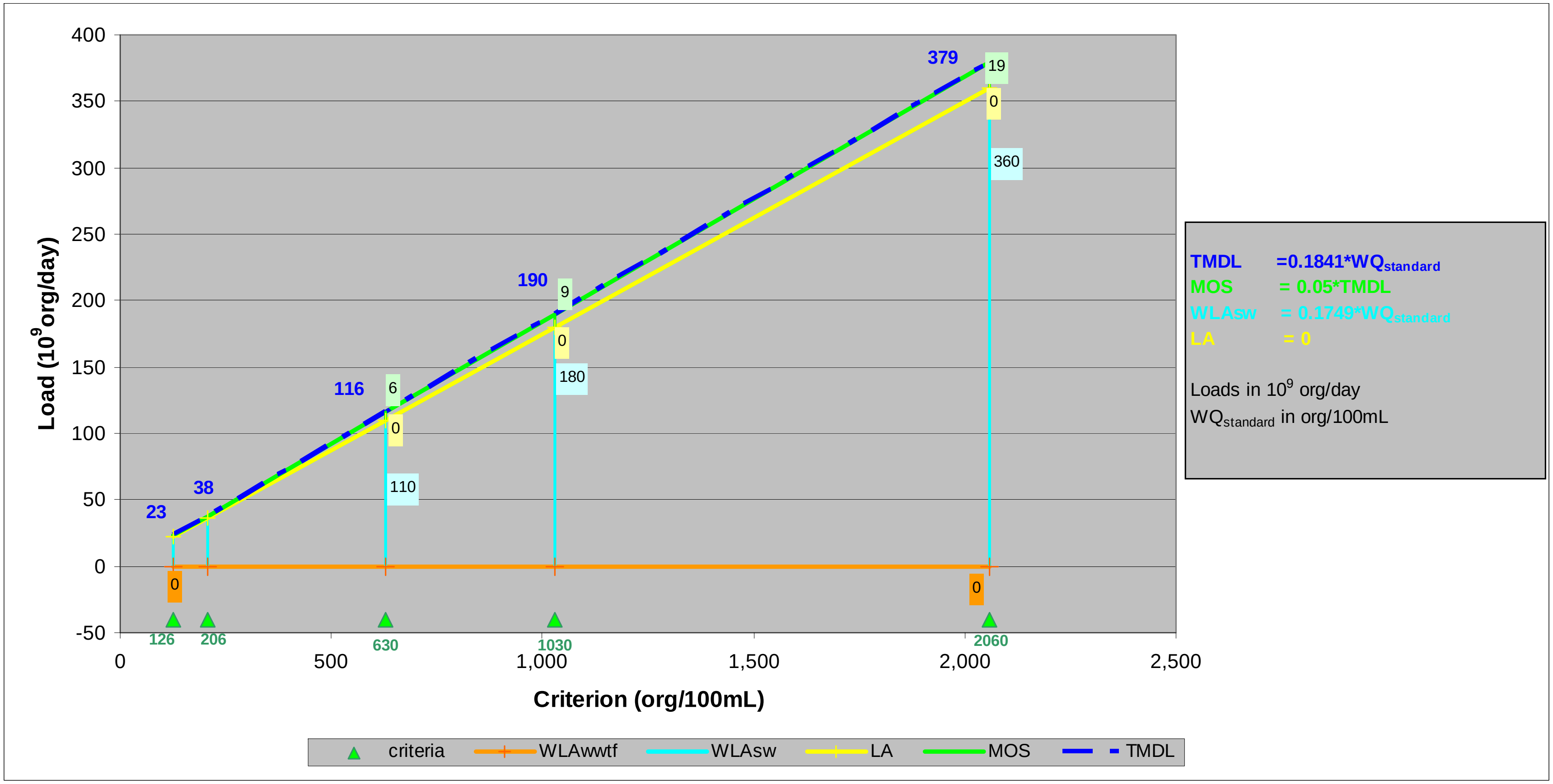


**Figure 5-10 Allocation Loads for AU 1007R_01 as a Function of WQ Criteria**

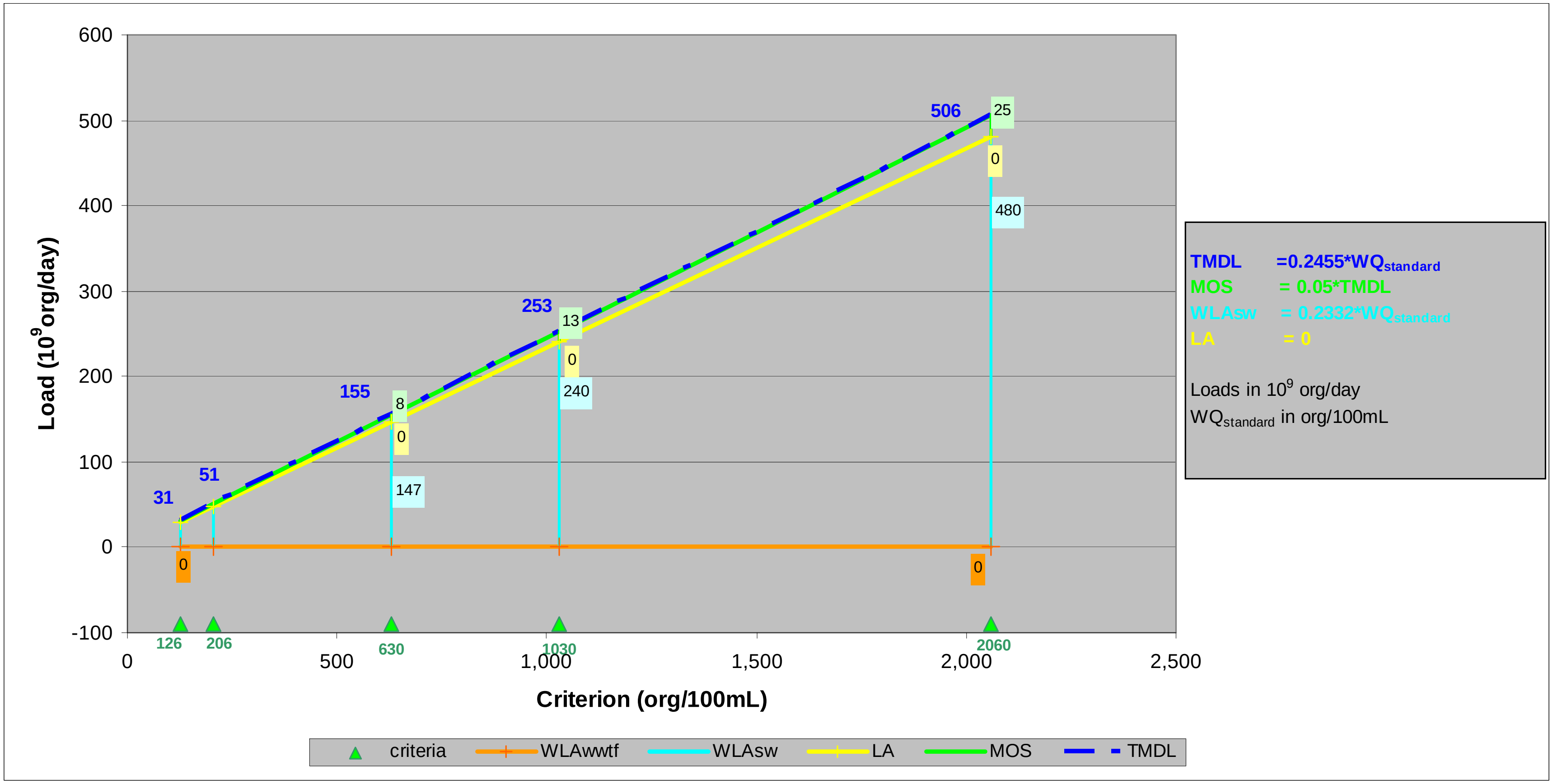


**Figure 5-11 Allocation Loads for AU 