FINAL MODELING REPORT FOR FECAL COLIFORM TMDL (TOTAL MAXIMUM DAILY LOAD) DEVELOPMENT FOR LEON RIVER BELOW PROCTOR LAKE, SEGMENT 1221

PROJECT AREA 2 - BASIN GROUPS D & E BACTERIA IMPAIRMENTS
WORK ORDER #5

Prepared For:

TMDL Unit
Texas Commission on Environmental Quality
Post Office Box 13087 MC 203
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November 2006

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2 November 2006

Mr. Kerry Niemann, Project Manager
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RE: Final Report, Modeling Report for Fecal Coliform TMDL Development for Leon River, Segment 1221
Project Area 2 - Basin Groups D & E Bacteria Impairments
Contract No. 582-2-44841
Work Order No.5 (582-2-44841-05)

Dear Mr. Niemann:

We are submitting a final modeling report for the Leon River TMDL for the subject project. We are providing two bound paper copies and a digital copy. The report describes bacteria modeling activities, including model setup, calibration, and allocations for Segment 1221, Leon River. The final report contains revisions pursuant to comments by TCEQ that were provided via letter dated 22 September 2006. A tabulation of comments and responses is also provided.

This report represents a final deliverable under Task 3.5 of Work Order 5.

If you have any questions, please do not hesitate to call me at (512) 327-2708.

Yours truly,

JAMES MIERTSCHIN & ASSOCIATES, INC.

James Miertschin, PE, PhD

TX021106.WPD

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1.0 INTRODUCTION

1.1 BACKGROUND

Section 303(d) of the Federal Clean Water Act and U.S. Environmental Protection Agency (EPA) regulation 40 CFR 130.7 require states to identify waterbodies that do not meet, or are not expected to meet, applicable water quality standards. The compilation of subject waterbodies is known as the 303(d) list. Each state must assign priorities to waterbodies on the list, in order to schedule development of total maximum daily loads (TMDL). The TMDL is an allocation of point and nonpoint source pollutant loadings that will enable the waterbody to meet water quality standards.

The Texas Commission on Environmental Quality (TCEQ), formerly Texas Natural Resource Conservation Commission (TNRCC), is responsible for the monitoring and assessment of water quality to evaluate compliance with State water quality standards. Pursuant to the Clean Water Act, one of the areas of TCEQ responsibility is the development of the 303(d) list for Texas and subsequent development of TMDLs.

Leon River, Segment 1221, was included on the Texas 303(d) list for the year 2000 developed by the TCEQ (TNRCC, 2000a). The Leon River was listed for elevated levels of bacterial indicators for pathogens and nonsupport of contact recreation use.

The TCEQ has retained James Miertschin & Associates, Inc. (JMA) to provide support for data analysis, mathematical modeling of water quality, TMDL development, and report preparation. Previous work efforts involved the compilation and assessment of historical water quality data for bacterial indicators on the study segments, followed by the development of monitoring plans for supplemental data collection, and execution of supplemental data collection activities.

1.2 GENERAL TMDL APPROACH

The essence of a TMDL has been described by the EPA as follows (Perciasepe, 1997):

> States identify specific waters where problems exist or are expected; States set priorities; States allocate pollutant loadings among point and nonpoint sources; and EPA approves State actions or acts in lieu of the State if necessary. Point and nonpoint sources then reduce pollutants to achieve the pollutant loadings established by the TMDL through a wide variety of Federal, State, Tribal, and local authorities, programs, and initiatives.

EPA has required States to develop an appropriate schedule for establishment of TMDLs for all waters on the most recent 303(d) list, beginning with the 1998 list. Subsequent to the establishment of TMDLs for a waterbody, it is the implementation of the prescribed pollutant loading allocations that will actually accomplish improvement in water quality. The potential ramifications of establishment of a TMDL are significant for both point and nonpoint sources. Permit effluent limits for point sources must be consistent with the TMDL load allocation. Implementation of load allocations for nonpoint sources may involve individual landowners or public and private entities. Examples offered for implementation of nonpoint load allocations include incentive-based

approaches and local regulations or ordinances related to zoning, land use, and storm water runoff (Perciasepe, 1997).

The EPA Region 6 office has prepared guidance for the conduct of a TMDL study (EPA, 1997). The general approach involves definition of the problem, identification of contributing pollutant sources, and allocation of loadings from the sources. The approach incorporates eight elements, as described below:

1. Problem definition: Pollutant of concern, pollutant sources, waterbody characteristics, and applicable water quality standards are identified.

2. Endpoint identification: The desired endpoint or measurable goal is identified.

3. Source analysis: The type, magnitude, and location of sources of pollutant loading are determined.

4. Linkage between sources and receiving water: The cause and effect linkage between the pollutant source and the endpoint is analyzed over an appropriate range of conditions, and the assimilative capacity of the waterbody is determined. Monitoring and water quality modeling are used to establish the linkage.

5. Margin of Safety: A margin of safety is incorporated into the analysis to account for uncertainty. This can take the form of conservative modeling assumptions or specification of a supplemental loading.

6. Loading allocation: Recommendations for loading allocations to all known or suspected point and nonpoint sources are developed.

7. Public Participation.

8. Implementation and Reasonable Assurances.

For TMDLs in Texas, the TCEQ will have the initial approval authority. The TCEQ developed guidance for TMDLs that incorporates the key elements from EPA guidance (TNRCC, 1999). The TCEQ's outline includes the following steps for TMDL development:

1. Water quality target identification: apply existing numeric water quality criterion from Texas Surface Water Quality Standards; develop additional targets; or, modify existing designated uses or water quality criteria.

2. Assess current watershed and water quality conditions: use available data or collect additional data.

3. Analyze pollutant sources (point, non-point, background, atmospheric): identify the location and types of sources; pollutant load from each source.

4. Allocate pollutant loads: allocate to point, non-point, and natural background sources; include margin of safety.

The present study was conducted to conform to both EPA and TCEQ guidance regarding the content of the TMDL study.

1.3 OBJECTIVES

The objectives of the present study address key tasks of the TMDL development project for the Leon River. Specific objectives include the following:

a) Development of a water quality model for simulation of bacteria in the study segment;

b) Development of loading allocations for achievement of water quality objectives and definition of the TMDL.

The scope of the present study was based upon application of the Hydrologic Simulation Program - Fortran (HSPF) model for simulation of the watershed and receiving stream. In preparation for the modeling analysis, field data collection was conducted to obtain site-specific water quality and hydrographic data. Historical flow and water quality data were also employed in the study. The available databases were used for calibration of the models, and the models were applied for a determination of loading allocation.

1.4 DESIGNATED USES AND APPLICABLE WATER QUALITY STANDARDS

1.4.1 Applicable Criteria

The most recent Texas Surface Water Quality Standards include criteria for *E. coli* and fecal coliform bacteria for each classified stream segment in the State (TNRCC, 2000b). The preferred indicator for freshwater is *E. coli*, but fecal coliform can still be used as an alternative indicator during the transition period to the new indicator. For saltwater, the new indicator is Enterococci bacteria. These bacteria all serve as indicators of the potential presence of pathogenic organisms. Classified segments are designated as either contact recreation or non-contact recreation waters.

For contact recreation waters, the *E. coli* counts should not exceed 126 colonies/100 mL, or, alternately, the fecal coliform content should not exceed 200 colonies per 100 mL, both expressed as geometric means. In addition, the *E. coli* content should not equal or exceed 394 colonies/100 mL, or, alternately, the fecal coliform content should not equal or exceed 400 colonies per 100 mL, in a single sample.

For non-contact recreation waters, the *E. coli* content should not exceed 605 colonies/100 mL, or, the fecal coliform content should not exceed 2,000 colonies per 100 mL, expressed as a geometric mean. In addition, the fecal coliform content should not equal or exceed 4,000 colonies per 100 mL in a single sample.

1.4.2 Assessment Guidance

The TCEQ has published guidance for assessment of impairment based upon bacterial indicators. The most recent TCEQ assessment methodology is described in the document "Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data, 2002" (TNRCC, 2001). This guidance document was based upon use of the Texas Surface Water Quality Standards that were adopted by the TNRCC in July 2000, but have not yet been approved by the US EPA. This latest methodology was used in the development of the draft 2002 305(b) list. In a previous phase of study, the JMA project team conducted an assessment of historical data based upon application of this most recent guidance, as directed by the TCEQ TMDL program (JMA and PES, 2002a, 2002b).

Exceedances for Partial Support and Non-support of Uses

The TCEQ has devised a procedure based upon the binomial method to estimate the probability of committing Type I and Type II classification errors for support of uses. With this method, the minimum number of required exceedances has been calculated for different sample sizes to determine if uses are fully supported, partially supported, or not supported. For contact recreation use evaluation, there is no designation of partial support. There are only classifications of fully supporting or not supporting. For example, with a sample size of 10 samples, 5 exceedances are required to classify a segment as not supporting, using the binomial method. The number of exceedances varies with sample size, as described in tabular form in the guidance document.

There are also exceedance requirements established to determine if there are "primary concerns." These concerns are also based upon the binomial method. Primary concerns are further subdivided into "Tier 1 concerns" and "Tier 2 concerns". Tier 1 concerns are defined for sample sizes of 4-9, while Tier 2 concerns are defined for sample sizes of 10 or greater. For example, with a sample size of 7 samples, three exceedances are required for a Tier 1 concern. With a sample size of 10 samples, three exceedances are required for a Tier 2 concern. The number of exceedances varies with sample size, as described in tabular form in the guidance document.

Flow Conditions

Samples in freshwater streams should be collected when stream flow is equal to or greater than the seven-day, two-year low flow (7Q2) condition. The data may include samples collected under high-flow runoff conditions.

The TCEQ has also developed guidance for appropriate flow conditions in small unclassified streams. For perennial streams, the contact recreation use is evaluated using data collected when the flow is equal to or greater than the 7Q2 flow or 0.1 cfs. For intermittent streams and intermittent streams with perennial pools, the bacterial indicator criteria apply at all times.

Assessment for Use Support

Contact recreation use support is evaluated based upon analysis of fecal coliform, *E. coli* (in freshwater), or Enterococci (in tidal waters) data. The typical available data base consists of samples collected at routine biannual, quarterly, or monthly frequencies. For this type of routine

data, assessment screening levels for single samples are set as 400 colonies/100 mL for fecal coliform, 394 colonies/100 mL for *E. coli*, and 89 colonies/100 mL for Enterococci. Geometric means are also included in the assessment protocol as follows: fecal coliform 200 colonies/100 mL, *E. coli* 126 colonies/100 mL, and Enterococci 35 colonies/100 mL. According to the TCEQ guidance document, the preferred indicator is *E. coli* in freshwater, and data for this indicator should be used when data for fecal coliform is also available.

For 10 or more samples, support of the contact recreation use is defined as "fully supporting" where the geometric mean is less than the criterion and 25% of the time, or less, concentrations exceed the single sample criterion at a frequency commensurate with the binomial method. The assessment is defined as "not supporting" where the geometric average exceeds the criterion or greater than 25% of all samples collected exceed the single sample criterion, with the required number of exceedances described by the binomial method. A "primary concern" can also be identified for the bacterial indicator data. A "Tier 2 primary concern" is designated where greater than 25% of all samples exceed the single sample criterion, at a frequency in accordance with the binomial method.

Procedures are modified for data sets of 4 to 9 samples. The contact recreation use is not assessed as either "fully supporting" or "not supporting" for small sample sets. However, a "Tier 1 primary concern" is assigned where the long-term geometric mean exceeds the criterion, or, greater than 25% of the time, concentrations exceed the single sample criterion at a frequency determined by the binomial method.

1.5 FECAL COLIFORM BACTERIA MONITORING AND ASSESSMENT

Historical water quality data was available at several monitoring stations on the Leon River. Historical data were available for both *E. coli* and fecal coliform indicator bacteria.

A prior study described assessment of water quality conditions in the waterbody identified in the preceding section, based upon application of available water quality data from a five-year period (JMA and PES, 2002a, 2002b). The available data (1996-2001) for bacterial indicators was analyzed using TCEQ Year 2002 guidance methodology.

Results for the assessment of the bacteria data are summarized in the following table. The data were assessed with respect to support of the contact recreation use.

WATERBODY	STATUS
Leon River below Proctor Lake, Segment 1221	"not supporting" based on fecal coliform for portions of segment

In this context, "not supporting" denotes that the water quality data indicates exceedance of applicable criteria and therefore the contact recreation use is not supported. Leon River below Proctor Lake, Segment 1221, was assessed based upon fecal coliform data and found to be "not supporting".

2.0 WATERSHED CHARACTERIZATION

2.1 WATERSHED BOUNDARIES

The Leon River Basin above Belton Lake, covering 2,675 square miles (1,712,000 acres), is located in the central portion of Texas, as shown in Figure 2-1. The Leon River flows through Proctor Lake in the northern part of the watershed and empties into Belton Lake to the south. The Leon River is located within the Brazos River basin. This study addresses Segment 1221 of the Leon River watershed, which extends from the dam at Proctor Lake to a point 100 meters upstream of FM 236 above Belton Lake. This watershed encompasses 1,375 square miles (880,000 acres). There are several mid-size towns located within the study area. These include Dublin, Comanche, Gustine, Hamilton, Gatesville, and Oglesby. The largest municipality located within the watershed is Gatesville with a population of 15,732 (US Census, 2000). The Leon River study watershed encompasses portions of Comanche, Hamilton, Mills, Erath, and Coryell Counties.

2.2 STREAM NETWORK

The Leon River originates in Eastland County and flows southeast finally ending at the confluence with the Lampasas River below Belton Lake. The Leon River drops in elevation from its headwaters by approximately 700 feet. The entire Leon watershed has 7 classified segments and 6 unclassified segments according to the TCEQ. The study segment (#1221) includes the portion of the river between Proctor and Belton Lakes. Within the study area, major tributaries include Walnut Creek, the South Leon River, Resley Creek, and Plum Creek.

2.3 TOPOGRAPHY

The topography of these watersheds is a combination of flat and hilly terrain. The elevations range from approximately 650 to 1500 feet above mean sea level. The watershed is dominated by two major land-resource areas: the Western Cross Timbers region and the Grand Prairie region. The Western Cross Timbers region is located in the northern part of the watershed. It is characterized by light sand and loamy soils that support mixed timber of cedars, oaks, mesquites, walnuts, ashes, and pecans. This region has a hilly, rolling terrain. The southern part of the watershed is in the Grand Prairie region. This region has rolling prairies marked by numerous flat-topped buttes that rise abruptly to stand on the divides between the streams. The region has dark waxy and dark loam soils, mostly alkaline, with limestone underneath. Indigenous trees include red cedar, live oak, Spanish oak, burr oak, shin oak, cedar elm, hackberry, pecan, redbud, Mexican plum, buckeye, ash, and Eve's necklace; native grasses include bluestems, gramas, and buffalo grass.

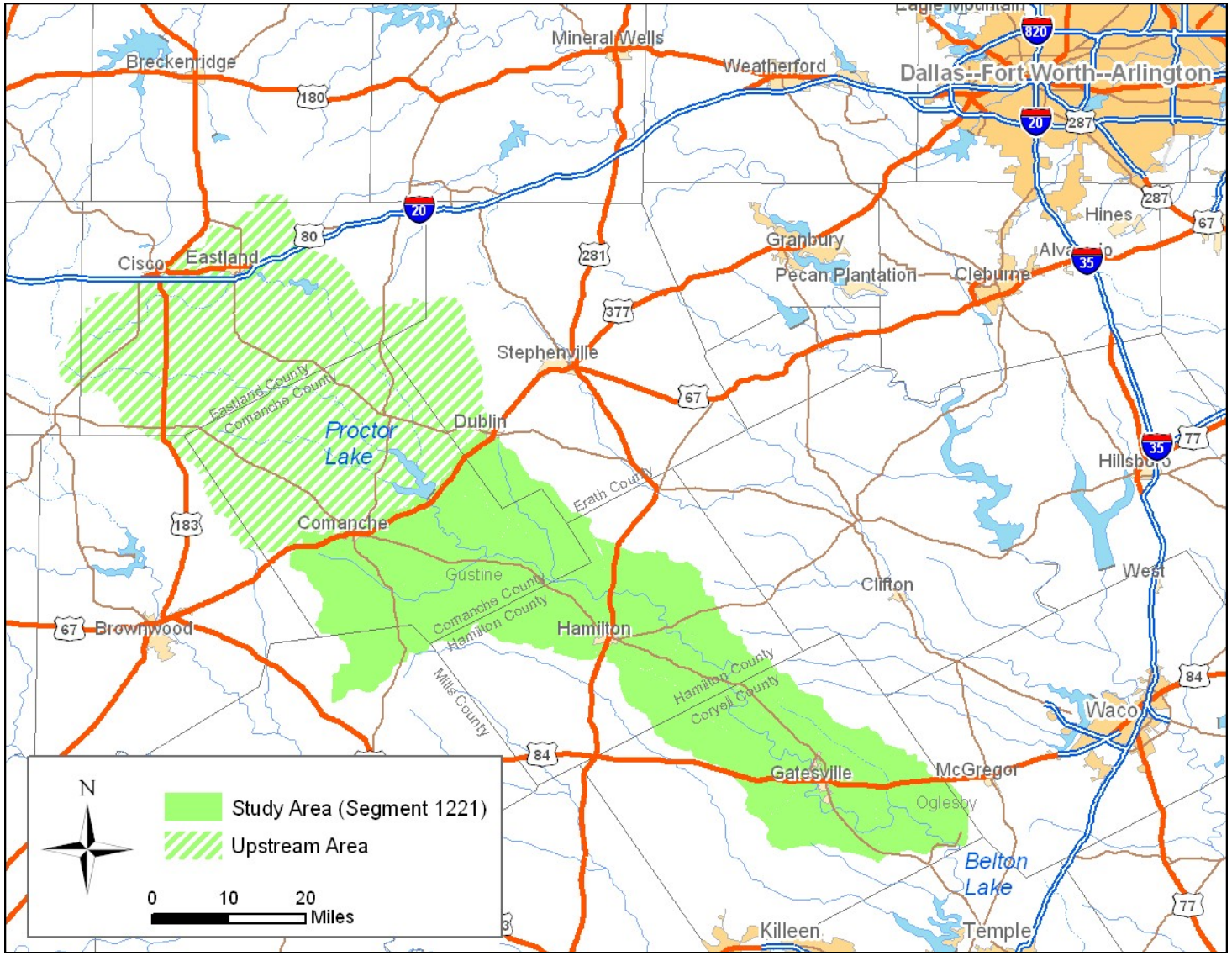

Figure 2-1 Leon River Basin above Belton Lake

2.4 CLIMATE

The study area is located primarily within the North Central Texas climatic division. The climate of the region is classified as subtropical subhumid. Summers are usually hot and humid, while winters are often mild and dry. The hot weather is rather persistent from late May through September, accompanied by prevailing southeasterly winds. There is little change in the day-to-day summer weather except for the occasional thunderstorm, which produces much of the annual precipitation within the region. The cool season, beginning about the first of November and extending through March, is typically the driest season of the year as well. Winters are typically short and mild, with most of the precipitation falling as drizzle or light rain. Although mean annual temperatures are basically uniform throughout the region, there are some marked seasonal variations, which lead to widely varied values for annual net lake surface evaporation.

