Technical Support Document for Bacteria TMDLs
Carters Creek Watershed (Segments 1209D, 1209L & 1209C)

Texas Commission on Environmental Quality
TMDL Program
Austin, Texas

Prepared by:

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Stephenville, Texas

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INTRODUCTION

1.1 Purpose and Scope

To fulfill the requirements of the federal Clean Water Act and its implementing regulations, the Texas 303(d) list identifies water bodies within the State that do not meet water quality standards, hence leading to concerns for public health, aquatic species, and other wildlife. Water bodies that are identified on the 303(d) list typically require development of a Total Maximum Daily Load (TMDL), which is the maximum pollutant loads a water body can receive daily without exceeding the water quality standards. The subsequent step to the TMDL is an implementation plan in which reductions of the pollutant loads are identified to sources in order to improve water quality and restore full use of the water body.

According to the 2008 303(d) list and draft 2010 303(d) list published by the Texas Commission on Environmental Quality (TCEQ) (Table 1-1), Carters Creek (Segment 1209C) was first listed in 1999 due to excessive bacteria levels and nonsupport of its recreation use, and then appeared repeatedly on the lists in 2000, 2002, 2004, 2006, 2008, and draft 2010. Burton Creek (Segment 1209L), a major tributary to Carters Creek and Country Club Branch (Segment 1209D), a tributary to Burton Creek, first appeared on the 2006 303(d) list due to excessive bacteria levels and nonsupport of its recreation use and is also on the 2008 and draft 2010 303(d) lists. As indicated in Table 1-1, each segment has been assigned one assessment unit by TCEQ. For Carters Creek the assessment unit (AU) designation is AU 1209C_01, for Burton Creek AU 1209L_01, and for Country Club Branch AU 1209D_01. Because all three creeks are comprised of only one AU, the AU descriptor is unnecessarily cumbersome and in this report Carters Creek will be referred to synonymously as Segment 1209C, Burton Creek as Segment 1209L, and Country Club Branch as Segment 1209D. In addition, the descriptor "Carters Creek Watershed" will be used when referring to all three impaired segments.

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards specifically identify appropriate uses for each segment, and list appropriate limits for water quality indicators to assure water quality and attainment of uses. The TCEQ monitors and assesses water bodies based on the water quality standards, and publishes the Texas Water Quality Inventory and 303(d) list biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2000) are rules that:

- designate the uses, or purposes, for which the state's water bodies should be suitable;
- establish numerical and narrative goals for water quality throughout the state; and

- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Table 1-1 TCEQ 2008 303(d) list – Carters Creek, Burton Creek, and Country Club Branch (TCEQ, 2008b)

SegID: 1209C **Carters Creek (unclassified water body)**
Perennial stream from the confluence with the Navasota River southeast of College Station in Brazos County upstream to the confluence of an unnamed tributary 0.5 km upstream of FM 158 in Brazos County

Area		Category	Year First Listed
1209C_01	*Entire water body*		
	bacteria	5a	1999

SegID: 1209L **Burton Creek (unclassified water body)**
From the confluence with Carters Creek in College Station, upstream to its headwaters located 0.4 miles east of Fin Feather Lake in Brazos County.

Area		Category	Year First Listed
1209L_01	*entire water body*		
	bacteria	5c	2006

SegID: 1209D **Country Club Branch (unclassified water body)**
From the confluence with Country Club Lake in Bryan in Brazos County to the dam at Fin Feather Lake in Bryan

Area		Category	Year First Listed
1209D_01	*entire water body*		
	bacteria	5c	2006

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the *Texas Surface Water Quality Standards* to water bodies are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

A number of different parameters are monitored as indicators of the water quality, including metals, organics, bacteria, dissolved oxygen, and dissolved solids. Bacteria are indicators of the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal coliforms are bacteria that originate from the wastes of warm-blooded animals. They usually live in human or animal intestinal tracts. *E. coli* (*Escherichia coli*) is a member of fecal coliform bacteria group (USEPA, 2009). The presence of these bacteria indicates that associated pathogens from the wastes may be reaching water bodies, because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets in urban areas, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006).

The best indicator of health risk from water contact in freshwater is *E. coli* as recommended by the U.S. Environmental Protection Agency (EPA). According to Section 307.7 (Site-Specific Use and Criteria) of the *Texas Surface Water Quality Standards*, for contact recreation in freshwater:

- the geometric mean of *E. coli* should not exceed 126 most probable number (MPN) per 100 mL, and
- single samples of *E. coli* should not exceed 394 MPN per 100 mL (TCEQ, 2000).

For the single sample criterion of 394 MPN per 100 mL, TCEQ has considered that a water body is fully supporting if 25% or less of the samples are in exceedance, and not supporting if greater than 25% of the samples are in exceedance. However, TCEQ recognizes that the chance of falsely classifying a station or segment as impaired (Type I Error) is relatively high for the historically utilized method. Therefore, the single sample criterion is evaluated using the binomial method, in order to maintain a Type I error probability below 20% (e.g., TCEQ, 2008a).

This report will address these criteria with the existing contact recreation use geometric mean criterion of 126 MPN/100 mL.

On June 30, 2010 the TCEQ Commission adopted revisions to the *Texas Surface Water Quality Standards* (TCEQ, 2010b). The 2010 standards revision is not approved by EPA at the time of this report (June 2011). Within these adopted Standards recreational use consists of four categories: primary contact recreation, secondary contact recreation 1; secondary recreation 2; and noncontact recreation waters. For freshwater the criteria are:

- Primary contact recreation: geometric mean criterion for *E. coli* of 126 MPN per 100 mL and single sample criterion for *E. coli* of 399 MPN per 100 mL;
- Secondary contact recreation 1: geometric mean criterion for *E. coli* of 630 MPN per 100 mL;
- Secondary contact recreation 2: geometric mean criterion for *E. coli* of 1,030 MPN per 100 mL; and
- Noncontact recreation: geometric mean criterion for *E. coli* of 2,060 MPN per 100 mL (TCEQ, 2010b).

Within the 2010 standards revision, the primary contract recreation geometric mean criterion is identical to the contact recreation criterion of the 2000 standards revision – 126 MPN per 100 mL.

1.3 Report Purpose and Organization

Through a contract between the TCEQ and Texas Institute for Applied Environmental Research (TIAER), the Carters Creek Watershed TMDL project was initiated in August 2007. The tasks of this project were to (1) acquire existing (historical) data and information necessary to support modeling and assessment activities; (2) perform the appropriate modeling activities necessary to allocate loadings; and (3) assist the TCEQ in preparing the TMDL. Using historical data and hydrologic modeling results, this portion of the project was to: (1) review the characteristics of the watershed and explore the potential sources of *E. coli* bacteria for Segments 1209C, 1209D, and 1209L (i.e., Carters Creek, Country Club Branch, and Burton Creek); (2) develop an appropriate tool for development of a bacteria TMDL for Segments 1209C, 1209D,and 1209L; and (3) submit the draft and final technical support document for the three segments. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for the Carters Creek watershed. This report contains:

- information on historical data,
- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas Section 303(d) listings of impairment due to presence of indicator bacteria (*E. coli*),
- development of load duration curves, and
- application of the load duration curve approach for the pollutant load allocation process.

SECTION 2
HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of Study Area

The Carters Creek watershed lies within the Navasota River watershed. Located within the Brazos Basin, the second largest river basin by area in Texas (Brazos River Authority, 2007), the drainage area of the Navasota River watershed is approximately 5,789 km^2 (2,235 mi^2). The Navasota River flows 200 km (125 miles) south to its confluence with the Brazos River (Brazos River Authority, 2007) (Figure 2-1). Carters Creek (Segment 2109C), a perennial stream, originates in southeastern Brazos County and flows 27 km (17 mi) before joining the Navasota River. Burton Creek (Segment 1209L) is a tributary of Carters Creek, and Country Club Branch (Segment 1209D) is a tributary to Burton Creek. In addition, two small lakes are also located within the Carters Creek watershed – Fin Feather Lake (Segment 1209B), which lies directly upstream of Country Club Branch, and Country Club Lake (Segment 1209A), which lies directly upstream of Burton Creek (Figure 2-2). The drainage area of the Carters Creek watershed covers about 150.3 square km (58.0 square miles). Portions of the growing Cities of Bryan and College Station, as defined in the 2000 U.S. Census as "Urbanized Area," lie within the Carters Creek watershed (Figure 2-2). (It is noted that the southeast extremity of the Carters Creek watershed lies in the Navasota River floodplain, an area of very low relief, and as such the delineation of this lowermost portion of the watershed was based on best professional judgment).

There are six regulated entities permitted to discharge treated wastewater in the watershed. Four are municipal wastewater treatment facilities (WWTFs) and two are industrial facilities (Figure 2-3). Photographs of the two major WWTFs in the watershed, City of College Station Carters Creek WWTF and the City of Bryan Burton Creek WWTF, were taken during a field reconnaissance trip in August 2007 (Figure 2-4).

The cities of Bryan and College Station represent a rapidly growing urban area with a combined estimated population of 133,600 in 2000. Based on U.S. Census Bureau census-tract level population data from the 2000 census, the population of entire Carters Creek watershed was estimated at 91,211 of which 23,006 were estimated to be in the Burton Creek watershed (US Census Bureau, 2009). To obtain these estimates, the tract-level data were multiplied by the proportion of each census tract within each watershed to generate an estimate of population. This estimation procedure assumes that the population is uniformly distributed within the area of each census tract.

TCEQ and the Brazos River Authority (as a cooperator through the Clean Rivers Program) have operated four stations to monitor the surface water quality in this watershed (Figure 2-5). Bacteria data collected at these four stations form the basis for the assessment of water quality in the Carters Creek watershed and for development of the bacteria TMDL load allocations.

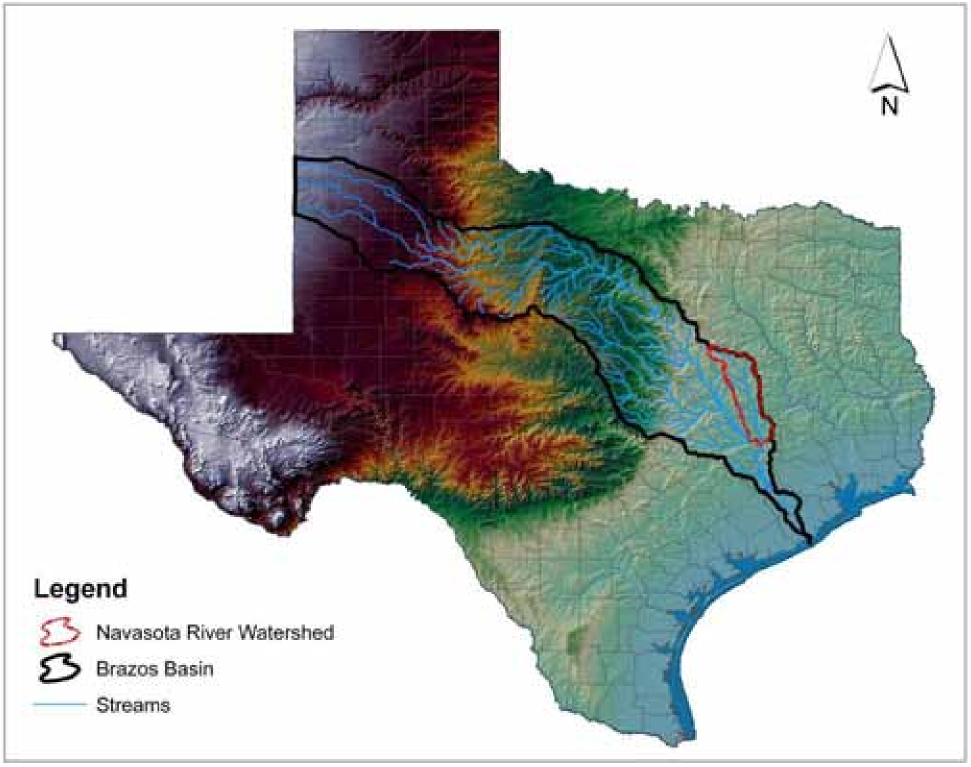

Figure 2-1 Locations of Navasota River watershed and Brazos River Basin in Texas

2.2 Watershed Climate and Hydrology

The climate in the Carters Creek watershed is classified as subtropical humid with characteristics of warm summers and dry winters (Office of Texas State Climatologist, 1983). As recorded by a National Weather Service Network Station in College Station, the normal (1971-2000) daily minimum temperature is 14.3 °C (57.7 °F), normal daily maximum temperature is 26.3 °C (79.4 °F) and normal daily average temperature is 20.3 °C (68.6 °F). The normal annual precipitation is 1007.6 mm (39.7 in). The climate atlases of College Station for each month are shown in Figure 2-6 (Southern Regional Climate Center, 2008).

While there are insufficient hydrologic (e.g., streamflow) data to characterize the hydrology of the Carters Creek watershed, the following can be surmised based on accepted hydrologic principles. It is expected that the more heavily urbanized western portion of the watershed will respond to rainfall events more rapidly and with proportionally greater runoff volume than the less urbanized rural eastern portion of the watershed, because of the greater amounts of impervious cover in urban areas as compared to rural areas. Also during low flow/drought periods, the streamflow of portions of the Carters Creek watershed is expected to be dominated by the effluent from the WWTFs.

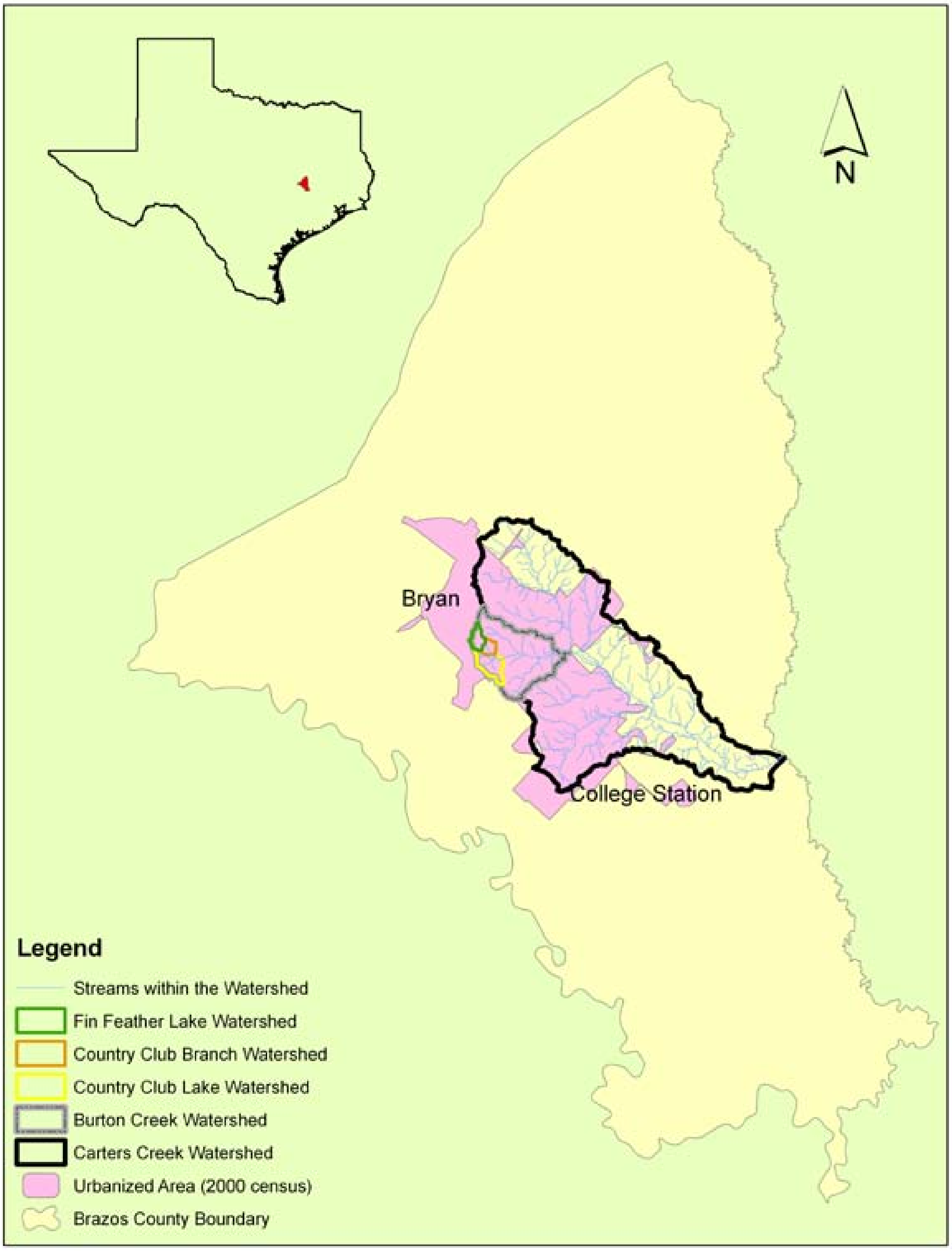

Figure 2-2 Cities of Bryan and College Station within the Carters Creek watershed

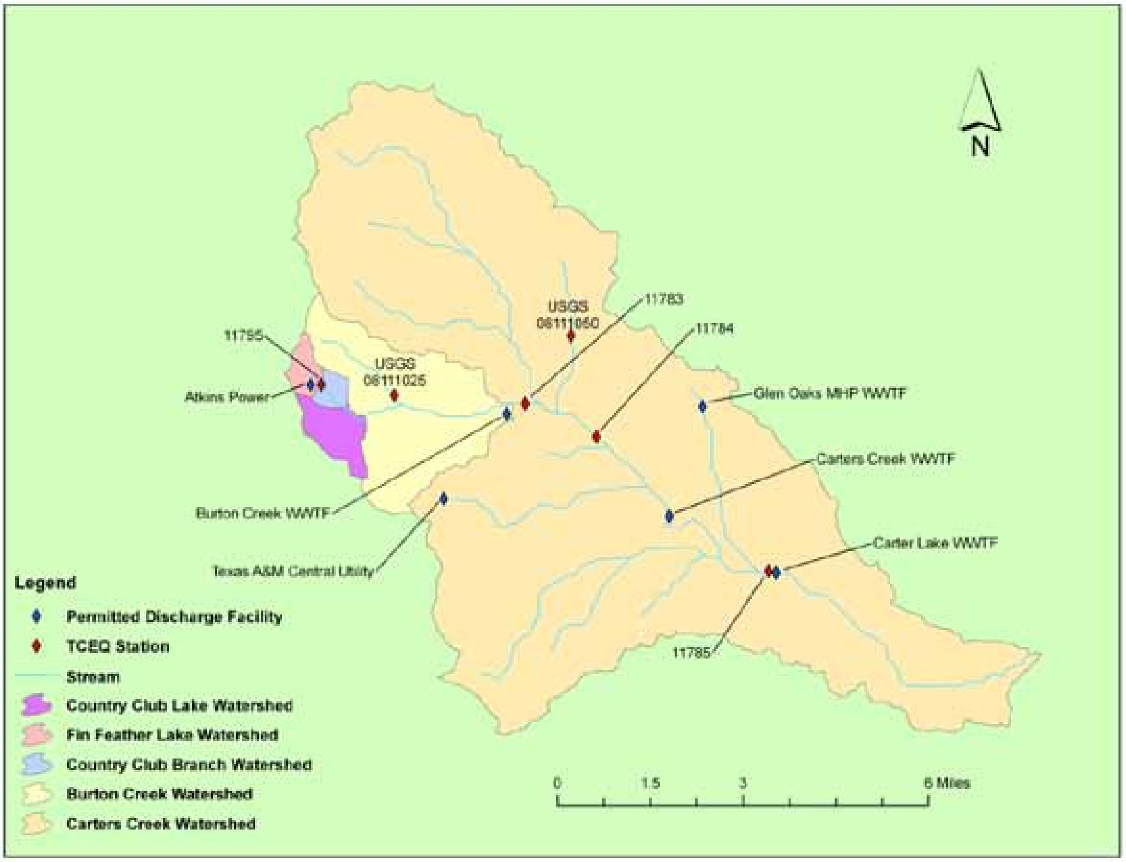

Figure 2-3 Wastewater treatment facilities (WWTFs) and monitoring stations within the Carters Creek watershed

City of Bryan Burton Creek Wastewater Treatment Facility (TX0022616; HWY 6 & University Dr.)