1007R_02 as a Function of WQ Criteria**

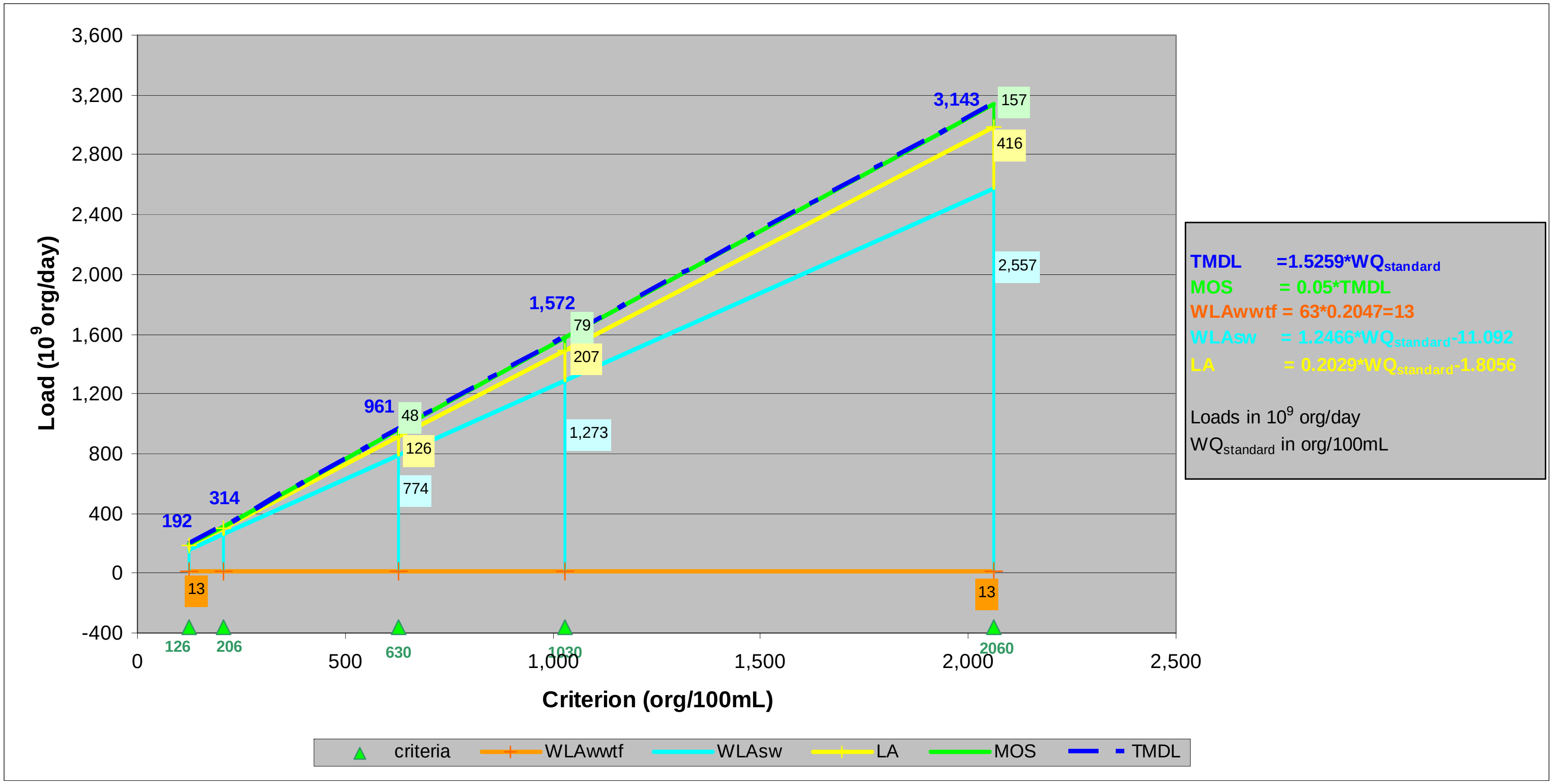


**Figure 5-12 Allocation Loads for AU 1007R_03 as a Function of WQ Criteria**

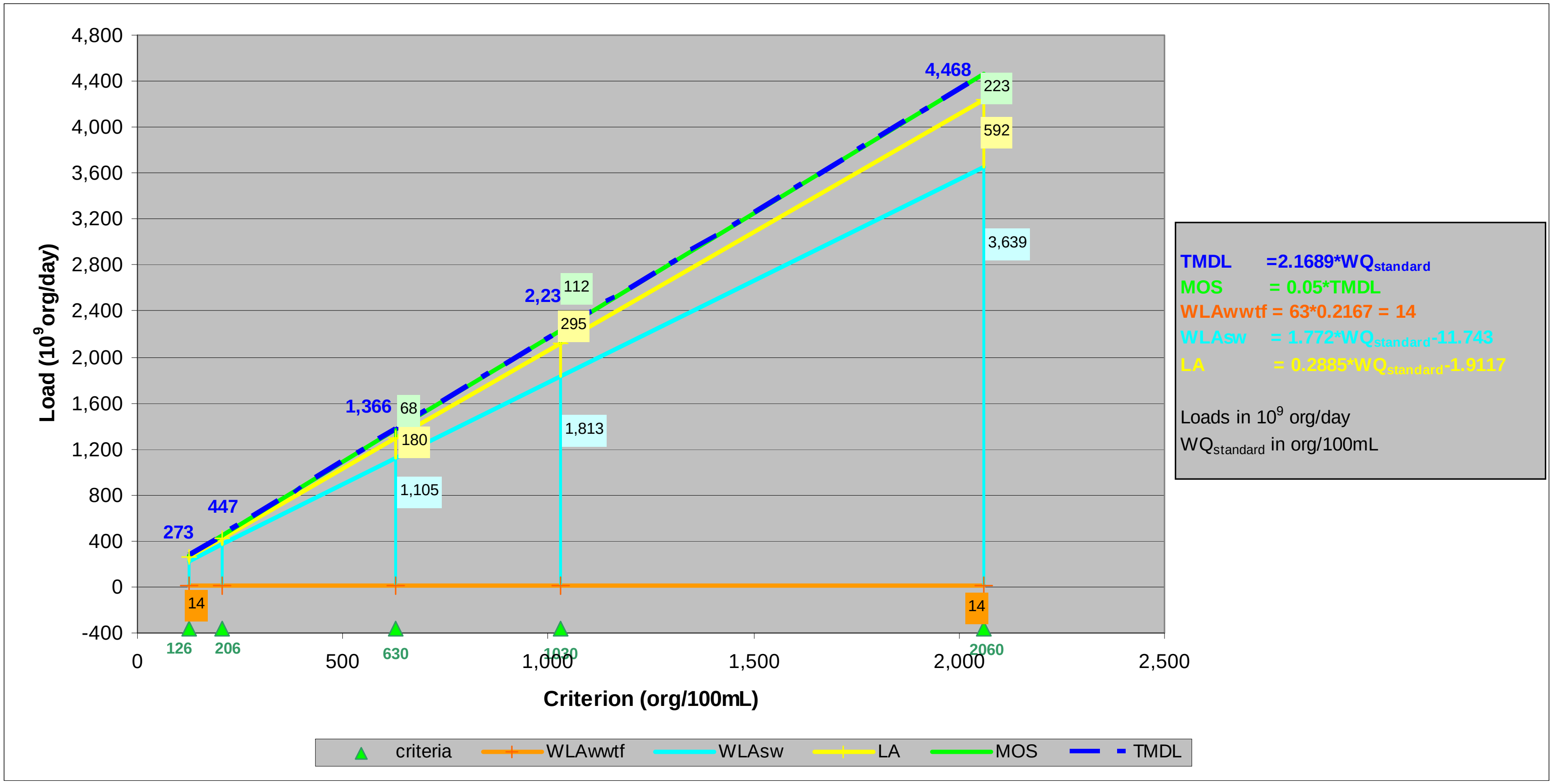


**Figure 5-13 Allocation Loads for AU 1007R_04 as a Function of WQ Criteria**

# SECTION 6
# PUBLIC PARTICIPATION

The Houston-Galveston Area Council is providing coordination for public participation in this project. To provide public involvement in the Eastern Houston Bacteria TMDL and the implementation phase, a public meeting was held on October 17, 2007. 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.