As with the rest of the interior of the State, maximum precipitation periods in the study area are typically late spring (May) and early autumn (September). Winter and summer periods are typically low precipitation periods. The maximum precipitation period in May is driven by the buildup of water vapor from the Gulf of Mexico from the prevailing winds from the south. Precipitation is caused by late season cold air migrations, warm season thunderstorms, and spring low pressure troughs. In September, cold air converges with moisture-laden southerly winds and late season convective thunderstorms drive the precipitation. It is also not unusual for hurricanes to effect rainfall in the early autumn period. Summer drought conditions are common in the study area, due to strong high pressure cells that result in lengthy dry spells.

Mean annual precipitation in the watershed ranges from 27 to 32 inches per year. Topography has a strong influence on rainfall throughout the state. When a moisture-laden prevailing wind encounters a mountain range or fault zone, rainfall would be expected to increase when the air is cooled as it rises up the slope. As the air cools, its ability to hold moisture is reduced, clouds are formed as the water vapor condenses, and continued cooling with movement upward results in rainfall.

Precipitation data employed in the present study were obtained from the National Weather Service. Records of daily rainfall for the National Weather Service co-op stations in Dublin, Hamilton, and Hurst Springs and records of hourly rainfall for the NWS co-op stations in Flat and Proctor were the primary source of data for modeling. The daily rainfall stations were disaggregated using the hourly rainfall data from either the Flat or Proctor stations.

2.5 LAND USE

The land use in the Leon River watershed is dominated by farms and ranches located on forested and rangeland areas. There are also some concentrated animal feeding operations located within the watershed. Land use data for the watersheds were based on the United States Geological Survey National Land Cover Dataset (USGS NLCD). Derived from the early to mid-1990s Landsat Thematic Mapper satellite data, the NLCD is a 21-class land cover classification scheme applied consistently over the United States. The spatial resolution of the data is 30 meters and mapped in the Albers Conic Equal Area projection, NAD 83.

3.0 TMDL ENDPOINT AND WATER QUALITY SUMMARY

3.1 ENDPOINT DETERMINATION FOR BACTERIA

The Leon River, Segment 1221, was listed as impaired due to *E. coli* or fecal coliform bacteria on the Texas 2000 303(d) list of impaired waters, based upon monitoring conducted from October 1996 to November 2001. Elevated levels of *E. coli* and fecal coliform bacteria were documented at several water quality monitoring stations on the Leon River during the assessment time period. It was determined, as a result, that the Leon River did not support the contact recreation use designation.

TMDL development requires the identification of a numeric endpoint that will allow for the attainment of designated uses and water quality criteria. Instream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementation of load reductions specified in the TMDL. For the Leon River TMDL, the applicable endpoint can be determined directly from the Texas surface water quality standards. The current water quality standards specify criteria for dual indicator bacteria. For fecal coliform bacteria, the criteria include a geometric mean concentration of 200 org/100 mL, with a single grab sample limitation of 400 org/100 mL to support the contact recreation use designation. For *E. coli* bacteria, the criteria specify a geometric mean concentration of 126 org/100 mL, with a single grab sample limitation of 394 org/100 mL.

The geometric mean for fecal coliform bacteria was employed as the principal endpoint for the present TMDL determination. Application of the geometric mean is facilitated because of the availability of continuous simulation modeling results for mean daily bacteria concentrations. Fecal coliform was selected as the principal constituent for the analysis, since most of the available literature regarding sources is based upon fecal coliform, rather than *E. coli*. However, the final allocation will also be assessed with respect to *E. coli*.

3.2 MONITORING STATIONS

Fecal coliform and *E. coli* bacteria data have been collected by various entities, including the BRA and TCEQ, at several monitoring stations on the Leon River. Supplemental data were collected in 2003 and 2004 in conjunction with the present study. Monitoring site locations for the Leon River are shown in Figures 3-1(a) and 3-1(b). Fecal coliform data collected on the Leon River are summarized in Table 3-1, while the *E. coli* data are summarized in Table 3-2.

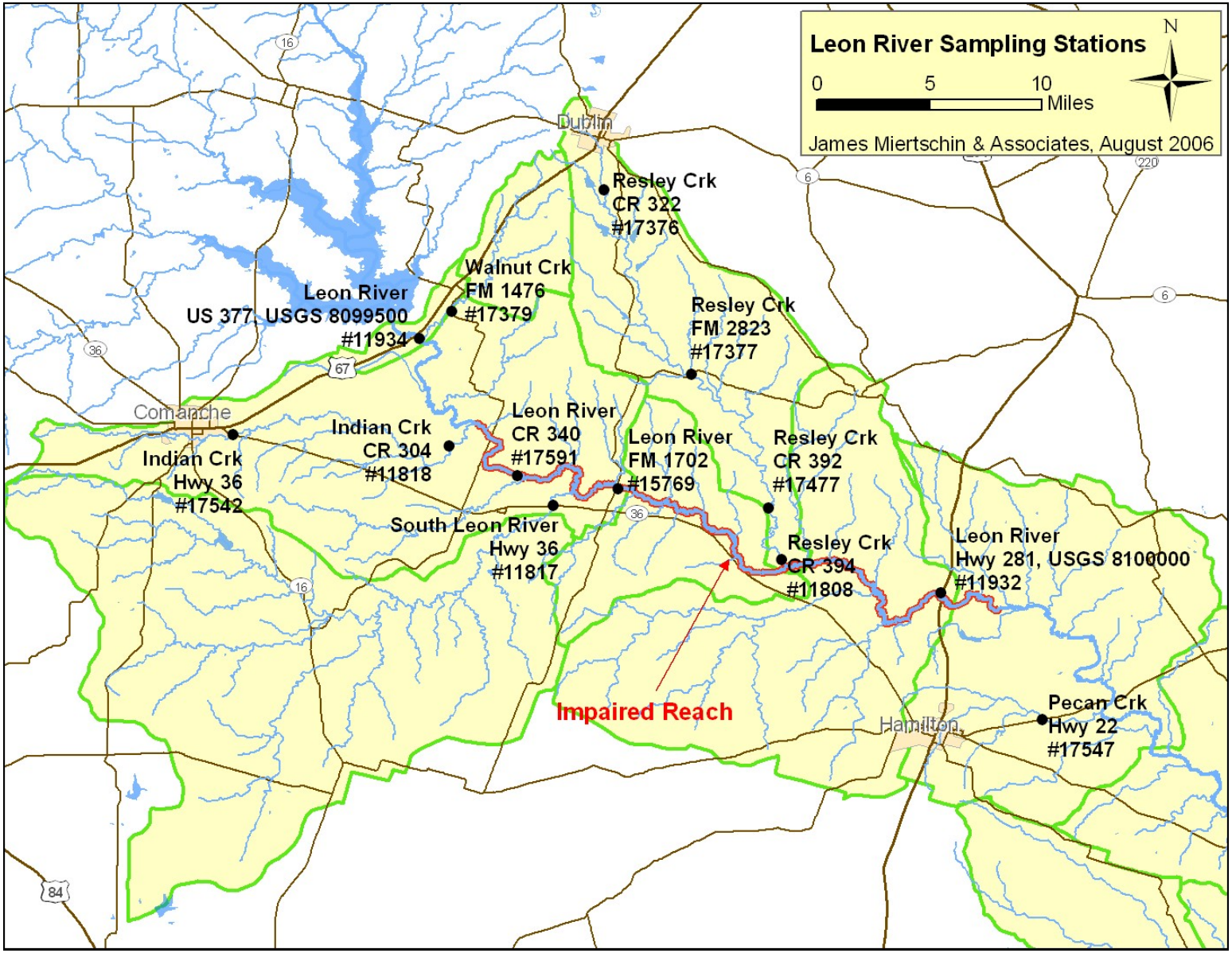

Figure 3-1(a) Leon River Sampling Stations

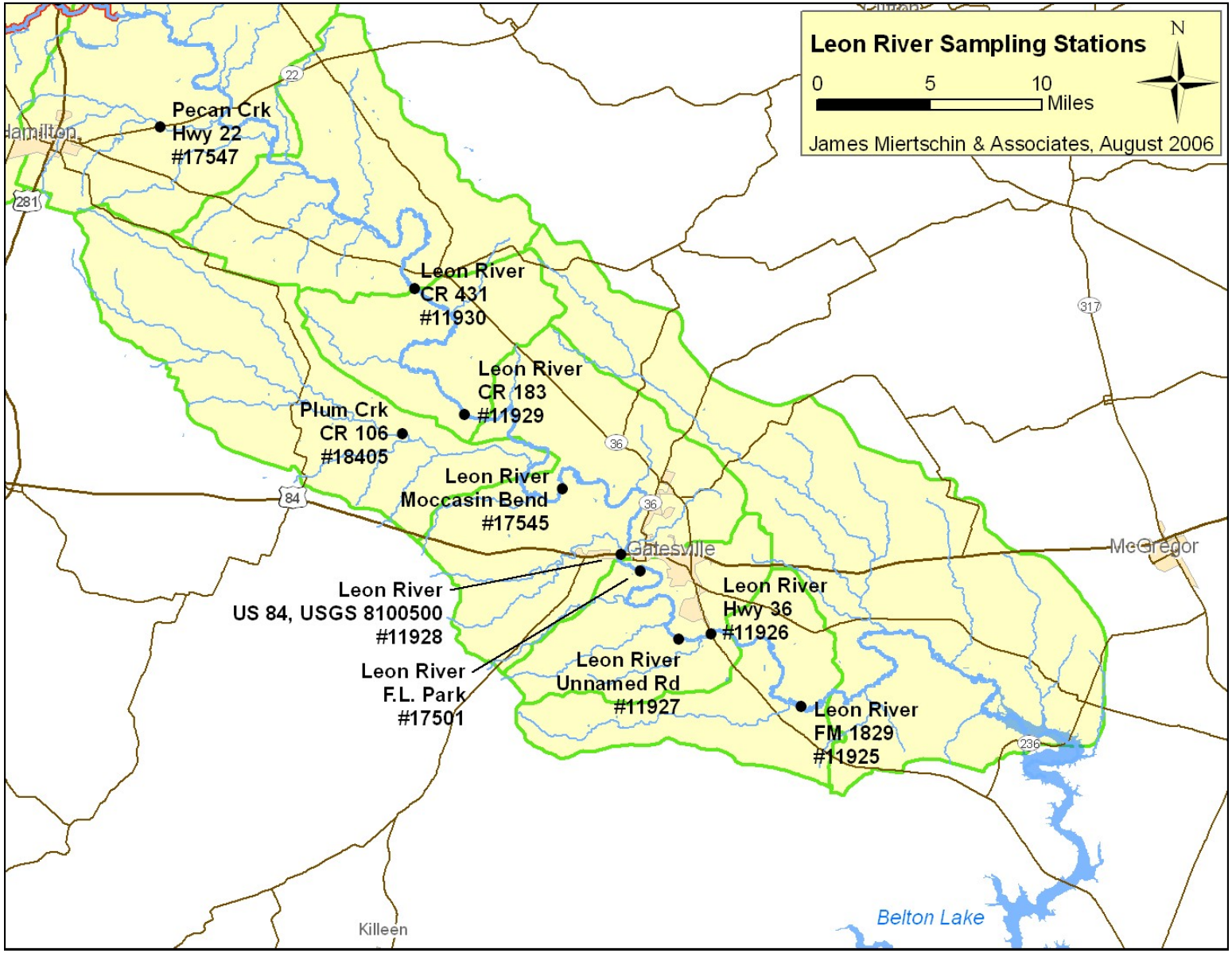

Figure 3-1(b) Leon River Sampling Stations

Table 3-1 Fecal Coliform Data Collected on Leon River, 1996-2004

Station	Stream	Location	Fecal Coliform		
			No. of Samples	No. of Exceedances	Geomean (org/100mL)
11934	Leon River	US 377	74	11	166
17379	Walnut Crk	FM 1476	29	11	411
17542	Indian Crk	Hwy 36	14	2	190
11818	Indian Crk	CR 304	15	7	497
17591	Leon River	CR 340	14	6	359
11817	South Leon River	Hwy 36	58	9	104
15769	Leon River	FM 1702	37	14	319
17376	Resley Crk	CR 322	30	14	370
17377	Resley Crk	FM 2823	31	6	162
17477	Resley Crk	CR 392	6	2	106
11808	Resley Crk	CR 394	32	13	276
11932	Leon River	US 281	48	12	207
17547	Pecan Crk	Hwy 22	14	3	127
11930	Leon River	CR 431	19	2	194
11929	Leon River	CR 183	-	-	-
18405	Plum Crk	CR 106	-	-	-
17545	Leon River	Moccasin Bend	12	1	75
11928	Leon River	US 84	-	-	-
17501	Leon River	F.L. Park	-	-	-
11927	Leon River	Unnamed Rd	23	5	177
11926	Leon River	Hwy 36	42	9	140
11925	Leon River	FM 1829	14	3	115

Table 3-2 E. *Coli* Data Collected on Leon River, 1996-2004

Station	Stream	Location	*E. coli*		
			No. of Samples	No. of Exceedances	Geomean (org/100mL)
11934	Leon River	US 377	27	4	150
17379	Walnut Crk	FM 1476	38	23	580
17542	Indian Crk	Hwy 36	15	4	197
11818	Indian Crk	CR 304	21	18	760
17591	Leon River	CR 340	18	9	383
11817	South Leon River	Hwy 36	41	14	265
15769	Leon River	FM 1702	32	16	538
17376	Resley Crk	CR 322	26	13	480
17377	Resley Crk	FM 2823	49	7	149
17477	Resley Crk	CR 392	13	3	101
11808	Resley Crk	CR 394	35	15	341
11932	Leon River	US 281	39	10	186
17547	Pecan Crk	Hwy 22	17	4	142
11930	Leon River	CR 431	3	0	168
11929	Leon River	CR 183	12	6	480
18405	Plum Crk	CR 106	13	2	81
17545	Leon River	Moccasin Bend	16	5	112
11928	Leon River	US 84	4	1	417
17501	Leon River	F.L. Park	42	5	122
11927	Leon River	Unnamed Rd	4	1	256
11926	Leon River	Hwy 36	2	0	108
11925	Leon River	FM 1829	30	9	236

3.3 WATER QUALITY SUMMARY

To summarize the water quality on the Leon River, four stations were selected for presentation in this section of the report to illustrate typical conditions. Fecal coliform and *E.coli* bacteria monitoring data for Leon River St. 11934 at US 67-377 for the period 1996-2004 are displayed in Figure 3-2. Figure 3-3 shows the bacteria monitoring data for St. 15769 at FM 1702. Figure 3-4 shows the bacteria monitoring data for St. 11932 at US 281. Figure 3-5 shows the bacteria monitoring data for St. 11926 at SH 36. Data analysis in a previous study showed no apparent seasonal trends or correlation with flow (JMA and PES, 2002b). It was observed, however, that higher counts are typically associated with runoff conditions.