City of College Station Carter Creek Wastewater Treatment Facility (TX0047163; HWY 6 & North Forest Parkway)

Figure 2-4 Two major wastewater treatment facilities in the Carters Creek watershed

Water Quality Station 11783 (Burton Creek at HWY 6 nr. University Dr.)

Water Quality Station 11784 (Carters Creek at SH 30)

Water Quality Station 11785 (Carters Creek at Bird Pond Rd.)

Water Quality Station 11795 (Country Club Branch at Duncan; near intersection of Duncan & Orman)

Figure 2-5 Four primary surface water quality monitoring stations within the Carters Creek watershed

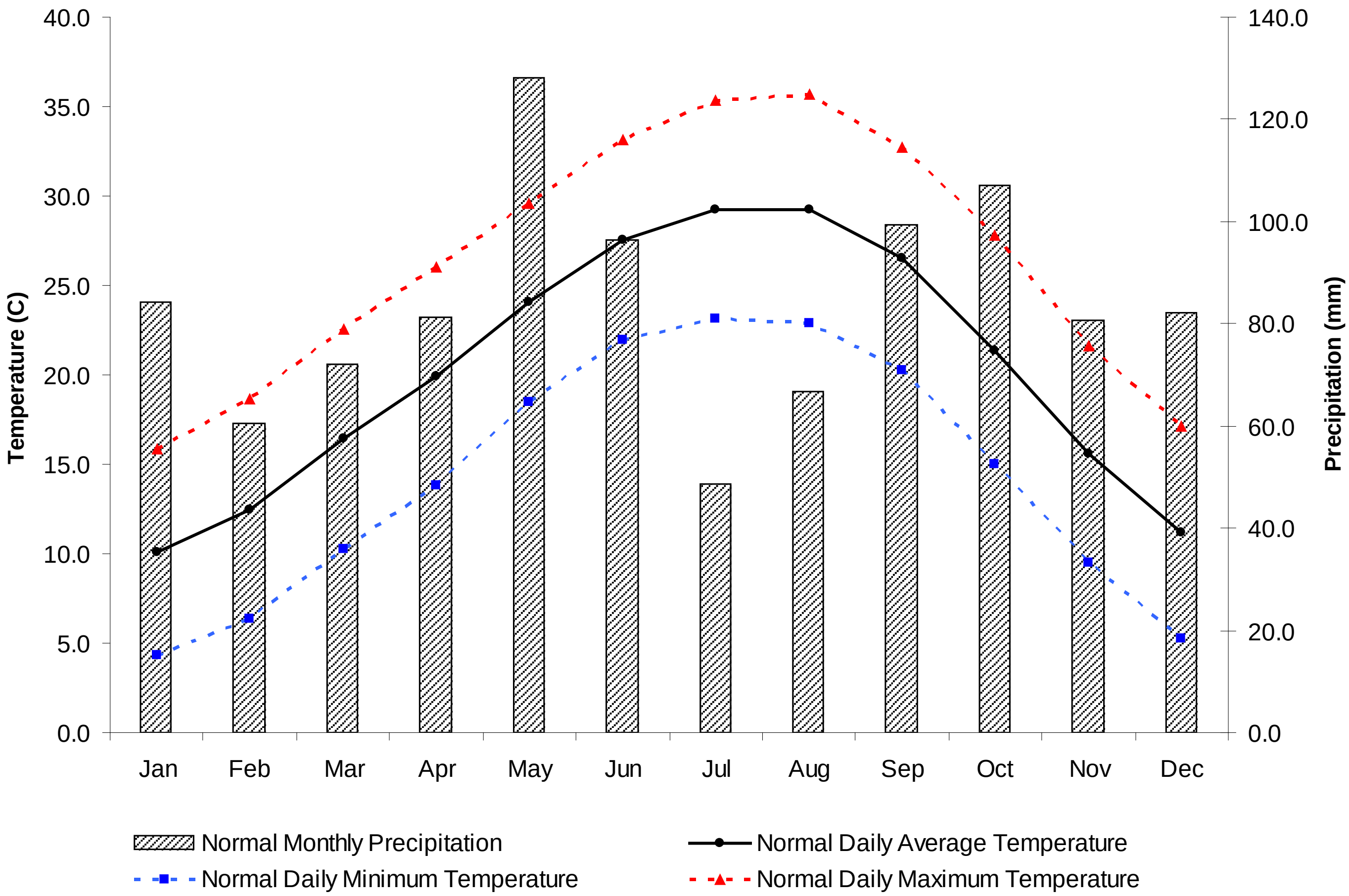

Figure 2-6 Normal monthly precipitation, daily average, minimum and maximum temperatures (1971-2000) in College Station (Source: Southern Regional Climate Center)

2.3 Review of Historical Data

The historical *E. coli* data for the four TCEQ monitoring stations in the Carters Creek watershed were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database. As compared with the geometric mean (126 MPN/100 mL) and the single sample (394 MPN/100 mL) criteria, the samples collected during 2001 to 2007 (and through 2010 for station 11785) exceeded these water quality criteria frequently at all four stations and often by large concentrations (Figure 2-7). Table 2-1 summarizes the statistics on the *E. coli* data from the four stations listed most upstream to most downstream, including the numbers of data samples, minimum and maximum measurements, geometric means, and the percentages of samples that exceeded the single sample criterion of 394 MPN/100 mL. The data analysis indicates that *E. coli* at all four stations do not support the contract recreation use based on both the geometric

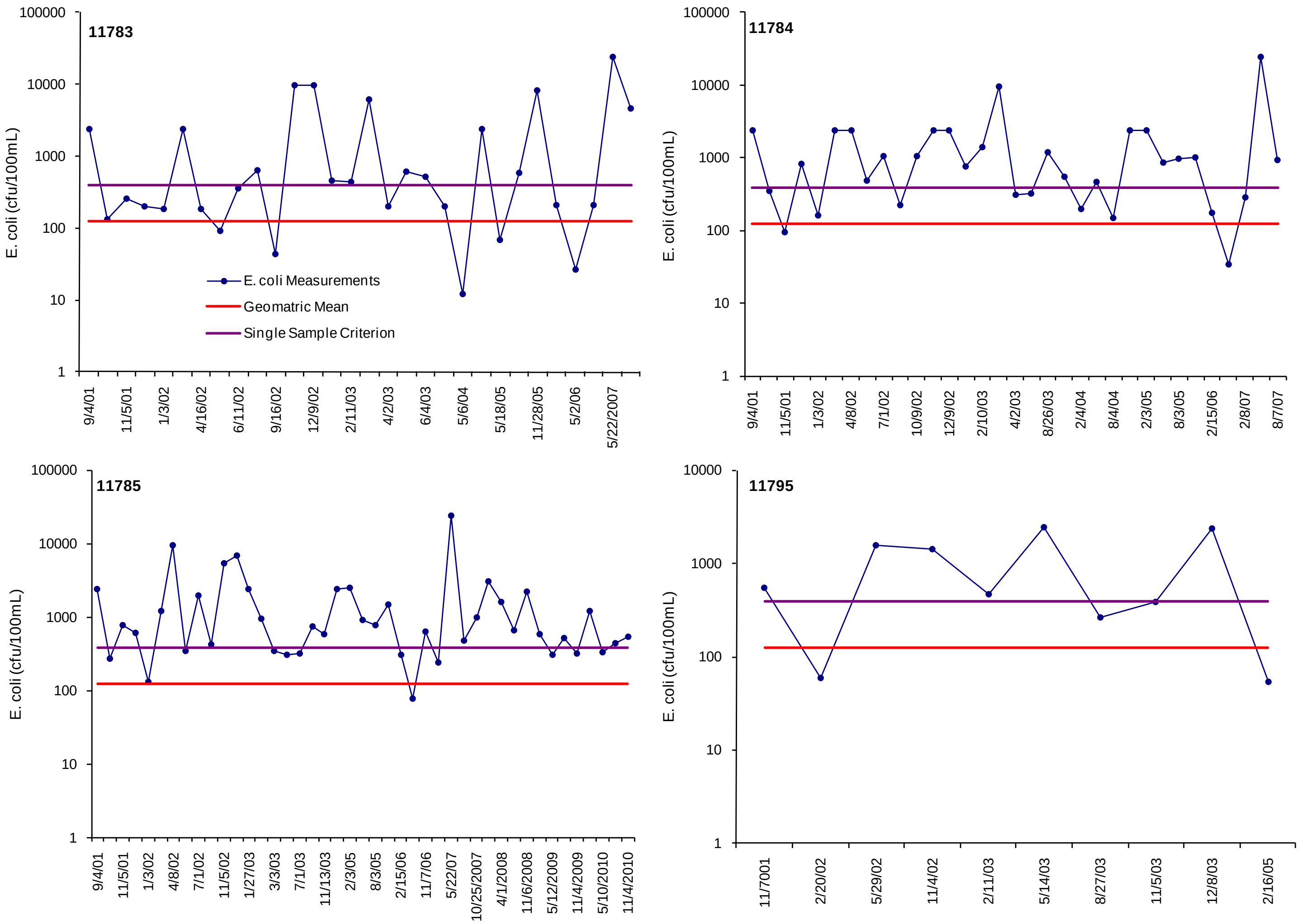

Figure 2-7 Historical *E. coli* data from the four monitoring stations in Carters Creek watershed

mean criterion and applying the binomial method with the single sample criterion. Further, both the geometric means concentrations and percentage of samples exceeding the single sample criterion increased in a downstream direction for the four stations.

Table 2-1 Statistics on *E. coli* data obtained from TCEQ

Station	Segment	Period Evaluated	Count	Minimum value of *E. coli* (MPN/100 mL)	Maximum value of *E. coli* (MPN/100 mL)	Geometric Mean (MPN/100 mL)	Percentage of samples exceeding 394 (%)
11795	1209D	1997-2005	11	2	>2,415	305	55*
11783	1209L	2001-2007	30	12	>24,000	517	50*
11784	1209C	2001-2007	33	34	>24,000	751	63*
11785	1209C	2001-2010	43	79	>24,000	856	72*

* Nonsupport of the single sample criterion indicated based on the binomial method.

2.4. Land Use

The 2006 land use/land cover data for Carters Creek, Burton Creek, and Country Club Branch watersheds were produced by Texas AgriLife Spatial Sciences Laboratory for the Texas State Soil & Water Conservation Board (TSSWCB). The land use/land cover layer was obtained from Texas AgriLife Texas Water Resources Institute with permission from the TSSWCB. The original land use/land cover data were aggregated into the following categories to simplify interpretations.

- **<u>Developed</u>** – Developed is property that contains single-family and multi-family housing units, commercial and industrial buildings, lawn grasses, and impervious surfaces.
- **Forest** – Forest is land that contains a relatively high density of trees.
- **Rangeland** – Rangeland includes areas of unmanaged shrubs, grasses, or shrub-grass mixtures.
- **Agricultural Land** – Agricultural land includes areas used for the production of annual crops and woody crops. Also included are areas of grasses, legumes, or grass legume mixtures planted for livestock grazing or the production of seed or hay crops. This class also includes all land being actively tilled.
- **Open Water** – Open water includes all areas of open water, generally with less than 25% cover of vegetation or soil.
- **Barren Land** – Barren land includes bare rock, sand, or clay areas; quarries, strip mines, gravel pits, or other “transitional” areas.

The land use/land cover within the Carters Creek watershed indicates that the western portion of the watershed is dominated by developed urban area, and the eastern portion is rural (Figure 2-8). The dominant land use category within the entire Carters Creek watershed is developed use which accounts for over 53% of the area followed by rangeland which comprises nearly 29% of the area (Table 2-2). Carters Creek watershed, excluding the Burton Creek watershed area, is predominately urban in its western portion and predominately rural (e.g., wooded, grassland, and agriculture) in its eastern portion with the urban landscape (developed use) accounting for over 47% of the area and the categories of forest and rangeland being the dominant uses for the rural portion of the watershed (Table 2-3). In contrast, the Burton Creek watershed, excluding Country Club Branch watershed is dominated by the urban landscape with the developed land use category comprising almost 100% of the area (Table 2-4). The developed land use category comprises 100% of the area within the Country Club Branch watershed (Table 2-5).

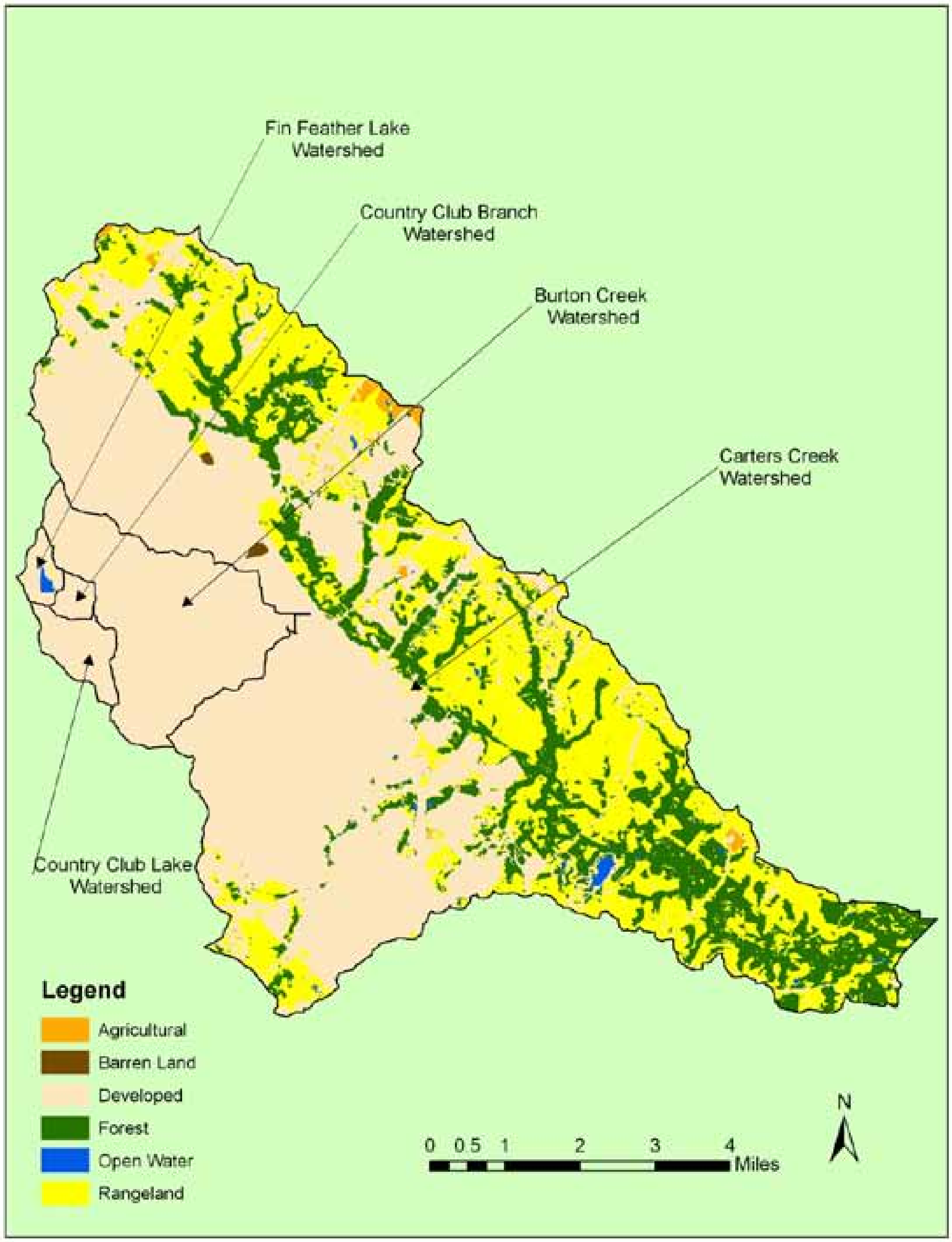

Figure 2-8 2006 Land use/land cover within the Carters Creek watershed (Source: Texas AgriLife Spatial Sciences Laboratory)

Table 2-2 2006 Land Use/Land Cover class within the Carters Creek Watershed (Includes Burton Creek watershed; Source: Spatial Sciences Laboratory)

Description	Area (ha)	% of Total
Developed	8,071	53.70
Rangeland	4,355	28.97
Forest	2,421	16.10
Agricultural Land	88	0.59
Open Water	80	0.53
Barren Land	16	0.11
Total	15,032	100

Table 2-3 2006 Land Use/Land Cover class within the Carters Creek Watershed excluding the Burton Creek Watershed (Source: Spatial Sciences Laboratory)

Description	Area (ha)	% of Total
Developed	6,292	47.52
Rangeland	4,353	32.88
Forest	2,420	18.28
Open Water	70	0.53
Agricultural Land	88	0.67
Barren Land	16	0.12
Total	13,240	100

Table 2-4 2006 Land Use/Land Cover class within the Burton Creek Watershed (Excludes area of Segments 1209A, 1209B, and 1209D; Source: Spatial Sciences Laboratory)

Description	Area (ha)	% of Total
Developed	1,410	99.996
Rangeland	0.058	0.004
Total	1,410	100

Table 2-5 2006 Land Use/Land Cover class within the Country Club Branch Watershed. (Source: Spatial Sciences Laboratory).

Description	Area (ha)	% of Total
Developed	70	100
Total	70	100

2.5 Source Analysis

Potential sources of indicator bacteria pollution can be divided into two primary categories: *regulated* and *non-regulated*. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES). Examples of regulated sources are wastewater treatment facility (WWTF) discharges and storm water discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities. Non-regulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and are usually carried to surface waters by rainfall runoff, and are not regulated by permit under the TPDES.

2.5.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the National Pollution Discharge Elimination System (NPDES). WWTF outfalls and storm water discharges from industries, construction, and MS4s represent the permitted sources in Segments 1209C, 1209D and 1209L.

2.5.1.1 Wastewater Treatment Facility Discharges

Among the six regulated facilities located within the watershed, four of the facilities treat domestic wastewater and two facilities involve industrial wastewater. The Texas A&M University Central Utility provides electric service and their discharge is associated with cooling water blow down. The City of Bryan Atkins Power Station discharge is into Fin Feather Lake, which is a water body that does not have elevated levels of bacteria. The remaining four facilities are authorized to treat and discharge residential and municipal wastewater. The four facilities authorized to treat and discharge residential and municipal wastewater and the Texas A&M University Central Utility plant are considered as potential sources of bacteria loadings to the watershed. The City of Bryan Atkins Power Station is not considered a potential source of bacteria loadings primarily because the discharge is not into a bacterially impaired water body. The permitted discharge limits for each facility and the actual average discharges for the period of available data from Discharge Monitoring Reports (DMRs) are provided in Table 2-6. As discussed in more detail in Section 2.5.1.5, the compliance histories for these permitted facilities indicate some situations have occurred in the past that had the potential of causing bacterial contamination in the watersheds.

2.5.1.2 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris. Inflow and infiltration (I/I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I/I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

The TCEQ maintains a database of SSO data reported by municipalities in the Carters Creek watershed. The SSO data from January 2005 through February 2010 is summarized in Table 2-7. There were 248 SSOs reported in the Carters Creek and Burton Creek watersheds with an average volume of 8,748 gallons per event. The volume of the median event was much lower at 100 gallons per event because most SSO events were small. The largest SSO event volume reported was 2 million gallons and it occurred on January 29, 2010. This large SSO volume accounted for 92% of the total SSO volume reported from all events.

Table 2-6 List of permitted discharge facilities

TCEQ/EPA Permit	Watershed	Facility Name	Expiration Date MM/DD/YY	Permitted Flow Limit (MGD)	Actual Avg. Flow (MGD) (Time period)	Standard Industrial Classification Description	Selected Permit Requirements on Final Permitted Discharge	
							Report *E. coli* Levels	Disinfection Requirement
WQ0004002 TX0002747	Carters	Texas A&M Central Utility (College Station)	05/01/14	0.93*	0.28 (Jan 2008-May 2009)	Electric services	No	None
WQ0010024-06 TX0047163	Carters	Carters Creek WWTF (College Station)	05/01/14	9.5**	5.92 (Jan 2008-May 2009)	Sewerage systems	Yes	UV system
WQ0010426 TX0022616	Burton	Burton Creek WWTF (Bryan)	05/01/14	8.0**	4.50 (Jan 2008-May 2009)	Sewerage systems	Yes	Chlorination & Dechlorination
WQ0012296 TX0085456	Carters	Glen Oaks MHP WWTF (Bryan)	05/01/14	0.013*	0.008 (Jan 2008-May 2009)	Operators of residential mobile home sites	No	Chlorination
WQ0013153 TX0098663	Carters	Carter Lake WWTF (College Station)	05/01/14	0.0085*	0.004 (Jan 2008-Sep 2009)	Sewerage systems	No	Total residence time ≥21 days
WQ0001906 TX0027952	Fin Feather Lake	Atkins Power Station (Bryan)	05/01/14	0.385	Not available (recent permit)	Electric services	No	None

Note: MGD denotes million gallons per day
* denotes daily average flow limit
** denotes annual average flow limit

Table 2-7 Summary of SSO incidences reported in the Carters Creek watershed from January 2005 – February 2010. Volumes are presented in gallons which were estimated by the reporting entity.