# SECTION 7
# REFERENCES

American Veterinary Medical Association. 2002. U.S. Pet Ownership and Demographics Sourcebook (2002 Edition). Schaumberg, IL.

ASAE. 1999. ASAE standards, 46th edition: standards, engineering practices, data. St. Joseph, MI.

Burian, S.J., J.M. Shepherd. 2005. "Effect of Urbanization on the Diurnal Rainfall Pattern in Houston" Hydrological Processes. 19.5:1089-1103. March 2005.

Canter, L.W. and R.C. Knox. 1985. Septic Tank System Effects on Ground Water Quality. Lewis Publishers, Boca Raton, FL.

Cogger, C.G. and B.L. Carlile. 1984. Field Performance of Conventional and Alternative Septic Systems in Wet Soils. *J. Environ. Qual*. 13(1).

Drapcho, C.M. and A.K.B. Hubbs. 2002. Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure. http://www.lwrri.lsu.edu/downloads/drapcho Annual%20report01.02.pdf

HCFCD. 2008. Tropical Storm Allison Recovery Project Webpage. http://www.tsarp.org/watershed/halls.html (July 1, 2008).

H-GAC. 2005. "Gulf Coast Regional Water Quality Management Plan Update: 2005; Appendix III: On-site sewer facilities - Considerations, Solutions, and Resources." H-GAC, Houston, TX.

H-GAC 2007, 2035 Regional Growth Forecast, Houston, Texas, <www.h-gac.com/community/forecasting/documents/2035RGF.pdf>

Hall, S. 2002. Washington State Department of Health, Wastewater Management Program Rule Development Committee, Issue Research Report - Failing Systems, June 2002.

Metcalf and Eddy. 1991. Wastewater Engineering: Treatment, Disposal, Reuse: 2nd Edition.

New England Interstate Water Pollution Control Commission (NEIWPCC). 2003. Illicit Discharge Detection and Elimination Manual. January 2003.

NOAA. 2007. http://www.csc.noaa.gov/crs/lca/gulfcoast.html

NRCS. 1994. http://soils.usda.gov/survey/geography/statsgo/

Reed, Stowe &Yanke, LLC. 2001. *Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas*. September 2001.

Schueler, T.R. 2000. Microbes and Urban Watersheds: Concentrations, Sources, and Pathways. In *The Practice of Watershed Protection,* T.R. Schueler and H.K. Holland, eds. Center for Watershed Protection, Ellicott City, MD.

TCEQ. 2000. Texas Surface Water Quality Standards. §307.1-307.10. Adopted by the Commission: July 26, 2000; Effective August 17, 2000 as the state rule. Austin, Texas.

TCEQ. 2008. http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/08twqi/twqi08.html

TCEQ. 2007. Draft 2006 Guidance for Assessing and Reporting Surface Water Quality in Texas.

TCEQ. 2008. Personal Communication between Charles Marshall and Randy Palachek. May 28, 2008.

Texas Water Development Board. 2005. Population Projections Data. http://www.twdb.state.tx.us/wrpi/data/popproj.htm.

University of Florida. 1987. Institute of Food and Agricultural Sciences, University of Florida, Florida Cooperative Extension Service, No. 31, December, 1987.

U.S. Census Bureau. 1995. http://www.census.gov/.

U.S. Census Bureau. 2000. http://www.census.gov (April 21, 2005).

