TCEQ Adopted: July 25, 2007

One Total Maximum Daily Load for Bacteria in the Guadalupe River Above Canyon Lake

For Segment Number 1806

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Total Maximum Daily Load Section
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087
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Development of this report was financed in part through grants from the
U.S. Environmental Protection Agency.

This document is based in large part on the technical report titled
"Final TMDL Allocation Report, Upper Guadalupe River, Segment 1806"
prepared by James Miertschin & Associates, Inc.

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Executive Summary

This document describes a project developed to address an impairment of water quality in the Guadalupe River Above Canyon Lake (Segment 1806), where high concentrations of *Escherichia coli* (*E. coli*) bacteria exceed the criteria used to evaluate the attainment of the contact recreation use. Recreational uses were first identified as impaired in the *2002 Texas Water Quality Inventory and 303(d) List*.

Segment 1806 is located in south-central Texas. It begins at the basin's drainage divide in western Kerr County and ends at Canyon Lake Reservoir in Comal County. However, only a small reach of Segment 1806, located within the City of Kerrville, is impaired. The impaired reach is defined as the Guadalupe River from its confluence with Town Creek downstream to Flat Rock Lake.

Indicator bacteria such as *E. coli,* although not generally pathogenic, are indicative of potential contamination from the feces of warm-blooded animals. The criteria for contact recreation are based on indicator bacteria rather than direct measurements of pathogens.

The standards for water quality are defined in the *Texas Water Quality Standards* (Chapter 307 of the Texas Administrative Code, Title 30). The criteria for assessing attainment of the contact recreation use are expressed as the number of organisms of bacteria per hundred milliliters (100 mL) of water. The number of organisms may not exceed certain concentrations in a single sample, nor as a geometric mean of all samples over a range of time.

Field investigations identified that excessive bacteria concentrations are confined to two small assessment areas within the city of Kerrville:

1) one mile upstream of Flat Rock Dam to a confluence with Camp Meeting Creek, and
2) from RR394 to one mile downstream.

Based on the load allocation analysis, the following reductions are needed to attain the contact recreation use:

- 70.5 percent reduction of loading from both mid-range and lower/mid-range flows at station 12617 (Guadalupe River at Highway 16 in L. Hays Park); and
- 52.1 percent reduction of loading from upper mid-range flows at station 12615 (Guadalupe River at Kerrville-Schreiner Park).

Introduction

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

In simple terms, a TMDL is like a budget that determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. TMDLs must also estimate how much the pollutant load must be reduced from current levels in order to achieve water quality standards.

This TMDL addresses impairments to the contact recreation use due to high concentrations of bacteria in the Guadalupe River Above Canyon Lake. The TMDL Program is a major component of Texas' overall process for managing surface water quality. The Program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses (such as drinking water supply, recreation, support of aquatic life, or fishing) of impaired or threatened water bodies.

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) in Title 40, Code of Federal Regulations, Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction for developing TMDLs in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines. The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

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

This TMDL document is based in large part on the report titled "Final TMDL Allocation Report, Upper Guadalupe River, Segment 1806" prepared by James Miertschin & Associates, Inc. (Miertschin 2006).

The commission adopted this document on July 25, 2007. Upon EPA approval, this TMDL will become an update to the state's Water Quality Management Plan.

Problem Definition

The TCEQ first identified the impairment to the contact recreation use of the Guadalupe River Above Canyon Lake in the *2002 Texas Water Quality Inventory and 303(d) List* (2002 Inventory and List). Segment 1806 is located in south-central Texas. It begins at the basin's drainage divide in western Kerr County and ends at Canyon Lake Reservoir in Comal County. However, only a small reach of Segment 1806, located within the City of Kerrville, is impaired for contact recreation. The impaired reach is defined as the Guadalupe River from its confluence with Town Creek downstream to Flat Rock Lake. The watershed study area for this project was limited to the area upstream of the town of Center Point, as illustrated in Figure 1.

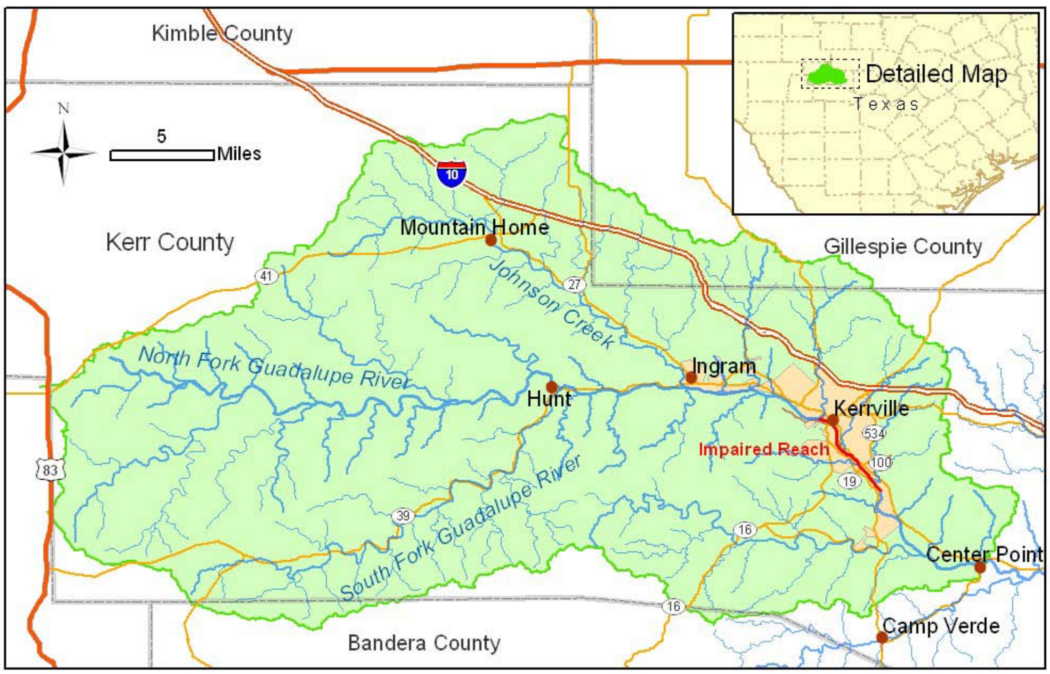


Figure 1: Upper Guadalupe River Watershed

Possible sources and/or causes of contamination include:

- leaking collection lines in sanitary sewer infrastructure
- nesting birds at bridge crossings
- urban storm water runoff
- failing septic systems
- swimmers

Designated Uses and Water Quality Standards

The State of Texas requires water in the Guadalupe River Above Canyon Lake to meet certain criteria in support of designated uses. The designated uses for Segment 1806 are contact recreation, aquifer protection, exceptional aquatic life uses, and public water supply in Section 307.7 of the *Texas Surface Water Quality Standards* (TCEQ 2000). The Upper Guadalupe River Authority (UGRA), Guadalupe Blanco River Authority (GBRA), TCEQ, and United States Geological Survey (USGS) conduct water quality monitoring in the Guadalupe River Basin Above Canyon Lake.

The *Texas Surface Water Quality Standards* (TCEQ 2000) provide numeric and narrative criteria to evaluate attainment of designated uses (Table 1). *E. coli* is the preferred indicator bacteria for assessing the contact recreation use in freshwater, but fecal coliform bacteria may also be used since it was the preferred indicator in the past. The numeric criteria defined in the Standards for support of the contact recreation use are as follows.

- *E. coli*
    - The geometric mean of *E. coli* should not exceed 126 organisms per 100 milliliters (126 org/100 mL)
    - Single samples of E. coli should not exceed 394 org/100 mL
- Fecal coliform
    - The geometric mean of fecal coliform should not exceed 200 org/100 mL
    - Single samples of fecal coliform should not exceed 400 org/100 mL

Table 1: Numeric Criteria for Guadalupe River Above Canyon Lake

Segment	Criteria						
	Cl (mg/L)	**SO4 (mg/L**	**TDS (mg/L)**	**Dissolved Oxygen (mg/L)**	**pH Range (SU)**	**Indicator Bacteria #/100mL (*E. coli*)**	**Temperature (°F)**
Guadalupe River Above Canyon Lake, Segment 1806	50*	50*	400*	6.0	6.5-9.0	126+/ 394++	90

* expressed as annual average values

\+ expressed as a geometric mean

++ expressed as a single sample

Description of the Watershed

The Guadalupe River Above Canyon Lake stretches from a point 1.7 miles downstream of Rebecca Creek Road in Comal County to the confluence in Kerr County of the North Fork Guadalupe River and the South Fork Guadalupe River. The watershed covers 415,592 acres and is principally a rocky, moderately dissected terrain which is fed by springs issuing from beds of limestone (Figure 2).

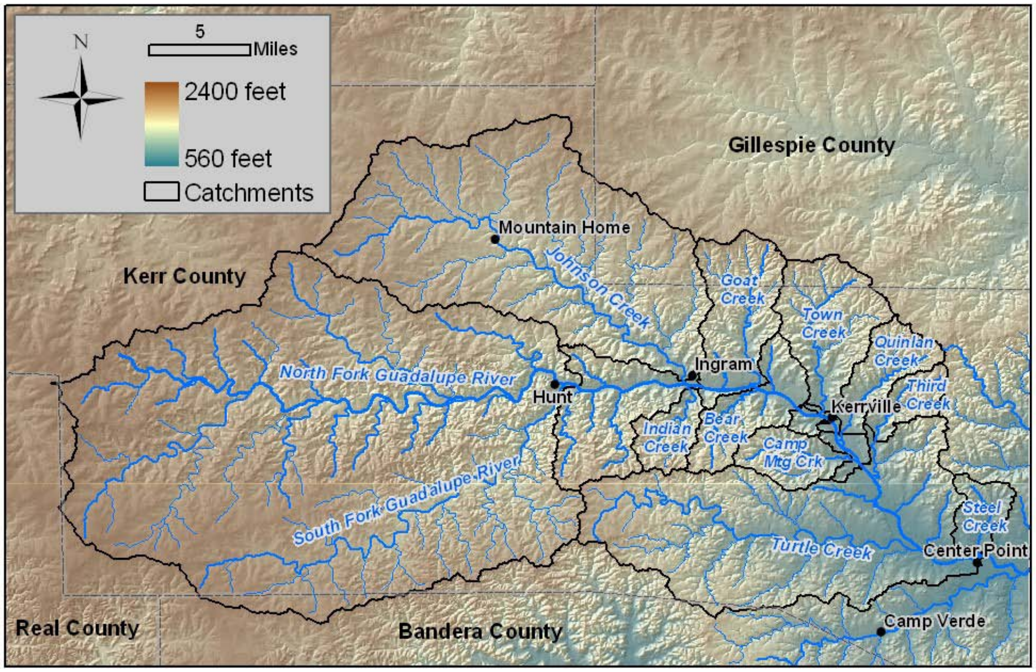


Figure 2: Map of Upper Guadalupe River Watershed depicting topography and drainage area

The land is used for recreation, raising livestock, and cultivating small grain crops. During the drier months of summer, pumps are brought into operation to divert water for irrigation and domestic purposes. Principal cities in the watershed are Mountain Home, Hunt, Ingram, Kerrville, and Center Point.

The base flow of the Upper Guadalupe River is sustained entirely by groundwater discharge. The main source of base flow is water discharged from the Edwards-Trinity formation and associated limestone.

Climate

The study area is located completely within the Edwards Plateau climatic division. The climate is semi-arid and sub-humid, with annual rainfall averages of about 29 inches (Figure 3). The Gulf of Mexico is the principal source of moisture that drives precipitation in the study area. As with the rest of the interior of the state, maximum precipitation periods in the study area are typically late spring (May and June) and early autumn (September and October). Winter and summer periods usually have low precipitation. The maximum precipitation period in May is driven by the buildup of water vapor from the Gulf of Mexico carried by the prevailing winds from the south. In September, cold air converges with moisture-laden southerly winds and late-season convective thunderstorms drive the precipitation. It is also not unusual for hurricanes to affect rainfall in the early autumn period. Summer drought conditions are common in the study area due to strong high-pressure cells that result in lengthy dry spells.

Precipitation data employed in the present study were obtained from the National Weather Service Station No. 414375, near Hunt, Texas. For the 15-year period of 1990 through 2004, the annual rainfall in the study area has ranged from 16 to 36 inches. The average annual rainfall for the entire 15-year period was 29 inches. Figure 3 shows the average monthly rainfall for the 15-year time period.

Economy

Since the 1950s, Kerr County has become a manufacturing center. Both the Mooney Aircraft Corporation and James Avery Craftsman, Inc., call Kerr County home. While some crops are still harvested in the county, raising livestock has continued to dominate agricultural activity; the sale of livestock and livestock products accounts for a substantial percent of agricultural receipts. In recent decades, the county has continued to prosper from its mixture of agriculture, tourism, health care, and manufacturing, and as a site for retirement communities and country retreats (Handbook of Texas Online).

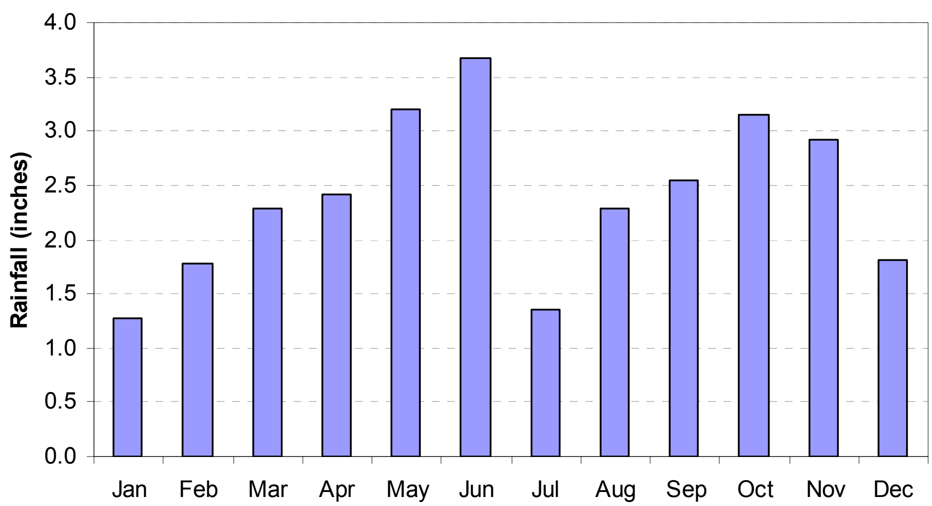


Figure 3: Average Monthly Rainfall (1990 – 2004)

Stream Segment Geology and Hydrogeology

The Trinity Aquifer is the principal source of groundwater in Kerr County. In the Hill Country, the Trinity Aquifer is an extension of the lower part of the Edwards–Trinity Aquifer of the Edwards Plateau, with the Edwards formations mostly removed. The Trinity Aquifer yields water from Cretaceous limestone and sand of the Trinity group.

The Trinity Aquifer is composed of three permeable zones separated by two relatively impermeable horizontal barriers. The Upper Trinity zone is made up of the upper member of the Glen Rose Limestone formation. The Middle Trinity is composed of the lower Glen Rose Limestone, the Hensell Sand, and the Cow Creek Limestone formations. The Lower Trinity zone consists of the Hosston and Sligo formations. Relatively impermeable, tight sediments within the Glen Rose Limestone formation separate the Upper and

Middle Trinity zones. The Hammett Shale formation separates the Middle and Lower Trinity zones.

Recharge of the Trinity Aquifer occurs through lateral flow of water from the Edwards Plateau, infiltration of precipitation on the outcrop area, and surface-water leakage from shallow, tributary streams in upland areas. Relatively impermeable inner beds in the Upper and Middle Glen Rose Limestone formations generally impede the downward percolation of precipitation.

Soils and Land Use

Soil characterization in the Upper Guadalupe River watershed was based on the Soil Survey of Kerr County, Texas (USDA Soil Conservation Service Series 1986). Kerr County encompasses 1,107 square miles, or about 708,480 acres. The county had a population of 43,822 in 2000, and has a growing season of 216 days. One to ten percent of the land is considered prime farmland.

In the northwest area of the county, soils are dark and loamy over limestone; to the south and east, soils are variable, with light-colored brown to red soils in some areas and dark loamy or loamy soils over clayey subsoils elsewhere. The landscape consists of gently undulating, clayey and stony soils in the western part of the county; gently sloping soils on hilltops; steep side slopes; narrow valleys in the central to eastern part; and nearly level to gently sloping, loamy and clayey soils along the Guadalupe River. The county is in the Edwards Plateau vegetation area, characterized by buffalograss, wildrye, and switchgrass, and by live oak, shinnery oak, juniper, and mesquite trees.