No. of Incidences	Total Gallons*	Average Volume (gallons)	Median Volume (gallons)	Min Volume (gallons)	Max Volume (gallons)
248	2,169,622	8,748	100	2	2,000,000

2.5.1.3 Regulated Stormwater

The TPDES/NPDES Municipal Separate Storm Sewer (MS4) Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities with populations less than 100,000 and are regulated by a general permit. The purpose of a MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six 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.

The geographic region of the Carters Creek, watershed covered by MS4 permits is that portion of the study area defined by the 2000 Census as being an Urbanized Area (Figure 2-2). The MS4 permitted entities in the watersheds are regulated under Phase II general permits (Table 2-8). The percentages of land area under the jurisdiction of storm water permits for each of the three impaired watersheds are presented in Table 2-9.

Table 2-8 Phase II MS4 permits associated with the TMDL area watersheds. (All Phase II entities are covered under TPDES General Permit No. TXR040000.)

Regulated Entity Name	NPDES Permit Number
Brazos County	TXR040172
City of Bryan	TXR040336
City of College Station	TXR040008
Texas A&M University	TXR040237
Texas Department of Transportation	TXR040181

Table 2-9 Area under the jurisdiction of storm water permits for Carters Creek, Burton Creek, and Country Club Branch

Segment	Area under jurisdiction of MS4 permits (ha)	Total watershed area (ha)	Percentage of drainage area under jurisdiction of MS4 permits (%)
1209D	70	70	100.0
1209L	1,394	1,411	98.8
1209C	6,754	13,240	51.0

2.5.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II MS4s as "Any discharge to a municipal separate storm sewer that is not entirely composed of storm water, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency fire fighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Direct illicit discharges:

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

Indirect illicit discharges:

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

2.5.1.5 Review of Information on Permitted Sources

Review of the files for the permitted facilities in the Carters Creek watershed was performed at TCEQ Central Records in August 2007. The following incidents were found in the files regarding matters with implications on bacteria levels in the watershed. The City of College Station Carters Creek WWTF files indicated two relatively recent incidences of discharge of high concentrations of fecal coliform bacteria that exceeded the allowable permitted maximum of 800 MPN/100 mL as specified in their permit. Both occasions were associated with high rainfall events, with one event occurring February 7, 2005 and the other during the period of October 16-19, 2006. The later event involved sufficient rainfall that flooding occurred that was higher than manholes resulting in great amounts of inflow to the WWTF. Also, a ruptured wastewater line to the Carters Creek

WWTF resulted in the discharge of 3.8 million gallons of untreated wastewater during the period of October 21-23, 2006. There were also two outstanding violations at the time of the review of permit files regarding failure of the permittee to ensure that all system of collection, treatment, and disposal were properly operated and maintained concerning the Carters Creek WWTF. According to the files at the TCEQ Central Records, one of the violation situations was corrected promptly. The permittee awarded a contract to a consulting company to correct the other one in a limited time period. More recent review (August 18, 2008) of the EPA Enforcement & Compliance History Online (ECHO) conducted for this report indicated that non-compliance issues with the Carters Creek WWTF had been resolved by Spring 2007.

The most recent review of EPA ECHO for this report was conducted on June 27, 2011. The review indicated that the two major WWTFs in the study area, City of Bryan Burton Creek WWTF and City of College Station Carters Creek WWTF, were in compliance with their *E. coli* permit limits for the period of data available (August 2009 through December 2010) with the exception of a single sample excursion in May 2010 at the Carters Creek WWTF. The three smaller facilities in the study area, Texas A&M Central Utility, Glen Oaks Mobile Home Park (MPH) WWTF and Carter Lake WWTF, are not required to report *E. coli* concentrations. It should be also noted that the Carter Lake WWTF discharge is downstream of all monitoring stations in the watershed, and the Texas A&M Central Facility and Glen Oaks MHP WWTF are on tributaries of Carters Creek and each facility discharges approximately three to four miles upstream of its tributary's confluence with Carters Creek (see Figure 2-3).

2.5.2 Nonpermitted Sources

Nonpermitted sources of indicator bacteria are generally nonpoint and can emanate from wildlife, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

2.5.2.1 Wildlife and Unmanaged Animal Contributions

E. coli bacteria are common inhabitants of the intestines of all warm blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff.

2.5.2.2 Failing On-Site Sewage Facilities

In July/August 2008 enquiries were undertaken by TIAER into the conditions of on-site sewage facilities (OSSFs) within the Carters Creek watershed. The following information was obtained through personal communications with Mr. Don Plitt; the Brazos County designated OSSF program representation (Plitt, 2008). According to an estimate generated by the Brazos County Health Department, 455 households operated OSSFs within the Carters Creek watershed portion of Brazos County (Table 2-10). The OSSF representative for Brazos County reported that the soils in the county were mainly tight clays, with little sand, which are not ideal for septic systems with traditional soil adsorption fields. The representative estimated that 98% of all newly permitted OSSFs in the county were aerobic systems with pressurized distribution systems. Problems with OSSFs in the county were reported to typically stem from overused and poorly maintained systems, although OSSFs in general within the county were regarded as being in good operation. It was also reported that the tight clay soils that predominate in the county mean that heavy rainfall events can cause particular problems for the underground septic systems with soil adsorption fields, many of which were installed in the 1970s.

Table 2-10 Carter Creek watershed OSSF count (Source: Brazos County Health Department)

Location	OSSF Count
Bird Pond Rd	31
Tonkaway Lake Rd	25
Rock Prairie Rd	30
Harris Lane	44
Carter Lake Rd	15
Nunn Jones	13
Ranchero Rd	11
Vista Lane	10
Pamela Lane	8
High Lonesome	9
Deer Run	23
Deerfield	11
Pate	9
Golden Nugget	10
Golden Trail	25
Rainbow Trail	3
Golden Mist	14
Roans Chapel	9
Hicks Lane	21
Wallis	13
Marino Rd	45
South Oaks	24
Sandpiper	21
Harpers Ferry Rd	31
Total	**455**

2.5.2.3 Non-Permitted Agricultural Activities and Domesticated Animals

A number of livestock are raised in Brazos County. Table 2-11 lists the statistics of livestock in Brazos County based on 2002 Census of Agriculture (USDA, 2002). It should be noted that the data in Table 2-11 are for the entirety of Brazos County, which is the lowest level of spatial data available on livestock. As countywide data the tabular values do not reflect actual numbers in the Carters Creek watershed, but do reflect anticipated relative livestock populations, e.g., more cattle and calves present in the watershed than goats. Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute *E. coli* to nearby water bodies. Furthermore, pets can also be sources of *E. coli* bacteria, because storm runoff carries the animal wastes into streams (USEPA, 2009). The county-wide livestock numbers in Table 2-11 are provided to demonstrate that livestock are a potential source of bacteria in the watershed. These livestock numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Table 2-11 Livestock statistics in Brazos County (Source: USDA, 2002); (Note: Countywide data, values not exclusively for the Carters Creek watershed.)

Livestock	Number
Cattle and Calves	67,675
Hogs and Pigs	2,326
Poultry (farms)	73
Ducks	258
Emus	9
Geese	114
Ostriches	20
Pheasants	(W)
Pigeons or Squab	102
Quail	(W)
Other poultry	1,216
Horses and Ponies	2,697
Sheep and Lambs	952
Milk Goats	171
Angora Goats	6
Miscellaneous Livestock and Animal Specialties/Bison	226
Deer	1,564
Elk	(W)
Goats, All	1,075
Meat and other goats	898
Llamas	47
Mules, Burros, and Donkeys	109

Note: W denotes withheld to avoid disclosing data from individual farms.

The number of domestic pets in the watersheds of the three creeks was estimated based on human population and number of households obtained from the U.S. Census Bureau (US Census Bureau, 2009). The information obtained from the U.S. Census Bureau included population and household projections based on the 2000 census for tracts that encompassed the watersheds of Segments 1209C, 1209D and 1209L. The tract level data were multiplied by the proportion of each census tract within the watershed to generate an estimate of the watershed's population and number of households. This estimation assumes that the population/households are uniformly distributed within the area of each census tract, which is the best estimate that can be made with the available data.

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 2-12 summarizes the estimated number of dogs and cats for each segment of the watershed with elevated bacteria levels.

Table 2-12 also provides an estimate of the fecal coliform loads from domestic dogs and cats. These estimates are based on estimated fecal coliform production rates of $5.4x10^8$ per day for cats and $3.3x10^9$ per day for dogs (Schueler, 2000). Pet population estimates were calculated as the estimated number of dogs (0.632) and cats (0.713) per household (AVMA, 2009). The actual contribution and significance of fecal coliform loads from pets reaching the Carters Creek watershed is unknown.

Table 2-12 Estimated households and pet populations within Carters Creek watershed (Segment 1209C, 1209D, and 1209L)

Segment	Estimated Number of Households	Estimated Dog and Cat Population		Estimated Fecal Coliform Production (10^9 organisms)	
		Dogs	Cats	Dogs	Cats
1209D	189	120	135	395	73
1209L	8,257	5,218	5,887	17,221	3,179
1209C	24,799	15,673	17,682	51,722	9,548

SECTION 3
BACTERIA TOOL DEVELOPMENT

This section describes the rationale of the bacteria tool selection for TMDL development, introduces the application of a mechanistic watershed-scale model used to simulate daily streamflow, and details the procedures and results of load duration curve development.

3.1 Model Selection

The TMDL allocation process for bacteria involves assigning bacteria, e.g., *E. coli*, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for the Carters Creek watershed considered availability of data and other information necessary for supportable application of the selected tool and guidance in the Texas bacteria task force report (TWRI, 2007). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models and an empirical approach referred to as the load duration curve.

Mechanistic computer models provide analytical abstractions of a real or prototype system—in this case, the Carters Creek watershed. Mechanistic models, also referred to as process models, are based on theoretical principles that provide for representation of governing physical processes that determine the response of certain variables, such as streamflow and bacteria concentration such as precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides understanding of the important biological, chemical, and physical processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The load duration curve (LDC) method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, the load duration curve method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations with bacteria TMDLs that constrain use of the more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the TSSWCB supports application of the load duration curve method within their three-tiered approach to TMDL development (TWRI, 2007). The LDC method lacks the predictive capabilities to evaluate alternative allocation approaches to reach TMDL goals, nor can it be used to quantify specific source contributions and instream fate and transport processes. The method does, however, provide a means to estimate the difference in bacteria loads and relevant criterion, and can give indications of broad sources of the bacteria, i.e., point source and nonpoint source.

Based on sufficient availability of discharge information for municipal WWTFs and the quantity of ambient *E. coli* data, the decision was made to use the LDC method over a more complex mechanistic watershed loading and hydrologic/water quality model. This decision also conforms to the guidance of the bacteria task force (TWRI, 2007).

To develop a TMDL using the load duration curve method, historical bacteria data and long-term, continuous daily streamflow data are needed for a period spanning multiple years. As previously presented and as summarized in Table 2-1, adequate historical *E. coli* data exist; however, there is an absence of continuous daily streamflow records on the Carters Creek watershed. On numerous creeks and rivers in Texas, U.S. Geological Survey (USGS) streamflow gauging stations have been in operation for a sufficient period to be used as the source of the needed streamflow records. There were two USGS gauges recording flow data within the watershed during 1968-1970. Since then, however, no USGS gauges have been operated within the watershed. In the absence of USGS streamflow records, it is a common practice to use the streamflow records from a nearby stream having a watershed with similar land use and geologic characteristics. No such gauge location exists in sufficient proximity to the Carters Creek watershed to serve that purpose. The approach for this project was to develop the daily streamflow records using an appropriate mechanistic watershed-scale model and to combine the predicted streamflow records with historical *E. coli* data to apply the LDC method.

3.2 Hydrologic Model Information

The Soil and Water Assessment Tool (SWAT) (Arnold *et al*., 1998) has been widely used in applications related to water resource, nonpoint-source pollution issues, and TMDL development (e.g., Gassman *et al*., 2007). SWAT is able to continuously simulate hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management on a daily time step (Borah *et al*., 2006).

For the purpose of this study, SWAT was employed to simulate the daily flow within the Carters Creek watershed over a desired time period. SWAT flow simulation is based on a daily water budget in which change in soil water content is the difference among precipitation, surface runoff, evapotranspiration, percolation, and groundwater return (base) flow. Through SWAT, the entire study watershed is divided into subbasins. Each subbasin is further subdivided into hydrologic response units (HRUs) based on unique combinations of soils and land uses. Each subbasin also contains a tributary channel and a main channel (or reach). The flow simulations are performed at the HRU level and the outputs are summarized in each subbasin. The simulated flows are routed through the stream network to the outlet: the lowest point of the entire watershed (Borah *et al*., 2006).

3.2.1 Data Preparation and Processing in AVSWAT

The ArcView Soil and Water Assessment Tool (AVSWAT) program provides a set of tools in an ArcView GIS environment to accomplish watershed delineation, definition and editing of the hydrological and agricultural management inputs, and other data files required for SWAT model (Di Luzio *et al*., 2004). AVSWAT program was used to generate and process necessary files for the model of the Carters Creek watershed. The modules included in AVSWAT used in this study were: (1) Watershed Delineation; (2) HRU Definition; (3) Weather Station Definition; and (4) SWAT Database.

Watershed delineation into the subbasins required in SWAT was based on surface topography data covering the study area. Digital Elevation Model (DEM) files with 10-meter resolution in the format of Spatial Data Transfer Standard (SDTS) for Brazos County, produced by the National Mapping Program of the USGS, were obtained from Geo Community (2008). The original data files were converted into ESRI grid files and mosaiced in ArcGIS, in preparation for AVSWAT procedures. Through defining outlets and inlets, a detailed stream network within the watershed was derived. A subbasin outlet is the point where streamflow exits the subbasin area (i.e., the most downstream location of the subbasin). SWAT predictions are provided at each outlet making it convenient to place outlets at the location of monitoring stations and other locations where model results are desired. An inlet is used to define a point-source discharge (e.g., a WWTF outfall in this case). The discharges from WWTFs within the watershed were included through the inlet designation. In SWAT, these WWTF discharges were routed through the channel network along with flows generated by groundwater and surface runoff from land areas. The subbasin delineation for the Carters Creek watershed was based on defining outlets at the 2 previously operated USGS flow stations, the regulated discharges from the 5 facilities considered as potential sources of bacteria loadings (see Section 2.5.1.1), 4 TCEQ water quality monitoring stations, and 18 manually added subbasin outlet points (Figure 3-1). Note that the watershed delineation by AVSWAT did not include the lowermost portion of the watershed, which lies within the Navasota River floodplain, because the low relief in that area provides challenges to automated delineation procedures. The delineation, however, included all required locations in the Carters Creek watershed. The purpose of manually adding outlet points was to divide some of the larger subbasins into smaller areas with similar land uses (i.e., rural or urban land uses) to provide for more model resolution of land use/land cover and to potentially enhance the performance of the SWAT model.

After the watershed delineation, land use and soil class combinations and their distributions (hydrologic response units or HRUs) for each delineated subbasin were determined, enabling SWAT model to set hydraulic and hydrological parameters for each HRU. The inputs for the HRU definition module included Soil Survey Geographic (SSURGO) Database provided by the USDA Natural Resources Conservation Service (2008), as well as the 2006 land use/land cover developed by Texas AgriLife Spatial Sciences Laboratory.

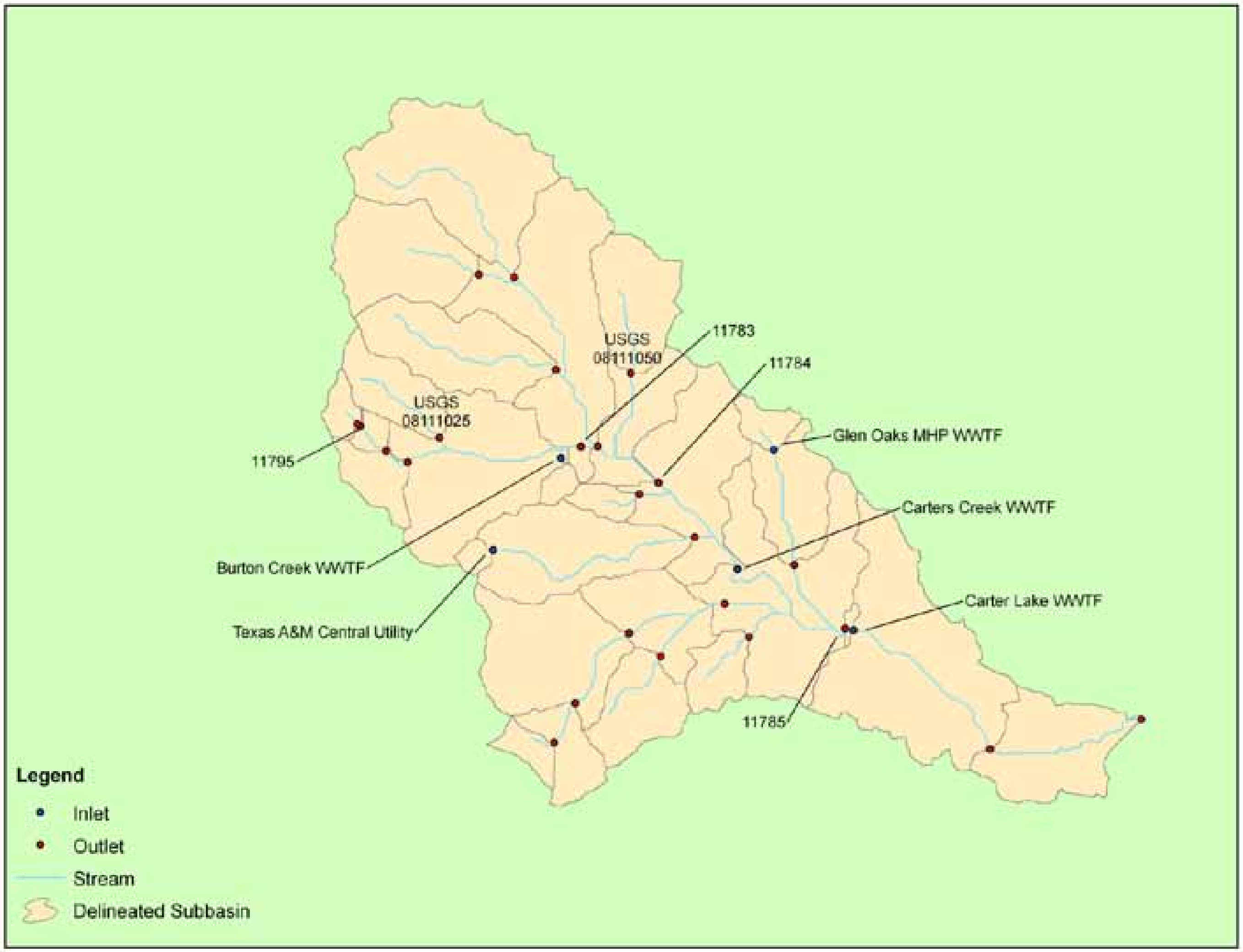

Figure 3-1 Carters Creek watershed showing SWAT subbasins and pertinent watershed features

In the next step, the nearest weather station was associated with the watershed. Climatic data provide the moisture and energy inputs, which control the water balance and the hydrological cycle components in the SWAT model. For the study area, the nearest station was a National Weather Network station located in the City of College Station, for which daily precipitation and maximum and minimum temperatures were obtained from the National Climatic Data Center (2011). Other necessary climatic variables, such as solar radiation, wind speed and relative humidity, were obtained from Weather Generator included in SWAT and based on statistical parameters of specified weather stations within the region.

In summary, the input databases required by SWAT include data that the define subbasins, daily average WWTF discharges and their outfall locations, HRUs, and weather. The input files for SWAT contained numerous parameters that can be adjusted during the model calibration procedure.