USACE. 2005. Greens Bayou Flood Damage Reduction - Draft General Reevaluation Report and Environmental Assessment. U.S. Army Corps of Engineers, Southwest Division.

USDA. 2002. Census of Agriculture, National Agricultural Statistics Service, United States Department of Agriculture. http://www.nass.usda.gov/Census/Create_Census_US_CNTY.jsp

USEPA. 1983. Final Report of the Nationwide Urban Runoff Program. U.S. Environmental Protection Agency, Water Planning Division.

USEPA. 1986. Ambient Water Quality Criteria for Bacteria – January 1986. Office of Water Regulation and Standards. USEPA 44015-84-002.

USEPA. 2001. Protocol for Developing Pathogen TMDLs. First Edition. Office of Water, USEPA 841-R-00-002.

USEPA. 2002. Implementation Guidance for Ambient Water Quality Criteria for Bacteria. May 2002 Draft. EPA-823-B-02-003.

USEPA. 2005. U.S. Environmental Protection Agency, Office of Water. Stormwater Phase II Final Rule. EPA833-F-00-002 Fact Sheet 2.0. December 2005.

USEPA. 2007. U.S. Environmental Protection Agency, Office of Water. An approach for using Load Duration Curves in the Development of TMDLs. EPA841-B-07-006. August 2007.

# APPENDIX A
# AMBIENT WATER QUALITY BACTERIA DATA – 1995 TO 2007

**(Electronic)**

# APPENDIX B
# FLOW DATA

**(Electronic)**

# APPENDIX C
# DISCHARGE MONITORING REPORTS FOR FLOW – JAN 1998 TO JUL 2007

**(Electronic)**

# APPENDIX D
# DISCHARGE MONITORING REPORTS FOR FECAL COLIFORM – SEP 1998 TO JUN 2000

**(Electronic)**

# APPENDIX E
# SANITARY SEWER OVERFLOWS DATA SUMMARY – 2001 TO 2003

**(Electronic)**

# APPENDIX F
# GENERAL METHODS FOR ESTIMATING FLOW AT WQM STATIONS

## Appendix F
## General Methods for Estimating Flow at WQM Stations

Flow duration curve analysis looks at the cumulative frequency of historic flow data over a specified period (USEPA 2007). Because stream flow conditions on any given day can be highly variable, depending on watershed characteristics and weather patterns, flow duration curves are a useful tool for characterizing the percentage of days in a year when given flows occur (USEPA 2007). To support the development of bacteria TMDLs, flow duration curves can be developed using existing USGS measured flow where the data exist at the same location as the WQM station, or by estimating flow for WQM stations with no corresponding flow record. Flow data are derived and synthesized to support preparation of flow duration curves and load duration curves for each WQM station in this report in the following priority.

### USGS Gage Coincides with WQM Station

In cases where a USGS flow gage coincides with, or occurs within one-half mile upstream or downstream of the WQM station the following protocols will be employed:

a. If simultaneous daily flow data matching the water quality sample date are available, these flow measurements will be used to prepare flow exceedance percentiles.
b. If flow measurements at the coincident gage are missing for some dates on which water quality samples were collected, the gaps in the flow record will be filled, or the record will be extended, by estimating flow based on measured streamflows at a nearby gages. First, the most appropriate nearby stream gages are identified as those within a 150 km radius that have at least 300 coincident daily flow measurements. For all identified gages, four regression equations are calculated on the coincident data. The calculated regressions include a linear regression, log-linear regression, logarithmic regression and a power curve regression. For each regression, the root mean square error (RMSE) is calculated and the equation with the best fit or lowest RMSE is chosen to represent that gage. The gages are ranked in order of best fit or increasing RMSE. As many data points requiring filling as possible are filled with the best fit gage (lowest RMSE). If dates remain to be filled, the process is repeated in an iterative fashion with the second best fit gage and so forth until all dates requiring filling have been filled.