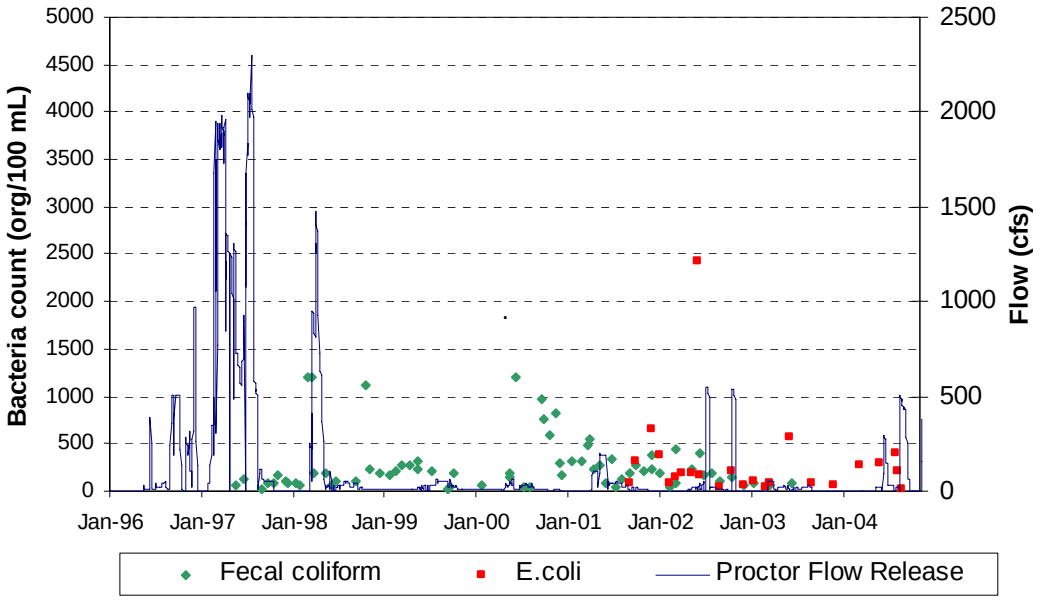

Figure 3-2 Bacteria Monitoring Data for Leon River at US 67-377, 1996-2004

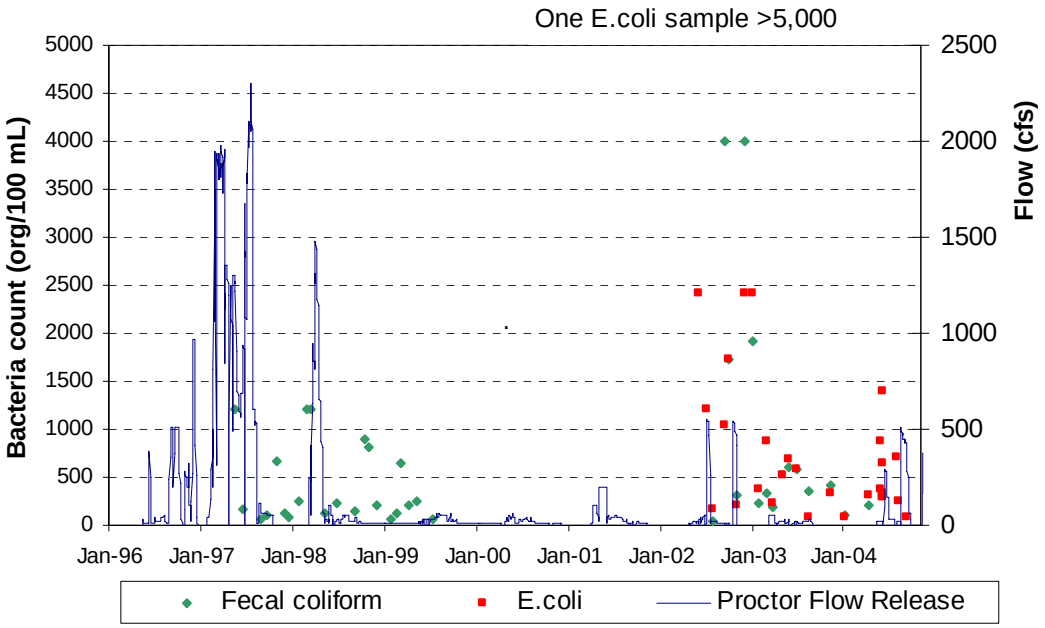

Figure 3-3 Bacteria Monitoring Data for Leon River at FM 1702, 1996-2004

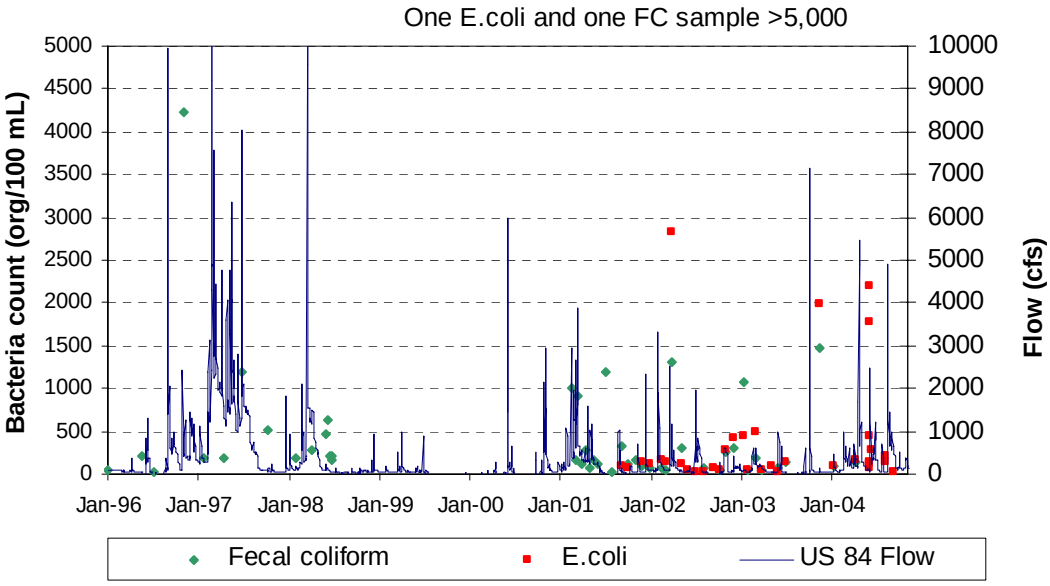

Figure 3-4 Bacteria Monitoring Data for Leon River at US 281, 1996-2004

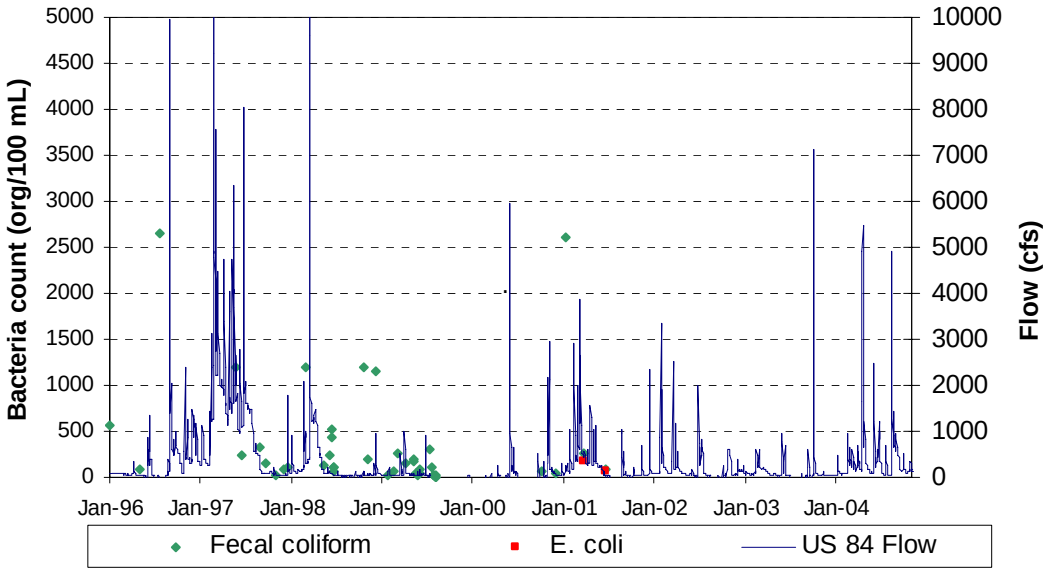

Figure 3-5 Bacteria Monitoring Data for Leon River at SH 36, 1996-2004

Fecal coliform and *E. coli* geometric mean values at selected stations are depicted in Figure 3-6 and 3-7, respectively. These mean values are calculated over the period of record tabulated in Table 3-1, namely available data over the period of 1996-2004. It is observed in Figure 3-6 that the highest mean fecal coliform values in the watershed of the impaired reach were recorded at on Indian Creek at CR 304 (#11818), on Walnut Creek at FM 1476 (#17379), on Resley Creek at CR 322 (#17376), and on the Leon River at CR 340 (#17591) and FM 1702 (#15769). In Figure 3-7, *E. coli* concentrations are relatively high at these same stations, as well as at CR 183 (#11929).

It should also be noted that the available data set contains apparent inconsistencies between the parameters of fecal coliform and *E. coli* bacteria. The fecal coliform test is designed to include organisms that are characteristic of the digestive tract of warm-blooded animals. One of the organisms that should always be included in the fecal coliform test is *E. coli* bacteria. Therefore, for a single sample, the fecal coliform result should always be greater or equal to the *E. coli* result. Unfortunately, the historical data base at most stations includes numerous instances where *E. coli* count exceeds the fecal coliform count for the same sample. These data have all met the Quality assurance guidelines required by TCEQ in order to be included in the data base. Resolution of this inconsistency is beyond the scope of the present study.

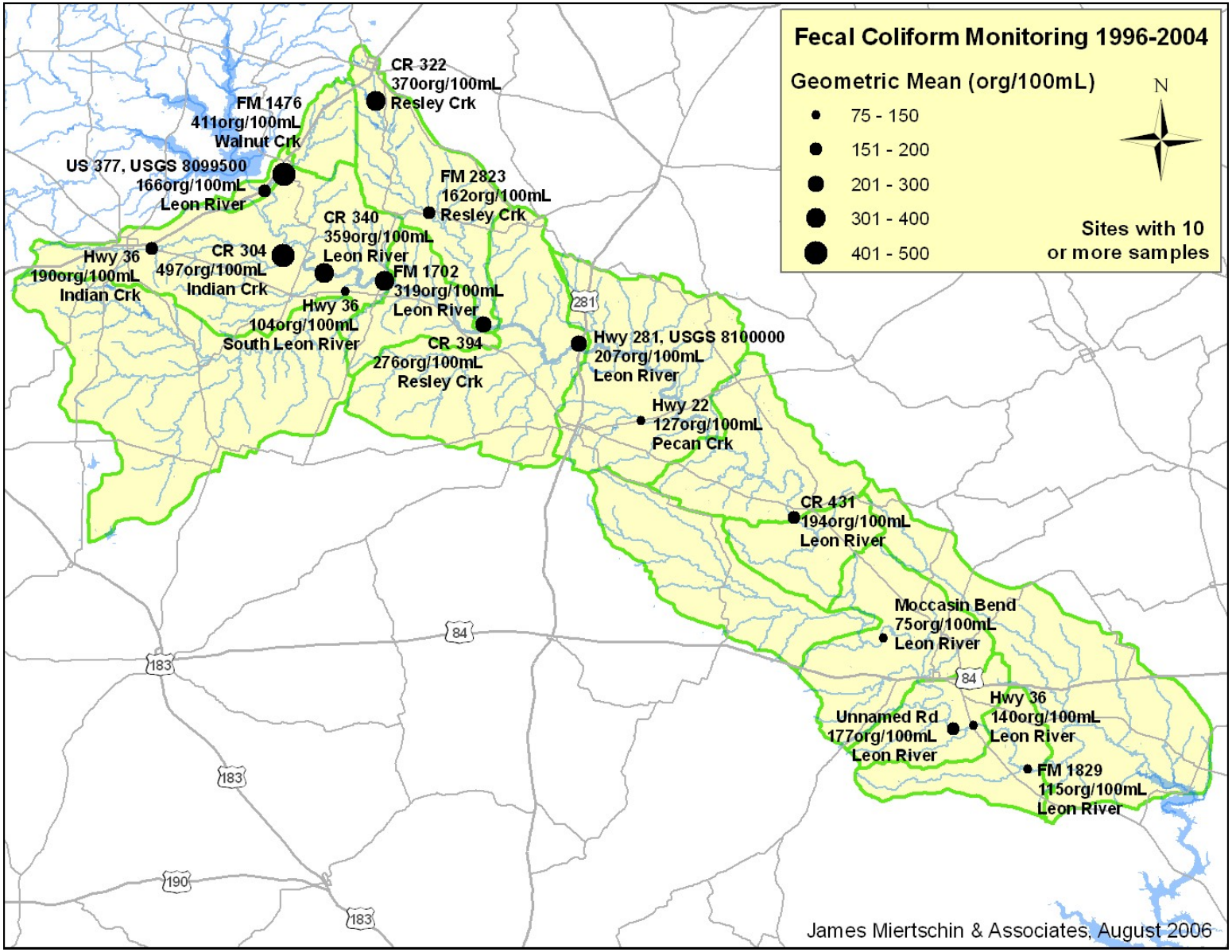

Figure 3-6 Fecal Coliform Results Across Leon River Watershed

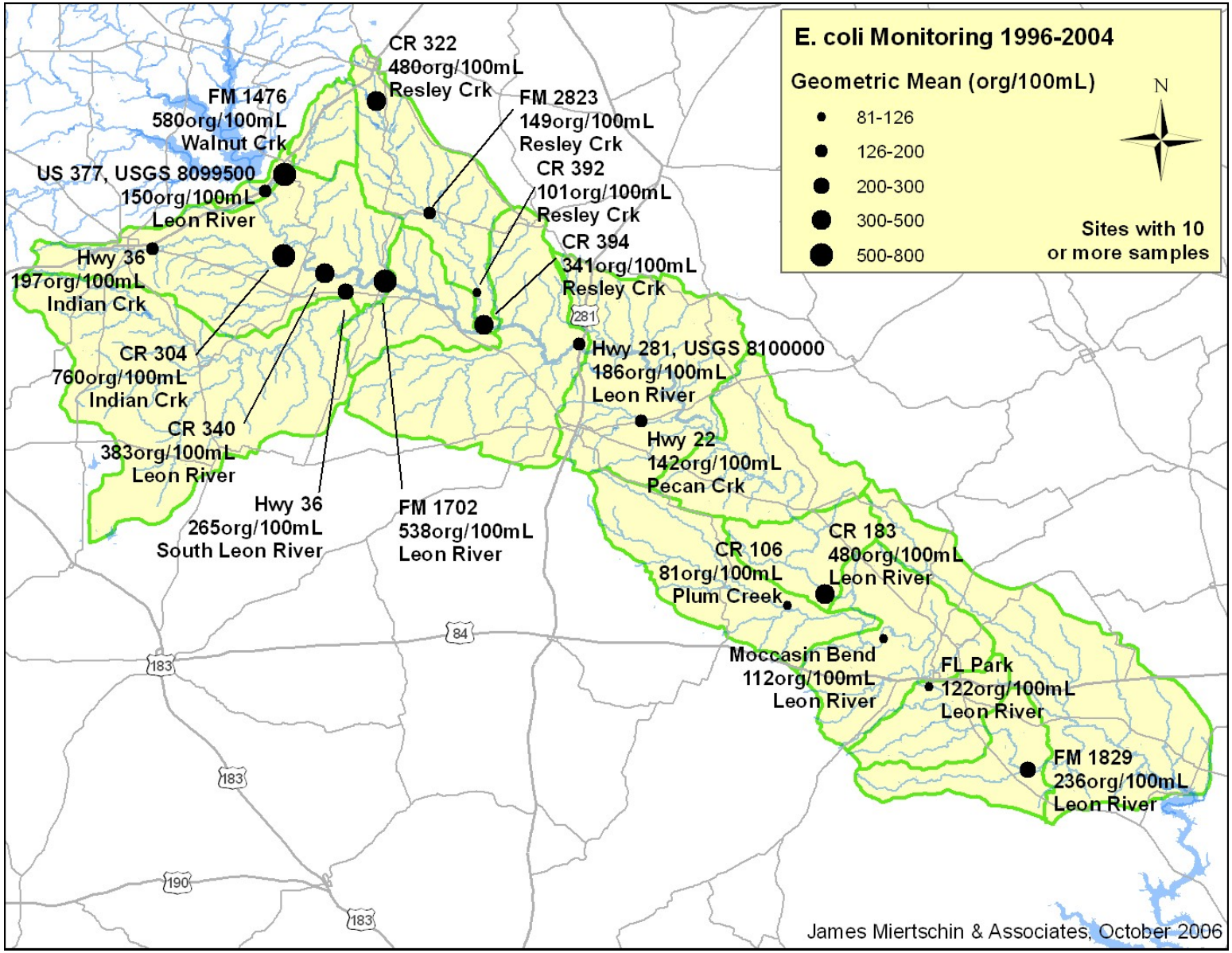

Figure 3-7 *E. coli* Results Across Leon River Watershed

4.0 SOURCE CHARACTERIZATION AND ASSESSMENT

The TMDL development described in this report included examination of all potential sources of bacteria loading in the Leon River watershed. The potential sources include both point and non-point sources. The source assessment was used as the basis of model development and the analysis of TMDL allocation scenarios. To characterize and evaluate the sources, a variety of information was employed, including agricultural and land use information, water quality monitoring and point source data, past TMDL studies, literature sources, and input from State and local management agencies. This section documents the available information and its interpretation. Procedures and assumptions used in estimating fecal coliform bacteria loads for representation in the model are discussed in the following Section 5.0.

4.1 ASSESSMENT OF POINT SOURCES

Point sources, such as municipal wastewater treatment plants (WWTPs), can contribute fecal coliform bacteria loads to surface water streams through effluent discharges. These point sources are permitted through the Texas Pollutant Discharge Elimination System (TPDES) program that is managed by the TCEQ. Table 4-1 lists all permitted point sources in the study area; and the location of each point source (except Comanche Pottery, which is located near the Comanche WWTP) is depicted in Figure 4-1.

The study area includes three permitted point sources that are not wastewater treatment plants and are not expected to contribute any significant bacteria loading to the segment:

- the Upper Leon River Municipal Water District (MWD) discharge is for a drinking water treatment facility
- the US Department of the Navy discharge is for a groundwater remediation facility
- the Comanche Pottery, Inc. discharge is for a plant that manufactures decorative clay pots

The rest of the point sources are wastewater treatment plants, which could release significant bacterial loads if not properly designed, maintained, and operated.

Permitted point sources that process wastewater associated with fecal matter are typically required to provide disinfection. Chlorination is often utilized within a mechanical wastewater treatment plant to achieve this disinfection. This type of system is typically required to monitor effluent for a residual chlorine concentration. Other wastewater treatment facilities utilize facultative lagoons for disinfection. These treatment facilities do not include chemical disinfection processes. Instead, it is assumed that a substantial reduction in bacteria is achieved via provision of 21 days of detention time within the pond system, during which bacteria are eliminated by solar radiation and other natural processes. This type of pond system is usually required to monitor effluent for fecal coliform.

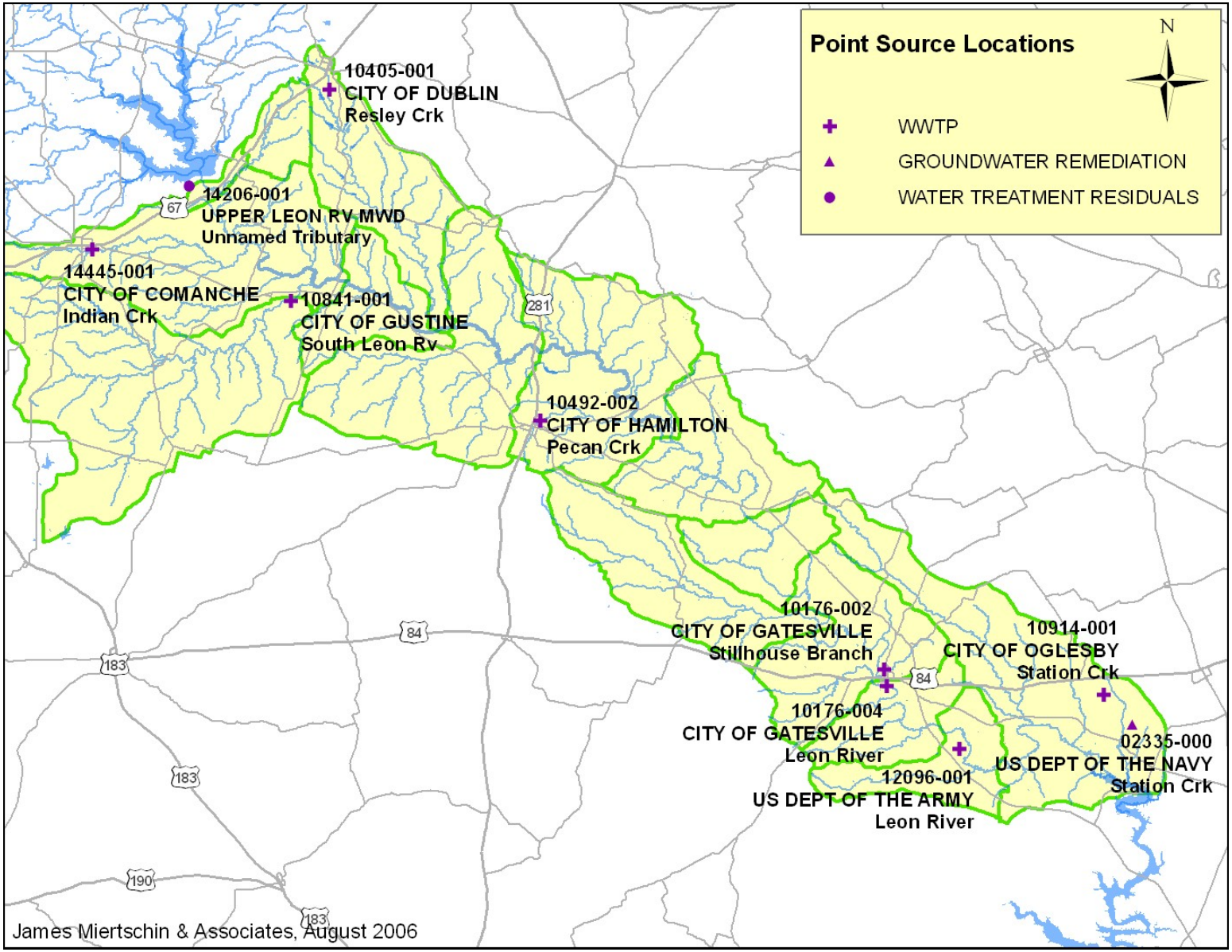

Figure 4-1 Leon River Point Source Locations

Table 4-1 Point Sources

PERMITTEE	TCEQ Permit #	EPA NPDES #	Receiving Stream	Permitted Flow (MGD)	Disinfection Verification
UPPER LEON RV MWD	14206-001	0122203	Unnamed Trib.	0.249	n/a
CITY OF COMANCHE	14445-001	0022730	Indian Crk	0.73	>1 mg/L Cl2
COMANCHE POTTERY	03931-000	0116041	Indian Crk	0.00035	n/a
CITY OF GUSTINE	10841-001	0117722	South Leon Rv	0.082	>1 mg/L Cl2
CITY OF DUBLIN	10405-001	0054348	Resley Crk	0.45	<800 org/100mL
CITY OF HAMILTON	10492-002	0026867	Pecan Crk	0.88	>1 mg/L Cl2
CITY OF GATESVILLE	10176-002	0111791	Stillhouse Br.	2.2	>1 mg/L Cl2
CITY OF GATESVILLE	10176-004	0024953	Leon River	1.0	>1 mg/L Cl2
US DEPT OF THE ARMY	12096-001	0063606	Leon River	0.25	>1 mg/L Cl2
CITY OF OGLESBY	10914-001	0100854	Station Crk	0.025	>1 mg/L Cl2
US DEPT OF THE NAVY	02335-000	0034321	Station Crk	n/a	n/a

The wastewater treatment plants for the cities in the Leon River watershed have been in operation for a number of years. Records for these municipal outfalls were obtained from TCEQ and the municipalities.