3.2.2 Validation of SWAT Model

Model calibration and verification, which collectively are referred to as validation, can be defined as follows:

- Calibration—the first stage testing and tuning of a model to a set of observational data, such that the tuning results in a consistent and rational set of theoretically defensible input parameters.
- Verification—Subsequent testing of a calibrated model to additional observational data to further examine model validity, preferably under different external conditions from those used during calibration. (from Thomann and Mueller, 1987)

Hence, calibration is a systematic procedure of selecting model input parameters that result in model predictions that best match the observational data. In addition, the adjustments of input parameters should be within literature-suggested ranges or limits provided in the user's manual for the model. Within the separate verification step, the input parameters remain at the values used in the calibration step and separate sets of observational data are used for comparison purposes.

Nash-Sutcliffe E Value (ENS) (Nash and Sutcliffe, 1970) was used as an indicator of the SWAT model performance during the validation process. The ENS value is computed as one (1) minus the quantity that is the sum of the absolute squared differences between the measured and predicted flow values divided by the variance of the measured values during a period of interest. The formula is as follows:

$$ENS = 1 - \frac{\sum_{i=1}^{n}(X_{mi} - X_{pi})^2}{\sum_{i=1}^{n}(X_{mi} - \overline{X}_m)^2} \qquad (3.1)$$

where X_{mi} is the measured flow at time i, X_{pi} is the corresponding predicted streamflow, and $\overline{X}_m$ is the average measured flow. An efficiency value of 1 ($ENS = 1$) indicates that the model predicted flow data perfectly match the measured data. An efficiency value of 0 ($ENS = 0$) indicates that the model predictions are as accurate as the mean of the measured data, whereas an efficiency less than zero ($-\infty < ENS < 0$) occurs when the mean measured value is a better predictor than the simulated value. The literature indicates that generally ENS > 0.5 is an indication of satisfactory validation of a model to daily streamflow data (Moriasi *et al.* 2007), and a goal of ENS > 0.5 was accepted for the SWAT validation process in this study.

For model calibration continuous daily streamflow records were used from two USGS streamflow gauges. The streamflow records for the two USGS gauges were for a relatively short period of approximately 27 months. The gauges were located on the headwaters of two creeks in small catchments that were defined as subbasins in SWAT (Figure 3-2). For model validation the data were more contemporary (mostly from the late 1980s through early 2000s) and generally at locations more downstream on the streams than the USGS gauges (Figure 3-2); however, the streamflow data were limited to roughly 20 instantaneous measurements made periodically at each water quality monitoring station during routine sampling events over multiple years. While the calibration and verification data sets provide much less than the optimal amount of streamflow data for model validation, these data sets constitute a surprisingly good amount of data for a relatively small watershed and provide adequate data for testing SWAT at the level of performance required for application of the LDC method.

As a final comment on the model validation process, only the calibration data set contained sufficient data to allow a quantitative measure of model performance using ENS, because of approximately 27 months of continuous daily streamflow data. In contrast, the limited verification data set provided neither enough data points nor daily average streamflow data (the data set contained instantaneous streamflow measurements) to allow quantitative measures to be applied. Therefore, visual comparison of graphical results was used to determine acceptability of model verification.

3.2.2.1 Calibration Step

As indicated previously in the discussion of data requirements for applying the load duration curve method, no long-term continuous streamflow records currently exist for the Carters Creek watershed. However, two independent sets of streamflow data for calibration do exist for small streams in the Carters Creek watershed during 1968-1970. The SWAT model was calibrated against those actually measured data so that the calibrated model would be able to more accurately simulate daily streamflow within the watershed over a more extended time period as needed for the streamflow record in the LDC method. Specifically, the calibration of SWAT was conducted by using the daily flow data measured from the two USGS stations: USGS 08111025 Burton Ck at Villa Maria Rd during June 24, 1968 – September 10, 1970, and USGS 08111050 Hudson Ck near Bryan during July 9, 1968 – September 11, 1970. The delineated subbasins for these two USGS flow stations are RCH1 (urban area dominated) and RCH2 (rural area dominated) (Figure 3-2).

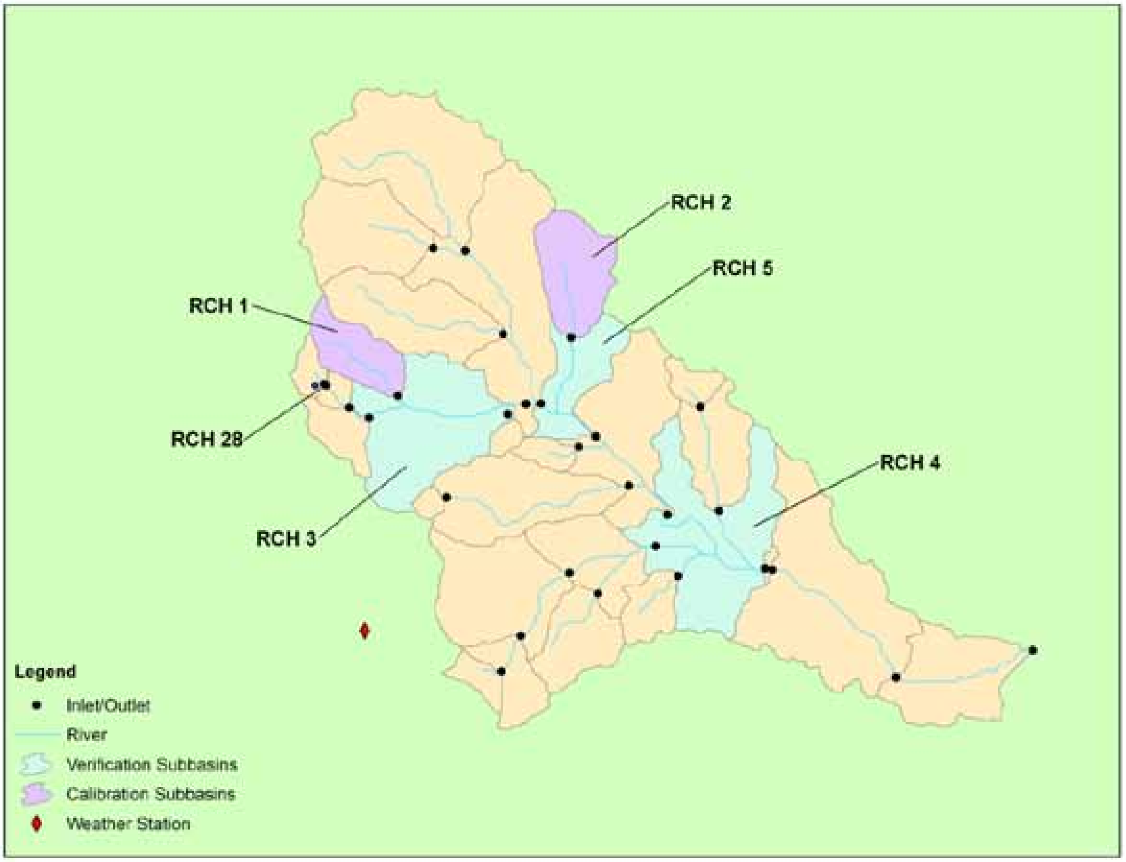

Figure 3-2 Weather station location, and calibration and verification subbasins outlets used in SWAT

The outlet flow data at RCH1 was in a reasonable agreement with the USGS gauge station data before adjusting any model parameters. However, the initial predicted streamflow at RCH2 had some large discrepancies when compared to the USGS gauge station records. The reason for some of the discrepancy could be that the precipitation data used in the flow simulation were not representative because the weather station was located further away from the subbasin RCH2 than RCH1 (Figure 3-2). (A search for a closer weather station for the western portion of the watershed was not successful.) Therefore, adjustment of SWAT input parameters was the only option to achieve better agreement of the predicted streamflow to the measured data.

By reducing CN2 (initial SCS runoff curve number for moisture condition II) by 10% for both RCH1 and RCH2, and adjusting GWQMN (threshold depth of water in the shallow aquifer required for return flow to occur; in units of mm of water) in RCH1 to 2000 mm, and in RCH2 to 4300 mm, the simulated flow data agreed better with the actual measured data in both subbasins. Thus, a 10% reduction on CN2 was applied to the entire watershed. GWQMN was adjusted differently in each subbasin, depending on the location of each subbasin. Because the model predicts groundwater flow into the reach of a subbasin only if the depth of water in the shallow aquifer is equal or greater than GWQMN and because headwater streams are less incised than more downstream streams, headwater subbasins were assigned a higher GWQMN value, subbasins in the middle of the watershed were assigned a smaller value, and main stream subbasins were assigned the smallest value based on elevation of each subbasin. As a result, the values of GWQMN ranged from 0 mm for the most downstream main stream subbasin to 5000 mm for the most upstream headwater subbasins.

Visual comparison of predicted and measured daily streamflows for the urban catchment (RCH1) indicated good responsiveness of the model predictions to precipitation events and that both low flow and high flows are reasonably predicted (Figure 3-3). Similar visual comparison for the rural catchment (RCH2) indicated that the model was also responsive to precipitation events and appropriately responsive under both low and high flows (Figure 3-4). Table 3-1 shows the ENS values for the daily and monthly simulated flows at RCH1 and RCH2. As can be seen, the ENS values for daily flow simulations at RCH1 and RCH2 all exceeded the acceptance value of 0.5 from Moriasi *et al.* (2007). As anticipated, when daily values are aggregated to monthly flows the ENS values at both sites were improved from the daily values and ranged from 0.8 to 0.9. Based upon these encouraging statistical measures of model performance, SWAT was considered calibrated for simulating daily flows.

Table 3-1 Nash-Sutcliffe E values for the model simulation

Subbasin	Flow Time Scale	Nash-Sutcliffe E Value (ENS)
RCH1	Daily flow	0.68
	Monthly average flow	0.82
RCH2	Daily flow	0.58
	Monthly average flow	0.89

3.2.2.2 Verification of SWAT

The methodology of verification consisted of operating the model using the input parameters developed in the calibration step and comparing predicted streamflow to an independent set of streamflow data from that used in the calibration step. Therefore, the adjusted parameters from the calibration step (i.e., CN2 and GWQMN) were applied to the entire watershed when SWAT was run for predicting streamflows for the period January 1, 1991 through December 31, 2010. To validate the SWAT predicted flows in recent years, the instantaneously measured streamflow data from the four TCEQ water quality monitoring stations (located in RCHs 10-13 in Figure 3-2) were compared with the model outputs at each corresponding subbasin outlet. The measured streamflow data were available for periods of different duration at each station and generally about 20 measurements were available per station.

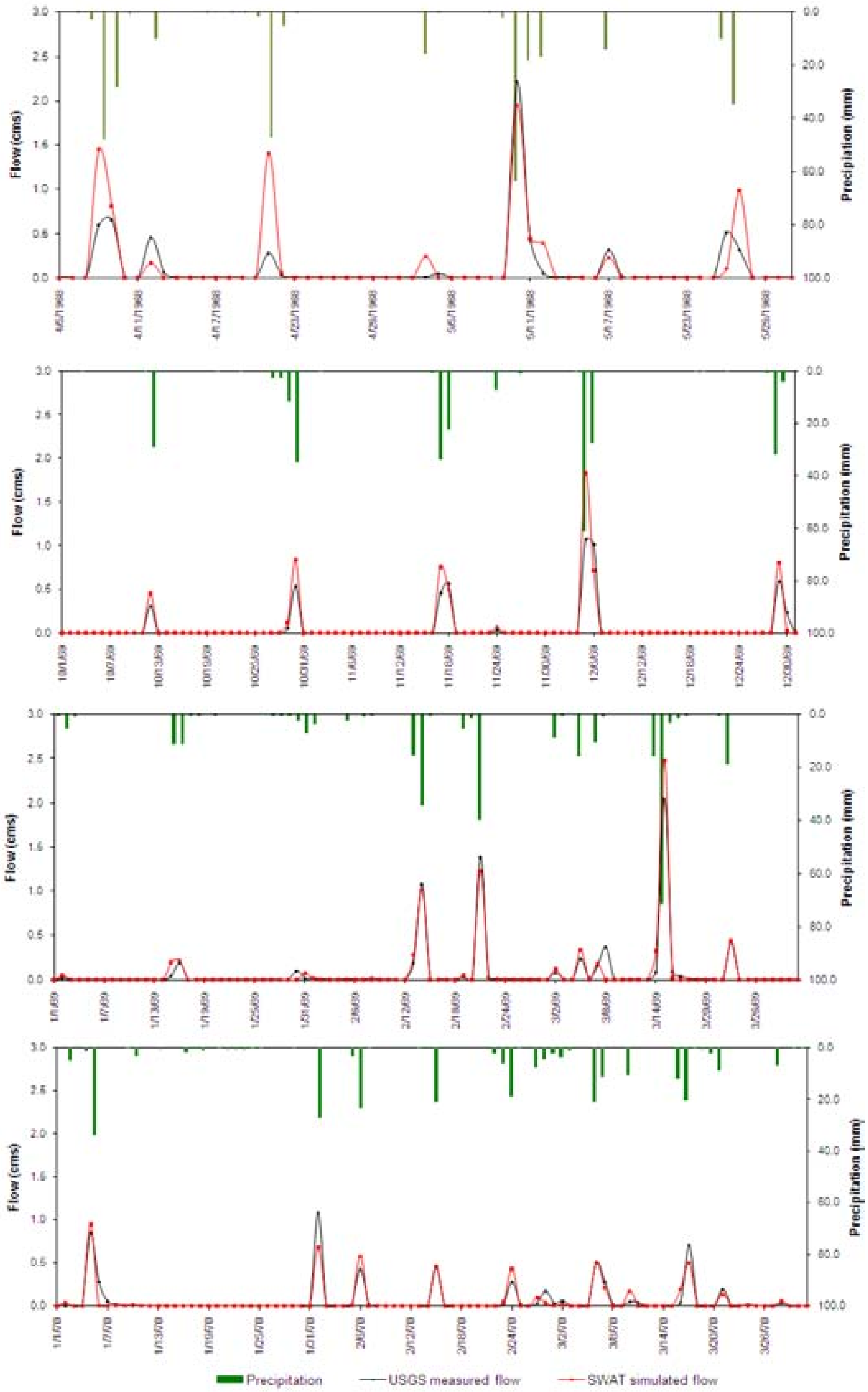

Figure 3-3 Comparison between the model-simulated flows and actual measured flows at RCH1 for selected periods during June 24, 1968 – September 10, 1970

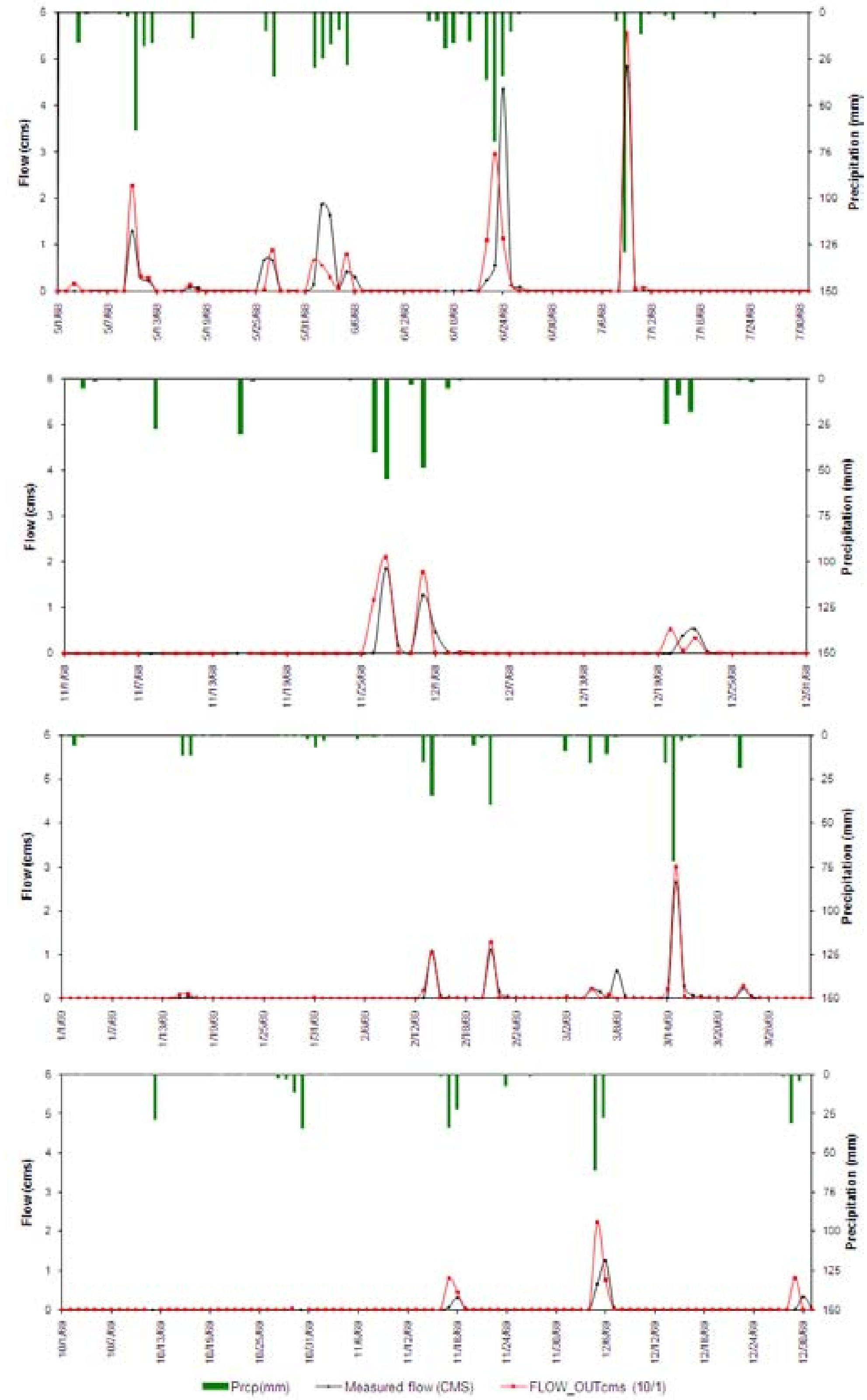

Figure 3-4 Comparison between the model-simulated flows and actual measured flows at RCH2 for selected period during July 9, 1968 – September 11, 1970

SWAT was able to closely simulate most moderate to low flow measurements under which conditions it would be anticipated that streamflow conditions would be relatively steady allowing the daily predictions of SWAT to more closely mimic the instantaneous flow measurements (Figure 3-5). The greatest discrepancies occurred during those conditions where model and measured flows were highest, which would indicate streamflow response to rainfall runoff. Under high flow conditions, the difference between the daily average streamflow predicted by the model and an instantaneous streamflow measurement was anticipated to be potentially large, especially for a watershed of this relatively small size where rise and fall of a rainfall-driven hydrograph would be over a period of hours rather than days. Under these higher flows, there were cases when SWAT either greatly overestimated or underestimated flows. However, those cases were relatively rare during the 15- or less year period for which the measured flow were available at the four TCEQ stations.

Though data limitations prevented a rigorous verification of the model, it was concluded that SWAT adequately predicted observed conditions at the four monitoring stations in the Carters Creek watershed. The adequate verification coupled with a good calibration resulted in the conclusion that the SWAT model of the watershed was acceptably robust for the purpose of predicting the daily flows needed for the load duration curve method.

3.2.3 Application of SWAT to Develop Streamflow

The period of the historical *E. coli* data for the four TCEQ monitoring stations used in LDC development (stations 11795, 11783, 11784, and 11785) as obtained from the TCEQ SWQMIS database was limited to 2001-2007 for stations 11783 and 11784, 2001-2010 for station 11785, and 1997-2005 for station 11795. In order to develop representative LDCs to be used in the TMDL load allocation process, the period simulated by SWAT needs to be long enough to include hydrologic responses over a reasonable range of flows encountered in the watershed and over a sufficiently wide variety of weather conditions and patterns, such as high and low precipitation periods. Thus the simulation period for this report was selected as 20 years: from January 1, 1991 to December 31, 2010. Because SWAT includes many soil-moisture related processes, the simulation period was extended to begin January 1, 1985 allowing 6-years for the model to overcome any biases to hydrologic predictions resulting from specification of inaccurate initial conditions in the model input, though only the last 20 years of daily streamflow predictions were used in the LDC method. Each of the five TPDES/NPDES regulated facilities considered as potential contributors of bacteria loadings to Carters Creek watershed were specified in SWAT as discharging at their full permitted flow limits provided in Table 2-4. These five facilities are Texas A&M Central Utility (0.93 MGD), Carters Creek WWTF (9.5 MGD), Burton Creek WWTF (8.0 MGD), Glen Oaks Mobile Home Park WWTF (0.013 MGD), and Carter Lake WWTF (0.0085 MGD). Atkins Power Station was excluded because it discharges into Fin Feather Lake (Segment 1209B), which does not show bacteria impairment.