Land use data were developed from the 1992 USGS Land Cover Dataset, which is the most recent source available. Almost 80 percent of the basin is undeveloped forest or shrub land. Developed urban areas constitute less than 3 percent of the basin; the remaining 17 percent is made up primarily of various agricultural uses (Figure 4).

Assessment of Data and Pollutant Sources

The data used to assess sources affecting the study area are discussed in the following sections. The inventory of data and information is outlined, along with monitoring, water quality, stream flow, and meteorological weather data.

Data and Information Inventory

A wide range of data and information were used in the development of the Guadalupe River Above Canyon Lake TMDL. Categories of data used include the following:

1) Hydrographic data that describe the physical conditions of the stream, such as the stream reach network and connectivity, and the stream channel depth, width, slope, and elevation.
2) Watershed physiographic data that describe the watershed's physical conditions such as topography, soils, and land use.
3) Data and information related to the use of, and activities in, the watershed that can be used in the identification of potential bacteria sources.

4) Environmental monitoring data that describe stream flow and water quality conditions in the stream.

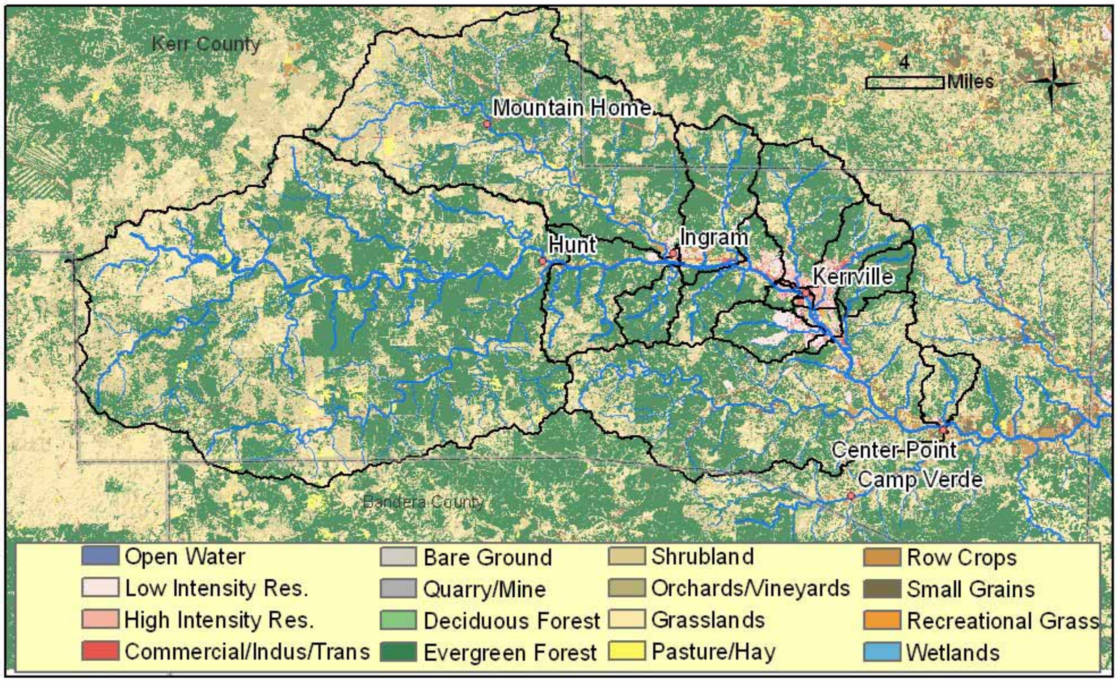


Figure 4: Guadalupe River Land Use Distribution

Water Quality Monitoring and Monitoring Stations

The UGRA is responsible for coordinating the monitoring activities of the Clean Rivers Program in the Upper Guadalupe River Basin. The data from these activities are included in the TCEQ's Surface Water Quality Monitoring (SWQM) database, which houses the primary data used for the state's biennial assessment of water quality. The TCEQ and the USGS also collect data within the basin for inclusion in the SWQM database. The UGRA collects data quarterly from 14 fixed stations within the study area. Data collected at 12 of those stations were used to develop this TMDL (Figure 5). Table 2 lists all 14 monitoring stations in the study area and summarizes the number of bacteria samples collected.

Monitoring Stations

E. coli bacteria data have been collected by various entities, including UGRA and TCEQ, at several monitoring stations along the Guadalupe River and its tributaries. Supplemental data were collected in 2005 by James Miertschin and Associates (JMA). The vast majority of the historical *E. coli* data were collected by the UGRA during the summer season. This intensive summer monitoring is in response to above-average bacteria levels that have been historically observed during this season.

The Guadalupe River is used extensively for contact recreation. The summer months have the highest potential for human contact recreation, and thus the highest potential for

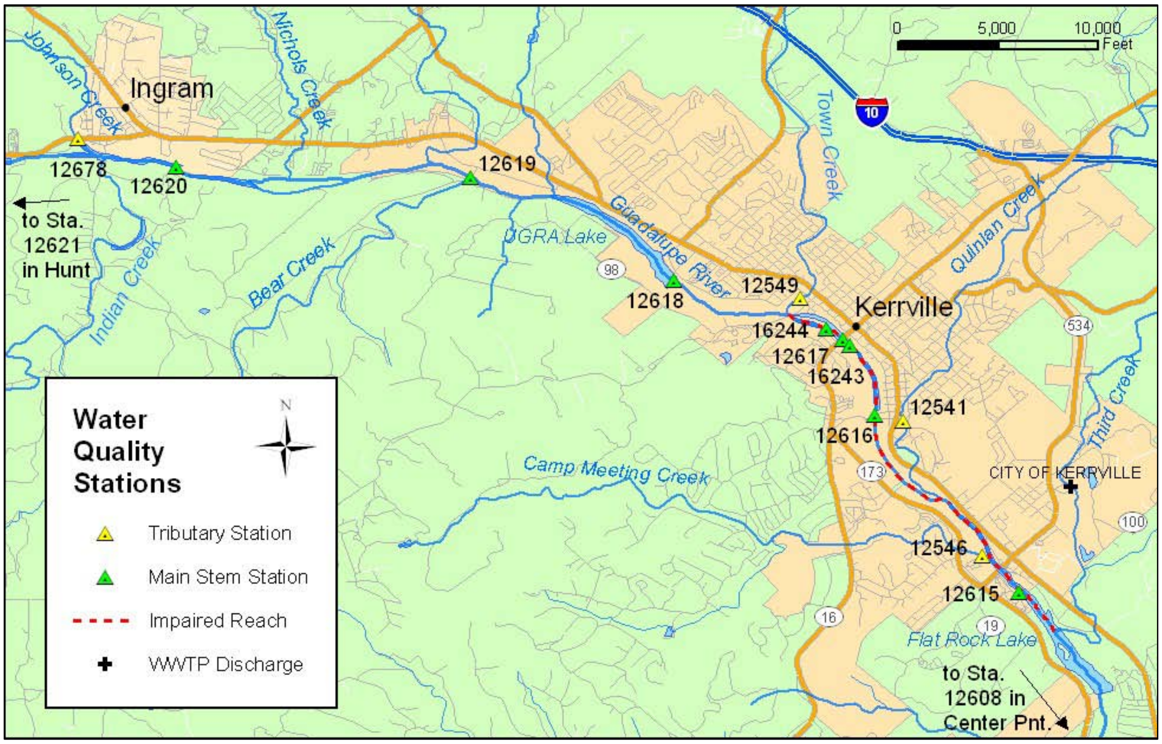


Figure 5: Water Quality Sampling Stations Map

Table 2: Monitoring Stations in the Segment 1806 Study Area

Station No.	UGRA / TCEQ Data Collection				JMA, 2005 Data Collection	
	Summer Season		Non-summer Season		Summer	Non-summer
	Years	# Samples	Years	# Samples	# Samples	# Samples
12621	93-05	138	93-98	19	6	4
12678	04-05	39	-	-	6	4
12620	93-05	138	93-98	15	6	4
12619	93-05	140	93-98	18	-	-
12618	93-05	138	93-98	17	6	4
12549	93-95	7	93-95	16	6	4
16244	98-05	131	-	-	-	-
12617	98-05	131	-	-	6	4
16243	98-05	131	-	-	-	-
12616	93-04	22	93-04	31	-	-
12541	93-99	7	93-98	18	6	4
12546	93-03	23	93-04	29	6	4
12615	93-05	145	93-03	26	6	4
12608	93-05	151	93-04	31	6	4
Total		**1341**		**220**	**60**	**40**

the transmission of waterborne diseases. Consequently, the period of intensive monitoring by UGRA begins around the first of May and ends around the 15th of September. This time frame will be referred to as the summer season.

Supplemental Water Quality Monitoring

Review of the available water quality data reinforced early assessments that Segment 1806 contains high levels of bacteria around the City of Kerrville. Concentrations of *E. coli* bacteria varied significantly among monitoring stations within the study area. Project staff determined a need for supplemental monitoring to support modeling and to further assess the severity and geographic extent of the impairment in the study area.

The supplemental data were collected at key stations by JMA from February through August in 2005 (Figures 6–10). Three types of supplemental monitoring were conducted:

1) *routine assessment monitoring* – periodic data collection to describe conditions within a water body
2) *base-flow sampling* – comprehensive data collection to track changes in constituent concentration as a mass load travels downstream
3) *runoff sampling* – data collection at a network of stations to provide spatial coverage of mass loadings associated with a rainfall runoff event

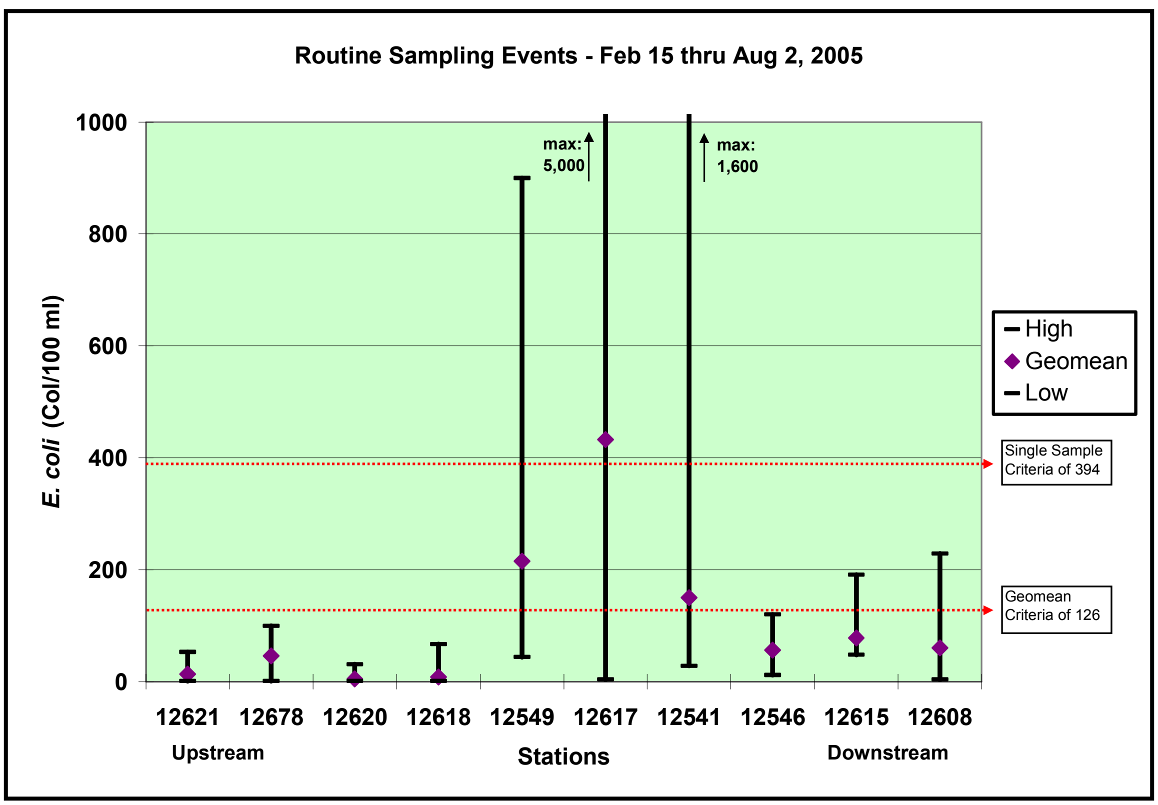


Figure 6: Summary of Routine Sampling Events Data

JMA conducted 10 surveys to collect the routine assessment data (Table 3), and one survey each to collect base-flow and runoff data. Mean daily streamflow data at USGS station No. 08166200, Kerrville, covering the period of routine sampling are displayed in Figure 3.

Spatial Variation of *E. coli* data

A spatial examination of the data provides significant information for developing the TMDL. The section of the river upstream of Station 12618 (Guadalupe River at UGRA Dam) has relatively low *E. coli* concentrations that do not exceed the geometric mean criterion. The considerable increase in *E. coli* concentrations at Station 12617 (Guadalupe River at L Hays Park, Hwy 16) suggests that a significant source of bacteria loading may exist within the vicinity of this station. *E. coli* concentrations remain relatively high throughout the impaired reach, through at least Station 12615 (Guadalupe River at Kerrville-Schreiner Park), as shown in Figure11.

Table 3: Summary of Routine *E coli.* Sampling Events (Col/100 mL)

Station	Station ID	2/15/2005	3/8/2005	3/29/2005	4/18/2005	5/10/2005	6/7/2005	6/21/2005	7/5/2005	7/19/2005	8/2/2005	Geo Mean	Max	Min
Guadalupe River at SH 39	**12621**	<1	20	4	8	16	20	32	53	20	31	14	53	1
Guadalupe River at Ingram Dam	**12620**	4	16	<1	<1	16	17	<1	<1	8	31	5	31	1
Johnson Creek at SH 39	**12678**	48	100	16	40	80	46	52	67	54	20	46	100	16
Guadalupe River at UGRA Lake Dam	**12618**	4	32	4	4	72	4	8	25	11	<1	8	72	1
Town Creek at Hamilton Street	**12549**	44	48	120	200	100	900	410	700	300	540	215	900	44
Guadalupe River at SH 16	**12617**	4	28	32	310	5000	3400	3000	1200	2100	1600	432	5000	4
Quinlan Creek at Travis Street	**12541**	28	36	40	76	260	184	230	1600	200	550	150	1600	28
Camp Meeting Creek	**12546**	12	72	36	72	40	46	120	81	88	96	57	120	12
Guadalupe River at Kerr-ville-Schreiner Park	**12615**	52	48	48	64	152	72	84	92	191	69	78	191	48
Guadalupe River at Center Point Lake	**12608**	64	48	16	28	156	39	84	44	229	92	60	229	16

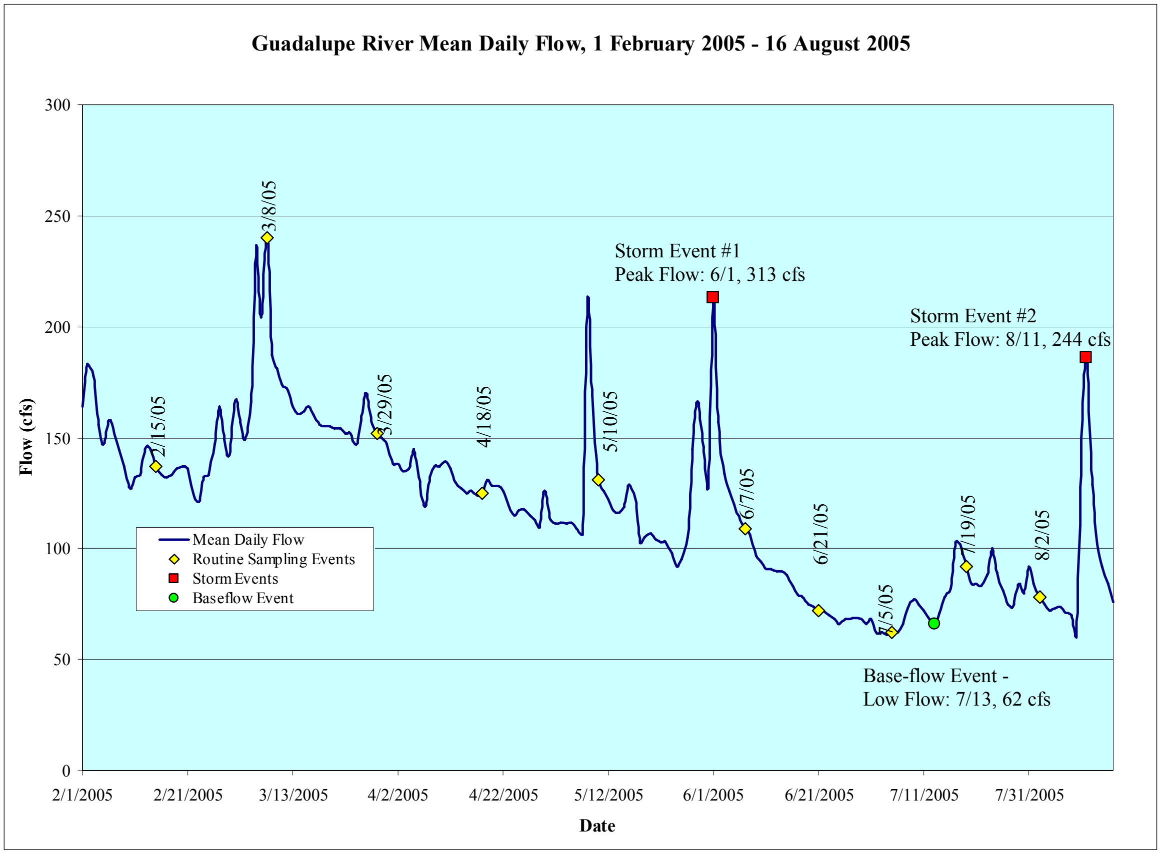


Figure 7: Summary of Routine Sampling Events Flow Data at USGS Station No. 08166200