4.2 ASSESSMENT OF NON-POINT SOURCES

In the Leon River watershed, both urban and rural non-point sources of fecal coliform bacteria were considered in the present analysis. The Texas 303(d) list for 2000 identifies unknown nonpoint sources and confined animal feeding operations as the primary source of pathogens in the subject watershed. Potential sources included in the present analysis include septic systems, wildlife, livestock and general urban runoff.

4.2.1 Failing Septic Systems

Private residential sewage treatment systems (septic systems) typically consist of one or more septic tanks and a drainage or distribution field. Household waste flows into the septic tank, where solids settle out. The liquid portion of the waste flows to the distribution system which may consist of perforated pipes buried in a soil or gravel bed. Effluent in the bed may move vertically to groundwater, laterally to surface water, or upward to the ground surface. As it moves, the majority of the liquid portion is consumed by evapotranspiration of vegetation planted on top of the distribution field or adjacent to it. Properly designed, installed, and functioning septic systems would be expected to contribute virtually no fecal coliform to surface waters. The principal removal mechanism for the fecal coliform would be die-off as the liquid moves through the soil. Various studies have attempted to quantify the transport and delivery of bacteria in effluent from septic systems. For example, it has been reported that less than 0.01% of fecal coliform originating in the household waste moves farther than 6.5 feet downgradient from the drainfield (Weiskel, 1996).

A septic system failure can occur via two mechanisms. First, drainfield failures, broken pipes, or overloading could result in uncontrolled, direct discharges to the streams. Such failures would not be expected to be common in the study watershed, but they could occur in reaches with older homes located near a watercourse or in remote areas. As a second mechanism, an overloaded drainfield could experience surfacing of effluent, and the pollutants would then be available for surface accumulation and subsequent washoff under runoff conditions.

The number of septic systems in the study area was estimated using information from the 1990 U.S. Census, which included a question regarding the means of household sewage disposal (USCB, 2006). Unfortunately, this question was not posed in the 2000 Census. Based on the 1990 data, the number of septic systems in the study area was estimated by intersecting the geographic census blocks with the study area watershed. Based on this analysis, there were an estimated 4,535 septic systems in the study area in 1990. In addition, there were an estimated 7,808 sewer connections and 122 "other" types of disposal. The spatial distribution of sewage disposal is shown in Figure 4-2.

Generally, only septic systems near streams have a high likelihood of contributing bacteria to the surface water. For this study, a riparian corridor of 300 feet (total width) was applied to all perennial streams in the study area. The overall watershed septic system density was applied to these corridor areas to obtain an estimate of near-stream septic systems, as shown in Table 4-2. Of these systems, only a small percentage would be expected to be failing. According to a report by Reed, Stowe, and Yank (2001), about 12% of the septic systems in Hamilton and Coryell Counties are chronically malfunctioning. For Comanche and Erath Counties, the failure rate is about 8%. For this analysis, only the potential direct discharges from failing septic systems were considered in the model. Fecal coliform loadings were calculated based upon a septic system fecal density of 10^4 org/100 mL, and a household flow of 210 gal/day (3 persons per household, at 70 gal/capita-day) (EPA, 2000).

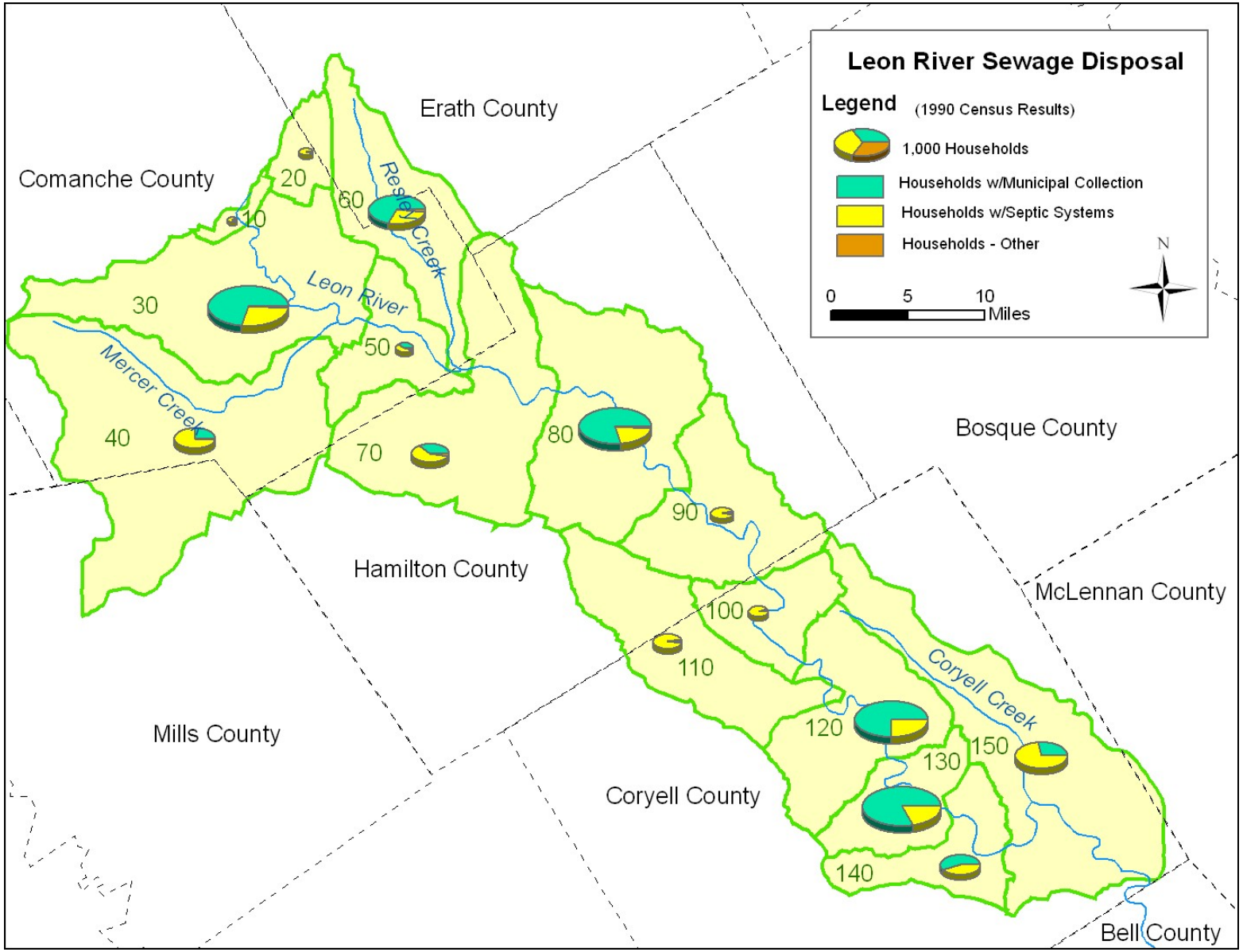

Figure 4-2 Sewage Disposal by Subwatershed

Table 4-2 Septic Systems by Subwatershed

Subbasin	Septic Systems (Total)	Septic Systems (Near-Stream)	Failure Rate	Failing Septic Systems (Near-Stream)
10	45	2	8%	0.14
20	106	1	8%	0.05
30	728	21	8%	1.66
40	496	7	8%	0.52
50	102	2	8%	0.15
60	460	10	8%	0.78
70	319	6	8%	0.50
80	420	7	12%	0.78
90	198	3	12%	0.31
100	282	5	12%	0.59
110	365	8	12%	0.94
120	690	8	12%	0.96
130	450	7	12%	0.82
140	241	3	12%	0.40
150	953	10	12%	1.25
Total	5855	100	-	9.85

4.2.2 Livestock

Livestock population estimates for Comanche, Hamilton, Mills, Bosque, Erath, and Coryell Counties were based upon the 2002 Agricultural Census (USDA, 2002) and TCEQ (Frazier, 2005) and Texas State Soil and Water Conservation Board (TSSWCB) registration records (Wendt, 2005). The types of livestock explicitly included in the present analysis included cattle, horses/donkeys, sheep/goats, hogs, and chickens. Census numbers by county were converted to densities and were then used to estimate livestock population in each subwatershed based on the proportion of each county present. Dairy cattle numbers were estimated based upon permitted numbers for each subwatershed provided by TCEQ and TSSWCB. It is recognized that the actual cattle numbers are probably less than these permitted numbers. For the purposes of this analysis, the permitted numbers will be employed. Livestock population estimates are presented in Table 4-3. Other types of livestock had small populations compared to the major livestock species listed above, and therefore, the fecal loads from these other animal groups were assumed to be negligible compared to the predominant sources.

Table 4-3 Livestock Population Estimates for Leon River Watershed

Sub watershed	Cattle & Calves	Dairy Cattle	Hogs and Pigs	Sheep	Horses & Donkeys
10	524	0	3	18	11
20	1,657	10,200	10	58	49
30	11,756	18,790	80	413	248
40	17,755	5,689	107	2,436	389
50	4,020	2,190	28	178	85
60	7,034	23,053	39	254	232
70	10,676	1,599	28	1,865	253
80	9,867	4,560	14	2,093	237
90	6,116	0	11	1,244	148
100	3,648	0	34	270	93
110	7,444	0	52	903	186
120	8,091	0	78	527	207
130	4,108	0	36	268	105
140	4,537	0	32	296	116
150	13,629	3,000	117	880	352
Total:	110,862	69,081	669	11,703	2,711

Fecal coliform bacteria produced by livestock can enter surface waters through several pathways: washoff of waste deposited on the land surface, washoff of concentrated waste from land application sites, direct deposition of waste material in the stream, and potential discharges from animal confinement areas or waste handling systems. The present analysis included dairy cattle within confined animal feeding operations as well as mechanisms of deposition of waste from grazing animals and the potential direct discharge of fecal material to the streams.

Grazing animals contribute fecal coliform bacteria to the land surface that is subsequently available for washoff to surface waters during storm events. The mechanism for the contribution is shown schematically in Figure 4-3. Thus, in the present analysis, deposition of waste from cattle, horses/donkeys, sheep/goats, and hogs onto the land surface was considered. It was assumed that grazing animals deposited waste on forest and rangeland land use categories.

Non-grazing, or confined, animals considered in the present analysis were dairy cattle. It was assumed that waste from dairy cattle could be represented predominately as contained within confined facility areas. It was assumed that manure was either stockpiled or sent to waste lagoons. For ultimate disposition, the manure is applied in solid or liquid form to waste application fields (WAFs). Once applied to the WAFs, the waste is subject to washoff from the land surface under runoff conditions. A map of WAFs, developed from information provided by TCEQ, is shown in Figure 4-4. It should also be noted that a portion of the manure generated in the study area is hauled out of the watershed to a regional composting facility.

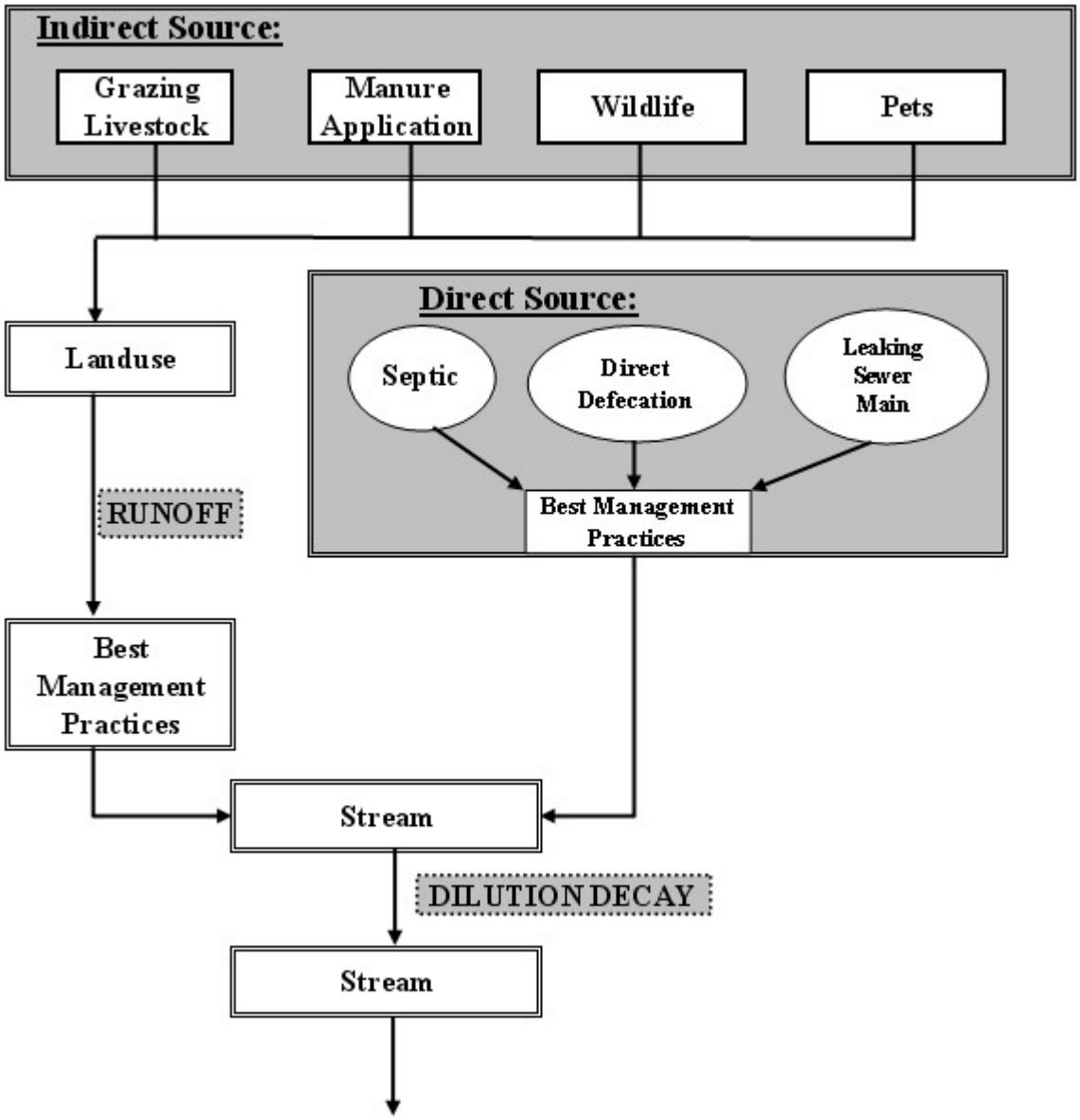

Figure 4-3 Mechanism of Fecal Coliform Nonpoint Source Accumulation

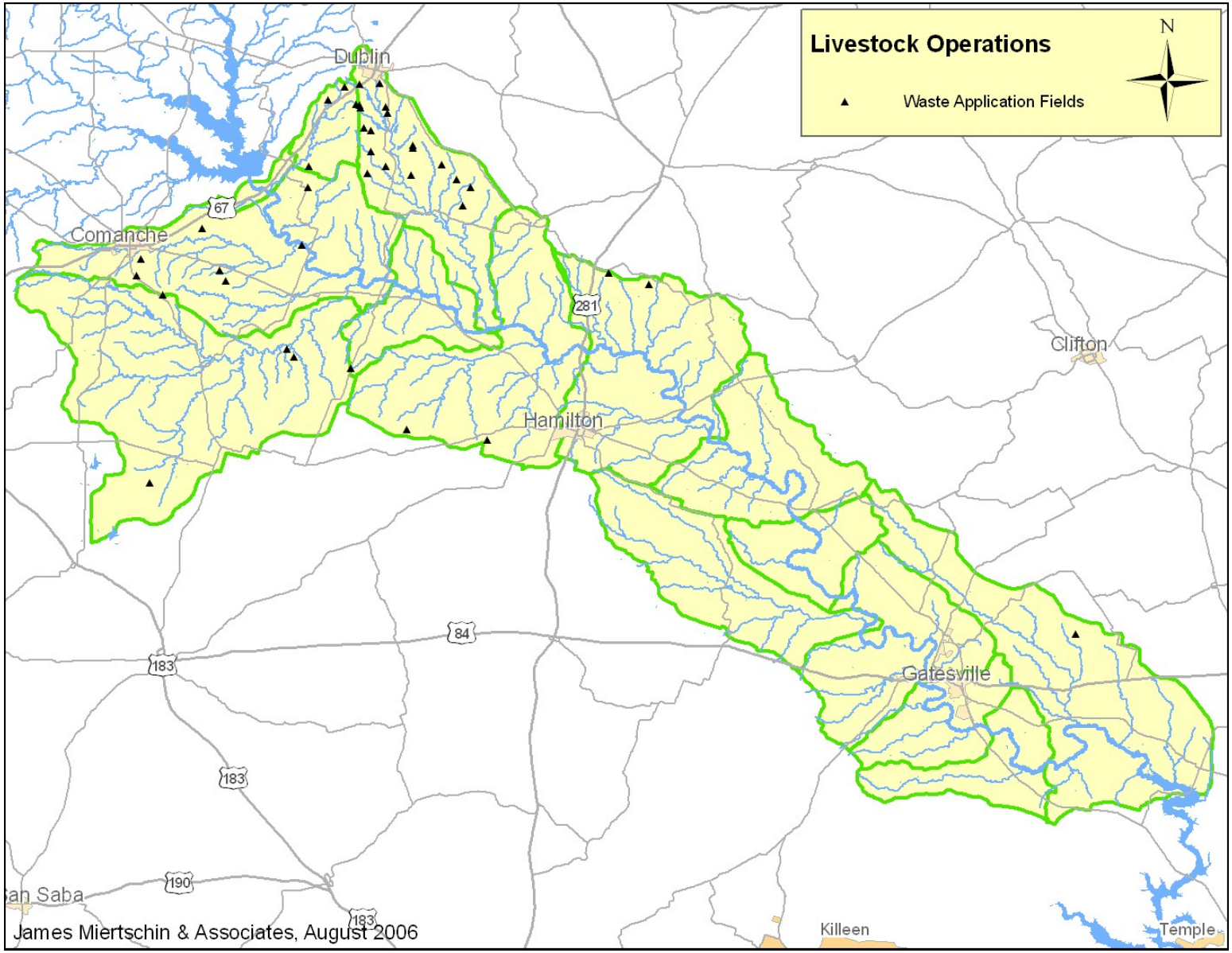

Figure 4-4 Waste Application Fields

Direct contributions from livestock into the stream were also considered in the present analysis. It was assumed that cattle and horses spent a small fraction of their time directly in the stream and therefore the potential exists for direct deposition. Other livestock, sheep/goats and hogs, were assumed to deposit all feces on pasture and forested areas. The amount of time that cattle and horses spend in direct contact with the stream depends upon the time of year and the availability of stream access and non-stream watering facilities. For the present analysis, the time spent was assumed to be related to mean monthly water temperature, with higher usage in warmer weather. Data for direct contact with the stream are shown in Table 4-4. These percentages indicate the assumed portion of time that a livestock animal spends directly in the stream, compared to the total time that the animal spends in the riparian area. To establish a reference point, it was assumed that animals spend 1% of their time in the stream in the coolest warm-season month of November. Time in the stream was then proportionally varied according to mean water temperature. For colder months, it was assumed that there was essentially no time spent in the stream.