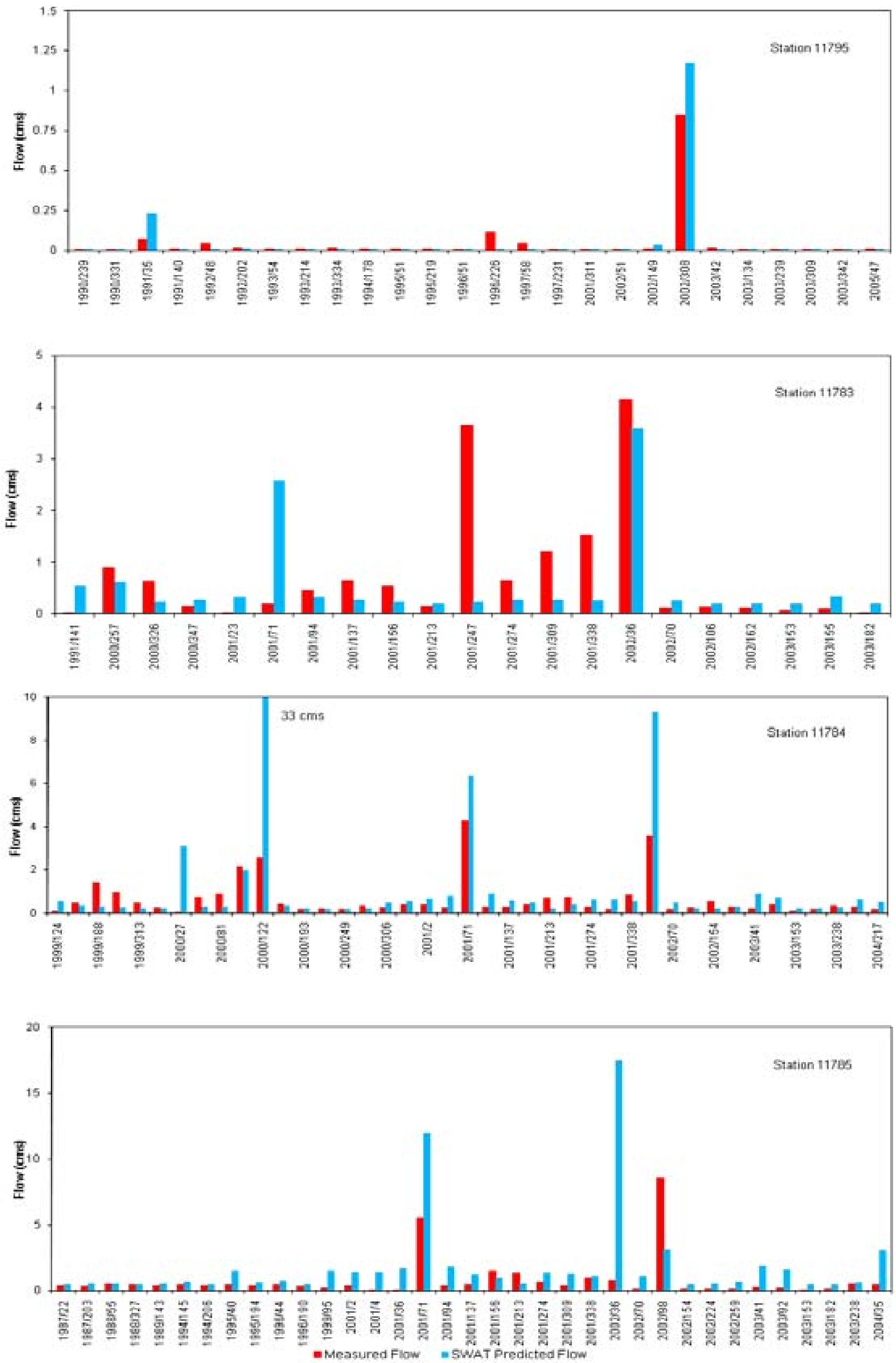

Figure 3-5 Comparison between the model-predicted flows and measured flows at four water quality monitoring stations

3.3 Flow Duration Curve and Load Duration Curve Methods

A flow (load) duration curve (FDC or LDC) is a graph indicating the percentage of time during which a certain value of flow (load) is equaled or exceeded. To develop a FDC for a location the following steps were undertaken:

- order the SWAT-simulated daily streamflow data for the location from highest to lowest and assign a rank to each data point;
- compute the percent of days each flow was exceeded by dividing each rank by the total number of data point plus 1; and
- plot the corresponding flow data against exceedance percentages.

Further, when developing a LDC:

- multiply the SWAT-simulated streamflow in cubic meters per second (cms) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL) and by a conversion factor (8.64×10^8), which gives a loading in units of MPN/day; and
- plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

The resulting curve represents the maximum allowable daily loadings for the geometric mean criterion. The next step was to plot the sampled *E. coli* data on the developed LDC using the following two steps:

- using the unique data for each monitoring station, compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (8.64×10^8); and
- plot on the LDC for each station the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots of the LDC with the measured loads (*E. coli* concentration times SWAT predicted streamflow) display the frequency and magnitude that measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

The FDC at the four TCEQ water quality monitoring stations are provided in Figure 3-6 for the predicted streamflows from January 1, 1991 through December 31, 2010. The FDCs show the anticipated increase in flow in the downstream direction from station 11795 near the upstream end of Country Club Branch, to station 11783 near the outlet of Burton Creek, to station 11784 near the middle of Carters Creek, and finally the most downstream station 11785 on Carters Creek. Of interest is the similarity of the low flows (exceedance > 70%) at stations 11783 and 11784, which reflects the dominance at low flow of the discharge from the City of Bryan Burton Creek WWTF at both stations. Station 11785 is predicted to have higher low flow conditions than the two upstream stations basically because of the discharge from the City of College Station Carters Creek WWTF, which enters Carters Creek upstream of station 11785 and downstream of the other two stations.

In addition to the FDCs developed for the four water quality monitoring stations, FDCs for the most upstream and downstream points (inlets and outlets) of Carters Creek (Segment 1209C), Country Club Branch (Segment 1209D), and Burton Creek (Segment 1209L) were developed (Figure 3-7). These FDCs display a similar pattern to those developed for the four water quality monitoring stations with flow increasing in the downstream direction. Flows predicted by SWAT for the inlets and outlets of each segment provide the basis for load allocations presented in Section 4 of this document.

The corresponding LDC with *E. coli* loadings from historical data are shown at the same four TCEQ water quality stations (11795, 11783, 11784, and 11785) in Figures 3-8 – 3-11, respectively. All four graphs depict the allowable loadings at the stations under the geometric mean criterion and show that existing loadings often exceed the criterion. The streamflows and associated *E. coli* concentrations used to develop these LDCs at each of the stations are provided in Appendix A. On each graph the measured *E. coli* data are presented as associated with a “wet weather event” or a “non-wet weather event,” wherein wet weather was considered cumulative 4-day antecedent precipitation exceeding 10 mm. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

The LDCs for the inlets and outlets of Segments 1209D, 1209L, and 1209C do not have associated historical *E. coli* data and were constructed for developing the TMDL allocation for each of the segments (Figure 3-12). The inlet LDC defines the upstream allowable loading entering the segment and outlet LDC defines the allowable loading leaving the segment. As anticipated the allowable loading increases in the downstream direction from inlet to outlet and from Segment 1209D to Segment 1209L to Segment 1209C.

3.4 Overview of Load Duration Curves

Further interpretation and application of the developed LDCs involve steps in the TMDL load allocation process that are discussed in the next section. Visual inspection of the LDCs for the four monitoring stations indicate existing *E. coli* loadings often exceed the allowable loading (geometric mean criterion of 126 MPN/100mL) under all flow conditions, i.e., the full range of exceedances on the x-axis. The analysis also shows that even though the more elevated *E. coli* data were related to high precipitation and flow, exceedances of the criterion occurred over the entire range of flows.

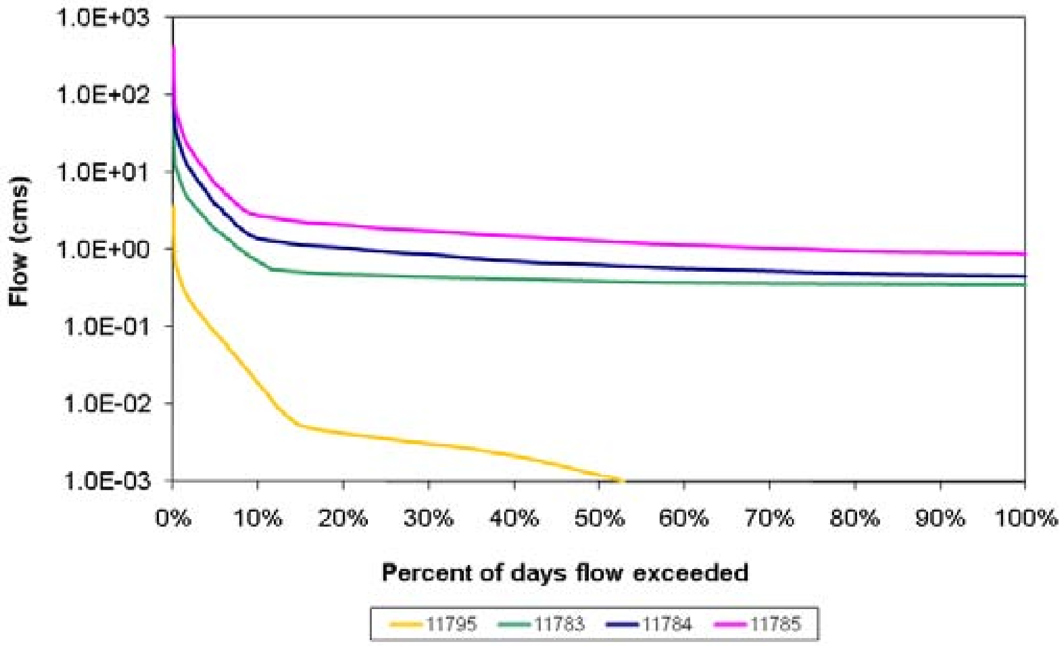

Figure 3-6 Flow duration curves at four water quality monitoring stations. (Note: Flows less than 0.001 cms (0.035 cfs) considered equivalent to no flow.)

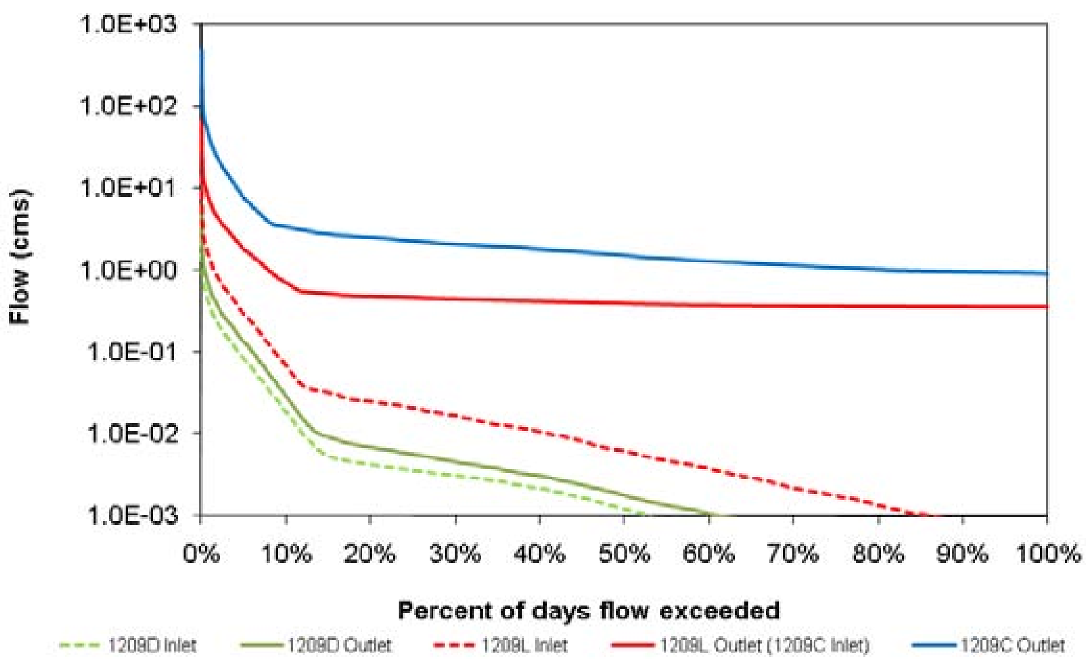

Figure 3-7 Flow duration curves at the inlets and outlets of impaired Segments 1209D, 1209L, and 1209C. (Note: Flows less than 0.001 cms (0.035 cfs) considered equivalent to no flow.)

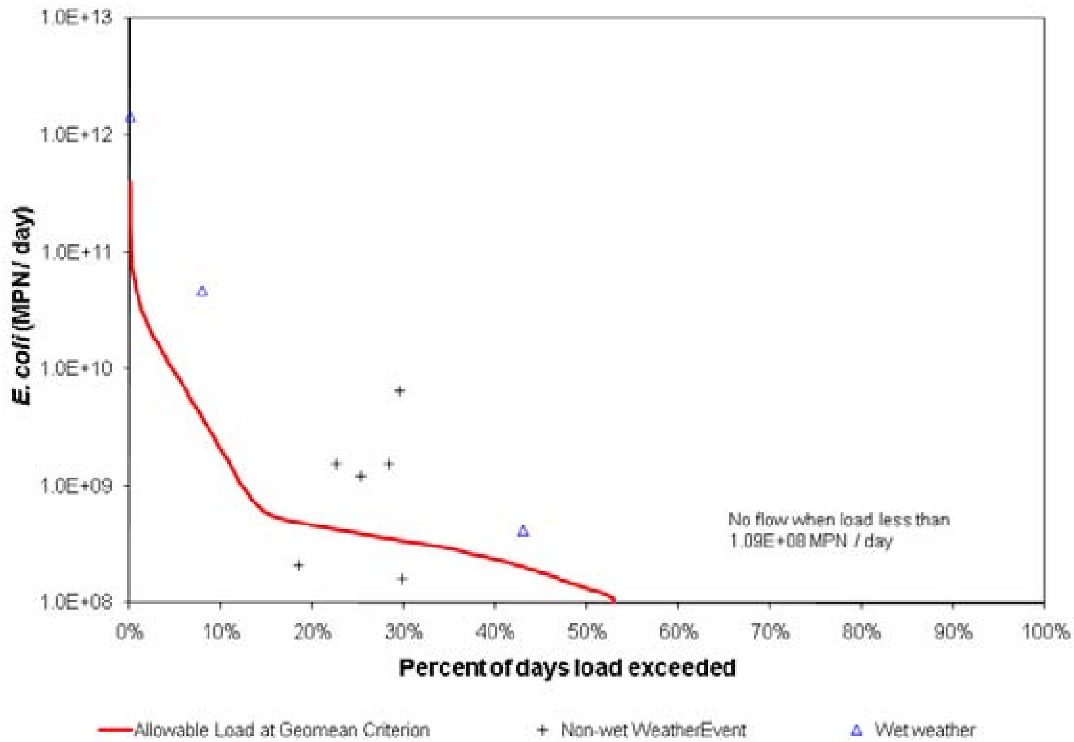

Figure 3-8 ***E. coli*** **load duration curve and measured loads at water quality monitoring station 11795**

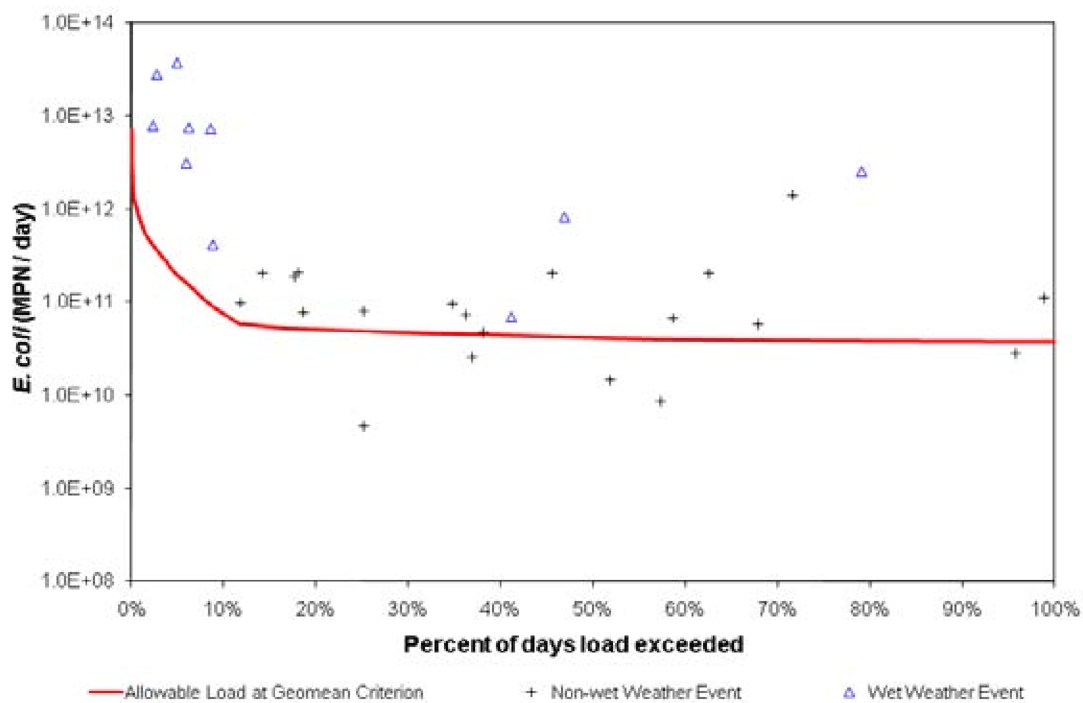

Figure 3-9 ***E. coli*** **load duration curve and measured loads at water quality monitoring station 11783**

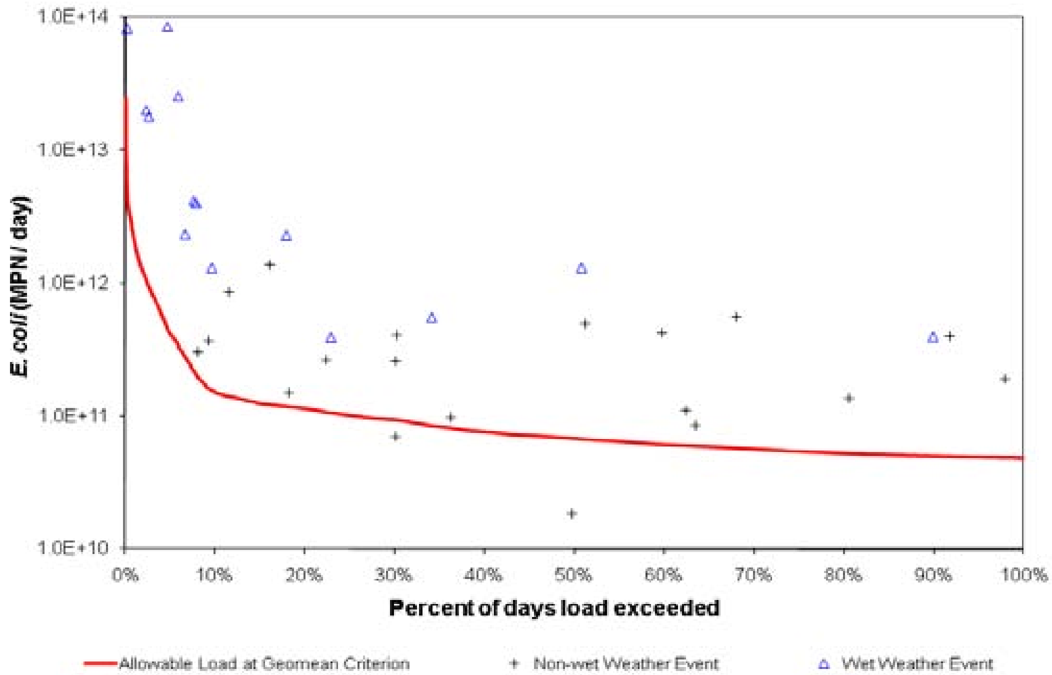

Figure 3-10 ***E. coli*** **load duration curves and measured loads at water quality monitoring station 11784**