### No USGS Gage Coincides with WQM Station

Where no coincident flow data are available for a WQM station, but flow gage(s) are present upstream and/or downstream, flows will be estimated for the WQM station from an upstream or downstream gage using a watershed area ratio method that includes a modification utilizing the NRCS Curve number (CN) to account for differences in watersheds (Wurbs & Sisson, 1999; Wurbs 2006). In coastal watersheds, where the choice of using an upstream or downstream station may be severely limited, it may be necessary to use a gage station from an adjacent watershed that has similar characteristics. These recent studies have demonstrated that, while flow predictions for a specific time with any flow distribution method are not highly accurate, RMSE, means and others flow characteristics can be estimated with an acceptable degree of accuracy. Since many of the flow frequencies important to a load duration curve involve the low end of the frequency range and the NRCS Curve method involves inherent limitations as flows approach the initial abstraction limit, another modification was applied to this method.

The Furness method (Furness 1959) employed by the USGS in Kansas (Studley 2000) estimates flow duration curves by estimating several descriptive statistics that describe the curve. The adaptation was included to utilize the existing period of record to calculate the flow frequency curve for an individual USGS gage, which completely describes the shape of the curve. The mean flow is then projected to the ungaged location utilizing the modified NRCS Curve method, which operates best around the mean of a distribution. Individual flow measurements and flow frequencies can then be projected to the ungaged location by normalizing them to the percent of the mean flow and multiplying the result by the newly projected mean flow for the ungaged location.

Drainage subbasins will first be delineated for all impaired 303(d)-listed WQM stations, along with all USGS flow stations located in the 8-digit HUCs with impaired streams. All the USGS gage stations will be identified that have a continuous period of record upstream and downstream of the subwatersheds with 303(d) listed WQM stations.

a. Watershed delineations are performed using ESRI Arc Hydro with a 30 meter resolution National Elevation Database digital elevation model, and National Hydrography Dataset streams. The area of each watershed will be calculated following watershed delineation.
b. The watershed average curve number is calculated from soil properties and land cover as described in the U.S. Department of Agriculture (USDA) Publication TR-55: Urban Hydrology for Small Watersheds. The soil hydrologic group is extracted from NRCS STATSGO soil data, and land use category from the NOAA Coastal Change Analysis Program (C-CAP). Based on land use and the hydrologic soil group, SCS curve numbers are estimated at the 30-meter resolution of the C-CAP grid as shown in Table F-1.
c. The average curve number is then calculated from all the grid cells within the delineated watershed.
d. The average rainfall is calculated for each watershed from average annual precipitation datasets for the period 1988-2007 from rainfall data obtained from Harris County Office of Emergency Management.

**Table F-1 Runoff Curve Numbers for Various Land Use Categories and Hydrologic Soil Groups**

| C-CAP Value | C-CAP Class | Group A | Group B | Group C | Group D |
|---|---|---|---|---|---|
| 2 | High-Intensity Developed | 89 | 92 | 94 | 95 |
| 3 | Medium-Intensity Developed | 77 | 85 | 90 | 92 |
| 4 | Low-Intensity Developed | 61 | 75 | 83 | 87 |
| 5 | Open-Space Developed | 39 | 61 | 74 | 80 |
| 6 | Cultivated Land | 67 | 78 | 85 | 89 |
| 7 | Pasture/Hay | 35 | 56 | 70 | 77 |
| 8 | Grassland/Herbaceous | 39 | 61 | 74 | 80 |
| 9 | Deciduous Forest | 30 | 55 | 70 | 77 |
| 10 | Evergreen Forest | 30 | 55 | 70 | 77 |
| 11 | Mixed Forest | 30 | 55 | 70 | 77 |
| 12 | Scrub/Shrub | 30 | 48 | 65 | 73 |
| 13 | Palustrine Forested Wetland | 0 | 0 | 0 | 0 |
| 14 | Palustrine Scrub/Shrub Wetland | 0 | 0 | 0 | 0 |
| 15 | Palustrine Emergent Wetland | 0 | 0 | 0 | 0 |
| 16 | Estuarine Forested Wetland | 0 | 0 | 0 | 0 |
| 17 | Estuarine Scrub/Shrub Wetland | 0 | 0 | 0 | 0 |
| 18 | Estuarine Emergent Wetland | 0 | 0 | 0 | 0 |
| 19 | Unconsolidated Shore | 0 | 0 | 0 | 0 |
| 20 | Bare Land | 77 | 86 | 91 | 94 |
| 21 | Water | 0 | 0 | 0 | 0 |
| 22 | Palustrine Aquatic Bed | 0 | 0 | 0 | 0 |
| 23 | Estuarine Aquatic Bed | 0 | 0 | 0 | 0 |