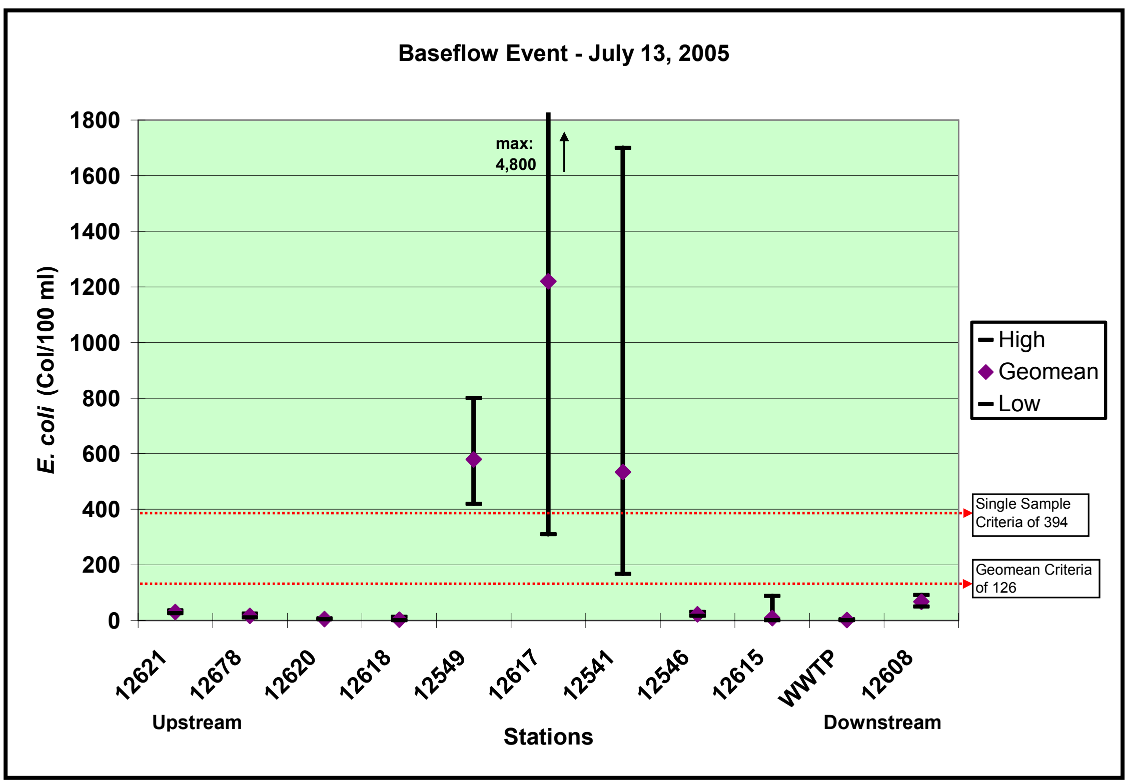


Figure 8: Summary of Base-flow Sampling Event Data

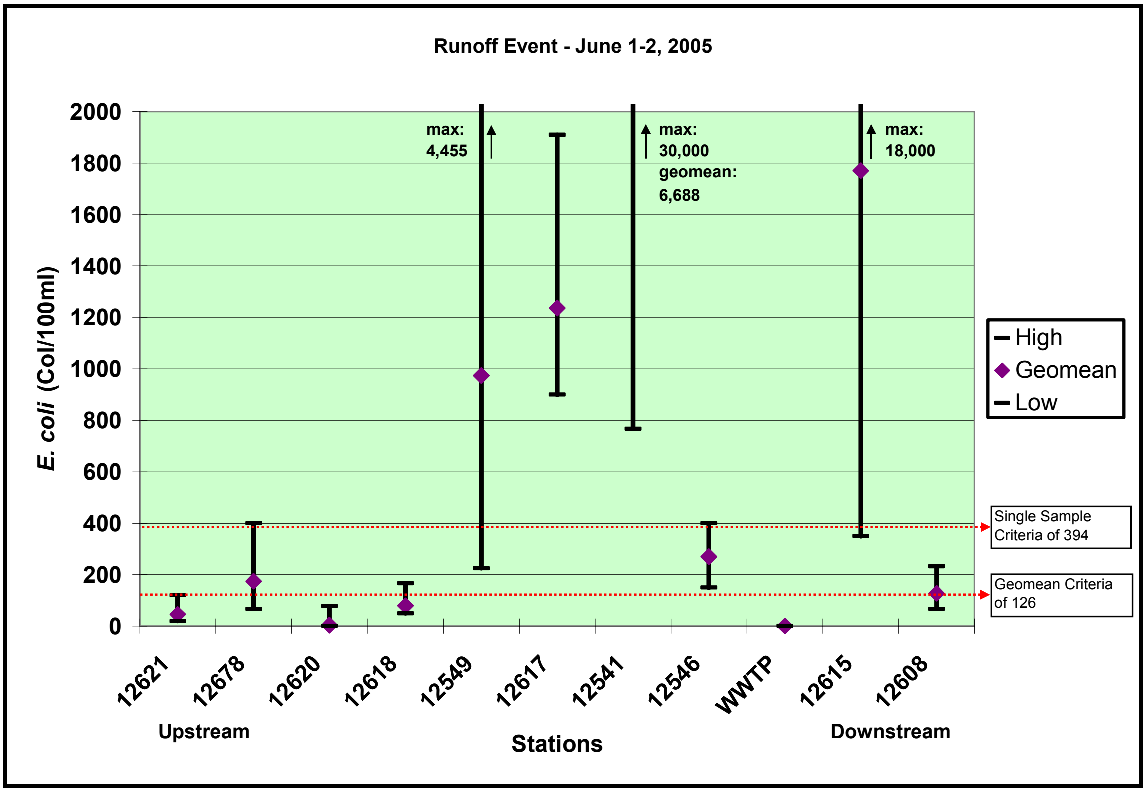


Figure 9: Summary of June Runoff Event Sampling Data

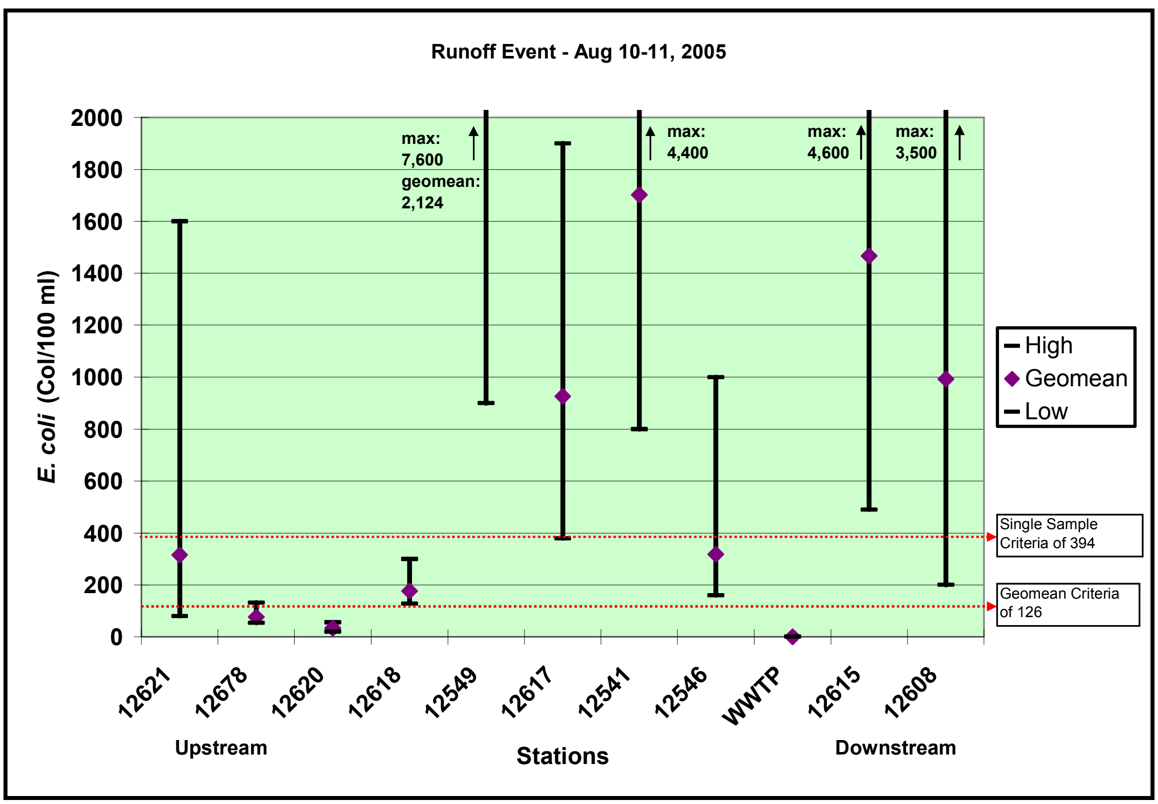


Figure 10: Summary of August Runoff Event Sampling Data

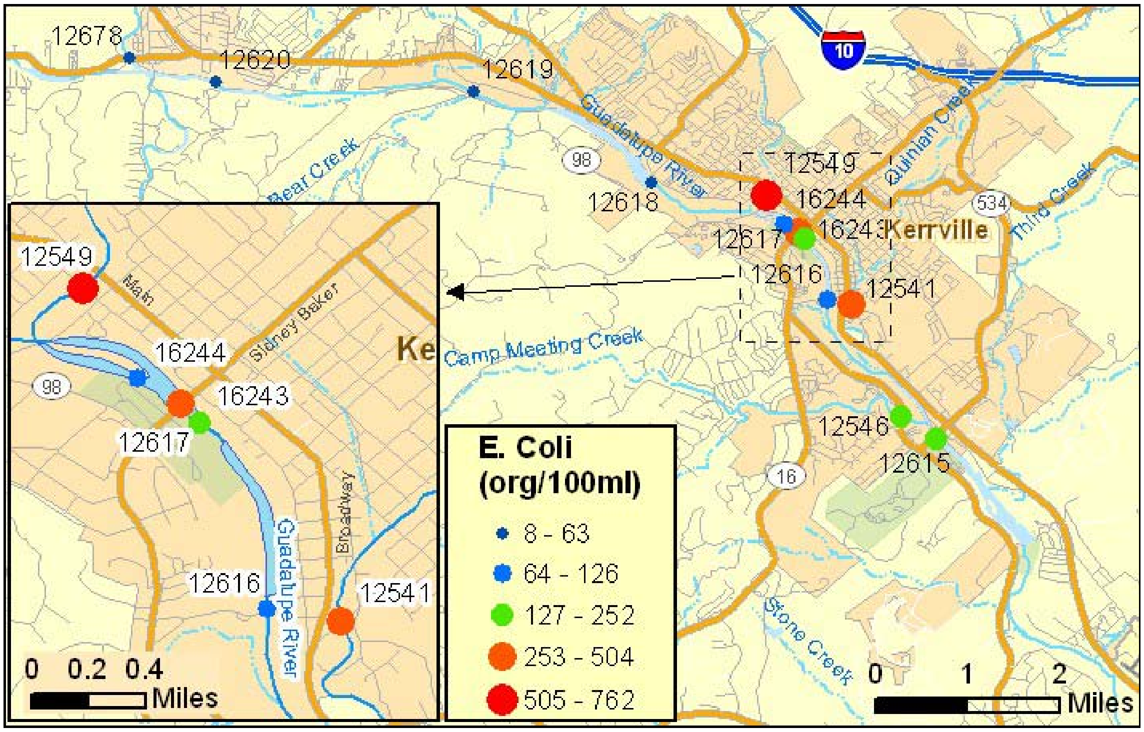


Figure 11: Spatial Variation in Summer Geometric Mean *E. coli* Concentrations

The Critical Condition

TMDLs must take into account critical conditions for stream flow, loading, and water quality parameters (40 CFR 130.7 (c) (1)). The intent of this requirement is to ensure that water quality is protected during times when it is most vulnerable. The critical condition is considered the "worst case scenario" of environmental conditions. If the TMDL is developed so that the water quality targets are met under the critical condition, then the water quality targets are likely to be met under all other conditions. The critical condition is important because it describes the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards.

Bacteria loadings result from sources that can contribute these pollutants during wet weather and dry weather. Three primary factors determine the critical conditions for Segment 1806—flow, season, and location. Critical conditions related to flow were determined from USGS stream flow data and the instream water quality data collected by the TCEQ. Using the load duration curve approach, the critical condition is defined as the flow regime that requires the maximum load reduction to achieve compliance with water quality standards. This TMDL uses the flow categories recommended by Cleland (2003) for determining the critical flow regime (see the section "Load Duration Curves" for further discussion).

In addition to flow regime, seasonal variation in concentrations was also considered. For the Guadalupe River, the summer season represents critical conditions with respect to bacteria concentrations. During the summer season, the river has relatively high bacteria levels; this is also the season when the highest levels of primary contact recreation occur. As a result, the load duration curves were developed using only summer sampling data, so that the analysis reflects both the critical flow regime and critical season.

Finally, critical conditions were determined in terms of location. Bacteria levels vary significantly up and down the river, and even within the city limits of Kerrville. The two stations with the highest bacteria levels were typically Station 12617 at Highway 16 in L. Hays Park and Station 12615 at Kerrville-Schreiner Park. These two stations represent the critical locations for this TMDL.

Seasonal Variation

Seasonal variations involve changes in stream flow and water quality as a result of hydrologic and climatic patterns. Seasonal variations were evaluated in the modeling approach for these TMDLs. This allowed the consideration of temporal variability in bacteria loadings within the study area.

Concentrations of *E. coli* bacteria have been observed to fluctuate significantly throughout the year. These variations are illustrated for selected stations in Figure 12. In this figure, geometric means are shown only where at least three data points were available for a particular month. The highest bacteria levels have been observed in the summer season, particularly in August. However, note that the most upstream station shown in Figure 12 (12618, Guadalupe River at UGRA Dam), which is well below the *E. coli* criterion, did not have elevated bacteria levels during summer months. This is probably due to low velocity and settling in the impounded area.