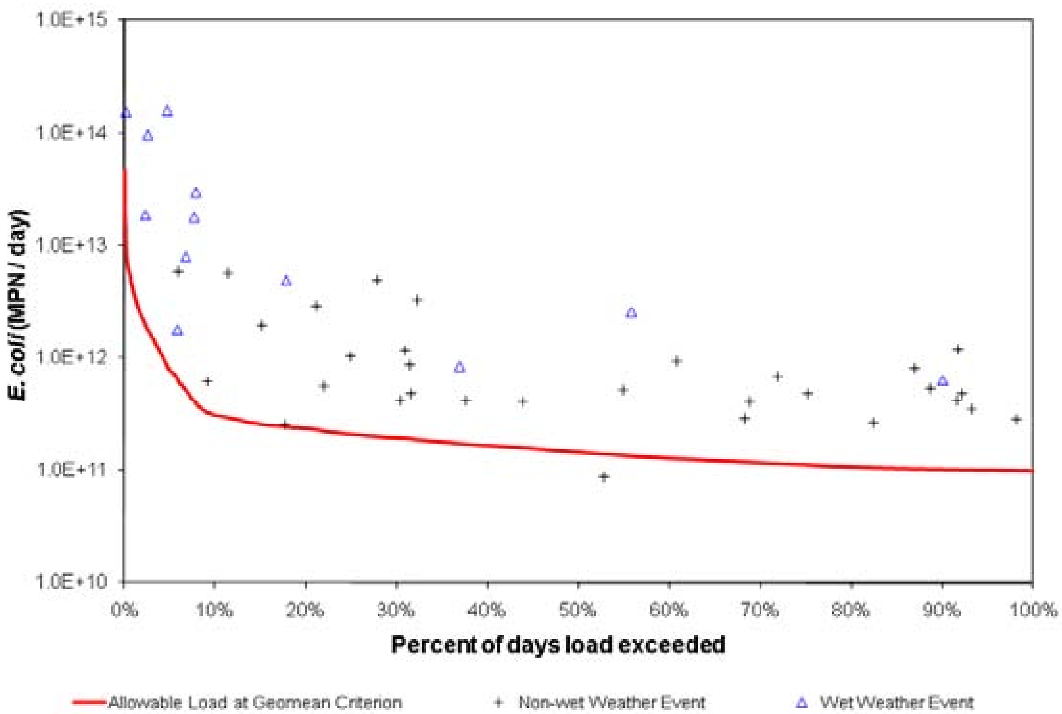

Figure 3-11 ***E. coli*** **load duration curves and measured loads at water quality monitoring station 11785**

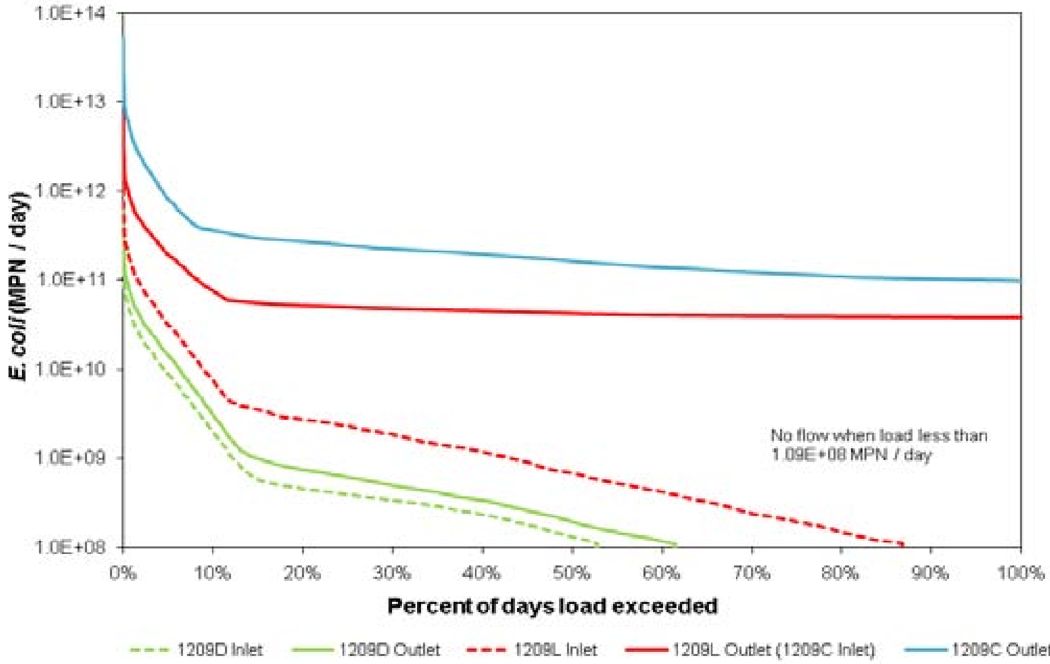

Figure 3-12 Load Duration curves for the inlets and outlets of 1209D, 1209L, and 1209C

SECTION 4
TMDL ALLOCATION ANALYSIS

Within this report section is presented the development of the bacteria TMDL allocation. The allocation tool used for Carters Creek (Segment 1209C) Burton Creek. (Segment 1209L), and Country Club Branch (Segment 1209D) bacteria TMDLs was the load duration curve method previously described in Section 3 — Bacteria Tool Development. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

The load duration curve method provided a flow-based approach to determine necessary reductions in bacteria loadings within Carters Creek, Burton Creek, and Country Club Branch. As developed previously in this report, the duration curve method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the contact recreation use.

For the purpose of this study, SWAT was employed to simulate the daily flow within the Carters Creek watershed. Within the subsequent Implementation Plan, an adaptive approach will be used to bring the necessary spatial focus to improving water quality and restoring the contact recreation use.

4.1 Endpoint Identification

Carters Creek, Burton Creek, and Country Club Branch have a designated use for contact recreation, which is protected by numeric criteria for the indicator bacteria of *E. coli*. Indicator bacteria are not generally pathogenic and are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. *E. coli* criteria to protect freshwater contact recreation consist of geometric mean concentrations not to be exceeded of 126 MPN/100 mL and a single sample concentration not to be exceeded of 394 MPD/100 mL (TCEQ, 2000). All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for the TMDLs in this report is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This endpoint applies to impaired Carters Creek (Segment 1209C), Burton Creek (Segment 1209L), and Country Club Branch (Segment 1209D). The endpoint for these TMDLs of 126 MPN/100 mL is identical to the proposed geometric mean criterion for primary contact recreation in the 2010 Surface Water Quality Standard, which have been adopted by the TCEQ Commission and are awaiting EPA approval (TCEQ, 2010b).

4.2 Assessment Results from Historical Monitoring *E. coli* Data

As previously presented in this report (Table 2-1), historical indicator *E. coli* data indicate that Segments 1209C, 1209D, and 1209L do not support the contact recreation use. As anticipated because of use of the common data source in SWQMIS, these results corroborate the TCEQ 2008 assessment findings (TCEQ, 2008b) and TCEQ draft 2010 assessment findings (TCEQ, 2010a).

4.3 Seasonality

Seasonal variations or seasonality occur when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents, which for this study was *E. coli*. 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 three years of water quality data and by using a 20-year period of SWAT-simulated daily streamflow data when developing flow exceedance percentiles.

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations obtained from routine monitoring collected in the warmer months (May – September) against those collected during the cooler months (October – April). Data obtained from stations 11784 and 11785 were combined into a single dataset for Carters Creek, while data obtained from station 11783 were the dataset used for Burton Creek and data from station 11795 were used for Country Club Branch. *E. coli* data were transformed using the natural log and then adjusted for flow using locally weighted scatter plot smoothing (LOWESS) (Helsel and Hirsch, 1992). Differences in *E. coli* concentrations obtained in warmer versus cooler months were then evaluated by performing a t-test on the adjusted dataset. Overall this analysis of *E. coli* data indicated that there was no significant difference (α=0.05) in indicator bacteria between cool and warm weather seasons for Carters Creek (ρ=0.87), Country Club Branch (ρ=0.73), and Burton Creek (ρ=0.43).

4.4 Linkage Analysis

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

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

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

Load duration curve (LDC) analyses were used to examine the relationship between instream water quality, the broad sources of indicator bacteria loads, and are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders, and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of this approach to characterize pollutant sources, and the Texas Bacterial Task Force identified this method as a tool for TMDL development (TWRI, 2007). In addition many other states are using this method to develop TMDLs.

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

The LDC method allows for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (*i.e.*, point source and storm water) and provides a means to allocate allowable loadings.

4.5 Margin of Safety

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

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

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

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

4.6 Flow Regimes for Load Duration Curves

A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0 – 10% (high flows); (2) 10 – 40% (moist conditions); (3) 40 – 60% (mid-range flows); (4) 60 – 90% (dry conditions); and (5) 90 – 100% (low flows).

For the Carters Creek watershed a three-interval system was selected based on the shape of the FDCs:

- Very high flow regime: 0-10 percentile range, related to flood flows
- High flow regime: 10-50 percentile range, related to high streamflow conditions
- Low flow regime: 50-100 percentile range, related to low and dry flow condition

The load duration curves with these three flow regimes for the four water quality monitoring stations are provided in Figures 4-1 through 4-4. Existing bacteria geometric mean loadings by flow regime have also been distinguished on each figure to aid interpretation. The LDCs for the four water quality monitoring stations provide a means of identifying the streamflow conditions under which exceedances in *E. co*li concentrations have occurred. Actual pollutant load computations were based on LDCs developed for the outlet (or most downstream point) and inlet (or upstream/tributary point) of each of the three impaired streams (Figure 4-5). The inlet LDC defines the allowable loading entering the segment from an upstream area or tributary segment and the outlet LDC defines the allowable loading leaving the segment.[1] The allowable

[1] TMDL load allocation calculations are required at the assessment unit level. Because all the segments in this study include only one assessment unit, segments become synonymous to assessment units. The term segment is used throughout this report instead of assessment unit.

loading increases in the downstream direction. For purposes of the pollutant load computations presented later in this section, the hydrologic records for the FDCs and subsequent allowable loads from the LDCs are adjusted to reflect future capacity estimates that account for the probability that additional flows from WWTF discharges may occur as a result of future population increases in the Carters Creek and Burton Creek watersheds (see Section 4.8.2.2).

For the segment-level TMDL calculations, the maximum allowable loading was determined at the median flow of the very high flow regime (0 – 10%) or 5% exceedance value at the outlet of each impaired segment. The maximum allowable loading is expressed in the following formula, which is the loading value at the 5% exceedance point on the appropriate LDC.

TMDL (MPN/day) = criterion * flow * conversion factor (Eq. 1)

Where:

criterion = 126 MPN/100 mL (*E. coli*)
flow = 5% exceedance flow in cubic meter per second (cms)
conversion factor = 8.64×10^{8} 100 mL/m^3 * seconds/day

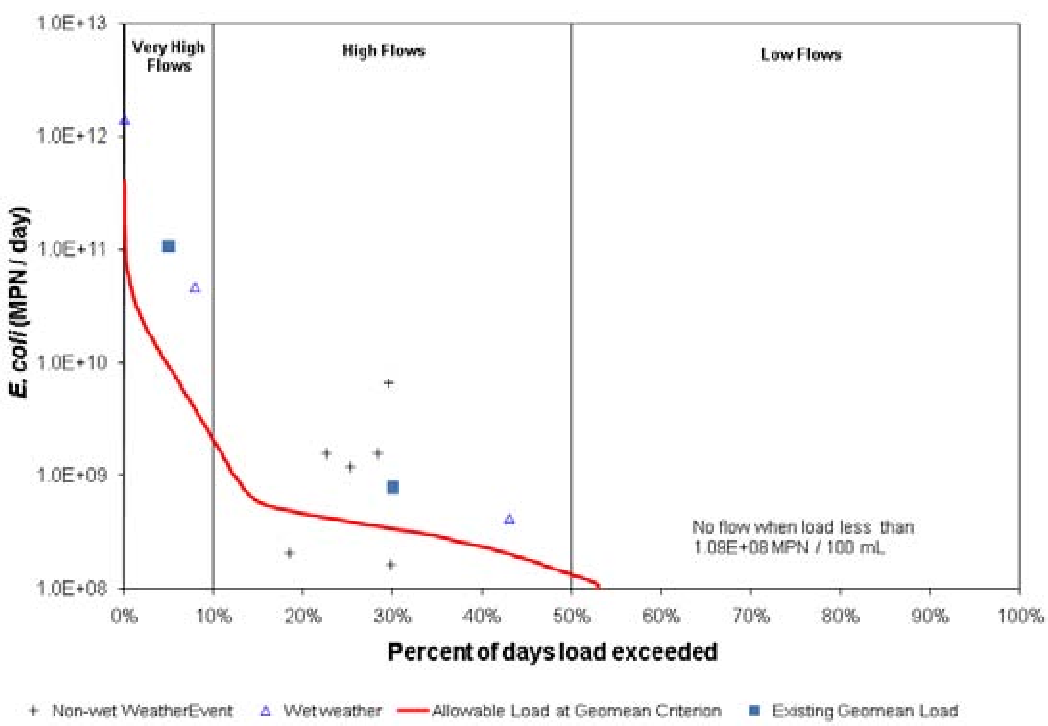

Figure 4-1 Load duration curve with flow regimes for station 11795, Country Club Branch, Segment 1209D

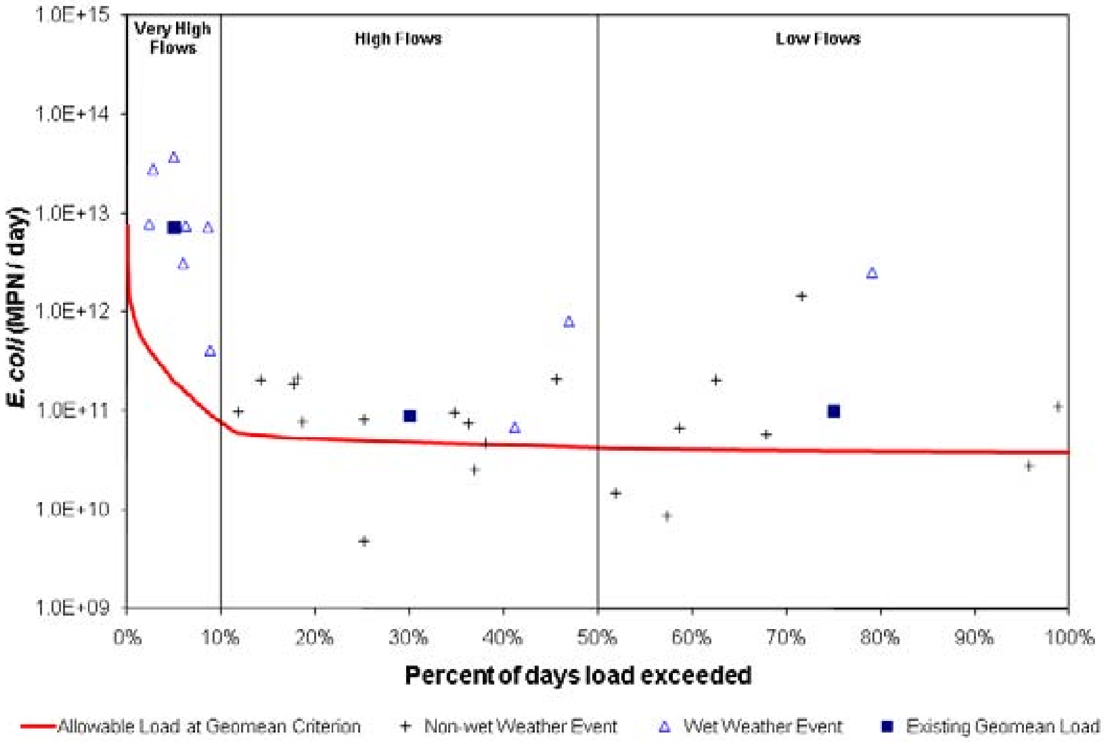

Figure 4-2 **Load duration curve with flow regimes for station 11783, Burton Creek, Segment 1209L**

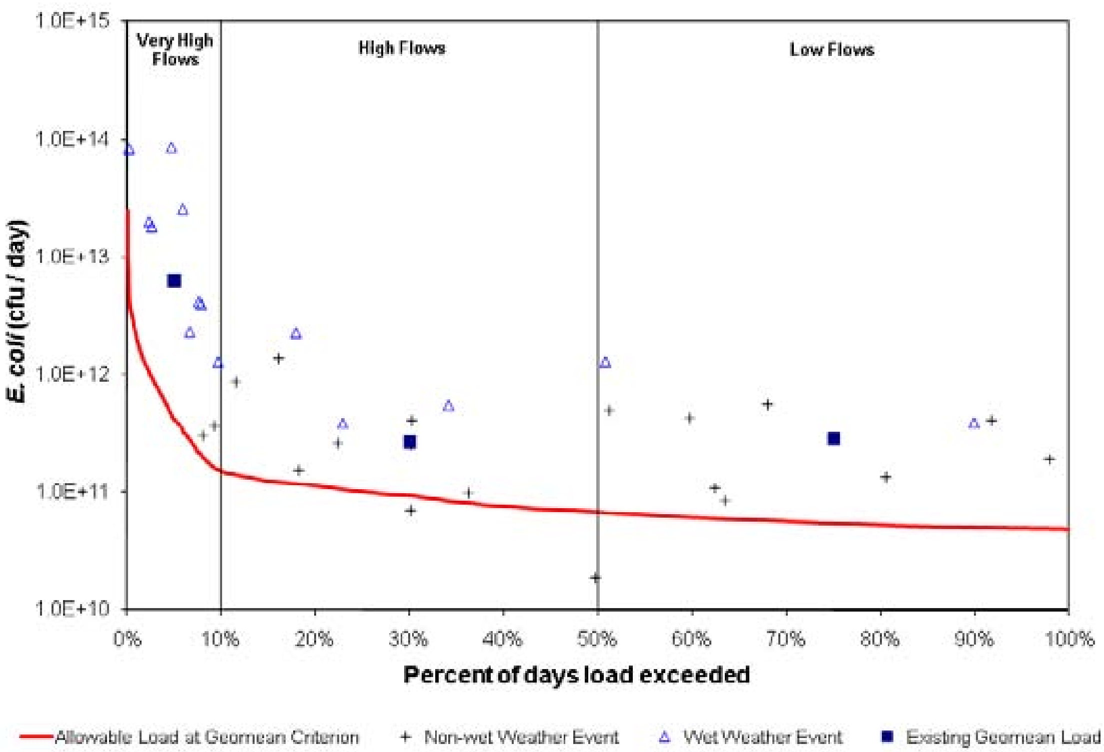

Figure 4-3 **Load duration curve with flow regimes for station 11784, Carters Creek, Segment 1209C**

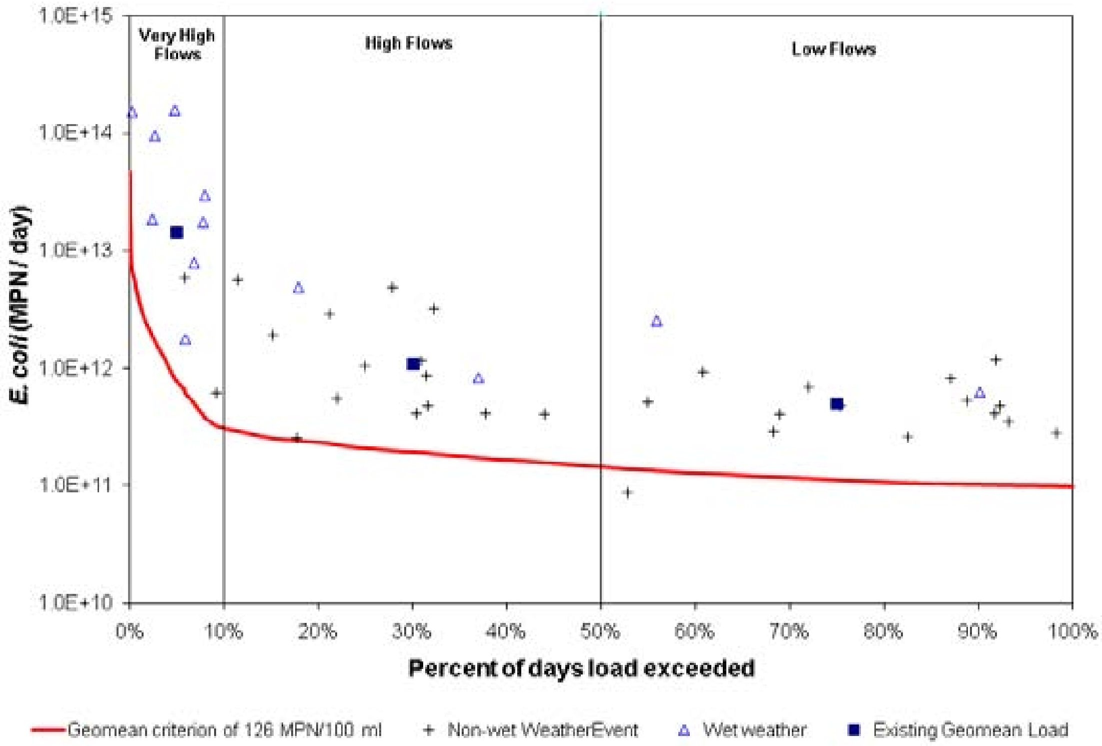

Figure 4-4 Load duration curve with flow regimes for station 11785, Carters Creek, Segment 1209C