e. The mean flow at the ungaged site is calculated from the gaged site utilizing the modified NRCS Curve Number method (Wurbs & Sisson, 1999). The NRCS runoff curve number equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

where:

Q = runoff (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

$I_a$ = initial abstraction (inches)

If $P < 0.2$, $Q = 0$. Initial abstraction has been found to be empirically related to S by the equation

$$I_a = 0.2*S \qquad (2)$$

Thus, the runoff curve number equation can be rewritten:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3)$$

S is related to the curve number (CN) by:

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

f. First, S is calculated from the average curve number for the gaged watershed. Next, the historic mean flow at the gage is converted to depth basis (as used in equations 1 and 3) by dividing by its drainage area, then converted to inches. Equation 3 is then solved for daily precipitation depth of the gaged site, $P_{gaged}$. The daily precipitation depth for the ungaged site is then calculated as the precipitation depth of the gaged site multiplied by the ratio of the long-term average precipitation in the watersheds of the ungaged and gaged sites:

$$P_{ungaged} = P_{gaged}\left(\frac{M_{ungaged}}{M_{gaged}}\right) \qquad (5)$$

where M is the mean annual precipitation of the watershed in inches. The daily precipitation depth for the ungaged watershed, along with the average curve number of the ungaged watershed, are then used to calculate the depth equivalent daily flow Q of the ungaged site. Finally, the volumetric flow rate at the ungaged site is calculated by multiplying by the area of the watershed of the ungaged site and converting the value to cubic feet.

g. If wastewater treatment facilities (WWTF) are located within the drainage area of the USGS gage, a base flow for the USGS gage should be calculated before projecting flow to an ungaged site. The base flow for the USGS gage is calculated by deducting the sum of the Average Monthly WWTF flow for all outfalls in the drainage area from the measured USGS flow record. The Average Monthly WWTF flows are applied for each day (1-31) of a given month.

$$Q_{baseflow} = Q_{USGSgage} - \sum_{\#wwtf}^{1} Q_{Avg.MonthlyWWTF}$$

If the base flow results in a negative value, that value is then set to zero.

h. After flow has been estimated for the ungaged site, average monthly flows from WWTFs that drain into the ungaged watershed are then added to the flow estimates.

In the rare case where no coincident flow data are available for a WQM station and no gages are present upstream or downstream, flows will be estimated for the WQM station from a gage on an adjacent watershed of similar size and properties, via the same procedure described above for upstream or downstream gages.

**References**

Furness, L.W. 1959. Kansas streamflow characteristics- part 1, Flow duration: Kansas Water Resources Board Technical Report No. 1, 213 p.

Studley, S. E. 2000. Estimated Flow-Duration Curves for Selected Ungaged Sites in Kansas. U.S. Geological Survey Water-Resources Investigations Report 01-4142

USEPA 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006 August 2007. http://www.epa.gov/owow/tmdl/techsupp.html

Wurbs, R.A. 2006. Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites. Journal of Hydrologic Engineering, Vol. 11, No. 1, January 1, 2006.

Wurbs, R.A. and E. Sisson. 1999. Comparative Evaluation of Methods for Distributing Naturalized Streamflows from Gauge to Ungauged Sites. Texas Water Resources Institute, Texas A&M University, TR-179 August 1999.

# APPENDIX G
# FLOW EXCEEDANCE PERCENTILES FOR TMDL WQM STATIONS

**(Electronic)**