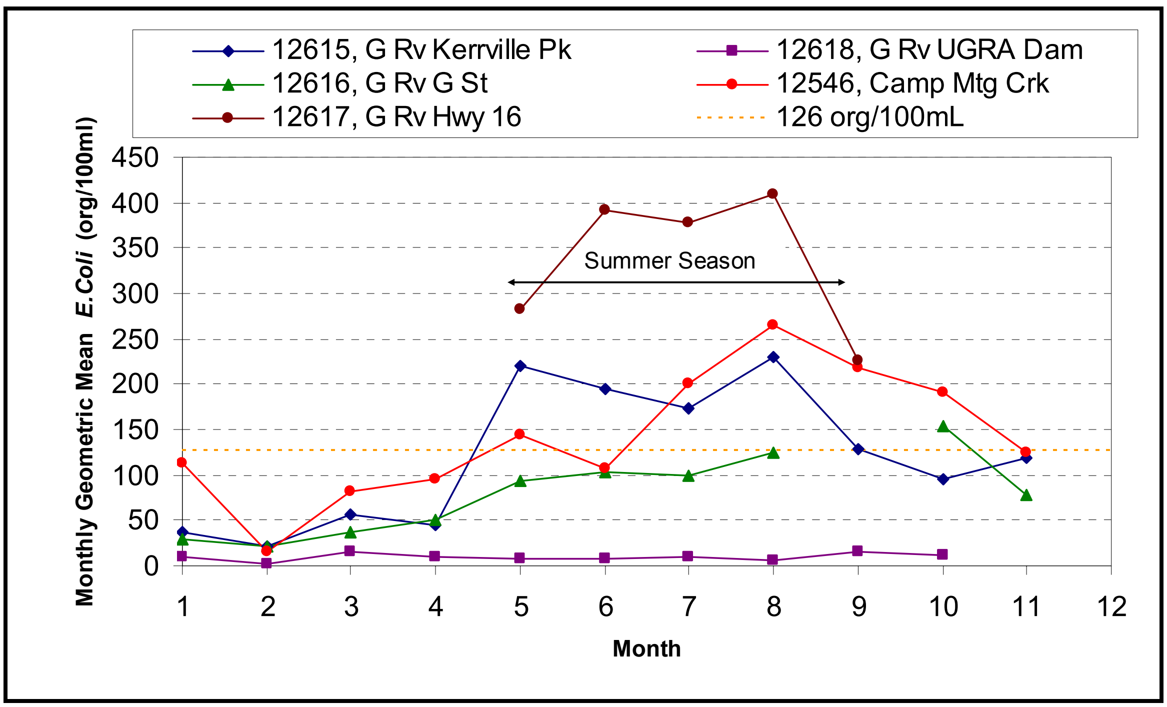


Figure 12: Seasonal Variation in *E. coli* Geometric Mean Concentration by Month, (1993-2005)

An understanding of the seasonal variability of bacteria levels is important for further data analysis, for determining bacteria sources, and for developing TMDL allocations. The seasonal characteristics of the stations shown in Figure 12 are representative of the entire study area. The following conclusions can be drawn about the seasonal variability of *E. coli* in the impaired reach:

- Stations that report the highest bacteria levels also have the greatest degree of seasonal variability.
- The highest *E. coli* concentrations are typically experienced in the late summer.

Stations that report the lowest bacteria levels exhibit little or no seasonal variability in *E. coli* concentrations.

Endpoint Identification

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

For bacteria, the primary water quality target has been established in the *Texas Surface Water Quality Standards*. As described in the TCEQ's *Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data* (TCEQ 2004), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. For this project, *E. coli* was used exclusively for supplemental data collection and modeling to support development of the TMDL.

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

- the geometric mean of all *E. coli* samples exceeds 126 org/100 mL; AND/OR
- individual samples exceed 394 org/100 mL more than 25 percent of the time.

The TCEQ uses a binomial method to specify the number of exceedances of the single sample criterion required to determine nonsupport of the contact recreation use.

Source Analysis

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

Point Sources

The only regulated point source in the study area is the Kerrville wastewater treatment facility (WWTF) identified in Table 4. The WWTF discharges to Third Creek, which enters Segment 1806, downstream of both the impaired area, and Station 12615 (Guadalupe River at Kerrville-Schreiner Park).

Based on samples taken at the Kerrville WWTF as part of the supplemental data collection by JMA, the mean effluent concentration was 2 org/100 mL of *E coli*. The Kerrville WWTF includes chlorination as a disinfection process, and its operating permit requires monitoring of chlorine residual. Since this facility's discharge enters below the impaired area, the loading from this facility was not figured into the TMDL equation. Bacterial loading from this facility is expected to continue to meet the water quality standards.

Table 4: Permitted Dischargers in the Upper Guadalupe River Study Area

Permit #	Name of Facility	Flow (MGD)
WQ0010576-001	City of Kerrville	4.5

Nonpoint Sources

In the Upper Guadalupe River study area, both urban and rural nonpoint sources of bacteria were considered. The bacteria data available for these sources was primarily measurements of fecal coliform, the alternate indicator to *E. coli* for assessing the contact recreations use. Sources include failing septic systems, wildlife, livestock, human swimmers, and general urban runoff.

Failing Septic Systems

Private residential sewage treatment systems (on-site sewage facilities) typically consist of one or more septic tanks and a distribution field. Household waste flows into the septic tank, where solids settle out. The liquid portion of the waste flows to the distribution system, which may consist of perforated pipes buried in a soil or gravel bed. Effluent in the bed may move vertically to groundwater, laterally to surface water, or upward to the ground surface. As it moves, the majority of the liquid portion is consumed by evapotranspiration of vegetation planted on top of the distribution field or adjacent to it.

Properly designed, installed, operated, and maintained septic systems would be expected to contribute virtually no bacteria to surface waters. The principal removal mechanism for bacteria would be die-off as the liquid moves through the soil. Various studies have attempted to quantify the transport and delivery of bacteria in effluent from septic systems. For instance, it has been reported that less than 0.01 percent of fecal coliform originating in household waste moves farther than 6.5 feet downgradient from a properly functioning drainfield (Weiskel, 1996).

The number of septic systems in the study area was estimated using information from the 1990 U.S. Census, which included a question regarding the means of household sewage disposal. Unfortunately, this question was not posed in the 2000 Census. Based on the 1990 data, the number of septic systems in the study area was estimated by intersecting the geographic census blocks with the study area watershed. Based on this analysis, there are an estimated 6,400 septic systems in the impaired reach area and an estimated 8,300 sewer connections. Spatial distribution of septic systems is shown in Figure 13.

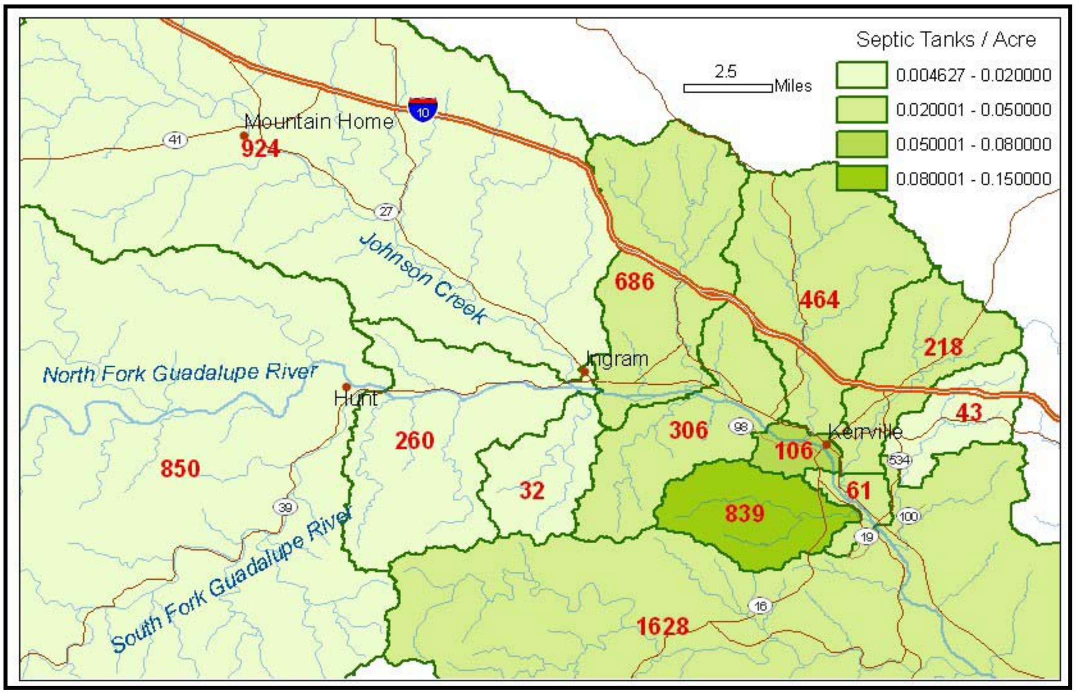


Figure 13: Number and Density of Septic Tanks by Subwatershed

A septic system failure can occur in two ways. First, drainfield failures or overloading could result in uncontrollable, direct discharges to streams. Such failures would not be expected to be common in the study watershed, but they could occur in reaches of the watershed with fractured limestone pathways and in older homes located near a watercourse. Second, an overloaded drainfield could result in surfacing effluent; the pollutants would then be available for surface accumulation and subsequent washoff under runoff conditions. According to a report by Reed, Stowe, and Yank (2001), septic systems in west Texas have a failure rate of about 12 percent.

Livestock

Livestock population estimates for the study area were based on data from the agricultural census (USDA 2002) and are presented in Table 5. These numbers were determined by intersecting county data with the watershed boundaries in a Geographic Information System (GIS). Other types of livestock in the watershed had small populations compared to the major livestock categories listed below; therefore, the fecal loads from these other animal groups were assumed to be negligible.

Table 5: Estimated Livestock Populations for the Study Area

Livestock Type	Population
Cattle and calves	13,319
Hogs and pigs	508
Horses and ponies	1,021
Sheep and lambs	8,217
Goats	12,356
Deer	15,626
Chickens	1,342
Turkeys	427
Ducks	113
Geese	296

Grazing animals deposit fecal coliform bacteria onto the land surface that is subsequently available for washoff to surface waters during storm events. Direct contributions from livestock into the stream are also possible.

Wildlife and Feral Animals

Primary sources of indicator bacteria from wildlife in this watershed are estimated to include deer, raccoons, opossums, feral hogs, and ducks/geese. Though there are numerous other species of animals that inhabit the watershed, there is no practical method to estimate the number of individuals in each species, or the distribution of their fecal deposition. As with livestock, there are two ways for bacteria loadings from wildlife to be transported to the study area. First, wildlife deposit waste on land surfaces that is subsequently available for washoff. Second, they may deposit waste directly into the stream.

Urban

The bacteria concentrations observed in urban runoff are relatively high. Urban loadings of bacteria sources may be derived from urban wildlife, pets, septic system failures, sewer system leaks, discharges of varied nature and composition, and any other sources that may be present. A comprehensive database of urban runoff contaminants, available from long-term studies by the City of Austin, can provide an indication of the magnitude of bacteria concentrations. Bacteria loadings from urban areas are relatively high due to elevated concentrations of bacteria from these sources, and runoff volume is increased due to impervious surfaces common to cities.

Sewer Collection Lines

Leaking wastewater collections lines are difficult to detect but are a severe potential source of bacteria. As with failing septic systems, wastewater lines located close to streams have a high potential to act as bacterial sources. Wastewater lines, especially large collection lines, tend to be installed along creeks and streams because the elevation profile along the waterway channel provides an economical arrangement for the gravity transport of collected sewage. Sewer lines typically leak when their hydraulic grade line is higher than that of the stream that they parallel. Such cases include sewer lines that are filled beyond capacity and sewer lines located along the upper bank of a stream (above the stream's water elevation).

An EPA Report (2003) summarizes factors that influence leaks in sewer collection lines:

1) Age of lines
2) Material of construction (vitrified clay pipe is particularly susceptible to leaks)
3) Type and spacing of pipe joints
4) Depth of flow in sewer
5) Surrounding groundwater depth
6) Surrounding soil type
7) Geologic faults

The City of Kerrville provided a GIS data set of its sanitary sewer system for use in developing this TMDL. The sewer lines were analyzed for their proximity to the Guadalupe River and its tributaries because lines located along these streams, or crossing them, have a relatively high potential to cause surface water contamination if a leak exists. The city's predominant material for main collection lines is vitrified clay pipe, though PVC is not uncommon, especially in the newer areas of the city that are further from downtown. Iron pipes are used at stream crossings.

Direct Human Deposition

Fecal contamination from human swimmers, especially children, is another potential source of bacteria along the Guadalupe River. Station 12617 is located immediately downstream of the public beach at L. Hays Park. Station 12615 is located at Kerrville Schreiner Park, where public swimming is a permitted activity. Both of these stations typically report relatively high *E. coli* levels, especially in summer months. According to officials at Kerrville Schreiner Park, 20 to 100 swimmers are typically swimming at the park on weekend afternoons in the peak season from May to July. This number typically drops to less than 10 swimmers on weekdays (Hufstedler 2006). The number of swimmers at L. Hays Park is expected to be similar (Hastings 2006).

Linkage Analysis

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

In the development of this TMDL, load relationship increases, reductions, and possible sources were defined through the use of load duration curves and flow duration curves, as summarized in the section "LDC Summary" later in this report. Two water quality stations were critical to this study—Station 12617 (Guadalupe River at Hwy 16 in L. Hays Park) and Station 12615 (Guadalupe River at Kerrville-Schreiner Park), at both of which bacteria concentrations regularly exceeded criteria. Bacteria source tracking (BST) was also used to better define sources of bacteria and will be particularly useful in implementation.

Load Duration Curves

Load duration curves (LDCs) are graphical tools for analyzing water quality data and are capable of promoting "effective communication between TMDL developers and implementers, so that actions will lead to measurable water quality improvements" (Cleland 2003). Many states have begun to use the LDC methodology for better characterization of pollutant sources, point versus nonpoint contributions, and for the development of more robust TMDL target than that achieved by less sophisticated methodologies (Nevada DEP 2003).

Load duration curves utilize historical flow data and water quality monitoring data to define a relationship between stream flow (volume per time) and pollutant load (mass or number of bacteria per time). A curve is generated to represent the maximum pollutant load allowable under different flow conditions, based on state criteria. This curve is then compared to actual water quality samples expressed as loads and plotted as points, falling either above or below the curve.

The load duration curve methodology is an appropriate method of TMDL development for the Guadalupe River. The large number of samples collected along the river provides good definition of the variation in bacteria load under different flow regimes. Furthermore, the limitations of LDCs can be mitigated by evaluating the loading reductions indicated by the curves against the historical data time series.

Load Duration Curve Development

This section describes the process used to develop the LDCs for this TMDL.

Flow Duration Curves

A flow duration curve (FDC) is a graphical plot of daily streamflow versus the percent of days that the streamflow value is exceeded. The creation of an FDC is the first step in the LDC development process. In fact, LDCs are created by modifying FDCs with pollutant criteria and pollutant sampling data.

FDCs were developed for USGS gauging stations located in the study watershed. These USGS curves could then be used as a basis for developing FDCs for all of the water sampling locations in the watershed. Flows for other ungauged monitoring locations can be obtained by application of the drainage area ratio between the gauged and ungauged sites, thereby formulating a synthesized flow record. Table 6 shows the USGS gauging stations utilized in this project. It is noted that another USGS station centrally located within the study area (USGS #8166140) was not utilized because it was not active throughout most of the period of water quality sampling. Table 7 lists the study's water quality sampling stations along with the USGS gauging stations that were used to develop their respective FDCs.

Summer and yearly flow duration curves for the two USGS stations are shown in Figures 14 and 15 using different y-axis options. Figure 14 uses a linear y-axis scale, and Figure

Table 6: USGS Stations Used for FDC Development

USGS Station No.	Location Description	Area (square miles)	Period of Record
8166000	Johnson Creek near Ingram	114	1987-2004*
8166200	Guadalupe River at Kerrville (UGRA Dam)	486	1986-2004

*Gage was inactive 1994-2000

Table 7: Water Quality Sampling Station FDC Information

Station No.	Short Description	USGS Station (for FDC development)	Drainage Area (sq. miles)
12546	Camp Mtg Crk	8166000	10
12541	Quinlan Crk	8166000	12
12549	Town Crk	8166000	24
12678	Johnson Crk	8166000	127
12620	G Rv at Ingram	8166200	447
12619	G Rv at Bear Crk	8166200	470
12618	G Rv at UGRA	8166200	486
16244	G Rv at LH Pk W	8166200	487
12617	G Rv at LH Pk 16	8166200	511
16243	G Rv at LH Pk E	8166200	511
12616	G Rv at G St	8166200	512
12615	G Rv at KS Pk	8166200	536

15 uses a logarithmic y-axis. Use of the logarithmic axis is more typical for flow duration curves because it provides more definition for low-range flows, but it is less intuitive for most observers. Since the vast majority of water quality sampling data were collected during the summer season, defined as 1 May to 15 September, it was determined that flow duration curves representative of that time period would be particularly useful. As illustrated in Figures 14 and 15, the average summer flow (as represented by the 50^{th} percentile) is typically less than the median annual flow. However, the summer season seems to have more flow variability, as indicated by the steeper shape of the summer curves.