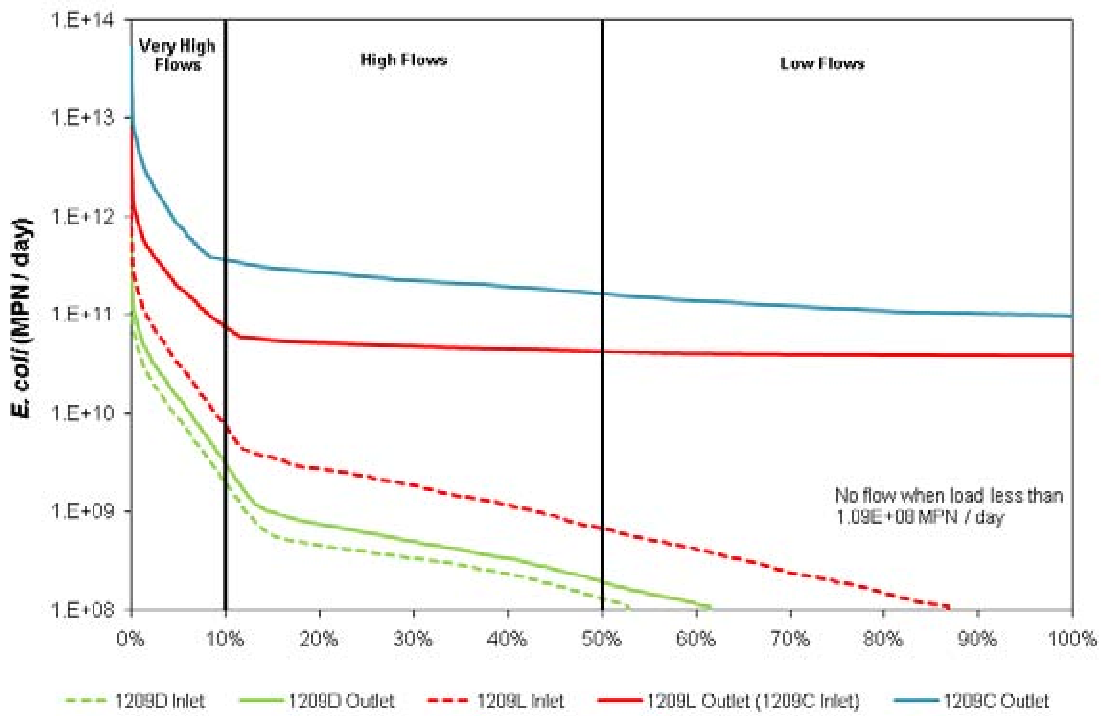

Figure 4-5 Load Duration curves with flow regimes for the inlets and outlets of 1209D, 1209L, and 1209C

4.7 Load Reduction Analysis

A single percent load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical *E. coli* data obtained from stations within the impaired reaches. It should be noted that even though reductions for all three flow regimes have been computed and presented in this report, for purposes of TMDL allocations only the very high flow regime will be considered. For simplicity of computation and presentation, the load reduction calculations were based on concentrations rather than loadings (concentration multiplied by flow), since the flow would be identical in both the existing and allowable loadings computations and, thus, the flow would effectively cancel out of the calculations. The following steps were used to determine the required percent load reduction for each station and each flow regime:

1. Develop load duration curves for all sampling stations within each segment. Station 11795 was used in Segment 1209D, station 11783 was used in Segment 1209L, and stations 11784 and 11785 were used in Segment 1209C (Figures 4-1 and 4-4).
2. For each station and flow regime, determine the geometric mean concentration of the historical data within each of the three flow regimes, which represent the appropriate concentrations for comparison to the geometric mean criterion (126 MPN/100 mL) (Table 4-1).
3. For each station and flow regime, determine the percent reduction required to achieve the geometric mean criterion by calculating the difference in the existing (or measured) geometric mean concentration and the 126 MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 4-1).

Table 4-1 Percent reduction calculations for stations within Segments 1209C and 1209L

Station	Segment	Very High Flows (0-10%)		High Flows (10-50%)		Low Flows (50-100%)	
		Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction
11795	1209D	1,481	92%	296	60%	NA *	NA *
11783	1209L	4,654	97%	233	49%	323	63%
11784	1209C	1,904	94%	358	67%	656	82%
11785	1209C	2,349	95%	711	83%	562	79%

* NA – Not applicable; flow absent for most of the Low Flow regime at Station 11795

4.8 Pollutant Load Allocations

4.8.1 TMDL Definition

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding water quality standards. The pollutant load allocations for Carters Creek (Segment 1209C), Country Club Branch (Segment 1209D), and Burton Creek (Segment 1209L) were calculated using the following equation:

$$TMDL = \Sigma WLA + \Sigma LA + \Sigma FG + MOS \quad \text{(Eq. 2)}$$

Where:

WLA = waste load allocation, the amount of pollutant allowed by existing regulated or permitted dischargers
LA = load allocation, the amount of pollutant allowed by non-regulated or non-permitted sources
FG = loadings associated with future growth from potential permitted facilities
MOS = margin of safety

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

The bacteria TMDLs for the 303(d)-listed Segments 1209D, 1209L, and 1209C as covered in this report were derived using the median flow (or 5% flow) within the very high flow regime of the LDC developed for the outlet of each segment.

4.8.1.1 Waste Load Allocation

TPDES-permitted wastewater treatment facilities are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion after reductions for the MOS. This is expressed in the following equation:

$$WLA_{WWTF} = [\text{criterion} * (1 - F_{MOS})] * \text{flow (MGD)} * \text{conversion factor} \quad \text{(Eq. 3)}$$

Where:

Criterion = 126 MPN/100 mL
F_{MOS} = fraction of loading assigned to margin of safety (5% or 0.05)
[Criterion * (1 – F_{MOS})] = [126 MPN/100 mL * (1.00 – 0.05)] = 119.7 MPN/100mL
Flow (MGD) = full permitted flow
Conversion factor = 3.7854E+07 100 mL / MGD

In Segment 1209C there are three facilities that treat domestic wastewater, Carters Creek WWTF (TX0022616), Glen Oaks MHP WWTF (TX0085456), and Carter Lake WWTF (TX0098663). In Segment 1209C there is also one facility that has a discharge associated with cooling water blowdown, Texas A&M Central Utility (TX0002747). The combined loading from these facilities represent the WLA_{WWTF} allocation for 1209C. In Segment 1209L there is only one facility, Burton Creek WWTF (TX0022616), therefore loading from this facility represents the entire WLA_{WWTF} allocation in that segment. Segment 1209D has no facilities regulated for discharge to include in the WLA_{WWTF} term.

Storm water discharges from MS4, industrial, and construction areas are considered permitted point sources. Therefore, the WLA calculations must also include an allocation for permitted storm water discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of storm water loading. The percentage of each watershed that is under the jurisdiction of storm water permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted storm water contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from storm water runoff and the portion allocated to WLA_{SW}. Thus, WLA_{SW} is the sum of loads from regulated (or permitted) stormwater sources and is calculated as follows:

$$\Sigma WLA_{SW} = (TMDL - \Sigma WLA_{WWTF} – LA - \Sigma FG - MOS) * FDA_{SWP} \quad \text{(Eq. 4)}$$

Where:

ΣWLA_{SW} = sum of all permitted storm water loads
TMDL = total maximum allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
LA = load allocation, the amount of pollutant allowed by non-regulated or non-permitted sources
ΣFG = sum of future growth loads from potential permitted facilities
MOS = margin of safety load
FDA_{SWP} = fractional proportion of drainage area under jurisdiction of storm water permits

4.8.1.2 Load Allocation

The load allocation is the sum of loads from non-permitted sources. The load allocation is the sum of the tributary bacteria load (LA_{TL}) entering the segment and all remaining loads in the segment from non-permitted sources (LA_{SEG}):

$$LA = LA_{SEG} + LA_{TL} \quad \text{(Eq. 5)}$$

Where:

LA = allowable load from non-permitted sources (predominately nonpoint sources)
LA_{SEG} = allowable loads from non-permitted sources within the segment
ΣLA_{TL} = tributary load allocations entering the segment

The LA_{TL} is calculated as:

$$LA_{TL} = \text{Criterion} * Q_{Trib} \quad \text{(Eq 6)}$$

Where:

Criterion = 126 MPN/100 mL
Q_{Trib} = median value of the very high flow regime at the tributary inlet to an impaired segment.

The non-permitted loading within the segment (LA_{SEG}) is calculated as:

$$LA_{SEG} = TMDL - \Sigma WLA_{WWTF} - \Sigma WLA_{SW} - LA_{TL} - \Sigma FG - MOS \qquad \text{(Eq 7)}$$

Where:

LA_{SEG} = allowable load from non-permitted sources within the segment
TMDL = total maximum allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
ΣWLA_{SW} = sum of all permitted storm water loads
LA_{TL} = tributary load allocations entering the segment
ΣFG = sum of future growth loads from potential permitted facilities
MOS = margin of safety load

The TMDL equation can thus be expanded to show the components of WLA and LA:

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{SW} + LA_{SEG} + LA_{TL} + \Sigma FG + MOS \qquad \text{(Eq 8)}$$

4.8.1.3 Computation of Margin of Safety

The margin of safety is only applied to the allowable loading for a segment and is not applied to the tributary load allocations (LA_{TL}) that enters the segment as an external loading (i.e., originates outside the segment). Therefore the margin of safety is expressed mathematically as the following:

$$MOS = 0.05 * (TMDL - LA_{TL}) \qquad \text{(Eq 9)}$$

Where:

MOS = margin of safety load
TMDL = total maximum allowable load
LA_{TL} = tributary load allocations entering segment

4.8.1.4 Future Growth

The Future Growth component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

Currently four WWTFs that service the Bryan/College Station area discharge into either Burton Creek or Carters Creek. Since the area within the Country Club Branch watershed is serviced by the Burton Creek WWTF, future growth for Country Club Branch is addressed in the Burton Creek TMDL computations. To account for the probability that new flows from WWTF discharges may occur in Carters and Burton Creeks, a provision for future growth was included in the TMDL calculations based on an estimate of the population increase for the cities of College Station and Bryan from year

2010 estimates to year 2030 projections obtained from the Texas Water Development Board (TWDB, 2006). Assuming an even distribution of estimated and projected populations the percent increase calculated was directly applied to current discharge amounts for each WWTF. The discharge from the Texas A&M Central Utility plant was not included in the future growth estimate since population growth should not directly impact future discharges from this facility.

4.8.2 Segment-Level TMDL Calculations

Based on Equation 1 the allowable loading of *E. coli* that Segments1209D, 1209L and 1209C can receive on a daily basis was determined based on the median value within the very high flow regime of the FDC (or 5% flow exceedance value) for the outlet of each segment (Table 4-2). In a similar fashion, the tributary load allocations (LA_{TL}) entering the segment can be computed using Equation 6 and the median value of the very high flow regime (Table 4-2). For Segment 1209D, LA_{TL} was computed based on the allowable loading calculated at the outlet of the non-impaired upstream segment 1209B (Fin Feather Lake). For Segment 1209L, LA_{TL} is the allowable loading calculated for the outlet of upstream non-impaired Segment 1209A (Country Club Lake). The LA_{TL} for Segment 1209C is the allowable loading calculated at the outlet of upstream Segment 1209L (Table 4-7).

Table 4-2 Summary of TMDL and LA_{TL} calculations for Country Club Branch (Segment 1209D), Burton Creek (Segment 1209L), and Carters Creek (Segment 1209C)

Segment	Receiving Water	Tributary Allowable Loading		Downstream Allowable Loading	
		Q_{inlet}[a] (cms)	LA_{TL}[b] (MPN/100 mL)	Outlet Flow[c] (cms)	TMDL[d] (MPN/100 mL)
1209D	Country Club Branch	0.0817	8.890E+09	0.132	1.438E+10
1209L	Burton Creek	0.288	3.131E+10	1.8359	1.999E+11
1209C	Carters Creek	1.8359	1.999E+11	7.483	8.146E+11

[a] Inlet median value from very high flow regime
[b] Inlet allowable loading; median value from very high flow regime (Figure 4-5)
[c] Outlet median value from very high flow regime
[d] Outlet allowable loading; median value from very high flow regime (Figure 4-5)

4.8.2.1 Margin of Safety Computations

Using the values of LA_{TL} and TMDL for each segment provided in Table 4-2, the margin of safety may be readily computed by proper substitution into Equation 9 (Table 4-3).

Table 4-3 Computed margin of safety for Country Club Branch (1209D), Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C

Segment	MOS (MPN/day)
1209D	2.746E+08
1209L	8.428E+09
1209C	3.074E+10

4.8.2.2 Future Growth Computations

The following computations were performed to account for the possibility of future WWTF discharges within the watersheds of Burton and Carters Creeks in response to population growth and associated additional wastewater production. As previously mentioned, the Country Club Branch drainage area is serviced by the Burton Creek WWTF so the future growth allocations for this segment are included in the Burton Creek TMDL load allocations. First the combined average daily discharge from the four municipal WWTFs within Burton Creek and Carters Creek watersheds was estimated based on DMR records for the year 2008 through the most recent available record (Table 4-4). Second, the population estimate for year 2010 and projections for 2030 for the cities of Bryan and College Station was obtained from the TWDB. The population of the cities of Bryan and College Station was estimated to increase by 28.4% from 155,570 in 2010 to 199,712 in 2030. Next the current wastewater discharge based on DMR records was increased by 28.4% for each of the four WWTFs within the impaired watersheds. Finally the additional wastewater discharge (MGD) was converted to a loading (MPN/day) by using a slightly modified version of Equation 3 where the full permitted flow component of the equation was replaced by the estimated additional wastewater discharge (Table 4-5).

Table 4-4 Actual discharge from domestic WWTFs into Segments 1209L and 1209C

TPDES/NPDES Permit	Watershed	Facility Name	Actual avg. Flow (MGD)	Time Period
WQ0010426 TX0022616	Burton	Burton Creek WWTF	4.50	Jan 2008—May 2009
Total Discharge	**Burton**		**4.50**	
WQ0010024 TX0047163	Carters	Carter Creek WWTF	5.92	Jan 2008—Mar 2009
WQ0012296 TX0085456	Carters	Glen Oaks MHP WWTF	0.008	Jan 2008—May 2009
WQ0013153 TX0098663	Carters	Carter Lake WWTF	0.004	Jan 2008—Sep 2008
Total Discharge	**Carters**		**5.932**	

Table 4-5 Future Growth computations for Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C)

Segment	2010 Population Estimate (Bryan & College Station)	2030 Population Estimate (Bryan & College Station)	Population Increase 2010 to 2030	Current Wastewater Production (MGD)	Additional Wastewater Production (MGD)	Future Growth* (MPN/day)
1209L	155,570	199,712	28.4%	4.50	1.28	5.785E+09
1209C	155,570	199,712	28.4%	5.93	1.68	7.625E+09

* Future growth includes a reduction for MOS of 5%

4.8.2.3 Regulated Wastewater Treatment Facility Computations

The daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of the four WWTFs located in Segment1209C and the one WWTF located in Segment 1209L and was calculated using Equation 3 (Table 4-6).

4.8.2.4 Regulated Storm Water Computation

Based on the 2000 US Census urbanized area (Figure 4-6), 100% of the area of Segment 1209D is located within the jurisdiction of regulated by storm water permits. The area of Segment 1209L that is located within the jurisdiction regulated by storm water permits constitutes 98.8% of its area (total segment area of 1,411 ha of which 1,394 ha are under storm water permit regulation). The area of Segment 1209C that is located within the jurisdictional area regulated by storm water permits constitutes 51.0% of its area (total segment area of 13,240 ha of which 6,754 ha are under storm water permit regulation). Table 4-7 summarizes the computation of term WLA_{SW} as calculated using Equation 4.

Table 4-6 Waste load allocations for TPDES-permitted facilities

Segment	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
1209L	WQ0010426	TX0022616	Burton Creek WWTF	8.0	3.625E+10
Total				**8.0**	**3.625E+10**
1209C	WQ0010024	TX0047163	Carter Creek WWTF	9.5	4.305E+10
1209C	WQ0004002	TX0002747	Texas A&M Central Utility	0.93	4.214E+09
1209C	WQ0012296	TX0085456	Glen Oaks MHP WWTF	0.013	5.890E+07
1209C	WQ0013153	TX0098663	Carter Lake WWTF	0.0085	3.851E+07
Total				**10.4515**	**4.736E+10**

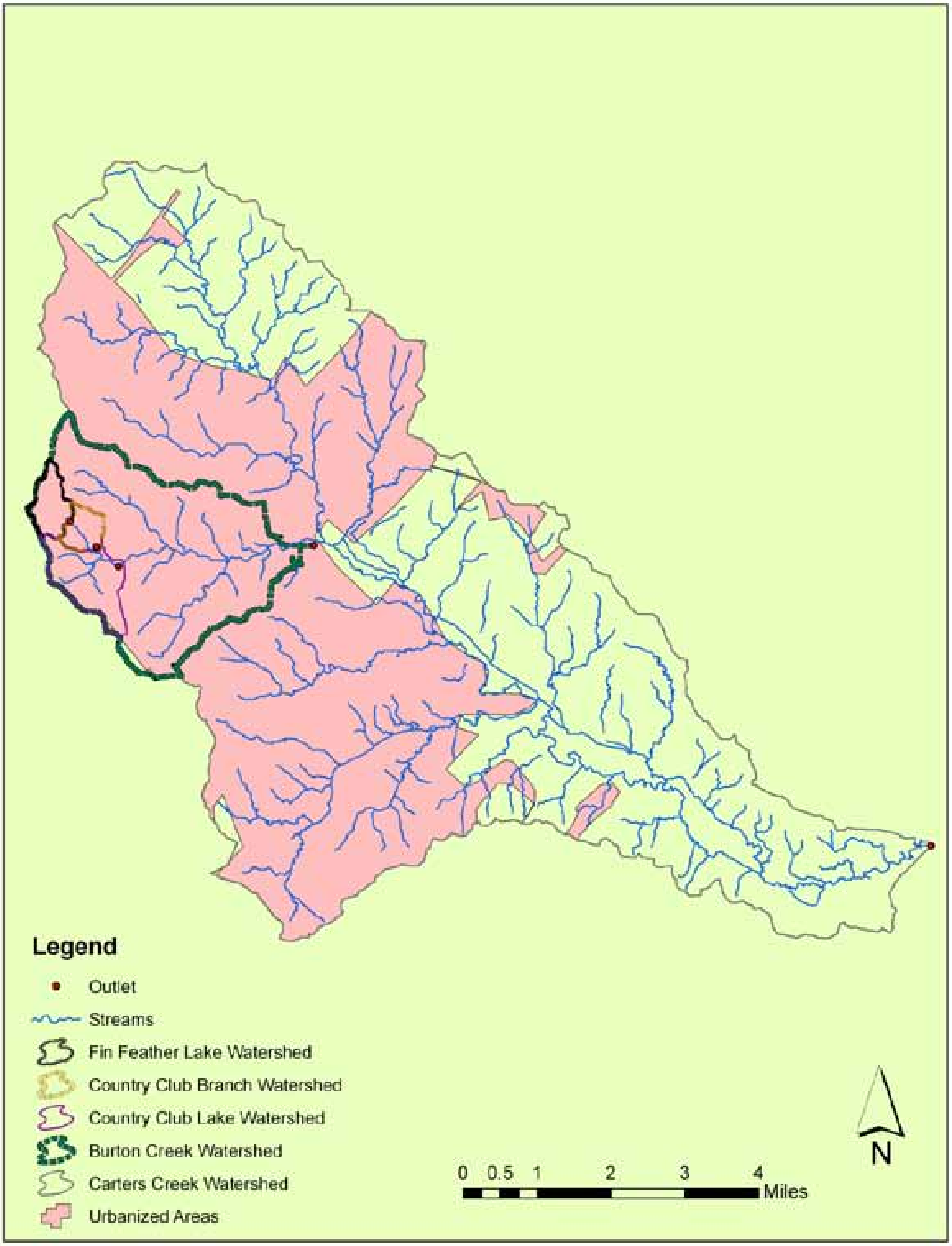

Figure 4-6 Urbanized Areas within the Carters Creek watershed (Source: 2000 Census)

Table 4-7 Regulated storm water computation for Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C)

Segment	TMDL (MPN/day)	WLA_{WWTF} (MPN/day)	Future Growth (MPN/day)	LA_{TL} (MPN/day)	MOS (MPN/day)	FDA_{SWP}	WLA_{SW} (MPN/day)
1209D_01	1.438E+10	0	0	8.890E+09	2.746E+08	1.000	5.217E+09
1209L_01	1.999E+11	3.625E+10	5.785E+09	3.131E+10	8.428E+09	0.988	1.167E+11
1209C_01	8.146E+11	4.736E+10	7.625E+09	1.999E+11	3.074E+10	0.510	2.698E+11

4.8.2.5 Non-Regulated Storm Water and Upstream Bacteria Load Computation

The LA_{SEG} is the allowable bacteria loading assigned to non-permitted sources within the Segment. The total segment area of Segment 1209D is regulated by storm water permits, therefore its LA_{SEG} is 0. For Segment 1209L, 17 ha or 1.2% of its drainage area is not regulated by storm water permits. For segment 1209C, 6,486 ha or 49.0% of its drainage area is not regulated by storm water permits. The LA_{SEG} for the impaired AUs was computed using Equation 7 (Table 4-8).