Table 4-4 Direct Animal Contact with Stream

Month	Cattle and Horses Grazing Time Spent in Streams
January	0%
February	0%
March	1.03%
April	1.14%
May	1.26%
June	1.36%
July	1.40%
August	1.40%
September	1.32%
October	1.18%
November	1.0%
December	0%

Fecal coliform bacteria production rates for livestock in the Leon River watershed are displayed in Table 4-5. For the present study, all of the data regarding manure production rates and fecal coliform density were based upon values reported in the literature (ASAE, 2003).

4.2.3 Wildlife

The predominant wildlife species to be included in the modeling analysis were determined by wildlife biologists on the project team based on their experience, literature (Davis and Schmidly, 1994; TPWD, 2004), site visits, and consultation with Texas Parks and Wildlife Department staff (Cain, 2004). The key species included deer, raccoons, opossums, feral hogs, and ducks/geese. Of course, there are numerous other species of animals that inhabit the watershed, but the species selected in the present analysis were chosen based upon population and fecal production potential. Wildlife density estimates were as follows:

Duck	30 #/sq. mile
Deer	50 #/sq. mile
Raccoons	40 #/sq. mile

Opossum	160 #/sq. mile
Feral Hog	20 #/sq. mile

Table 4-5 Fecal Coliform Bacteria Production Rates for Livestock and Wildlife

Animal	Fecal Coliform (count/animal/day)
Dairy Cow	1.01×10^{11}
Beef Cow	1.04×10^{11}
Hog	1.08×10^{10}
Sheep	1.20×10^{10}
Horse	4.20×10^{8}
Chicken	1.36×10^{8}
Turkey	9.30×10^{7}
Duck	2.43×10^{9}
Opossums	1.25×10^{8}
Deer	5.00×10^{8}
Feral Hogs	1.08×10^{10}
Raccoon	1.25×10^{8}

The population of each wildlife species was developed using estimated population densities per square mile of habitat and the total area of suitable habitat available in each subwatershed. This wildlife inventory is shown in Table 4-6.

Table 4-6 Inventory of Wildlife in Subwatersheds

Subwatershed No.	Ducks	Deer	Raccoons	Opossums	Feral Hogs
10	4	327	261	1,045	131
20	14	941	753	3,011	376
30	39	7,238	5,790	23,161	2,895
40	53	10,731	8,585	34,341	4,293
50	20	2,293	1,834	7,337	917
60	50	3,790	3,032	12,128	1,516
70	19	6,903	5,522	22,088	2,761
80	34	6,636	5,309	21,234	2,654
90	33	4,148	3,319	13,275	1,659
100	23	2,193	1,754	7,017	877
110	35	4,624	3,699	14,797	1,850
120	38	4,522	3,618	14,471	1,809
130	22	2,213	1,771	7,083	885
140	18	2,418	1,934	7,737	967
150	48	8,192	6,554	26,215	3,277
Total:	450	67,169	53,735	214,940	26,867

This inventory of wildlife populations can be applied to develop initial estimates of bacteria loading in the watershed. Exact counts are not available for any of the species in the watershed. Even if exact numbers for deer, raccoons, etc. were available, there will always be some species of wildlife animals that are not specifically counted, such as mice, sparrows, and many more. To support water

quality modeling, a general estimate of the overall load contribution from wildlife is needed. Since wildlife populations cannot be precisely known, all loading parameters that represent wildlife are subject to adjustment in the model calibration process.

As with livestock, there are two mechanisms considered for bacteria loadings from wildlife to be transported to the stream segment. First, wildlife deposit waste on land surfaces that accumulates and is subsequently available for washoff with runoff. Second, wildlife may deposit waste directly into the stream.

For specification of the number of animals that may be engaged in direct deposition to the stream, the area of a riparian habitat corridor approximately 300 feet in width was calculated, and the prescribed animal density was applied to this riparian area in order to provide an initial estimate of the near-stream populations. Then, a small fraction of this population was assumed to directly deposit waste in the stream. A seasonal component for the frequency of wildlife visitation to the stream was developed as a function of mean ambient water temperature, with the assumption that water visitation would be more likely under warm-weather conditions, similar to the livestock approach described previously.

Fecal coliform bacteria production rates for wildlife in the Leon River watershed are shown in the above Table 4-5. For the present study, all of the data regarding fecal production rates and fecal coliform density was based upon values reported in the EPA Fecal Tool (EPA, 2000).

4.2.4 Urban Loadings

Some of the study area is comprised of the urban landscape of residential, commercial, and industrial areas. While the initial estimates of bacteria mass loadings for non-urban land use areas were developed based upon an inventory of septic systems, livestock, and wildlife, the myriad of sources in the urban areas were represented by typical loading rates from literature sources (EPA, 2000). These generalized urban loading rates thus represent bacteria loadings that may be derived from urban wildlife, pets, septic system failures, sewer system leaks, discharges of varied nature and composition, and any other sources that may be present. The specific factors employed in the present analysis for the initial urban loading estimates are summarized in Table 4-7.

Table 4-7 Typical Bacteria Loading Rates from Urban Land Uses

Land Use	*Median FC count/acre/day*
Road	2.00×10^5
Commercial	6.21×10^6
Single family low density	1.03×10^7
Single family high density	1.66×10^7
Multifamily residential	2.33×10^7

5.0 WATERSHED MODELING

Establishing the relationship between instream water quality targets and the source loadings of bacteria is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. The link can be established through a variety of techniques, ranging from qualitative assumptions based on scientific principles to sophisticated mathematical modeling techniques. In the development of a TMDL for the impaired reach of the Leon River, the relationship was defined through computer modeling based upon data collected throughout the watershed. Monitored flow and water quality data were used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, setup, and model application are discussed.

5.1 MODELING FRAMEWORK SELECTION

The US EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) system Version 3.1 (EPA, 2004) and the Hydrologic Simulation Program - Fortran (HSPF) water quality model were selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. BASINS is a multipurpose environmental analysis system for use in performing watershed and water quality-based studies in a wide variety of areas. BASINS includes a geographic information system (GIS) for integration of landscape information, including land uses, monitoring stations, point source locations, and watershed delineation. The HSPF model is a continuous simulation model for watershed hydrology and water quality. The model can account for both point source loadings and non-point source loadings in the watershed. HSPF includes simulation of the receiving stream that receives mass loadings from the watershed. The features of HSPF that led to its selection are summarized below:

- Full capabilities for long-term simulation of hydrologic response
- Full capabilities for simulation of dynamic mass transport from the watershed surface
- Adaptability to urban and non-urban land uses
- Built-in receiving water module with instream source/sink terms
- Successful application to bacteria TMDLs demonstrated throughout the country.

The HSPF model is comprehensive in its treatment of the watershed. Land surfaces are simulated as either pervious or impervious land segments, labeled as PERLNDs and IMPLNDs, respectively. The model is driven by input of precipitation data. Runoff in response to rainfall is generated on the surfaces of the PERLNDs and IMPLNDs. Pollutant mass is also generated on these land surfaces and is available to be washed off by the runoff. The runoff volume and the pollutant mass volume are transported to the nearest channel, referred to as a RCHRES. Segmentation of the receiving stream is constructed as a series of RCHRES segments, with each transporting flow and mass to the next downstream segment, in the same configuration as the real stream segments in the physical world.

5.2 MODEL SETUP

Segment 1221 of the Leon River watershed was subdivided into several subwatersheds to adequately represent the spatial variation in fecal coliform sources, watershed characteristics, hydrology, and the location of water quality monitoring and streamflow gaging stations. Since Proctor Reservoir lies at the upstream end of segment 1221, boundary conditions for flow and fecal coliform concentration were created from dam release time series obtained from the US Corps of Engineers.

BASINS provides standard 8-digit Hydrologic Unit Code (HUC) boundaries developed by the USGS. The Leon River watershed boundary exists within HUC #12070201. This watershed was segmented to delineate the hydrologically connected subwatershed boundaries. These subwatersheds were delineated by using topographical data contained in a Digital Elevation Model (DEM), along with published USGS topographical mapping.

BASINS provides a processed DEM with a resolution of 90 meters. In order to get a better resolution in the subwatershed boundaries, a DEM from TNRIS with a resolution of 30 meters was used. This improved resolution provided more accurate topography of the study area.

Segment 1221 of the Leon River watershed was subdivided into 15 subwatersheds, including distinct subwatersheds for the tributaries such as Walnut, Resley, and Plum Creeks along with the South Leon River, as shown in Figure 5-1. The spatial division of the watershed into subwatersheds allows for a more refined representation of pollutant sources and a more realistic description of hydrologic factors in the watershed. The schematic of the subwatershed network developed in BASINS is shown in Figure 5-2. Each of the 15 subwatersheds has associated with it a defined stream reach (RCHRES segment). The numbering of the RCHRES segments and subwatersheds followed the pattern 10, 20, 30, …through 150 in an upstream to downstream sequence.

As the work was underway, an additional RCHRES segment was incorporated. RCHRES 41 was added as a hydraulic segment downstream of RCHRES 30. As a hydraulic segment, RCHRES 41 does not have a watershed assigned to it, however, flow and mass from two other segments enter and flow through it. It was provided to better reflect concentrations at FM 1702, one of the key water quality accounting points in the model formulation.

The stream reach that has been designated as impaired by bacteria constitutes only a portion of the complete watershed of segment 1221 of the Leon River. According to TCEQ, the impaired reach extends from just below Hwy 281 near Hamilton upstream to the confluence with Indian Creek, just above FM 1476 near Gustine, a distance of approximately 44 miles. In the model, this impaired reach is represented by the series RCHRES 30, 41, 50, and 70 on the mainstem of the Leon. Addition of the contributing headwater reach and tributary reaches pulls in RCHRES 10, 20, and 40. Therefore, the complete impairment zone is represented by the composite watershed of RCHRES 10 through 70, which constitutes roughly the upper half of the Segment 1221 watershed.

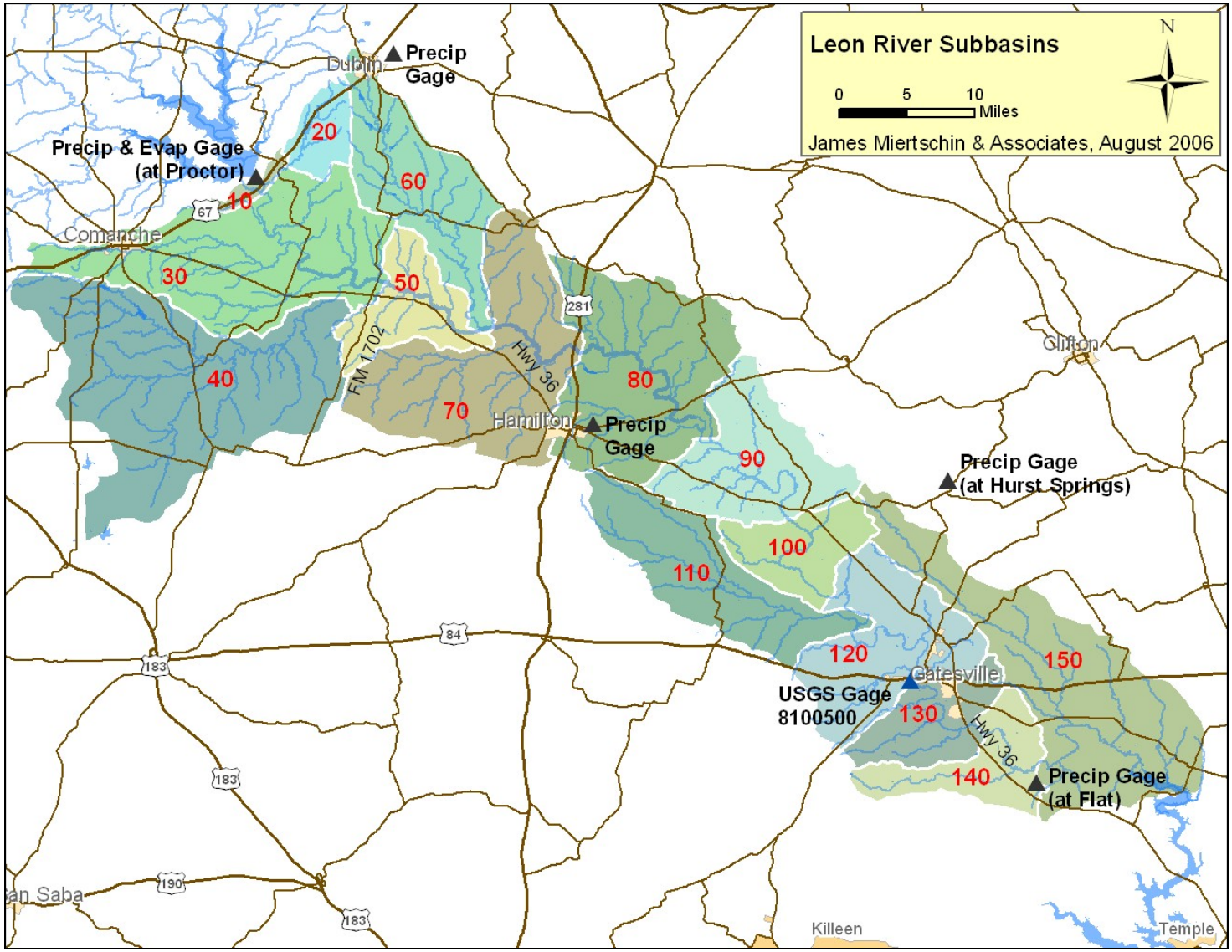

Figure 5-1 Leon River Subwatersheds

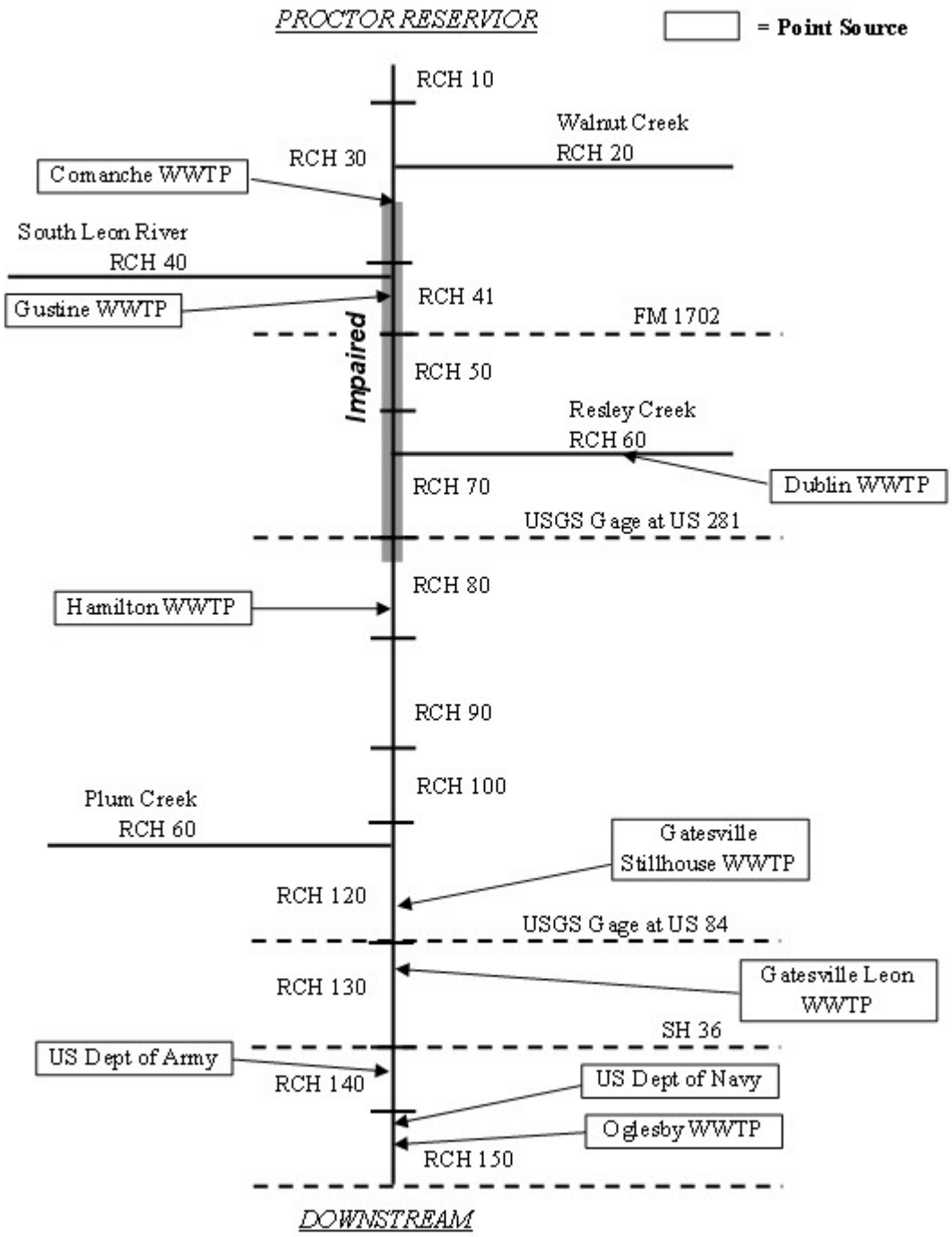

Figure 5-2 Schematic of Leon River

Land use data for the watersheds were based on the USGS National Land Cover Dataset (NLCD) found in BASINS. Derived from the early to mid-1990s Landsat Thematic Mapper satellite data, the National Land Cover Data (NLCD) is a land cover classification scheme applied consistently over

the United States. The spatial resolution of the data is 30 meters. Table 5-1 shows land use coverages provided by NLCD and the consolidated land use list employed in the present study.

Table 5-1 Land Use Coverages used in Model

Consolidated Land Uses	BASINS Land Uses
Residential	Low Intensity Residential
	High Intensity Residential
Commercial/Industrial	Commercial/Industrial/Transportation
	Quarries/Strip Mines/Gravel Pits
Rangeland	Bare Rock/Sand/Clay
	Deciduous Shrubland
	Grassland/Herbaceous
	Pasture/Hay
	Other Grasses (Urban/recreational)
	Emergent Herbaceous Wetlands
Forest	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Woody Wetlands
Crop	Planted/Cultivated (orchards, vineyards, groves)
	Row Crops
	Small Grains

Multiple land use types were represented in the model. The five fundamental land use types included rangeland, forested land, crop/pastureland, residential land, and commercial/industrial land. Each land use type could have both PERLND and IMPLND segments. With each PERLND and IMPLND type were associated specific hydrologic and mass loading parameters. Some of the parameters were developed from site-specific data sources, while others were developed via the calibration of the model. An inventory of the various land use types and the area of each type within each subwatershed is displayed in Table 5-2 for the Leon River watershed.

Table 5-2 Various Land Use Types and Areas for Leon River Watershed

Land Use Type	Area (acres)	% of Total
Pervious:		
Forest	144,029	16.3%
Crop/Pastureland	87,813	10.0%
Rangeland	627,906	71.2%
Residential	3,886	0.4%
Comm/Ind	2,731	0.3%
WAF1	6,159	0.7%
WAF2	7,344	0.8%
Impervious:		
Residential	686	0.1%
Comm/Ind	1,821	0.2%
Total	882,375	100%

5.3 SOURCE REPRESENTATION

Both point and nonpoint sources were represented in the model. Point sources were added to the model as time-series of pollutant (bacteria) and flow inputs to the stream. Land-based nonpoint sources were represented in the model through an accumulation of pollutant mass on the land surface, where some portion is available for washoff and transport with runoff. The amount of accumulation and availability for transport vary with land use type. The model allows for a maximum accumulation to be specified.