The flow distribution has been divided into five flow regimes as recommended by Cleland (2003). These flow regimes are listed in Table 8, and are illustrated in all FDC and LDC figures. For the Guadalupe River, the "High Flows" category typically represents large runoff events generated by storm systems delivering multiple inches of rainfall over a short period of time. The "Upper/Mid-Range flows" typically represent smaller runoff events, periods of flow recession following large storm events, and periods of high base flows. The "Mid-range Flows" typically represent periods of moderate base flows, but can also represent small runoff events. The "Lower Mid-range Flows" typically represent periods of moderate to low base flow conditions. The "Low Flows" represent relatively dry conditions, resulting from extended periods of little or no rainfall.

These regimes represent flow ranges that are influenced by certain sources (point, non-point, both). In addition, this allows for the development of controls which target these specific flow ranges.

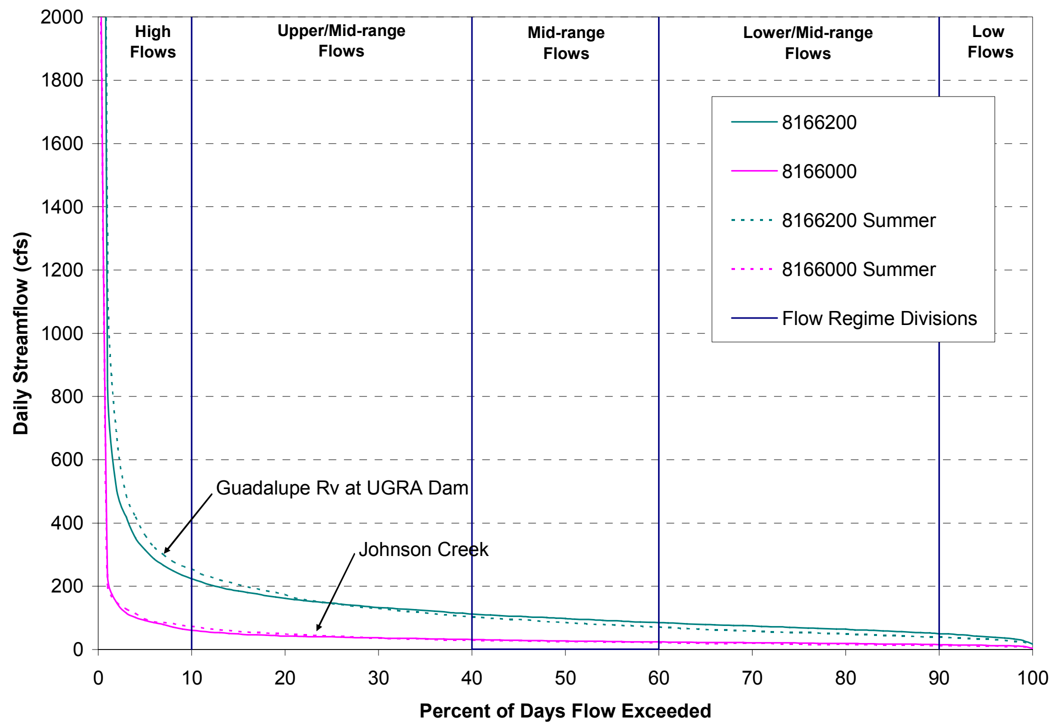


Figure 14: Flow Duration Curves for USGS Stations, Linear Scale

Table 8: Flow Regime Classifications

Flow Regime Classification	Flow Duration Interval
High Flows	0 - 10%
Upper/Mid-Range Flows	10 - 40%
Mid-Range Flows	40 - 60%
Lower/Mid-Range Flow	60 - 90%
Low Flows	90 - 100%

Application of Water Quality Criteria

FDCs can be multiplied by water quality criteria to create LDCs. This study considered the maximum allowable value for both the geometric mean of *E. coli* samples (126 org/100 mL) and for single samples (394 org/100 mL). When a flow (volume/time) is multiplied by a bacterial concentration (number/volume), the result is a pollutant-loading rate (number/time). Figure 16 shows the resulting summer LDCs for USGS Station No.

8166200, which is at the same location as water quality sampling Station 12618 (Guadalupe River at UGRA Dam).

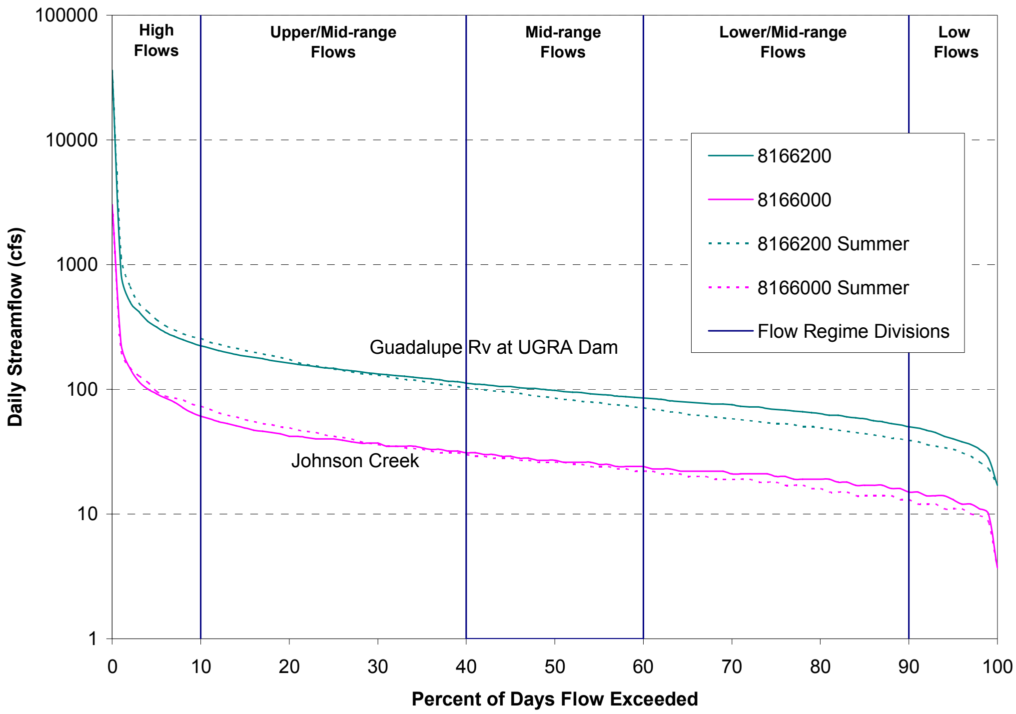


Figure 15: Flow Duration Curves for USGS Stations, Logarithmic Scale

Integration of Water Quality Sampling Data

The next step in the development of LDCs is plotting existing water quality sampling data. The measured pollutant concentration must first be converted to daily loads. This can be approximated if the single-sample concentration generally reflects the average, flow-weighted concentration for the day on which it was collected. This average concentration can then be multiplied by the daily average value for stream flow in order to calculate the daily load. These loads are then plotted against their corresponding daily streamflow exceedance percentile.

The plotted loads can then be compared to the LDCs for the single-sample water quality criterion. The degree to which a plotted load exceeds the criterion LDC reflects the degree to which the measured concentration exceeded the criterion on the day the sample was taken. For example, if a load is plotted 50 percent higher than the 394 org/100 mL criterion LDC, this means that the concentration sampled on that day was 591 (394 x 1.5) org/100 mL.

Figure 17 shows the summer LDC for Station 12620 (Guadalupe River at Ingram Dam), including the sampled *E. coli* loads. This figure shows that the location is in compliance with both the geometric mean and single sample criteria. However, at other stations, compliance or noncompliance is less obvious. For that reason, to characterize the data two different trend lines were utilized (Figures 18-23).

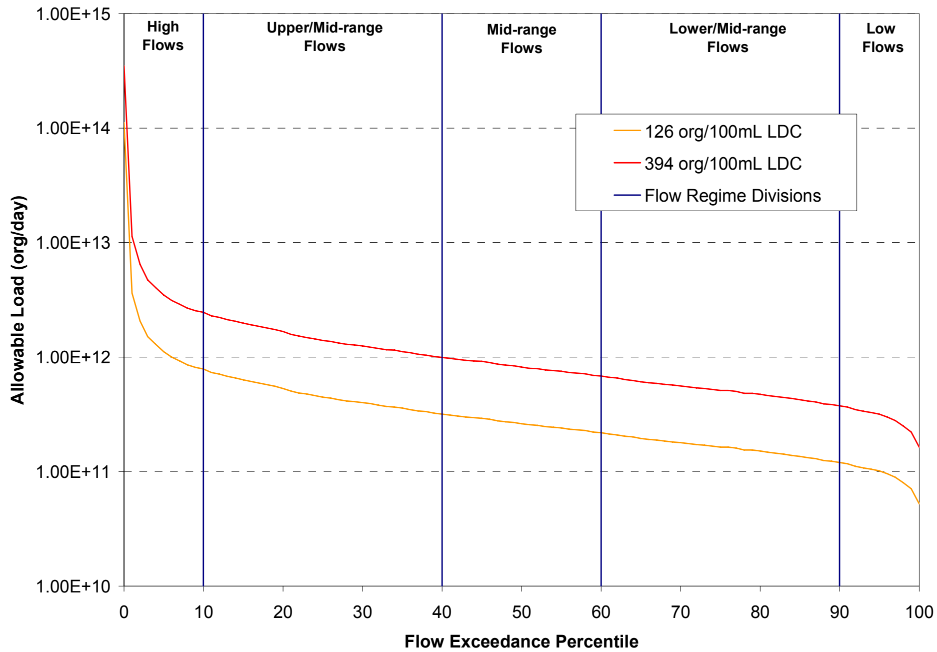


Figure 16: Summer LDC for USGS Station No. 8166200, UGRA Dam

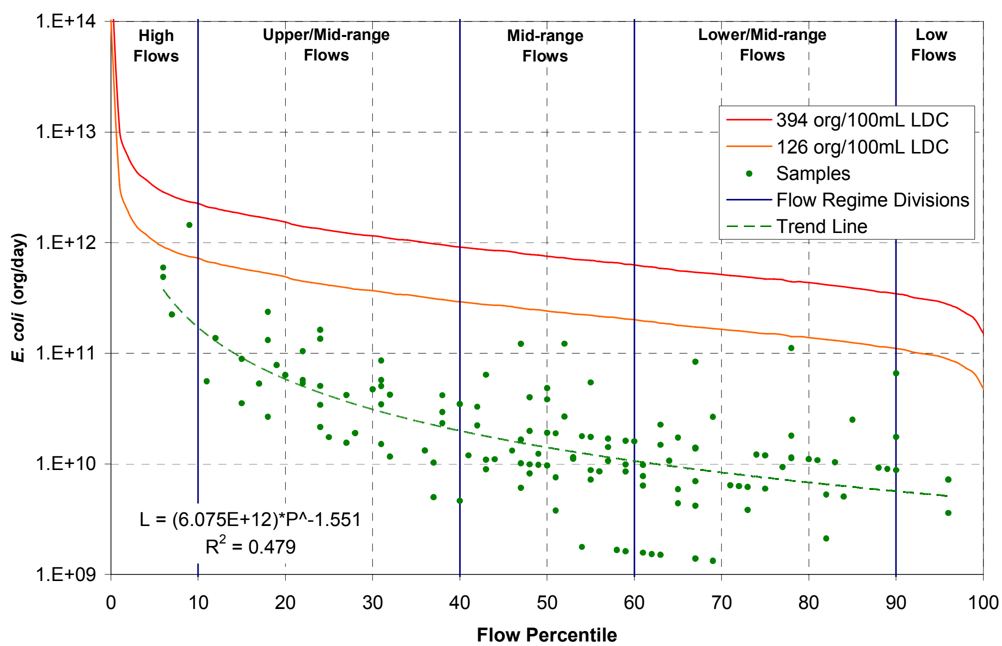


Figure 17: Summer LDC for 12620 (Guadalupe River at Ingram Dam)

Power function and exponential trend lines have different characteristic shapes. When shown on an LDC (semi-log) plot, the power function trend line is more curved than the exponential trend line. In Figure 17, sampling data plotted are best represented by a power-function trend line, which are most suitable when bacteria concentrations increase substantially under high flow conditions. Exponential trend lines are not as steep as power-function trend lines under high flow conditions. In general, these flatter trend lines would be expected to be more suitable for stations under the influence of both wet- and dry-weather bacteria sources. LDCs were calculated for many other stations throughout the watershed, and are presented in the following section.

Summer Versus Annual LDCs

As shown in Table 2, about 85 percent of the bacteria samples for the Guadalupe River were collected during the summer season, which is when most of the river's primary contact recreation occurs. Also, bacteria levels are typically at their peak during summer months. For these reasons, summer LDCs have been chosen over annual LDCs as the most appropriate method for determining compliance with water quality criteria.

The use of summer LDCs also helps to ensure that the loads observed at different stations are comparable. At many stations, the bacteria samples taken during non-summer conditions are typically much lower than samples taken under summer conditions (see Figure 12). Therefore, when using an annual LDC, the trend line (or average load) observed at a station will be skewed downward based on the number of non-summer samples collected at that station. Since different numbers of non-summer samples have been collected at the different stations, some stations would have their data skewed downward more than others. This makes it more difficult to compare the loads at different stations if annual LDCs are used.

Load Duration Curve Analysis

This section presents load duration curves for various water quality-sampling stations throughout the study area. The bacterial loads are the product of each single sample bacteria concentration and the corresponding mean daily streamflow rate. The LDCs are analyzed for compliance with respective criteria and for assessing sources. Sources are assessed by observing how bacteria levels vary under different flow conditions (flow percentile). The presence of point sources is observed as exceedances at low-flow exceedance frequencies. Trend lines and data scatter are also considered, and comparisons are made between LDCs at upstream and downstream locations.

LDCs for Stations along the Main Stem of the Guadalupe River

LDCs were developed for seven monitoring locations along the main stem of the Guadalupe River. The following discussion does not attempt to quantify load reductions. LDCs are presented in order, from most upstream to most downstream location.

Station 12620 – Guadalupe River at Ingram Dam

The load duration curve for Station 12620 is shown in Figure 17. Based on comparison of sample loadings with criteria, this station usually meets the criteria for contact recreation use. None of the historic samples exceeded the single sample criterion of 394 org/100 mL.

The sampling data plotted are best represented by a power-function trend line. Nonpoint, wet-weather sources related to runoff seem to be the dominant method of bacterial loading in this reach. The R^2 value, which tests how well the data variation is explained by the trend line, is 0.48. Compared to the other load duration curves, this suggests a relatively strong trend.

Station 12619 – Guadalupe River at Bear Creek Crossing

The load duration curve for Station 12619 is shown in Figure 18. Based on comparison of sample loadings with criteria, this station also usually meets both criteria. However, it is apparent that loads are significantly higher under mid-range and low flow conditions than at the previous, upstream station. This suggests that a direct, dry-weather source could be present. Also, the loads at the previous station may have been particularly low because the previous station was an impounded location at Ingram Lake. It was observed at other stations that impoundments seem to result in lower bacteria levels. Regardless of the sources, loads at Station 12619 are still very low when compared to downstream stations. A power-function trend line still provides the best fit, suggesting that wet-weather sources are still dominant.

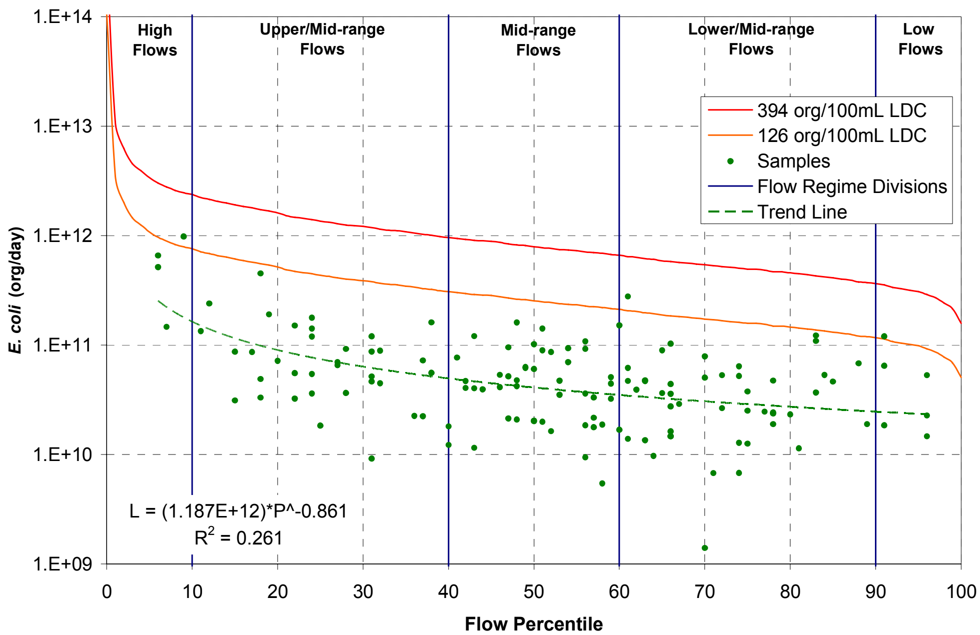


Figure 18: Summer LDC for 12619 (Guadalupe River at Bear Creek Crossing)

Station 12618 – Guadalupe River at UGRA Lake Dam

The load duration curve for Station 12618 is shown in Figure 19. It is clear that bacteria criteria are not exceeded at this location. At this station, the loads associated with low and mid-range flows are significantly less than at the previous, up stream station. This reduction could be due to bacterial settling and removal that occurs as a result of the UGRA Lake impoundment.