Table 4-8 Computed non-regulated storm water term for Country Club Branch (1209D), Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C)

Segment	LA_{SEG} (MPN/day)
1209D	0
1209L	1.409E+09
1209C	2.592E+11

4.9 Summary of TMDL Calculations

Table 4-9 summarizes the TMDL calculations for Segments 1209D, 1209L, and 1209C. The TMDL was calculated based on the median flow in the 0-10 percentile range (very high flow regime) for flow exceedance from the LDC developed for the outlet of each segment. Allocations are based on the current geometric mean criterion for *E. coli* in freshwater of 126 counts/100 mL for each component of the TMDL.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF} while allocations to permitted MS4 entities are designated as WLA_{sw} (Table 4-10). The LA component of the final TMDL allocations includes both tributary bacteria loadings (LA_{TL}) and loadings arising from within each segment from non-permitted sources (LA_{SEG}). In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix B provides guidance for recalculating the allocations in Table 4-9. Figures B-1, B-2 and B-3 of Appendix B were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for *E. coli*. The equations provided, along with Figures B-1, B-2, and B-3, allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*.

Table 4-9 TMDL allocation summary for Country Club Branch (Segment 1209D), Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C)

All loads expressed as MPN/day

Segment	Stream Name	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA_{SEG}	LA_{TL}	LA Total	Future Growth
1209D	Country Club Branch	1.438E+10	2.746E+08	0	5.217E+09	0	8.890E+09	8.890E+09	0
1209L	Burton Creek	1.999E+11	8.428E+09	3.625E+10	1.167E+11	1.409E+09	3.131E+10	3.272E+10	5.785E+09
1209C	Carters Creek	8.146E+11	3.074E+10	4.736E+10	2.698E+11	2.592E+11	1.999E+11	4.590E+11	7.625E+09

Table 4-10 Final TMDL allocations for Country Club Branch (Segment 1209D), Burton Creek (Segment 1209L) and Carters Creek (Segment 1209C)

All loads expressed as MPN/day

Segment (showing assessment unit)	TMDL	WLA_{WWTF}*	WLA_{SW}	LA	MOS
1209D_01	1.438E+10	0	5.217E+09	8.890E+09	2.746E+08
1209L_01	1.999E+11	4.203E+10	1.167E+11	3.272E+10	8.428E+09
1209C_01	8.146E+11	5.498E+10	2.698E+11	4.590E+11	3.074E+10

*WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities

SECTION 5
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APPENDIX A
BACTERIA DATA USED IN DEVELOPING LOAD DURATION CURVES

Table A-1 Measured *E. coli* concentration and estimated streamflow at station 11795, Country Club Branch, Segment 1209D.

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)
8/19/1997	2	0.0001
11/7/2001	548	0.0033
2/20/2002	60	0.0031
5/29/2002	1553	0.0349
11/4/2002	1413	1.1761
2/11/2003	461	0.0039
5/14/2003	2415	0.0003
8/27/2003	260	0.0019
11/5/2003	390	0.0036
12/8/2003	2400	0.0031
2/16/2005	54	0.0045

Table A-2 Measured *E. coli* concentration and estimated streamflow at station 11783, Burton Creek, Segment 1209L.

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
9/4/2001	2419	0.450	0.506
10/1/2001	132	0.473	0.529
11/5/2001	261	0.481	0.537
12/4/2001	197	0.465	0.521
1/3/2002	186	0.535	0.591
2/5/2002	2419	3.804	3.860
4/16/2002	187	0.418	0.474
5/14/2002	92	0.406	0.462
6/11/2002	364	0.405	0.461
8/27/2002	649	0.422	0.478
9/16/2002	44	0.437	0.493
10/9/2002	9677	0.922	0.978
12/9/2002	9677	3.397	3.453
1/28/2003	461	0.571	0.627
2/11/2003	445	0.539	0.595
3/3/2003	6212	1.451	1.507

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
4/2/2003	205	0.512	0.568
5/1/2003	600	0.453	0.509
6/4/2003	512	0.536	0.592
10/22/2003	205	0.477	0.533
5/6/2004	12	0.512	0.568
2/1/2005	2419	1.549	1.605
5/18/2005	70	0.475	0.531
8/2/2005	579	0.886	0.942
11/28/2005	8248	0.412	0.468
2/15/2006	210	0.425	0.481
5/2/2006	27	0.427	0.483
2/8/2007	210	0.599	0.655
5/22/2007	24000	1.847	1.903
8/7/2007	4600	0.416	0.472

*A constant future growth discharge of 1.277 MGD (0.056 cms) was added to estimated daily streamflow values for load duration curve development.

Table A-3 Measured *E. coli* concentration and estimated streamflow at station 11784, Carters Creek, Segment 1209C.

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
9/4/2001	2419	0.647	0.776
10/1/2001	344	0.891	1.021
11/5/2001	93	0.891	1.021
12/4/2001	816	0.806	0.936
1/3/2002	162	1.110	1.240
2/5/2002	2419	9.605	9.734
4/8/2002	2419	1.931	2.060
6/3/2002	488	0.479	0.609
7/1/2002	1046	2.595	2.725
9/16/2002	228	0.580	0.710
10/9/2002	1046	1.460	1.589

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
11/5/2002	2419	2.013	2.143
12/9/2002	2419	8.621	8.750
1/27/2003	770	1.318	1.447
2/10/2003	1414	1.151	1.280
3/3/2003	9677	3.063	3.193
4/2/2003	308	1.012	1.142
7/1/2003	326	0.511	0.640
8/26/2003	1203	0.558	0.687
11/13/2003	550	0.888	1.017
2/4/2004	195	1.819	1.948
5/12/2004	461	1.003	1.133
8/4/2004	151	0.778	0.907
11/22/2004	2419	39.404	39.534
2/3/2005	2419	1.117	1.246
6/2/2005	866	0.592	0.721
8/3/2005	980	0.491	0.620
11/29/2005	1006	0.487	0.617
2/15/2006	178	0.576	0.706
5/3/2006	34	0.656	0.786
2/8/2007	290	1.505	1.634
5/22/2007	24000	4.127	4.257
8/7/2007	920	0.643	0.773

*A constant future growth discharge of 2.959 MGD (0.130 cms) was added to estimated daily streamflow values for load duration curve development.

Table A-4 Measured *E. coli* concentration and estimated streamflow at station 11785, Carters Creek, Segment 1209C.

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
9/4/2001	2419	1.243	1.372
10/1/2001	272	1.781	1.910
11/5/2001	770	1.771	1.900
12/4/2001	613	1.598	1.727

Sample Date	*E. coli* (MPN/100 ml)	Estimated Daily Flow on Sampling Date (cms)	Estimated Daily Average Flow Including Allowance for Future Discharges (cms)*
1/3/2002	133	2.240	2.370
2/5/2002	1203	17.862	17.991
4/8/2002	9677	3.557	3.687
6/3/2002	355	0.933	1.063
7/1/2002	1954	4.698	4.828
9/16/2002	434	1.099	1.229
11/5/2002	5475	3.756	3.886
12/9/2002	6931	15.991	16.121
1/27/2003	2452	2.690	2.820
2/10/2003	960	2.342	2.472
3/3/2003	354	5.815	5.945
4/2/2003	315	2.060	2.190
7/1/2003	316	0.984	1.113
8/26/2003	757	1.071	1.201
11/13/2003	582	1.754	1.883
11/22/2004	2419	73.138	73.267
2/3/2005	2557	2.237	2.367
6/2/2005	924	1.180	1.309
8/3/2005	780	0.956	1.085
11/29/2005	1478	0.950	1.080
2/15/2006	307	1.104	1.234
5/3/2006	79	1.290	1.419
11/7/2006	630	1.924	2.053
2/8/2007	240	2.996	3.126
5/22/2007	24000	7.613	7.743
8/7/2007	490	1.258	1.387
10/25/2007	1000	0.965	1.095
1/24/2008	3100	1.841	1.970
4/1/2008	1600	2.107	2.237
7/23/2008	660	0.960	1.089
11/6/2008	2200	1.726	1.855
2/25/2009	600	0.949	1.079
5/12/2009	310	1.583	1.712
8/6/2009	520	0.951	1.081
11/4/2009	320	1.752	1.881
2/4/2010	1200	5.664	5.794
5/10/2010	330	1.460	1.589

Sample Date	***E. coli*** **(MPN/100 ml)**	**Estimated Daily Flow on Sampling Date (cms)**	**Estimated Daily Average Flow Including Allowance for Future Discharges (cms)***
8/17/2010	440	0.946	1.076
11/4/2010	550	1.042	1.171

*A constant future growth discharge of 2.959 MGD (0.130 cms) was added to estimated daily streamflow values for load duration curve development.

APPENDIX B
EQUATIONS FOR CALCULATING TMDL ALLOCATIONS FOR CHANGED CONTACT RECREATION STANDARD

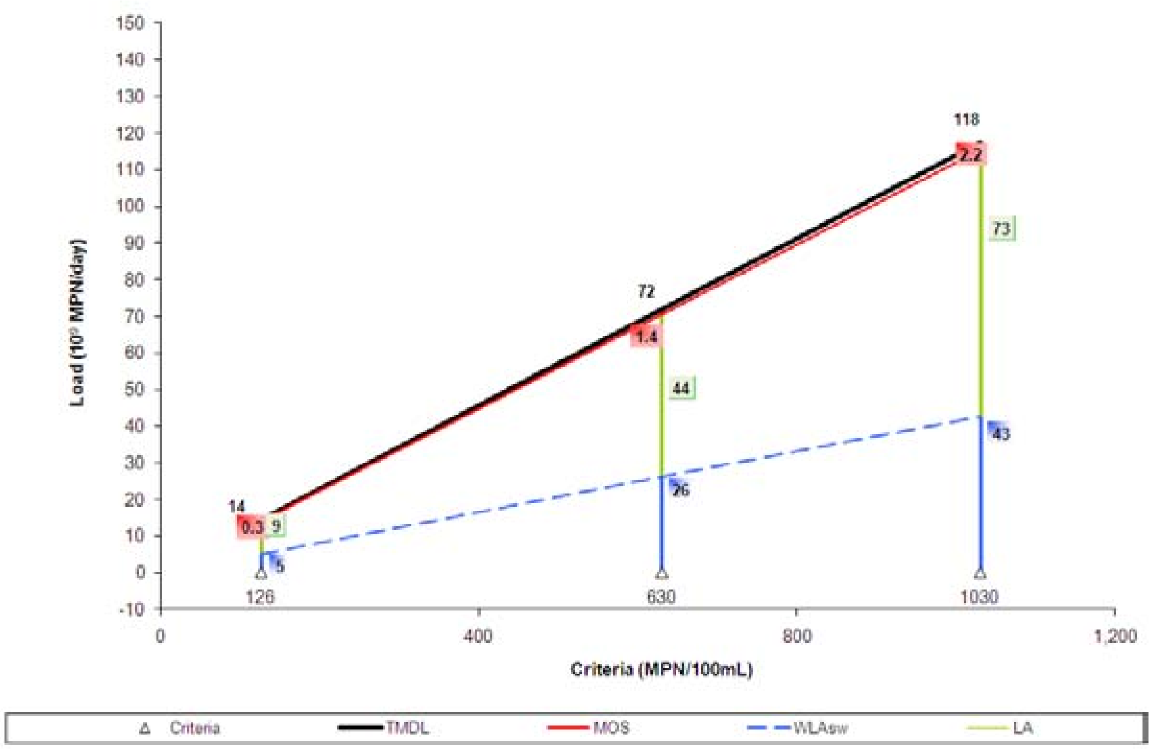

Figure B-1. Allocation loads for Segment 1209D as a function of water quality criteria

Equations for calculating new TMDL and allocations (in 10^9 MPN/day)

TMDL = 0.11413 * Std
WLA_{WWTF} = 0
WLA_{sw} = 0.04140 * Std
LA = 0.07055 * Std
MOS = 0.002179 * Std

Where:
Std = Revised Contact Recreation Standard

WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted storm water)
LA = Total load allocation (non-permitted source contributions)
MOS = Margin of Safety

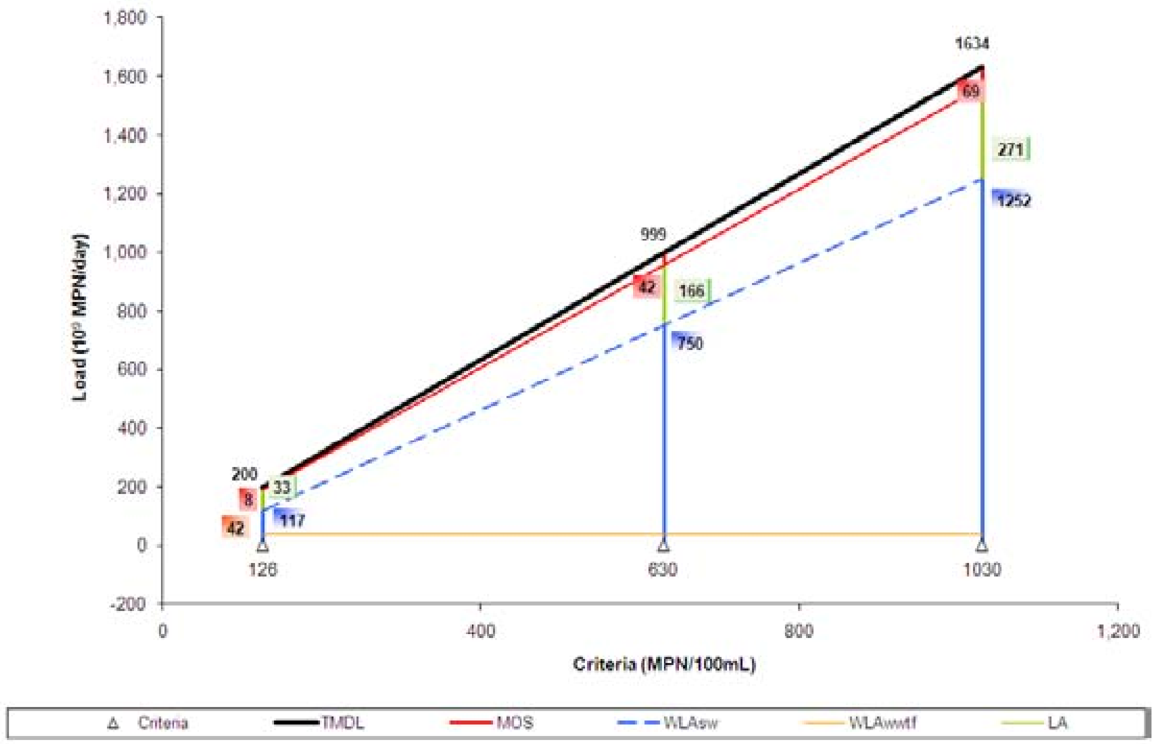

Figure B-2. Allocation loads for Segment 1209L as a function of water quality criteria

Equations for calculating new TMDL and allocations (in 10^9 MPN/day)

TMDL = 1.58624 * Std
WLA_{WWTF} = 42.03
WLA_{sw} = 1.25571 * Std – 41.53227
LA = 0.26364 * Std – 0.50134
MOS = 0.06689 * Std

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted storm water)
LA = Total load allocation (non-permitted source contributions)
MOS = Margin of Safety

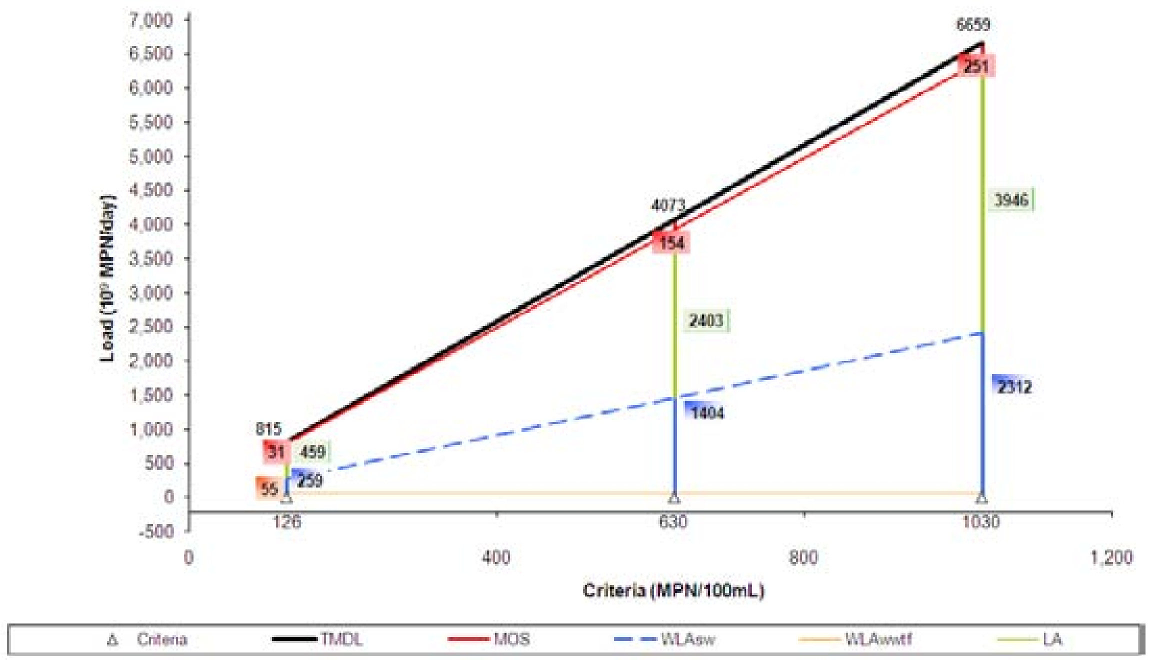

Figure B-3. Allocation loads for Segment1209C as a function of water quality criteria

Equations for calculating new TMDL and allocations (in 10^9 MPN/day)

TMDL = 6.4650 * Std
WLA_{WWTF} = 54.98
WLA_{sw} = 2.3642 * Std – 28.046
LA = 3.8569 * Std – 26.9359
MOS = 0.2440 * Std

Where:

Std = Revised Contact Recreation Standard
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted storm water)
LA = Total load allocation (non-permitted source contributions)
MOS = Margin of Safety