Some nonpoint sources, rather than being land-based, were represented in the model as being deposited directly to the receiving stream, for example defecation by animals directly to a stream. These sources were labeled as "direct sources" in the model, and they were modeled in a manner similar to point sources. As such, they do not require a runoff event for delivery to the stream.

5.3.1 Point Sources

Existing point sources were explicitly included in the model. In the Leon River watershed, these point sources consisted of several municipal wastewater treatment facilities. Records for discharges from these outfalls during the simulation period were obtained from the TCEQ and the municipalities. The wastewater treatment facilities that include disinfection process units are generally not required to monitor fecal coliform concentrations, so the daily discharge of fecal coliform was estimated to be relatively low for these facilities. One of the wastewater treatment facilities uses facultative lagoons and is currently required to monitor fecal coliform concentrations five times per week and report their monthly averages to TCEQ. A time series for daily discharge flow and fecal coliform concentration was included for each municipal point source.

In addition, a time series was developed for each municipal discharger in the impaired reach to represent potential overflows under wet weather conditions. These time series represent the relatively uncontrolled phenomena that can and do occur with municipal wastewater systems:

passage of peak flows through the treatment facility with diminished disinfection, overflows from lift stations, breaks in sewer lines, and exfiltration from sewer lines. The concept of the overflow loading was developed after review of TCEQ compliance reports and data for the municipal systems. The available information indicated that occasional discharges of raw sewage or effluent with relatively high bacteria concentrations do occur, but there is no documentation to define at what frequency, magnitude, and duration the events occur.

These overflow time series were calculated only for the days receiving more than 0.5 inch of precipitation. The flow rate of the overflow scenario was taken to be 3 times the reported daily flow rate on the assigned day of the overflow. This peak flow for the wastewater treatment plant was assumed to persist over a 6 hour period. The fecal coliform concentration during these overflow events was assumed to be 30,000 org/100 mL. This concentration should be a reasonable approximation of high-flow bypasses from either the treatment plant itself or from a lift station or collection system source, though the fecal coliform concentration could be substantially greater if raw sewage is released. There are many uncertainties regarding this overflow assumption, but the present formulation does accomplish the objective of incorporating a mechanism for simulation of high-flow releases from the municipal point source sector.

5.3.2 Failing Septic Systems

Septic systems provide the potential to deliver bacteria loadings to receiving streams via two mechanisms. First, drainfield failures or overloading could result in uncontrolled, direct discharges to the streams. Such failures would not be expected to be common in the study watershed, but they could occur in reaches with older homes located near a watercourse or in remote areas. As a second mechanism, an overloaded drainfield could experience surfacing of effluent, and the pollutants would then be available for surface accumulation and washoff.

The total number of septic systems in the watershed was estimated from available US Census data. A nominal assumed failure rate of 8 - 12% was applied, as discussed in Section 4.2.1. For this analysis, only the potential direct discharges from failing septic systems were considered in the model. Fecal coliform loadings were calculated based upon the fecal density of septic effluent and the flow from a household assuming a population of 3.0 persons per household.

The approach represents a method to incorporate explicitly bacteria loadings from failing septic systems into the modeling analysis. The precise number of actual failures and their loadings within the study area is unknown, and no data base is available to accurately quantity this mechanism. Instead, the present approach provided an input to the model, which could be adjusted via the calibration process, to account for some measure of loadings from this particular potential source of bacteria.

5.3.3 Livestock

Fecal coliform bacteria produced by livestock can enter surface waters through several pathways: washoff of waste deposited on the land surface, washoff of concentrated waste from land application sites, direct deposition of waste material in the stream, and potential discharges from animal confinement areas or waste handling systems. Each of these pathways can be accounted for in the

model. The population of each livestock species considered in the modeling analysis was distributed among subwatersheds based upon the total area of forest and rangeland in each subwatershed. This livestock inventory was shown in Table 4-3.

Grazing animals contribute fecal coliform bacteria to the land surface that is subsequently available for washoff to surface waters during storm events. The mechanism for the contribution was shown schematically in Figure 4-3. The inventory of livestock animals and their waste loadings was analyzed using a modification of the EPA's Fecal Tool spreadsheet (EPA, 2000). This spreadsheet tool includes the necessary specifications of waste generation, fecal coliform density, and bacteria counts per animal unit for calculation of loads. It enables calculation of loading parameters for direct input into the modeling analysis, specifically, fecal coliform accumulation rates (in count/acre/day) and the maximum accumulation (in count/acre).

Dairy cattle populations for each subwatershed were estimated from data provided by the TCEQ and TSSWCB. There is no information available describing what fraction of the cattle population sends manure as a solid for land application versus as a liquid for sprinkler application. Another complication is the fact that some portion of the manure generated in the watershed is hauled out of the watershed for composting. For the present study, it was initially assumed that the cattle population was divided evenly between the two forms of disposal. Two disposal area categories were established in the model, namely, WAF1 and WAF2. WAF1 represents land surfaces that receive solid manure application. WAF2 represents land surfaces that receive sprinkler waste application. Theoretically, the number of cattle that contribute waste to WAF1 or WAF2 could be used to determine distinct bacteria loading factors for the two types of land use in each subwatershed. For the present analysis, in recognition of the many uncertainties regarding the number of cattle, their manure generation rate, the bacterial content of the manure, and the ultimate disposal location, it was assumed that the two WAF categories would be assigned similar bacterial loading rates for application in the modeling analysis. The two WAF categories will remain in the modeling formulation as a feature that could potentially be differentiated in future work.

Direct contributions from livestock were also included as inputs in the modeling analysis. It was assumed that grazing cattle and horses spent a small fraction of their time directly in the stream and therefore the potential exists for direct deposition. Other livestock, sheep/goats and hogs, were assumed to deposit all feces on pasture and forested areas. The potential direct contribution was estimated for each subwatershed using the parameters contained in the Fecal Tool spreadsheet. Results from this analysis were provided in terms of direct bacteria loadings (in counts/day) per stream segment. The analysis also enables calculation of the associated flow rate from these direct animal contributions, but this flow rate was not included in the hydrologic balance of the present analysis because of its extremely small size.

5.3.4 Wildlife

Wildlife species explicitly included in the modeling analysis included deer, raccoons, opossums, feral hogs, and ducks/geese. The population of each wildlife species was developed using estimated population densities per square mile of habitat and the total area of suitable habitat available in each subwatershed. This wildlife inventory was shown in Table 4-6. As with livestock, there are two mechanisms considered for bacteria loadings from wildlife to be transported to the stream segment.

First, wildlife deposit waste on land surfaces that accumulates and is subsequently available for washoff with runoff. Second, wildlife may deposit waste directly into the stream.

Wildlife loadings were calculated within the framework of the modified EPA Fecal Tool spreadsheet (EPA, 2000), in a manner analogous to that applied for livestock. For specification of the number of animals that may be engaged in direct deposition to the stream, the area of a riparian habitat corridor approximately 300 feet in width was calculated, and the prescribed animal density was applied to this riparian area in order to provide an initial estimate of the near-stream populations. Then, a small fraction of this population was assumed to directly deposit waste in the stream. A seasonal component for the frequency of wildlife visitation to the stream was developed as a function of mean ambient water temperature, with the assumption that water visitation would be more likely under warm-weather conditions.

5.3.5 Urban Loadings

Some of the study area is comprised of the urban landscape of residential, commercial, and industrial areas. While the initial estimates of bacteria mass loadings for non-urban land use areas were developed based upon an inventory of septic systems, livestock, and wildlife, the myriad of sources in the urban areas were represented by typical loading rates from literature sources (EPA, 2000). These loading rates provided an initial estimate, and the final specification of loading parameters was derived via calibration exercises. These generalized urban loading rates thus represent bacteria loadings that may be derived from urban wildlife, pets, septic system failures, sewer system leaks, discharges of varied nature and composition, and any other sources that may be present.

5.3.6 Proctor Lake Releases

At the upstream boundary of the simulated reach in the model, flow and bacteria enter the river through releases from Proctor Lake. Flows were based on historical reservoir release data provided by the United States Army Corps of Engineers (USACE). Bacteria levels were based on historical monitoring data for bacteria at the dam floodgate (TCEQ monitoring station #11935). Since bacteria concentrations at the dam are only monitored on certain days, unmonitored days were assigned bacteria concentrations based on the closest available sample in the temporal record.

5.3.7 Incorporation of Sources in the Model

The preceding representations of bacteria sources were incorporated in various ways into the modeling framework. There were five fundamental categories of loads in the analysis:

- Point source loads
- Septic loads
- Direct source loads
- Land-based washoff loads
- Upstream loads

Point Source Loads

The category of point source loads is represented in the model in a straightforward manner. A time series of daily flow and bacteria for each point source was developed and these sources are then input directly into the specific RCHRES where each is situated. The bacteria loading time series is provided in units of org/day, and is input into the model in units of 10^6 org/hr. This source is a continuously discharging source of bacteria that occurs on a daily basis. As described previously, the point source component consists of a routine daily discharge load along with a synthesized overflow load. The routine point source load occurs daily with no association with rainfall runoff, therefore it is a source of bacteria under all stream flow conditions. Conversely, the overflow point source load occurs sporadically under conditions of high rainfall only.

Septic Loads

The category of septic loads is represented in the model as a continuous daily discharge of bacteria in each reach, similar to the point source mechanism. Because the flow contribution is negligibly small, only the bacteria contribution is represented in a time series. The septic loading time series is provided in units of org/day. The septic load category discharges with no association with rainfall runoff events, therefore it is a source of bacteria under all stream flow conditions.

Direct Source Loads

The direct source category captures bacteria loadings that are discharged to the stream on a continuous basis, with no association with rainfall runoff. The loading time series was provided in units of org/day. A time series for direct source bacteria discharge was developed for each reach, based upon assumptions described previously for direct wildlife and livestock deposition to the stream. Because the flow contribution is negligibly small, only the bacteria contribution was represented in a time series. These time series values were applied as initial estimates only, and factors were applied to adjust the direct source values up or down in the calibration process. The direct source category was the primary source variable that was adjusted in the model calibration process to achieve an acceptable water quality calibration under baseflow conditions in the receiving stream. With this procedure, the initial estimates based upon presumed animal populations were not critical to the analysis. Even though the initial estimates were developed based upon presumed direct animal defecation, this category of direct source loads would also capture any other continuous daily releases of bacteria that may be occurring in the stream but that are difficult to quantify. For example, in some locations, leaking sewer mains could contribute a steady source of bacteria to the stream that would constitute a direct source component.

Land-Based Washoff Loads

The land-based washoff loads are expected to be the source of the largest quantity of bacteria. As the category name implies, these loads represent bacteria that are deposited on the land surface and are subsequently washed off the land surface to the receiving stream under conditions of rainfall runoff. As such, loads from this category exert an influence on instream bacteria concentrations primarily under runoff and high flow conditions, and they would not be expected to be a substantial contributor to instream bacteria on a daily basis.

The land-based washoff loads are formulated as loading rates of bacteria to the land surface on a daily basis, along with a limit on the total amount of bacteria that can be stored on the land surface at any point in time. Initial estimates (starting values) for these loading rates were developed based upon assumptions related to wildlife and livestock populations that were described previously. However, these loading rates were ultimately set based upon adjustments during the model calibration process. Therefore, the initial assumptions regarding animal populations were not critical to the process, serving only to establish a hypothetical loading rate based upon assumed population numbers.

Upstream Loads

The releases from Proctor Lake were input into the modeling analysis as time series for flow and bacteria. This category is a continuous source of bacteria, operative on a daily basis.

5.4 STREAM CHARACTERISTICS

Application of the HSPF model requires that stream reaches be represented by constant characteristics that relate flow rate, surface area, depth, and volume. Each reach also is described by a unique length, slope, and Manning's "n" coefficient for resistance to flow. The length and slope were obtained from digital elevation records based upon 7.5 minute USGS topographic maps, as well as from observations from paper copies of the same maps. Manning's *n* was estimated based upon literature values.

The hydraulic function tables (F-tables) used in HSPF describe the relationship among flow rate, surface area, depth, and volume in each stream reach. The flow and geometry relationships were developed based upon available physical data from USGS streamflow gaging records. These records were analyzed to develop a typical cross section and relationships at the gaging station location, then the data were extrapolated upstream and downstream to provide coverage of the entire reach. This extrapolation was based on the overall slope of the stream channel in each subwatershed, but the F-tables were modified on a reach-by-reach basis in recognition of other available data, such as field measurements of cross sections and observations of channel characteristics.

5.5 SELECTION OF REPRESENTATIVE MODELING PERIOD

The selection of a representative modeling period was based upon the availability of stream flow and water quality data and the need to represent critical hydrological conditions. With respect to streamflow data, records for the Leon River at Gatesville were available from October 1950 to the present. The most comprehensive time period for reported fecal coliform concentrations consists of the period from 2001 to the present. Some data are available prior to that time, however, it was assumed that the more recent data would be more representative of current water quality conditions. The period selected for hydrologic calibration encompassed the years 2000 through 2004. Application of a five-year hydrologic calibration period is generally recommended for application of the HSPF model. This modeling period has good availability of streamflow data, and it incorporates numerous wet, dry, and average flow conditions that typically occur in the study area. The period

selected for water quality calibration was 2001 through 2004. This simulation period incorporates a full range of seasonal and hydrologic conditions in the study area.

5.6 MODEL CALIBRATION PROCESS

In order to develop a representative linkage between the sources and the instream water quality response in the Leon River watershed, model parameters were adjusted to accurately represent hydrology and streamflow as well as fecal coliform bacteria loading and instream concentrations. Hydrologic parameters in the model were set and adjusted based upon available soils, land use, and topographic data. Bacteria loading parameters in the model were based upon the linkages with the various explicit and implicit sources described previously.

5.6.1 Hydrologic Calibration

Hydrologic calibration entails adjustment of pertinent model parameters in order to achieve agreement between simulated streamflow rates and observed streamflow rates. Ideally, a stream to be modeled will have one or more continuous streamflow gaging stations with long-term records available. These records would supply the data base of observed flows for a specific location within the stream segment.

There were several model parameters that were adjusted to achieve hydrologic calibration. Key parameters included the following:

LZETP - evapotranspiration from the root zone
AGWRC - recession rate for groundwater
IRC - recession rate for interflow
LSUR - length of overland flow plane
UZSN - soil moisture storage in the upper zone
LZSN - soil moisture storage in the lower zone
CEPSC - interception storage on pervious surfaces
INFILT - infiltration capacity of the soil
INTFW - soil water contributing to interflow
DEEPFRC - loss to lower groundwater storage
RETSC - interception storage on impervious surfaces

For the Leon River, continuous streamflow records are available at the USGS monitoring station no. 08100500, located at Hwy 84 at Gatesville, near the lower end of the stream study segment. Mean daily streamflow records for this station were obtained for application to the modeling analysis.

The hydrologic calibration for the Leon River focused upon quantitative comparison between simulated streamflow and observed streamflow at the location of the Hwy 84 USGS gaging station. In the Leon River model, this location corresponds to RCHRES 120. For the present analysis, the calibration period encompassed the years 2000 through 2004. Results for the entire calibration period are displayed in Figure 5-3. This figure shows simulated flow and observed flow as a function of time.

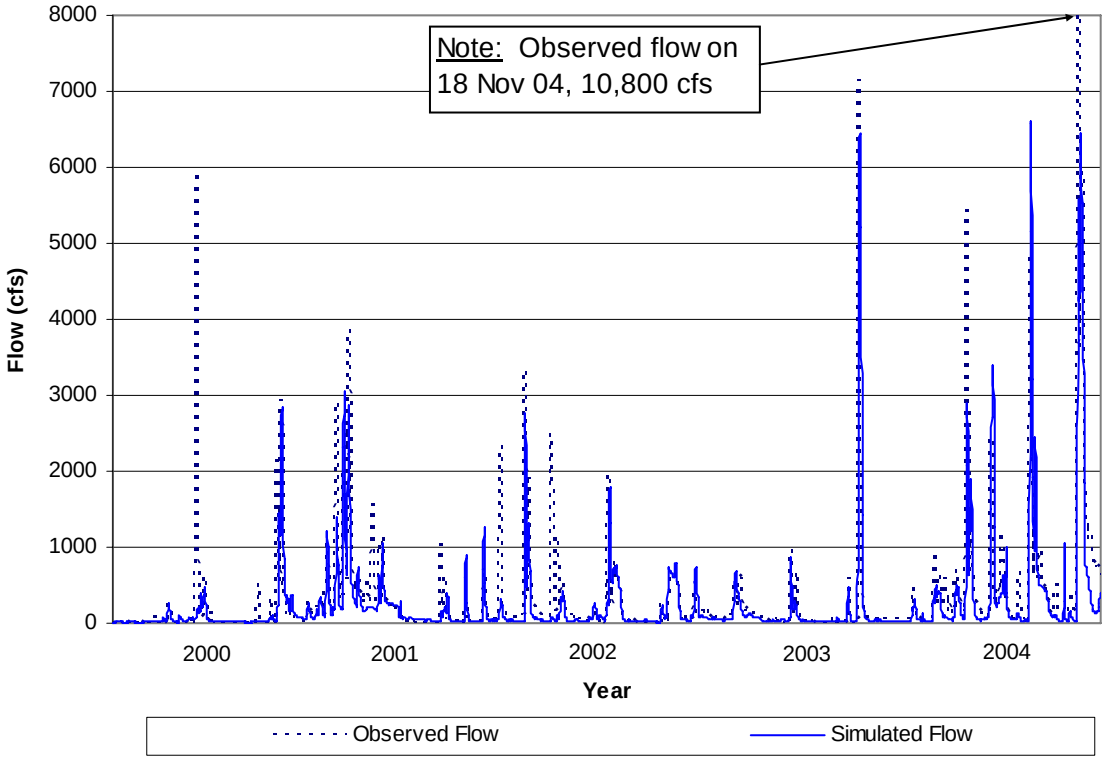

Figure 5-3 Hydrologic Calibration Results for Leon River at Hwy 84, 2000-2004

To provide some additional visual resolution, results are also presented for each individual simulation year in Figures 5-4 through 5-8. Precipitation records for the gage at Flat (see Figure 5-1) are also shown in these figures.