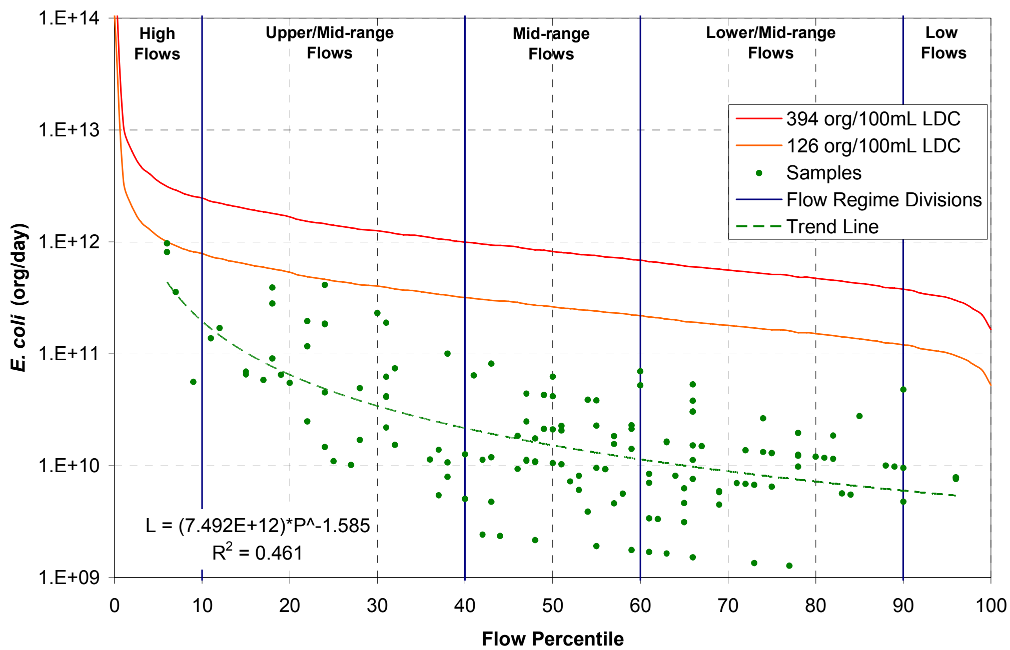


Figure 19: Summer LDC for 12618 (Guadalupe River at UGRA Lake Dam)

Station 16244 – Guadalupe River at L. Hays Park Footbridge

The load duration curve for Station 16244 is shown in Figure 20. This station is not always in compliance with the criteria. Seven samples, or 5 percent, exceed the single sample criterion of 394 org/100 mL. A larger number of samples exceed the geometric mean criterion of 126 org/100 mL. However, the trend line for the sampling data is below the geometric mean criterion.

At Station 16244, a power-function trend line still provides the best data representation. Loads at low and mid-range flows are a full order of magnitude (10x) higher that at the previous upstream station. This suggests that a significant, dry-weather, direct source exists between the two stations.

Station 12617 – Guadalupe River at Hwy 16 in L. Hays Park

The load duration curve for Station 12617 is shown in Figure 21. This station regularly exceeded both criteria. In fact, concentrations are typically higher at this location than at any other station along the main stem of the Guadalupe River. Forty-six percent of the samples exceed the single sample criterion of 394 org/100 mL. At this location, data are scattered and exceedances of criteria are experienced throughout all flow conditions. At Station 12617, the loads are about three times greater than the loads experienced at the next upstream station (16244, Guadalupe River at L. Hays Park Footbridge) from low flow conditions. This suggests that the station is influenced by significant, dry-weather, direct sources.

At Station 12617, an exponential trend line provides the best data characterization. For Station 12617, the low R^2 value of 0.04 is indicative of the considerable scatter in the samples at this location.

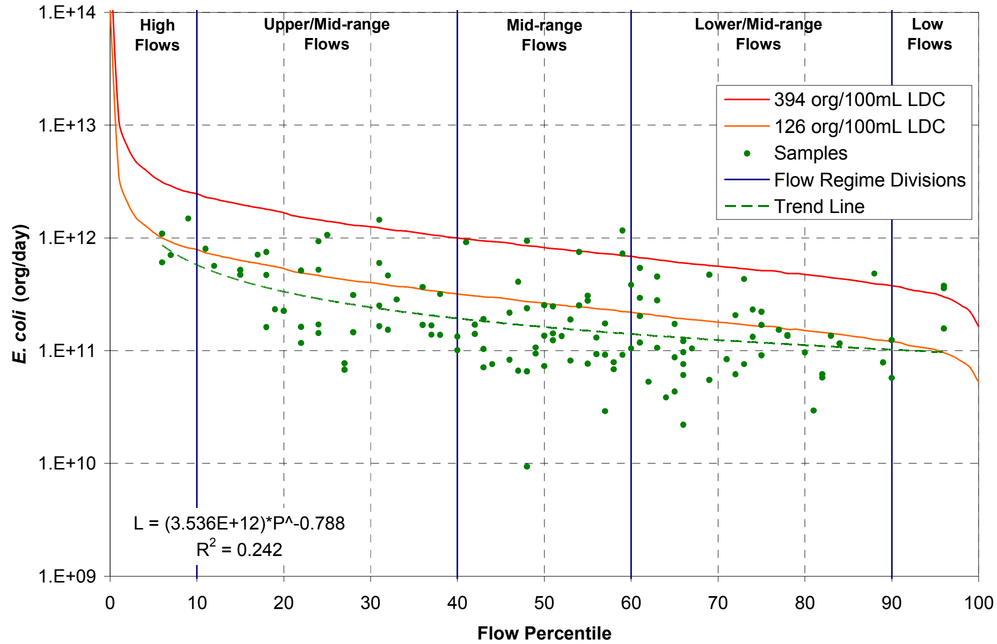


Figure 20: Summer LDC for 16244 (Guadalupe River at L. Hays Park Footbridge)

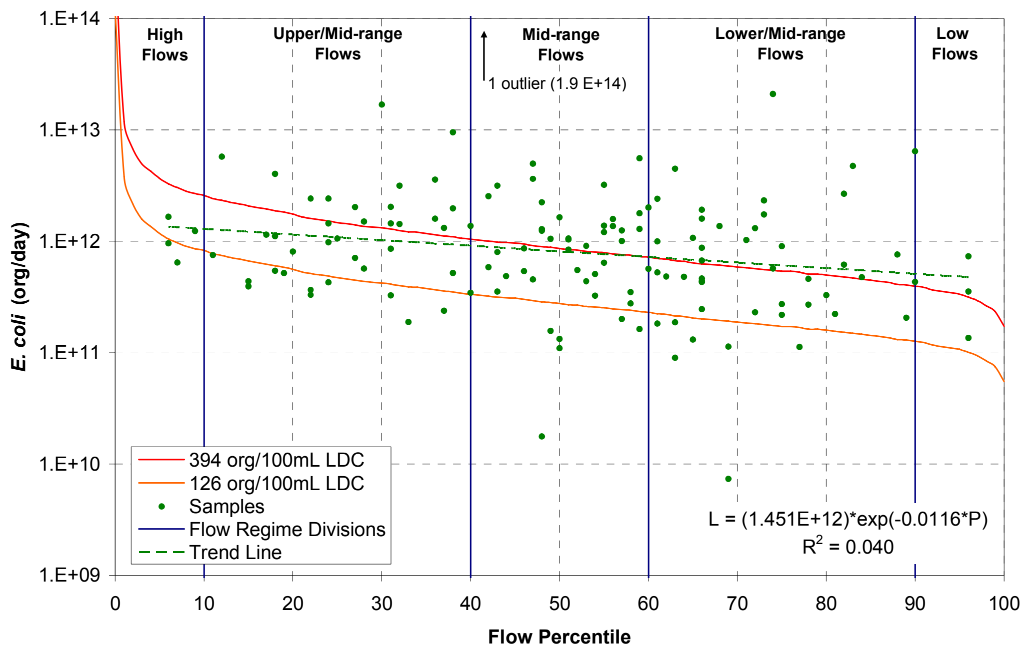


Figure 21: Summer LDC for 12617 (Guadalupe River at Hwy 16 in L. Hays Park)

Station 16243 – Guadalupe River at L. Hays Park Dam

The load duration curve for Station 16243 is shown in Figure 22. At this location, just seven samples, or 5 percent, exceed the single sample criterion of 394 org/100 mL. However, the exponential trend line suggests that average bacteria levels often exceed the geometric mean criterion of 126 org/100 mL.

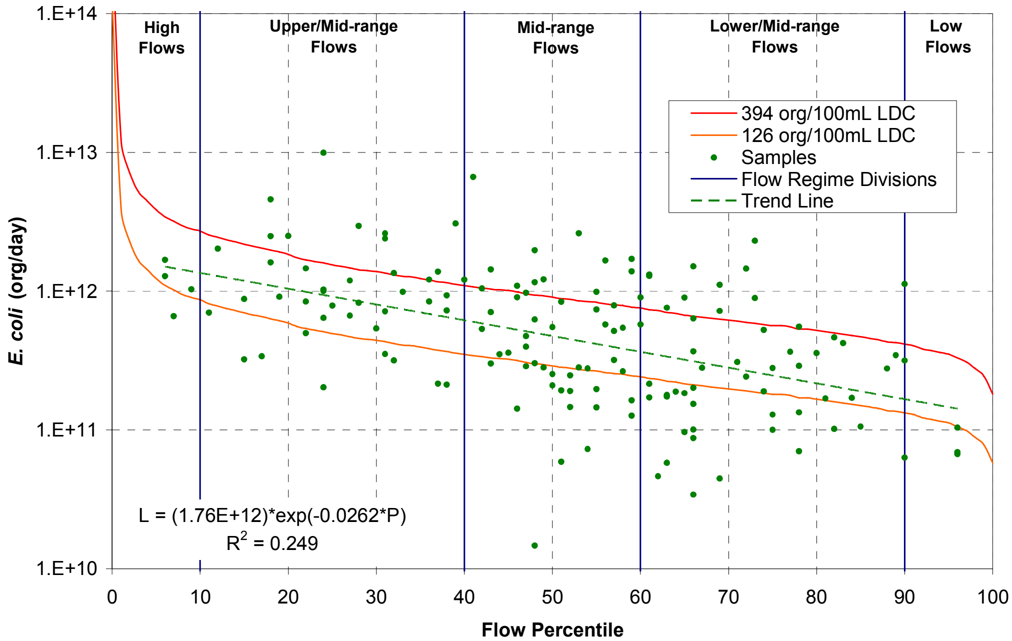


Figure 22: Summer LDC for 16243 (Guadalupe River at L. Hays Park Dam)

At this station, the loads are markedly lower and less scattered than the next upstream station (12617, Guadalupe River at Highway 16 in L. Hays Park), which is located only 500 feet away. One possible explanation for this is that the impoundment of water provided by the dam results in a positive influence on water quality. As noted, the stations at Ingram Dam and UGRA Dam (Station 12620 and 12618) also exhibited relatively low bacteria levels with relatively little scatter.

Below Station 16243 is Station 12616 (Guadalupe River at G Street Bridge). This station exhibited somewhat lower bacterial loads than Station 16243, but was not plotted as an LDC curve because the sampling was much less extensive and no monitoring was performed in 2005.

Station 12615 – Guadalupe River at Kerrville-Schreiner Park

The load duration curve for Station 12615 is shown in Figure 23. At this location criteria are regularly exceeded. Twenty-four percent of samples exceed the single sample criterion of 394 org/100 mL. Also, the exponential trend line for the samples is significantly higher that the geometric mean criterion of 126 org/100 mL.

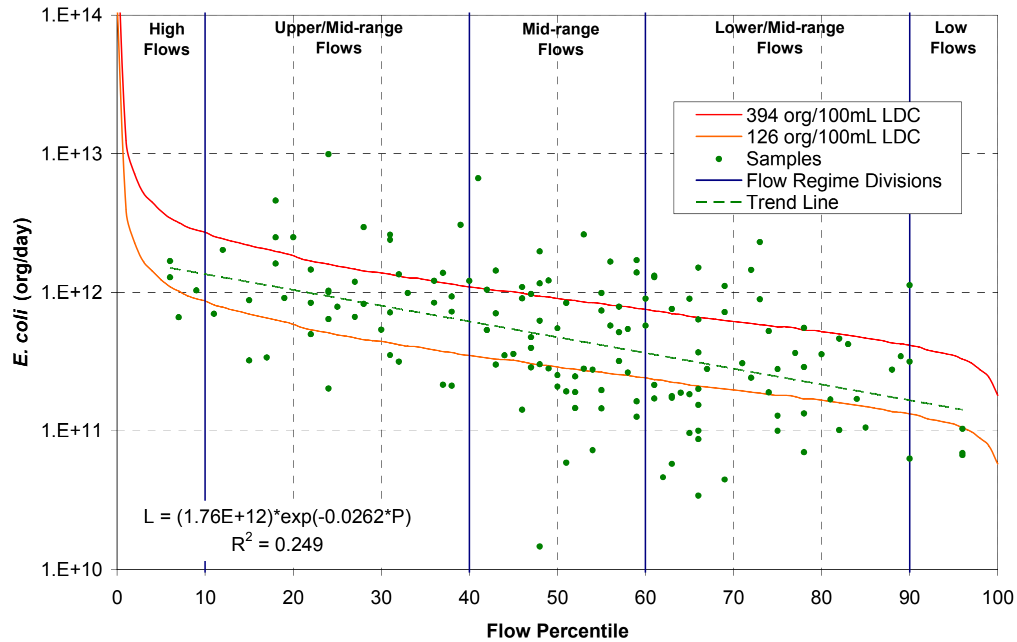


Figure 23: Summer LDC for 12615 (Guadalupe River at Kerrville-Schreiner Park)

At Station 12615, the loads are significantly higher than at the upstream Station 16243 (Guadalupe River at L. Hays Park Dam) under both low flow and high flow conditions. This suggests that both dry-weather and wet-weather sources are likely to exist between the L. Hays Park Dam and Kerrville-Schreiner Park.

LDC Summary

Figure 24 shows the LDC trend lines developed for the stations located along the main stem of the Guadalupe River. This figure is plotted using a linear (not logarithmic) y-axis so that the actual magnitude of the load variation is more easily observed. The allowable geometric mean criterion load is plotted based on the flow duration curve for Station 12617 (Guadalupe River at Highway 16 in L. Hays Park). Because the flows at the other stations are similar in magnitude, this criterion curve is useful for comparison with all of the stations shown. The arrows in the figure point to the next downstream station.

From Figure 24, it is clear that bacteria loading is relatively low for stations upstream of the impaired reach (upstream of L. Hays Park). Loads are generally the highest at Station 12617 (Guadalupe River at Hwy 16 in L. Hays park), and Station 12615 (Guadalupe River at Kerrville-Schreiner Park).

The greatest increase in load occurs between Station 16244 (Guadalupe River at L. Hays Park Footbridge) and Station 12617 (Guadalupe River at Highway 16 in L. Hays Park). This is especially notable since these two stations are located less than 900 feet apart from each other. The most obvious explanation for this is that there is a major bacteria source located between these two stations. It may also be possible that the configuration of the L. Hays reservoir could result in different bacteria levels at different locations. Station

16244 (Guadalupe River at L. Hays Park Footbridge) is located on the south side of a long island that essentially splits the western half of the lake into a north and south channel, as shown in Figure 11.