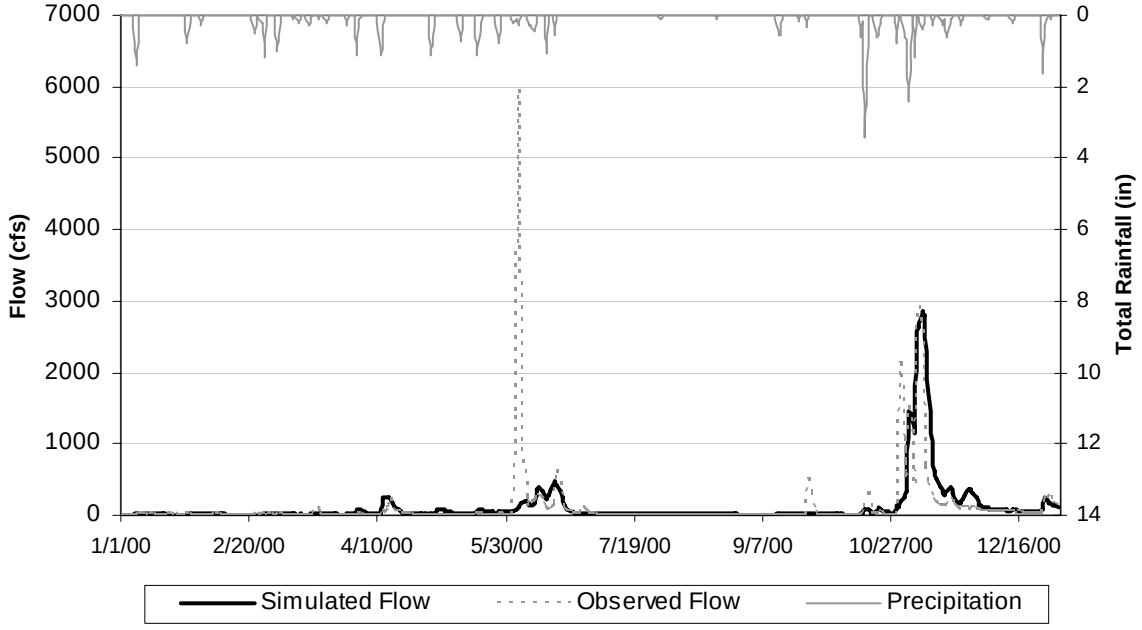

Figure 5-4 Hydrologic Calibration Results for Leon River at Hwy 84, 2000

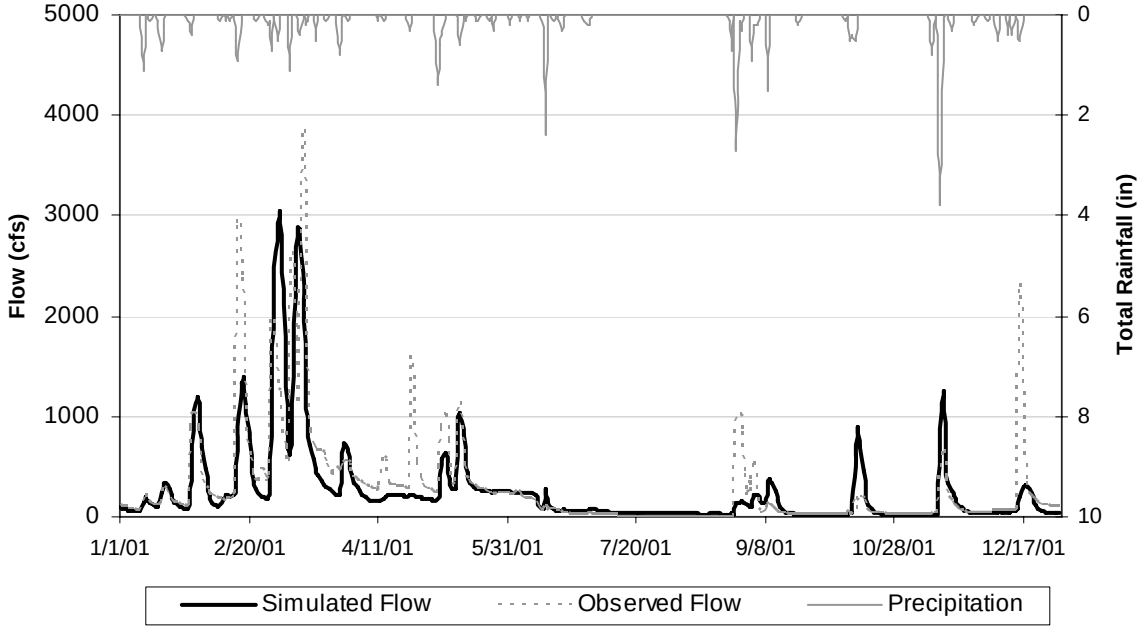

Figure 5-5 Hydrologic Calibration Results for Leon River at Hwy 84, 2001

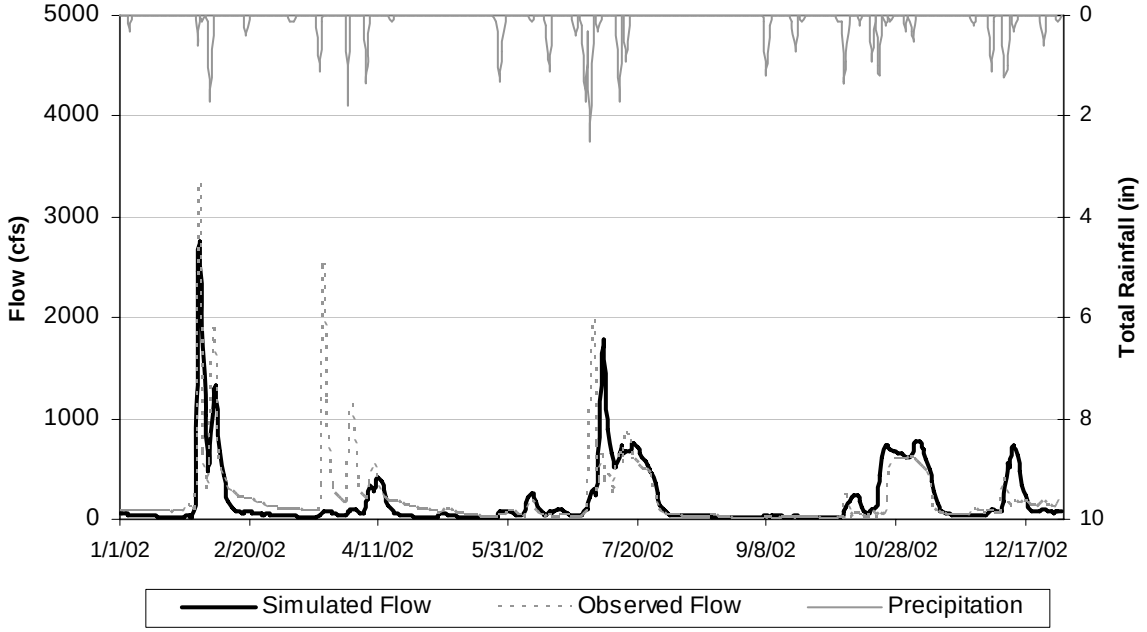

Figure 5-6 Hydrologic Calibration Results for Leon River at Hwy 84, 2002

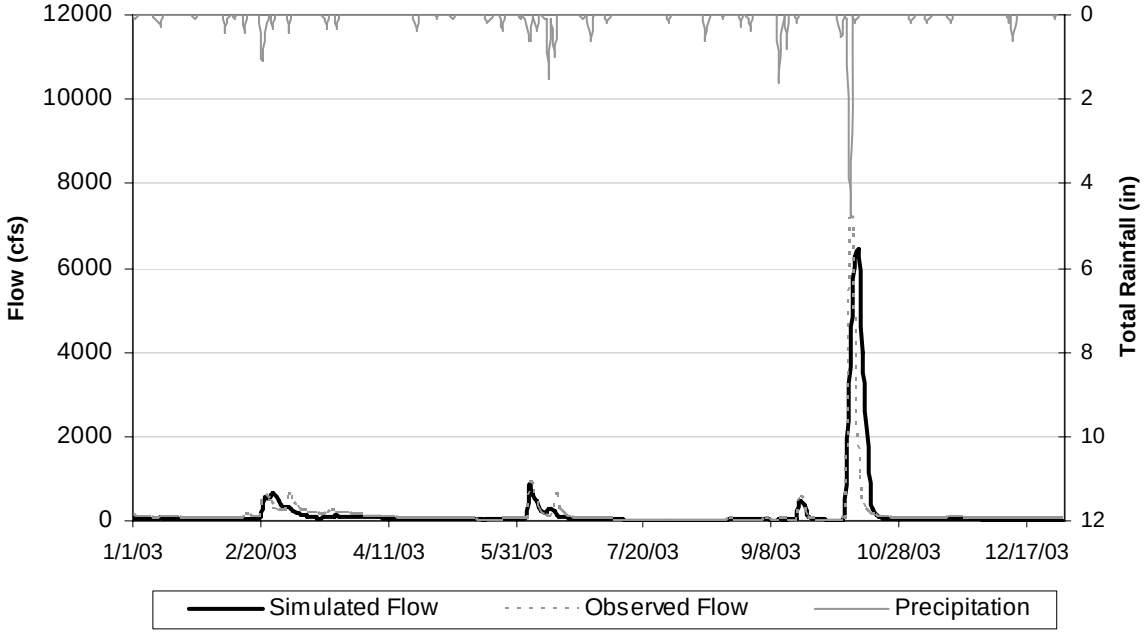

Figure 5-7 Hydrologic Calibration Results for Leon River at Hwy 84, 2003

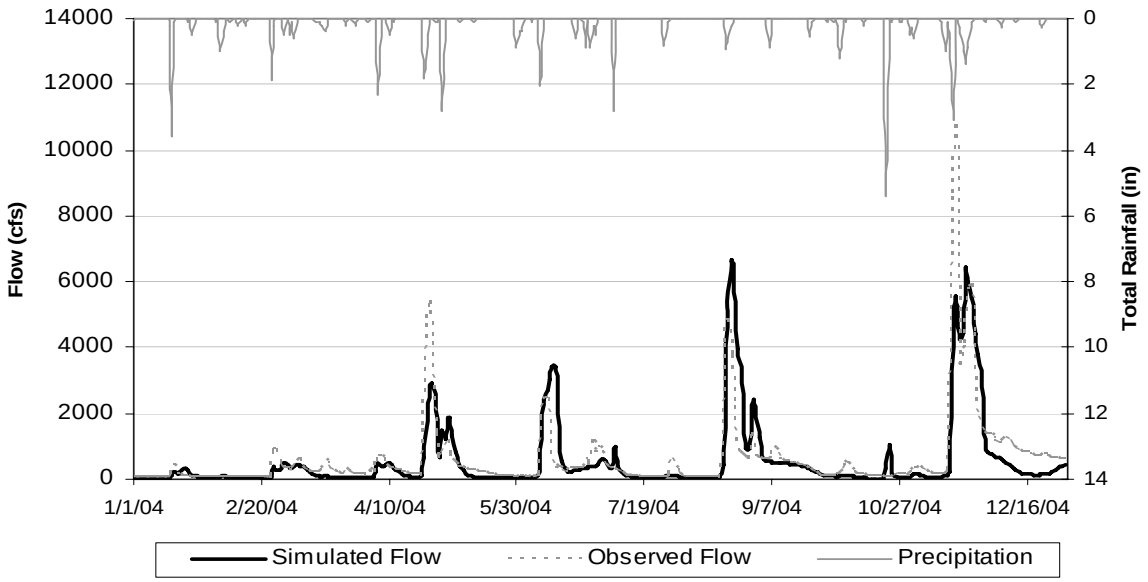

Figure 5-8 Hydrologic Calibration Results for Leon River at Hwy 84, 2004

Calibration statistics and their acceptable or desired ranges are summarized in Table 5-3 for the Leon River. The results indicate that the hydrologic calibration has been successfully achieved. The calibration generally demonstrates compliance with desired criteria. The model's largest percent error is associated with the category of summer storm volume, but it is still very near the criterion. This is understandable, because under summer conditions the prevalence of widely varying scattered thunderstorms is common, and this precipitation is what drives the hydrologic response. A flow duration curve for the Leon River is shown in Figure 5-9. A comparison of the observed and simulated average monthly runoff at RCHRES 120 is presented in Figure 5-10.

Table 5-3 Hydrologic Calibration Statistics for Leon River at Hwy 84, 2000-2004

Annual Averages	Simulated	Observed
Total flow (in/yr)	3.11	3.15
Highest 10% of flows (in/yr)	2.08	1.92
Storm flow (in/yr)	1.44	1.29
Storm peaks (cfs)	2877.1	3800.5
Summer flow (in/yr)	0.92	0.74
Winter flow (in/yr)	1.16	1.3
Summer storm flow (in/yr)	0.92	0.74
Winter storm flow (in/yr)	0.53	0.58

	% Error	Criteria
Total flow	-1.33	10%
Highest 10% of flows	8.49	15%
Error in storm peaks	-24.3	15%
Summer volume	24.01	25%
Winter volume	-11.23	25%
Summer storm flow	51.34	50%
Winter storm flow	-9.0	50%

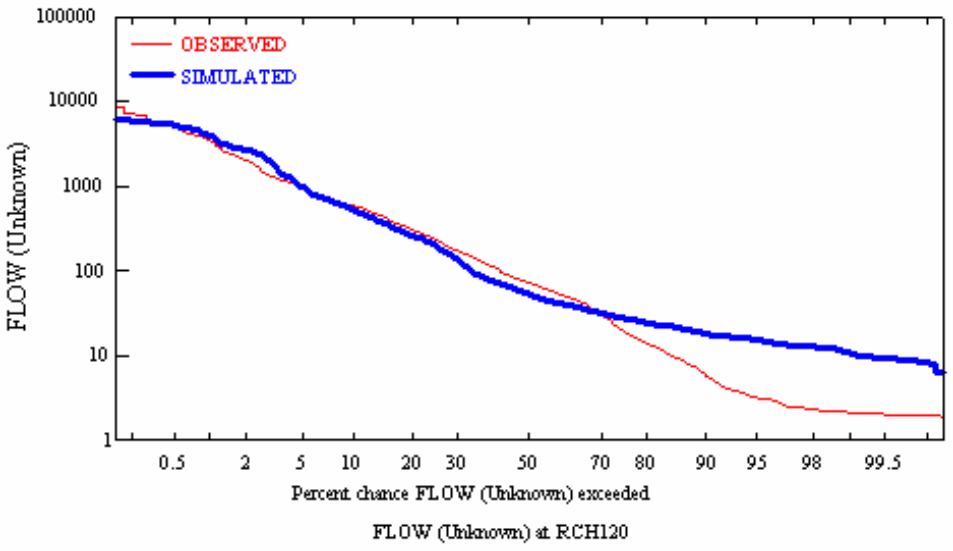

Figure 5-9 Flow Duration plot for Leon River at Hwy 84, 2000-2004

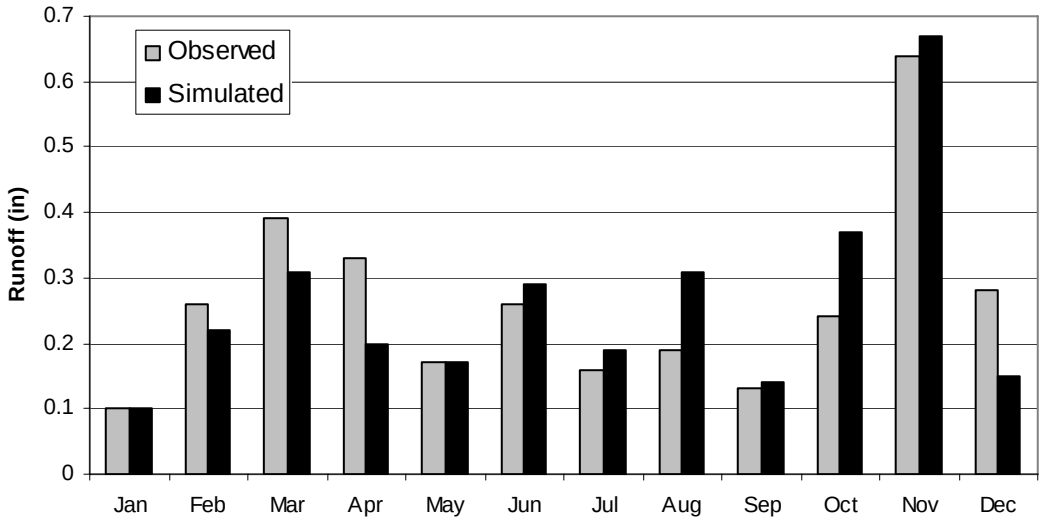

Figure 5-10 Comparison of Average Monthly Runoff for Leon River

5.6.2 Water Quality Calibration

Compared to the hydrologic calibration, water quality calibration is considerably more challenging. For hydrologic calibration, ample observed data is often available for the stream segment, typically consisting of continuous records of mean daily streamflow. By contrast, water quality calibration usually has to proceed with limited sets of observed data, and the data that is available typically consists of sporadically collected grab samples that each represent a single point in time.

For the present evaluation, the available water quality data set is somewhat limited. There are a few water quality monitoring stations with available fecal coliform data in the study reach, so the spatial

extent of data is acceptable. The frequency of data collection at several sites has historically been steady. And as is the case with almost all bacteria data bases, the available fecal coliform data set consists of grab samples that provide an instantaneous measurement of instream concentration, rather than a daily mean or an event mean concentration. Fecal coliform measurements exhibit a high degree of variability and an acceptable laboratory precision test may encompass as much as 1-log of variability (ten times greater to one-tenth of actual value). Despite these potential difficulties, the available bacteria data set for the study area is sufficient to accomplish the study objectives and it is comparable to data sets that have been successfully employed in other TMDL determinations.

The water quality calibration for the Leon River was conducted using available fecal coliform data for the Leon River study area for the period 2001 - 2004. Most of the available data originated from routine agency monitoring programs. Additional monitoring of bacteria concentrations was conducted in 2003 and 2004 in conjunction with the present study. The available data sets were examined closely for input to the model calibration process. This available water quality data base represents the site-specific data that is available for calibration of the model. Many of the bacterial loading parameters and variables in the modeling analysis are based upon assumptions and best professional judgment, but the measured values of fecal coliform bacteria concentrations within the Leon River provide the test for the validity of the multiple assumptions.

The population of available fecal coliform measurements at each monitoring station was analyzed to provide information that might establish approximate calibration targets for the stream. At any one monitoring station, the available data set typically consists of a set of grab samples that were collected under a range of streamflow conditions and that exhibit a substantial range of values. There is typically no direct correlation of streamflow rate and concentration. However, intuition would suggest and observations do indicate that there is some correspondence of higher bacteria concentrations with elevated streamflow rates. This correspondence was analyzed in detail for the bacteria data set at three key monitoring stations located on the Leon River study segment. Attendant streamflow and antecedent streamflow was analyzed for individual data points and each point was classified as either baseflow or runoff related. Statistical analysis of the baseflow and runoff data sets was conducted to define median values and 99 percent confidence intervals for each population. While these statistics on the limited historical data base provided guidance, the primary calibration benchmark was the achievement of a reasonable visual conformance between simulated and observed fecal coliform values.

Calibration of the Leon River model entailed adjustment of bacteria-related parameters to achieve agreement of the simulated model results with observed fecal coliform measurements. Several parameters were available for adjustment in the model. To achieve calibration under baseflow conditions, adjustment was made to parameters that represent continuous discharges and are not dependent upon transport via runoff mechanisms. For the present analysis, the primary parameter that was adjusted was the magnitude of loading derived from the category of direct sources. The direct sources category nominally includes contributions of fecal coliform from direct deposition from wildlife or livestock, but this type of continuous source could also include contributions of fecal coliform from failing septic systems and leaking wastewater collection system infrastructure. This direct source category could also represent other mechanisms that are difficult to quantify explicitly, including resuspension of bacteria associated with sediment and illicit discharges.

Calibration under runoff conditions was achieved through adjustment of parameters that relate to washoff of bacteria from land surfaces. The accumulation rate of bacteria on land surfaces (ACQOP) and the maximum accumulation (SQOLIM) were adjusted to render either more or less bacterial mass available for washoff. These bacterial accumulation rates represent the contributions from wildlife, livestock, and general urban loadings to the land surfaces in the watershed. The rate of surface runoff that will remove 90% of stored fecal coliform (WSQOP) was adjusted, which effects the proclivity for washoff to occur. These key model parameters were adjusted based upon the site-specific bacteria concentration data collected in the Leon River.