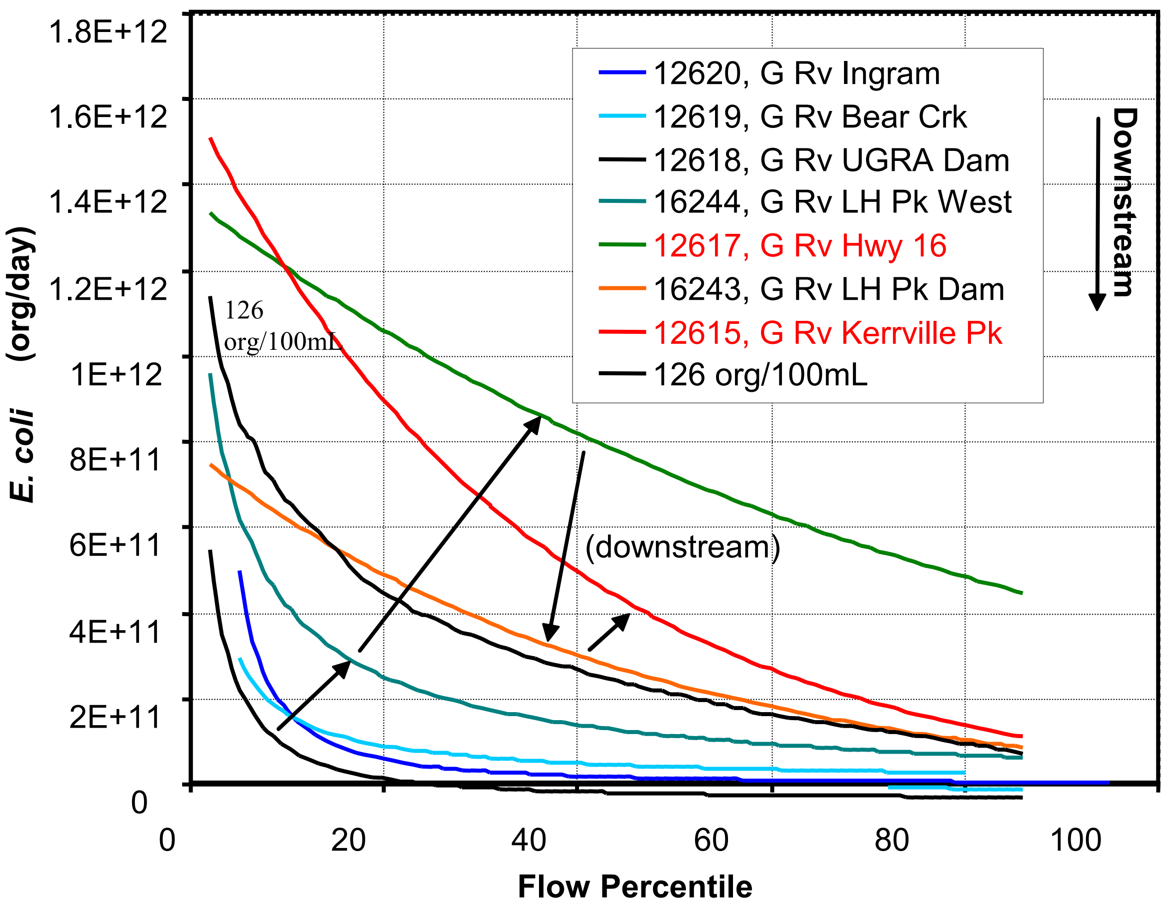


Figure 24: Summary of LDC Geometric Mean Trend Lines for the Main Stem of the River

The bacteria load increases substantially again at Station 12615 (Guadalupe River at Kerrville-Schreiner Park). Unlike the increase in load at Station 12617 (Guadalupe River at Highway 16 in L. Hays Park), here the greatest increase in load occurs under high flow conditions. This loading suggests the presence of nonpoint, wet-weather sources. It is also interesting to note that if the upstream trend line for Station 16243 (Guadalupe River at L. Hays Park Dam) were subtracted from the trend line at Station 12615 (Guadalupe River at Kerrville-Schreiner Park), then the resulting trend line would be under the 126 org/100 mL criterion. This suggests that if the loads contributing to L. Hays Park Lake (upstream of Station 16243, Guadalupe River at L. Hays Park Dam) can be removed, then Station 12615 (Guadalupe River at Kerrville-Schreiner Park) may also fall into compliance.

Bacteria Source Tracking

Watercourses can be affected by many different sources of microbial pollution. In a given watershed, the primary potential sources of microbial pollution include human and animal populations, as well as soil and plants as secondary sources. During the past decade, several methods have been proposed for identifying the sources of microbial pollution in the environment. BST can be useful in the development of TMDLs as part of the source assessment, load allocation, and in the development of an implementation plan to target specific sources of bacteria entering a respective water body. Given the plethora of potential sources of fecal waste in any watershed, it is seldom possible to determine with certainty the major sources without some application of BST methods.

Currently there are a number of research groups and commercial laboratories that conduct source tracking and source identification studies using a variety of different methods and target organisms (EPA 2005). The methodologies that have been used to determine the sources of microbial contamination in the environment include phenotypic-based methods such as antimicrobial resistance profiles (ARP), and genotypic-based methods such as ribotyping, macrorestriction fingerprinting using pulsed field gel electrophoresis (PFGE), polymerase chain reaction (PCR) based methods, and many others. ARP and ribotyping have been used far more than the other BST methods, and are somewhat well developed with respect to their application to water quality studies.

Available BST methods were evaluated and ribotyping was selected to meet the needs of this study. All BST laboratory work was conducted by Source Molecular Corporation, located in Miami, Florida. The source identification portion of the method relies on generating genetic fingerprints of *E. coli* strains and comparing the fingerprints to those of *E. coli* strains isolated from potential sources of fecal pollution. The genetic fingerprints are prepared by applying restriction enzymes to the Ribosomal RNA of bacteria.

The BST process involves two primary steps. First, a library of the genetic fingerprints of known sources is created. This was accomplished through the field collection of fecal matter samples from animals within the Upper Guadalupe River watershed. As the data were gathered, they were sent to SMC to be analyzed and added to the library of fingerprints. This sampling also included the Kerrville wastewater treatment facility.

Once the BST library was created, bacteria of unknown origin (*E. coli* isolates), collected in water quality samples, could then be compared to the fingerprints in the library to determine source classification. For this project, BST samples were collected at the four stations listed in Table 9.

Table 9: BST Sampling Stations

Station No.	Location Description
12546	Camp Meeting Creek at Hwy 173
12621	Guadalupe River at SH 39 in Hunt
16243	Guadalupe River at L. Hays Park Dam
12615	Guadalupe River at Kerrville-Schreiner Park

Source Molecular Corporation employed two methods for comparison and classification of DNA fingerprints. First, the Bionumerics statistics program from Applied Maths, Inc. was used to assign a probable match between each isolate from the water samples and the isolates from the fecal source library. The second method was a visual assessment of each individual band, or DNA fingerprint, generated throughout the study. Only isolate matches with a stringent confidence level of 90 percent or more were accepted as probable matches in the classification protocol for this TMDL. This conservative cut-off criterion was designed to avoid misclassification errors.

The classification results indicate that the predominant sources of *E. coli* in the watershed include humans, ducks, cows, pigeons, and goats. Overall results (for all samples at all stations) for the BST were:

- 22% of the isolates originated from human or septic tank sources
- 16% of the isolates originated from wildlife, mostly birds
- 13% of the isolates originated from livestock, primarily goats
- 2% of the isolates originated from pets
- 46% of the isolates were indeterminate

Results can also be evaluated at each individual station. Table 10 presents these results in detail. Figure 25 represents the sampling results for each location graphically.

The bacterial source composition results from the present study appear to be reasonable. The three predominant sources identified were humans, wildlife (mostly birds), and livestock (mostly goats). However, since more than 40% of the samples could not be identified, these results must be interpreted with caution.

Margin of Safety

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

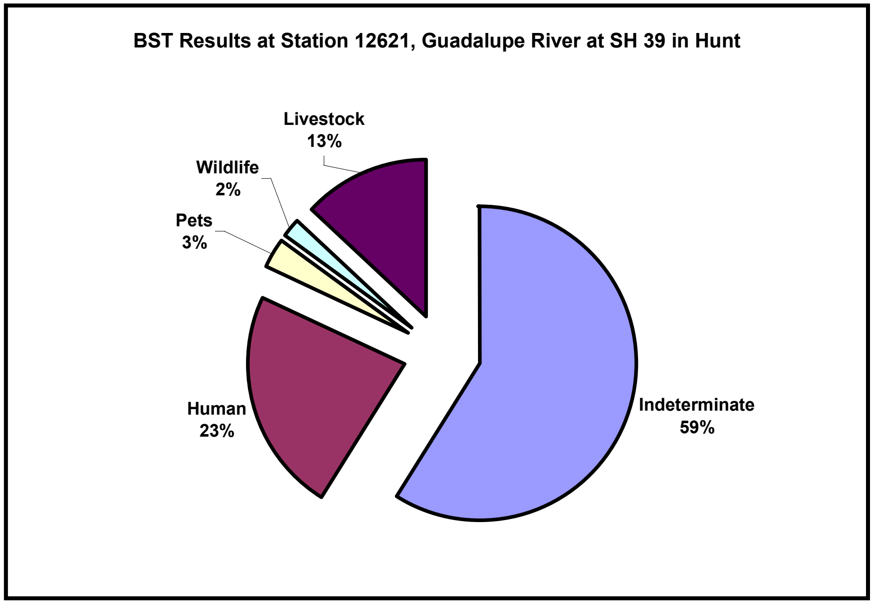
- implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- explicitly assigning a loading amount for the MOS.

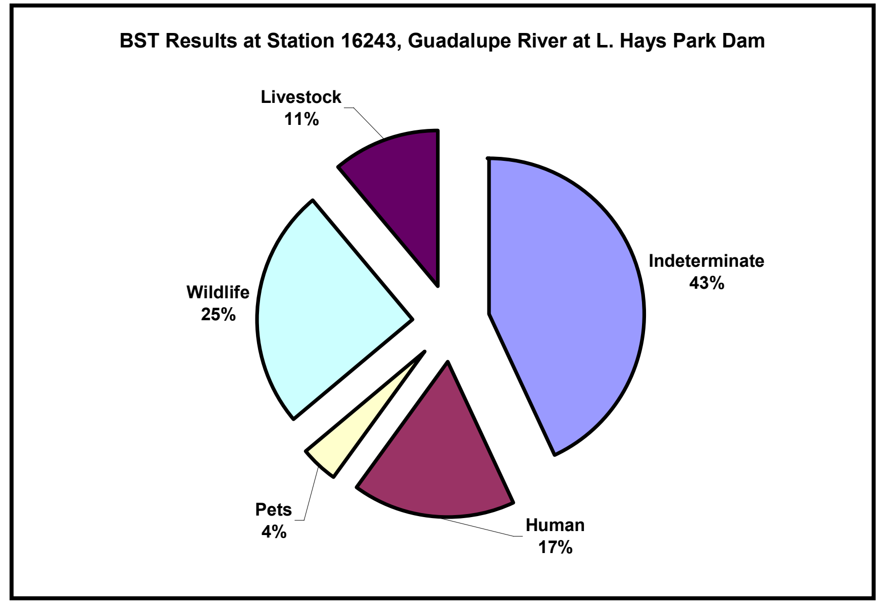
The margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

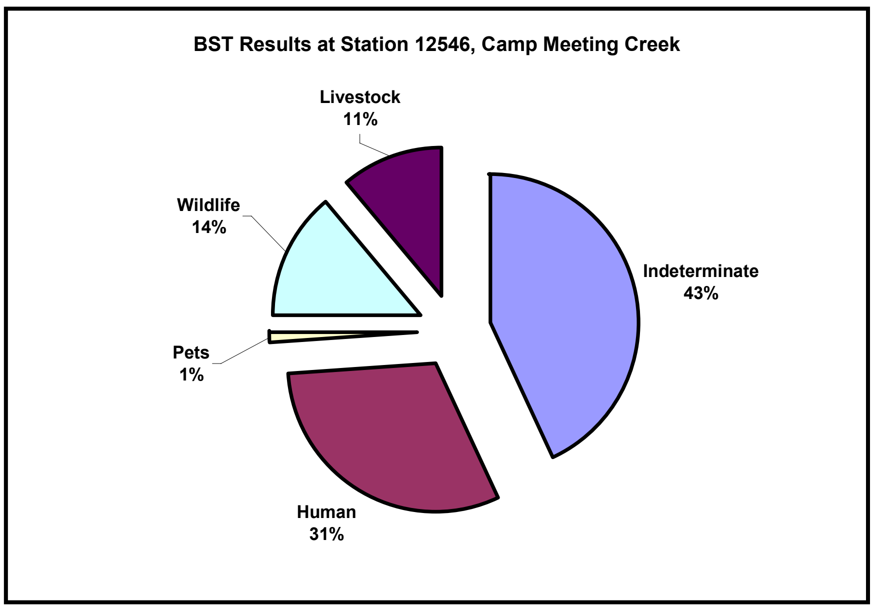
The MOS was explicitly incorporated into this TMDL. Because there is a high degree of contact recreation in the study area, it was concluded that it would be better to err on the side of caution to protect public health and provide the most reasonable safeguards. Bacteria can also display substantial variation, and are subject to numerous sources and processes that may affect concentrations at any point in a stream or any point in time. Conse-

Table 10: Guadalupe River BST Sampling Results

		Guad. R. at SH 39 (12621)		Guad. R. at L. Hays Park Dam (16243)		Camp Meeting Creek (12546)		Guad R. at Kerrville-Schreiner Park (12615)	
		Number Isolates (>90% Similarity)	% of Total Isolates	Number Isolates (>90% Similarity)	% of Total Isolates	Number Isolates (>90% Similarity)	% of Total Isolates	Number Isolates (>90% Similarity)	% of Total Isolates
Human	Human	12	23%	8	17%	3	31%	8	17%
	Septic	11		9		28		9	
Pets	Dog	3	3%	4	4%	1	1%	2	2%
Wildlife	Deer	1	2%	3	25%	3	14%	1	22%
	Grackle	0		1		0		3	
	Pigeon	0		12		7		5	
	Duck	1		8		4		8	
	Raccoon	0		0		0		1	
	Swallow	0		1		0		4	
Livestock	Horse	0	13%	0	11%	0	11%	0	19%
	Donkey	0		0		0		0	
	Mule	0		2		0		1	
	Sheep	0		0		0		4	
	Goat	12		4		9		6	
	Cow	1		5		2		8	
Indeterminate		60	59%	43	43%	43	43%	40	40%







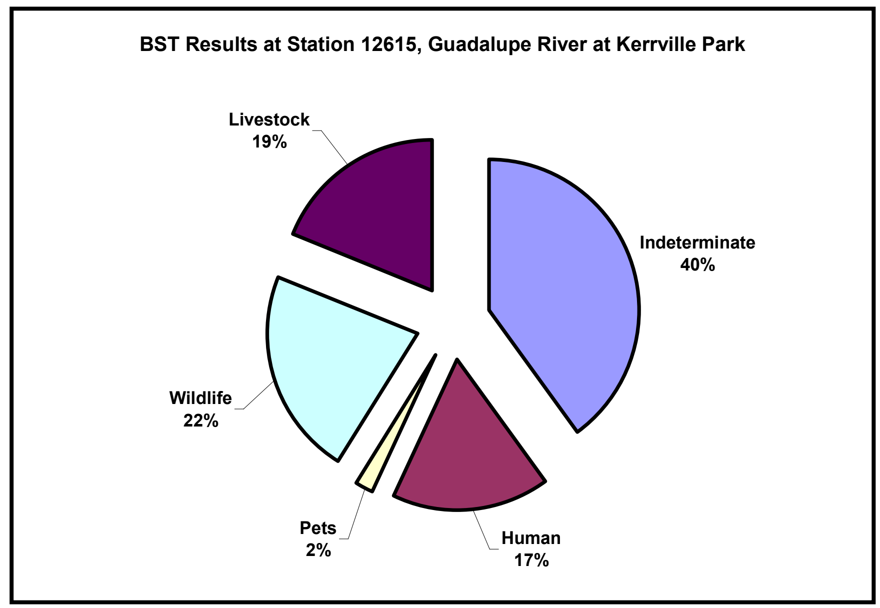


Figure 25: Guadalupe River BST Sampling Results

quently, a 5 percent explicit margin of safety was used to account for these uncertainties. The MOS was incorporated into the TMDL by requiring that geometric mean concentrations not exceed 120 org/100 mL and single sample concentrations not exceed 374 org/100 mL, a 5 percent reduction as compared to the criteria of 126 org/100 mL and 394 org/100 mL designated in the water quality standards. It is also worth mentioning that there is an implicit margin of safety built into the criteria, which were developed using a low illness rate of less than 1.0 percent.

Pollutant Load Allocation

The purpose of the TMDL allocation is to develop the framework for reducing bacteria loadings under the existing watershed conditions so water quality standards can be met. The TMDL represents the maximum amount of pollutant that the stream can receive daily without exceeding the water quality standard. The load allocations for the selected scenarios were calculated using the following equation:

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

Where:

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

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

The numeric criteria defined in the Standards for bacteria are expressed in terms of geometric mean and single sample concentrations. The TMDL is represented by load duration curves at 5 percent less than those criteria, or 120 org/100 mL for geometric mean concentrations and 374 org/100 mL for single sample concentrations, in order to incorporate a margin of safety.

Figures 26 and 27 include these targets for the two critical stations. Also shown in these figures are the loads corresponding to the geometric means and the 75th percentiles of the sample concentrations for each flow regime. The 75th percentile is used because TCEQ guidance states that 25 percent of the samples must exceed the criterion for single samples before the water body is assessed as not supporting the contact recreation use (TCEQ 2004). The required loading reduction for single samples can be determined for each flow regime by calculating the difference between the 75th percentile load and the 374 org/100 mL target curve. Similarly, the required loading reduction for the geometric mean can be determined for each flow regime by calculating the difference between the geometric mean load and the 120 org/100 mL target curve.

The critical reductions are determined by calculating the greatest percent load deviation from the criterion curves. For Station 12617, Guadalupe River at Hwy 16 in L. Hays Park (Figure 26), the greatest percent reductions are required under lower/mid- and mid-range

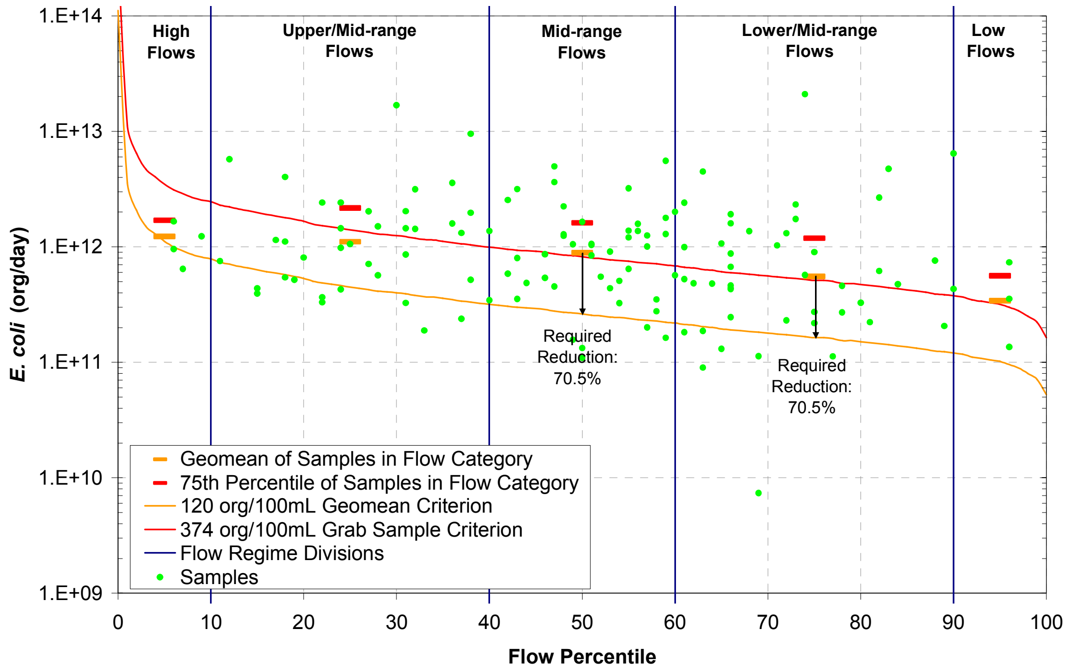


Figure 26: Load Duration Curve Reductions for Station 12617 (Guadalupe River at Highway 16 in L. Hays Park)

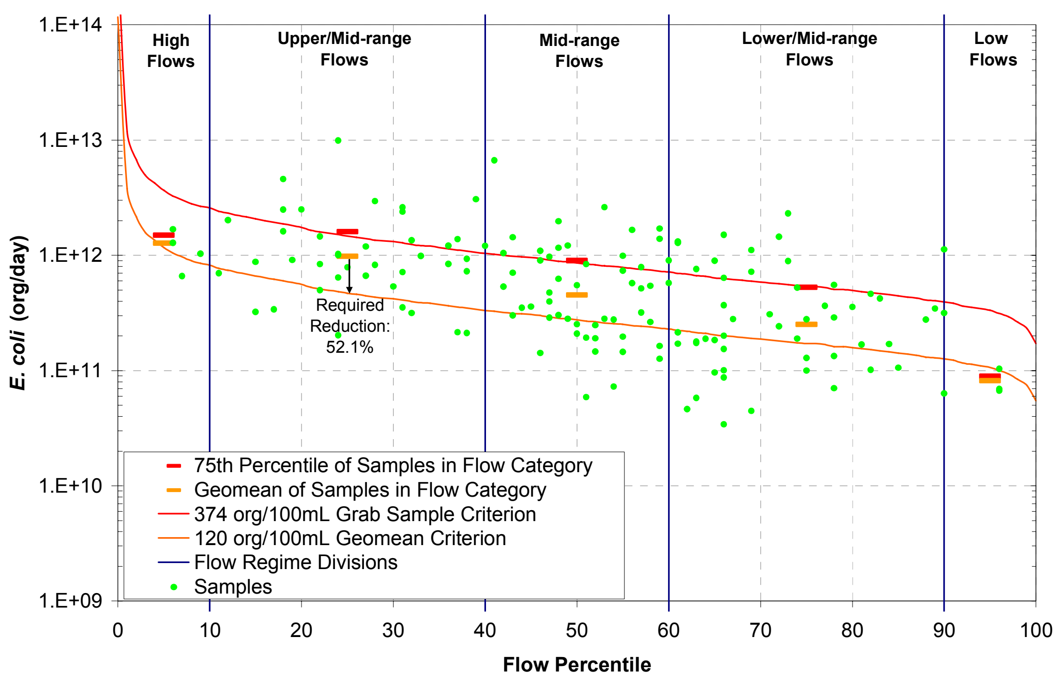


Figure 27: Load Duration Curve Reductions for Station 12615 (Guadalupe River at Kerrville-Schreiner Park)

flow conditions. Under these conditions, a 70.5% reduction is required to bring the river into compliance. It is simply a coincidence that the same reduction is required for both flow categories. For Station 12615, Guadalupe River at Kerrville-Schreiner Park, (Figure 27), the greatest percent reduction is required under the upper/mid-range flow regime. For this condition, a 52.1% reduction is required to bring the river into compliance. The critical load reductions for both stations are based on the geometric mean criterion, which appears to be more stringent that the single sample criterion at these locations.

Allocation Scenario Development

Allocation scenarios that would reduce the existing bacteria loads to support the contact recreation use were simulated using load duration curves.

Wasteload Allocation

A TMDL wasteload allocation represents the maximum allowable contribution of point sources. Kerrville WWTF is the only potential point source for bacteria in the study area. The WWTF is located on Third Creek, a tributary of the Guadalupe River. Third Creek enters the Guadalupe River at Flat Rock Lake, as shown in Figure 5. Station 12615 at Kerrville-Schreiner Park is also located on Flat Rock Lake, but it is about 2,500 feet upstream from the confluence with Third Creek. Because of its downstream location, the WWTF source was not included in the TMDL allocation. Therefore, in the absence of contributing point sources to the identified impaired reaches, no wasteload allocation was developed for this TMDL.

At this time, it could not be determined if the City of Kerrville must have a Municipal Separate Storm Sewer System (MS4) permit under the new Phase II requirements. The City of Kerrville's urban runoff has been allocated to the load allocation (LA). The TCEQ will move the city's loading from LA to WLA, if appropriate, when an implementation plan (I-Plan) is developed. The total load allocation for the study area will not change.

Load Allocation

Load allocations represent the maximum allowable contribution of nonpoint sources. Nonpoint sources can include both "wet weather" and "dry weather" sources. Wet weather sources include animal deposition onto the watershed and septic system failures that result in the buildup of bacteria at the land's surface. Dry-weather nonpoint sources include sewers and septic systems leaking directly into the water body, and direct animal deposition into a water body.

The total LA is calculated using the TMDL equation described in the preceding section. If wasteload allocations are zero and a 5% margin of safety is used, then the equation can be simplified as follows:

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

$$Q * C = 0 + LA + (Q * C * 0.05)$$

$$LA = 0.95 * Q * C * 86,400$$

Where:

Q = median flow * 283.2 (converting from cfs to 100 mL/cubic foot)

C = geometric mean criterion of 126 org/100 mL
86,400 = conversion factor to express the LA as org/day

Because the geometric mean criterion is most stringent, the LAs are based on the mean rather than on the single sample criterion. Table 11 and 12 show the load allocations and required reductions for each flow regime. For each of the five regimes, existing loads were determined by calculating the median flow and the geometric mean concentration of the historical bacteria data. For example, for the 10-40th percentile flow regime, the flow corresponding to the 25th percentile was used. The concentration was then multiplied by the flow to determine the existing load. The critical load allocations and reductions are shown in bold.

Table 11: Load Allocations and Reductions for 12617 (Hwy 16)

Station 12617					
Flow Regimes (%)	0-10%	10-40%	40-60%	60-90%	90-100%
Median Flow, Q (cfs)	381	153	89	56	35
Target, 0.95*C (org/100 mL)	120	120	120	120	120
Existing Load (10^9 org/day)	1230	1107	888	553	342
TMDL (Q*C) (10^9 org/day)	1175	472	274	172	108
MOS (Q*C*0.05) (10^9 org/day)	59	24	13	8	5
Load Allocation, TMDL - MOS (10^9 org/day)	1116	448	**261**	**164**	103
Load Reduction (10^9 org/day)	114	659	627	390	240
Load Reduction (%)	9.2%	59.6%	**70.5%**	**70.5%**	70.2%

Table 12: Load Allocations and Reductions for 12615 (Kerrville-Schreiner Park)

Station 12615					
Flow Regimes (%)	0-10%	10-40%	40-60%	60-90%	90-100%
Median Flow, Q (cfs)	400	160	94	58	36
Target Criteria, 0.95*C (org/100mL)	120	120	120	120	120
Existing Load (10^9 org/day)	1277	979	453	252	82
TMDL (Q*C) (10^9 org/day)	1233	493	290	179	111
MOS (Q*C*0.05) (10^9 org/day)	62	24	15	9	6
Load Allocation, TMDL - MOS (10^9 org/day)	1171	**469**	275	170	105
Load Reduction (10^9 org/day)	106	510	178	80	0
Load Reduction (%)	8.3%	**52.1%**	39.3%	31.9%	0.0%

TMDL Expressions

The total load allocations, wasteload allocations, and margins of safety for *E coli.* are expressed as org/day times 10^9 for all flow categories. The TMDLs for each flow category are summarized in Tables 13 through 22 for the two critical stations—Station 12617 (Guadalupe River at Highway 16 in L. Hays Park) and Station 12615 (Guadalupe River at Kerrville-Schreiner Park).

Station 12617, Guadalupe River at Highway 16 in L. Hays Park

Table 13: High Flow (0-10% Regime) TMDL at Station 12617

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
1175	0	1116	59

Table 14: Upper Mid-range Flow (10-40% Regime) TMDL at Station 12617

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
472	0	448	24

Table 15: Mid-range Flow (40-60% Regime) TMDL at Station 12617

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
274	0	261	13

Table 16: Lower Mid-range Flow (60-90% Regime) TMDL at Station 12617

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
172	0	164	8

Table 17: Low-range Flow (90-100% Regime) TMDL at Station 12617

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
108	0	103	5

Station 12615, Guadalupe River at Kerrville-Schreiner Park

Table 18: High Flow (0-10% Regime) TMDL at Station 12615

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
1233	0	1171	62

Table 19: Upper Mid-range Flow (10-40% Regime) TMDL at Station 12615

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
493	0	469	24

Table 20: Mid-range Flow (40-60% Regime) TMDL at Station 12615

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
290	0	275	15

Table 21: Lower Mid-range Flow (60-90% Regime) TMDL at Station 12615

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
179	0	170	9

Table 22: Low-range Flow (90-100% Regime) TMDL at Station 12615

TMDL (10^9org/day)	WLA (10^9org/day)	LA (10^9org/day)	MOS (10^9org/day)
111	0	105	6

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. The project team also recognized that communication and comments from stakeholders in the watershed would strengthen development of the TMDL and its implementation.

In accordance with requirements of law promulgated in 2001 under TX House Bill 2912, an official steering committee of stakeholders was established. Notices of meetings were posted on the TMDL program's web calendar. Two weeks prior to scheduled meetings, media releases were initiated and steering committee stakeholders were formally invited to attend. To ensure that absent stakeholders and the public were informed about meetings and other pertinent material, a web page was established to provide meeting summaries, presentations, ground rules, and a list of official steering committee stakeholders. The project web page is available at <www.tceq.state.tx.us/implementation/water/tmdl/65-guadalupeabovecanyon.html>.

Throughout the term of the project, from 2004 to 2006, a total of two meetings were held in Kerrville, in Kerr County. Based on interest and attendance, meetings were held in both the afternoon and evening. The objectives of the first meeting, held in February of 2005, were to:

- Introduce the project team and summarize the public participation process
- Define what the project was intended to accomplish
- Provide historical monitoring data, information, issues, and potential sources

The objectives of the second stakeholders meeting, held in June of 2006 were to:

- Inform the stakeholders on the status of work being performed on the project
- Provide information on the TMDL stakeholder process
- Provide information on the monitoring results and flow and load duration curves
- Provide information on the project's remaining phases, specifically approval and implementation.

The project team received and responded to a number of questions and comments at both meetings, all of which were taken into account when developing the TMDL report.

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

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

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

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

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

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

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

Implementation Processes to Address the TMDL

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

A TMDL I-Plan specifically identifies required or voluntary implementation actions that will be taken to achieve the pollutant loading goals of the TMDL. Regulatory actions identified in the I-Plan could include adjustment of an effluent limitation in a wastewater permit, a schedule for the elimination of a certain pollutant source, identification of any nonpoint source discharge that would be regulated as a point source, a limitation or prohibition for authorizing a point source under a general permit, or a required modification to a storm water management program (SWMP) and pollution prevention plan (PPP). Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to impairment.

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

The I-Plan will be developed through effective coordination with stakeholders affected by or interested in the goals of the TMDL. In determining which sources need to accomplish what reductions, the I-Plan may consider factors such as cost, feasibility, the current availability or likelihood of funding, existing or planned pollutant reduction initiatives such as watershed-based protection plans, whether a source is subject to an existing regulation, the willingness and commitment of a regulated or unregulated source, and a host of additional factors. Ultimately, the I-Plan will identify the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the I-Plan that is adopted may not approximate the predicted loadings identified category by category in the TMDL and its underlying assessment, but with certain exceptions, the I-Plan must nonetheless meet the overall loading goal established by TMDL adopted by the commission and approved by the EPA.

An exception would include an I-Plan that identifies a phased implementation that takes advantage of an adaptive management approach. It is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction was required by the TMDL, high uncertainty with the TMDL analysis exists, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements. Instead, activities contained in the first phase of implementation may be the full scope of the initial I-Plan and include strategies to make substantial progress towards source reduction and elimination, refine the TMDL analysis, conduct site-specific analyses of the appropriateness of an existing use, and monitor in stream water quality to gage the results of the first phase. Ultimately, the accomplishments of the first phase would lead to development of a phase two or final I-Plan or revision of TMDL. This adaptive management approach is consistent with established guidance from EPA (EPA 2006).

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

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, the TCEQ certifies additional "water quality management plan elements" to the WQMP once the I-Plan is adopted by the commission. Based upon the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits. The TCEQ would normally establish BMPs, which are a substitute for effluent limitations in TPDES MS4 storm water permits as allowed by the federal rules where numeric effluent limitations are infeasible (EPA 2002). Thus, TCEQ would not identify specific implementation requirements applicable to a specific TPDES storm water permit through an effluent limitation update. However, the TCEQ would revise a storm water permit, require a revised SWMP or PPP, or implement other specific revisions affecting storm water dischargers in accordance with an adopted I-Plan.

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Appendix A.
Routine Sampling Survey Data

Appendix B.
Baseflow Sampling Data

Appendix C.
Runoff Sampling Data

Appendix D.
Bacterial Source Tracking Data