The final values for ACQOP and SQOLIM established in the calibration are shown in Table 5-4. Uniform values of ACQOP and SQOLIM were applied to all of the land use categories in the subwatersheds in the present study.

Table 5-4 ACQOP and SQOLIM Loading Rates

Description	ACQOP (10^6 counts/ac/d)	SQOLIM (10^6 counts/ac)
Forest	600	1,800
Cropland	300	900
Rangeland	600	1,800
Residential	5,000	15,000
Comm/Ind	3,000	9,000
Res. Impervious	2,500	7,500
Comm/Ind Imp.	1,500	4,500
WAF1	2,000	6,000
WAF2	2,000	6,000

Figure 5-11 shows the results of the calibration as simulated fecal coliform at US 281. The simulated results display good visual agreement with the available fecal coliform data. Note that the simulated fecal coliform values are mean daily concentrations, while plotted observed concentrations are for the most part instantaneous grab measurements. It would be unrealistic to expect simulated mean daily fecal coliform concentrations to match precisely observed grab sample concentrations. The degree of correspondence between simulated and observed values is similar to standards of performance exhibited in other TMDL determinations for bacteria. Comparison of baseflow and runoff population median concentrations for simulated results versus observations is summarized in Table 5-5. The calibration results shown in Table 5-5 indicate that the modeled concentrations closely correspond to the observed fecal coliform values.

Figure 5-11 Water Quality Calibration Results for Leon River at US 281, 2001-2004

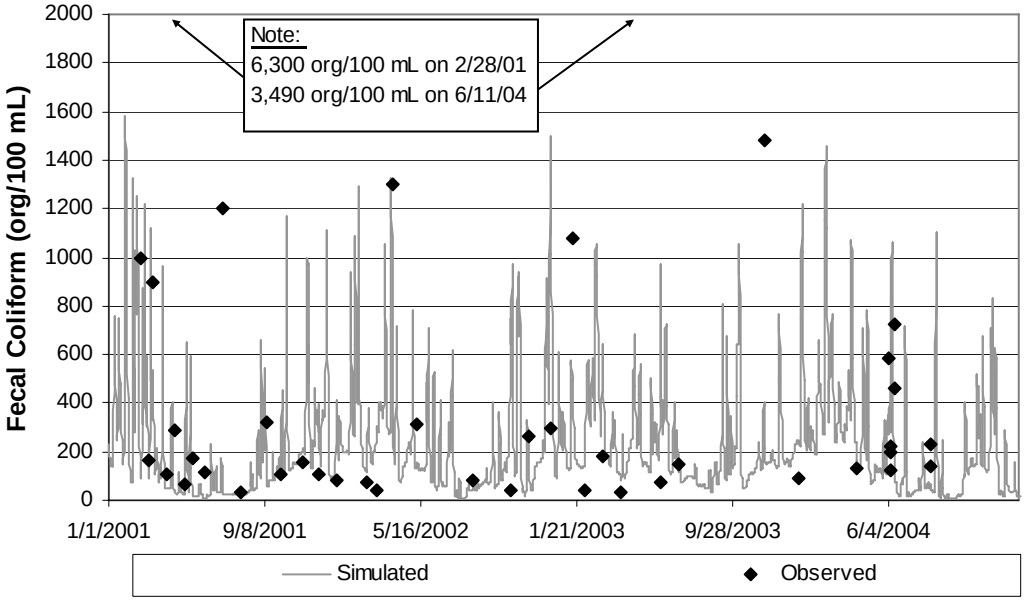

Figure 5-11 Water Quality Calibration for Leon River at US 281, 2001-2004

Table 5-5 Comparison of Observed and Simulated Fecal Coliform Concentrations

	Observed Concentration		Simulated Concentration
	Median	99% Confidence Range	Median
Key Mainstem Stations			
FM 1702 - RCH 41			
Baseflow	173	98 - 246	95
Runoff	820	535 - 1882	558
US 281- RCH 70			
Baseflow	113	73 - 169	63
Runoff	900	281 - 1397	488
SH 36 - RCH 130			
Baseflow	100	70 - 193	75
Runoff	1200	608 - 2643	522
Additional Stations			
US 377 - RCH 10			
Baseflow	113		112
FM 1476 - RCH 20			
Baseflow	308		358
CR 394 - RCH 60			
Baseflow	215		251

One additional check of the reasonableness of the water quality calibration was performed. A specific reach was selected and the model simulated bacterial loads emanating from each land use category were inventoried. These loads were then applied to the annual runoff volume emanating from each land use category in order to calculate an average annual runoff concentration. Reach 60 was selected for this analysis in the present study. The typical annual average runoff fecal coliform concentrations that were simulated in the modeling analysis for Reach 60 are displayed in Table 5-6. These simulated concentrations appear reasonable based upon best professional judgment. To obtain an additional perspective, the simulated values can be compared to ranges of typical concentrations reported in the literature, as shown in Table 5-7. It is apparent for this comparison that the fecal coliform concentrations simulated in the model are within the range of values reported from other studies.

Table 5-6 Typical Fecal Coliform Washoff Concentrations in Model (Reach 60)

Land Use	Concentration (org/100 mL)
Forest	2,800
Cropland	962
Rangeland	1,751
Residential	13,429
Comm/Ind	8,193
WAF1	5,431
WAF2	5,430
Residential Imp.	5,319
Comm/Ind Imp.	3,195

Table 5-7 Typical Fecal Coliform Washoff Concentrations in Other Studies

Land Use	Concentration (org/100 mL)
Forest	200 - 50,000
Cropland	200 - 10,000
Rangeland	200 - 50,000
Residential	5,000 - 50,000
Comm/Ind	5,000 - 50,000
WAF1	10,000 - 100,000
WAF2	10,000 - 100,000
Residential Imp.	5,000 - 50,000
Comm/Ind Imp.	5,000 - 50,000

The typical bacteria concentration ranges reported in Table 5-7 were derived from a variety of sources. The concentrations characteristic of urban land uses were based largely upon available bacteria data collected in two Texas cities, Austin and San Antonio, along with national-level data (Glick, 2005; Miller, 2005; EPA, 1986). Bacteria data for agricultural related land uses were derived from numerous available reports and studies from across the country that investigated bacteria concentrations in runoff from specific land use types (see for example, Baxter-Potter and Gilliland, 1988; Buckhouse and Gifford, 1976; Doran and Linn, 1979; Drapcho and Hubbs, 2003; Edwards, et al, 2000; Edwards, et al, 1997; Inamdar, et al, 2002; Kress and Gifford, 1984; Mau and Pope, 1999; Moore, et al, 1989; Ockerman, 2002; Robbins, et al, 1972; Selvakumar and Borst, 2004;

Smith and Douglas, 1973; Thelin and Gifford, 1983; Weidner, et al, 1969). Most of these studies examined bacteria runoff from grazed pastures and agricultural operations and the effects of factors such as loading rate, time, rainfall intensity, and distance. Though these various agricultural studies were located at various places throughout the country, it is expected that bacteria transport and processes resident within the Leon River watershed would be generally similar.

In many water quality modeling studies, calibration exercises are followed by a validation exercise, which typically entails exercise of the calibrated model and comparison to an independent set of observed measurements. This type of exercise is particularly valuable when two distinct set of observed conditions are present, for example, when simulating a dissolved oxygen sag below a wastewater discharge under first warm-weather, then cold-weather conditions, or under two distinctly different streamflow regimes. For the present analysis of bacteria concentrations, there does not exist a distinct set of observed data that reflect conditions that are not already embodied within the calibration data set. It was more important to apply the complete contemporary available bacteria data set to the calibration exercise, in order to have the greatest confidence in the calibration results.

The bacterial loads associated with the model calibration can be readily examined in terms of load originating from the land use categories and point sources embodied in the analysis. The simulated loads for the impaired reach of the Leon River (Reaches 10 through 70) are compared graphically in Figure 5-12 and are tabulated in the subsequent Table 6-2. The loads presented are the total annual average loads that enter the impaired stream, contributed by the various sources. The loads do not account for decay that occurs as the bacteria travel downstream.

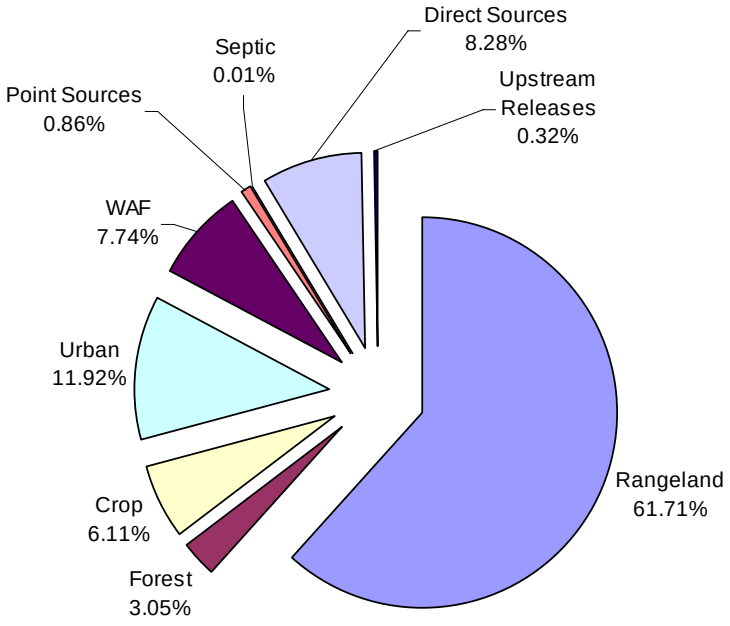

Figure 5-12 Comparison of Fecal Coliform Sources for the Leon River

For the study reach, it is apparent that the largest presumed source of fecal coliform bacteria is rangeland. This is attributable to the fact that rangeland is the largest land use category in terms of acreage, and it is the recipient of bacterial deposition from wildlife and livestock. The next largest contribution is estimated to be urban land uses, and the third largest source is shown to be the category of direct sources. The urban areas and WAFs have relatively small acreages but their assumed loading parameters are relatively large.

Now that the calibration of the water quality model is complete, it may be instructive to put in perspective some of the initial assumptions. Preceding sections described the development of initial estimates of livestock and wildlife populations by subwatershed. This was followed by calculation of the potential fecal coliform contributions from each source based upon application of literature values for mass of fecal material and bacterial density. These source representations were employed to develop initial values of ACQOP and SQOLIM for input into the modeling analysis. These initial values should be considered to represent the potential loading parameter values that are based upon numerous assumptions. The initial values of ACQOP and SQOLIM underwent substantial adjustment during the process of model calibration. Typically, the initial values to establish loading parameters were reduced substantially to achieve model calibration, typically arriving at values that were 1 – 10% of the initial theoretical value. The exception to this trend was the adjustment of urban land use contributions. These areal loading rates were increased substantially in the calibration process. So, this discussion should illustrate that the model calibration is not directly related to the initial assumptions on animal counts. Even if the initial counts were substantially revised, it would not necessarily affect the ultimate calibration of the model.

5.7 SENSITIVITY ANALYSIS

Sensitivity analyses were conducted to demonstrate the effects of variability in key modeling parameters. This type of analysis provides an indication of the impacts of various assumptions and calibration parameters.

The following parameters were selected for the sensitivity analysis:

ACQOP - the bacterial areal loading rate to land surfaces, in units of 10^6 org/acre/day. This is a key calibration parameter for washoff of bacteria from land surfaces during runoff conditions. It represents the cumulative daily loading of bacteria from a variety of potential sources, including wildlife and livestock, that is deposited on the land surface and subsequently available for washoff by runoff. Calibration values for ACQOP were developed for each land use category empirically during the calibration exercises. Values range from approximately 400 – 9000 10^6 org/acre/day in the model (see Table 5-4 for loading rates). Larger ACQOPs would represent larger numbers of bacteria deposited daily.

SQOLIM - the maximum accumulation of bacteria on the land surfaces, in units of 10^6 org/acre. This is a key calibration parameter that affects the washoff of bacteria from land surfaces during runoff conditions. It accounts for the decay of bacteria deposited on the land surface by establishing a maximum value that can be in place, available for washoff. Calibration values for SQOLIM were developed for each land use category empirically during the calibration exercises, and were set at three times the ACQOP. In effect, this limits the

amount of bacteria available for washoff to three days of accumulation. A larger SQOLIM would mean that more bacteria are allowed to accumulate on the land surfaces.

FSTDEC - the first-order decay rate for bacteria, in units of 1/day. This is a key calibration parameter that effects bacteria numbers within the watercourse. It accounts for the decrease in bacteria numbers, or die-off, as they are transported downstream. The value used in calibration was 0.7 / day in the impaired reach. A larger decay rate would mean that bacteria die-off more rapidly.

WQSOP - the rate of surface runoff required to remove 90% of the bacteria accumulated on the land surfaces, in units of inches/hour. This is a key calibration parameter that affects the ability of deposited bacteria to be washed off the land surfaces during runoff conditions. It specifies the runoff rate and relates it to the ease with which bacteria are removed from the land surfaces. Two values for WQSOP were used in the calibration; a rate of 1.8 inches/hour was specified for PERLND (pervious) land surfaces, while a rate of 1.0 inches hour was specified for IMPLND (impervious) land surfaces. A larger WQSOP would mean that a larger runoff rate is needed to remove bacteria, in effect making it more difficult for the bacteria to wash off the surface.

Direct Nonpoint Sources - the contributions of bacteria directly to the receiving stream from wildlife, livestock, and leaking septic systems, in units of 10^6 org/day. This is a key source loading of bacteria in the modeling analysis under lower flow conditions, since this mechanism is not related to runoff. It was developed empirically during the calibration exercises. A larger value for direct nonpoint source would mean a larger contribution from the various potential sources that contribute directly to the stream.

Proctor Lake Boundary Condition - the bacteria loading from the reservoir, in units of 10^6 org/day. This is a significant source loading of bacteria in the modeling analysis, particularly under lower flow conditions. It was based upon data for releases from the reservoir provided by the USACE and historical monitoring data for bacteria at the dam floodgate (TCEQ monitoring station #11935). A larger value would represent a higher concentration and therefore higher load from the reservoir.

Each of the preceding parameters was analyzed individually at a level of plus or minus 50% of the base value. In this parlance, the base value is the calibrated set of model coefficients and parameter values. The ACQOP and SQOLIM were analyzed individually and, in addition, as a paired set of values where the inter-parameter ratio employed in the model was maintained. In other words, when ACQOP was varied by plus or minus 50%, the SQOLIM was varied accordingly, consistent with the fundamental assumption in the base case.

For each sensitivity condition, the model was rerun and results obtained as simulated daily bacteria concentrations for the period 2001 - 2004. To facilitate comparison of the results, the daily bacteria concentrations simulated at Hwy 281 (RCHRES 70) were transformed to moving 91-day geometric mean values. Plots for each parameter are displayed in Figures 5-13 through 5-19. In these plots, only the geometric mean values for the year 2004 are presented in order to amplify the results.

In Figure 5-13 are shown the results for the sensitivity analysis on ACQOP. Variation of this parameter individually demonstrated relatively small differences in the results. The range of plus or minus 50% represents a reasonable range for ACQOP, but actual values could be much higher.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
ACQOP	10^6 org/ac/d	Bacterial areal loading rate	400-9000, depending on land use category	Relatively small differences in results; simulated instream bacteria concentration change less than 10% on geometric mean	Relates to bacteria washoff during runoff; cumulative loading of bacteria from wildlife, livestock to the land surface; +/- 50% could relate to total number of animals in the watershed

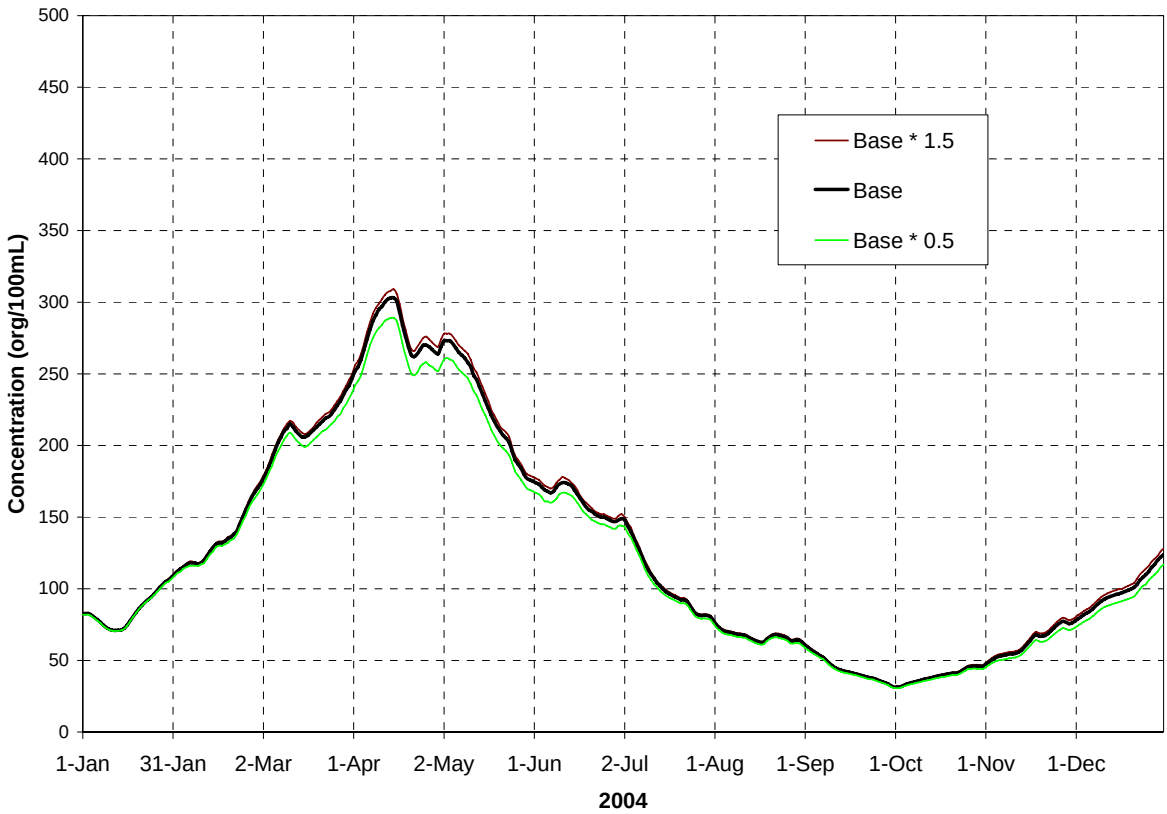

Figure 5-13: ACQOP Sensitivity Analysis, 91-Day Geometric Mean

The sensitivity analysis on SQOLIM is shown in Figure 5-14. Variation of this parameter individually showed a moderate amount of differences in the results, compared to the base case. The range of plus or minus 50% represents a reasonable range for SQOLIM, but actual values could be much higher.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
SQOLIM	10^6 org/ac	Bacteria maximum accumulation	1200-27000, depending on land use category	Moderate differences in results; simulated instream bacteria concentration change 15-25% on geometric mean	Relates to bacteria washoff during runoff; maximum loading of bacteria from wildlife, livestock to the land surface that can accumulate; 3 days of accumulation base, so sensitivity looked at 1.5 – 4.5 days

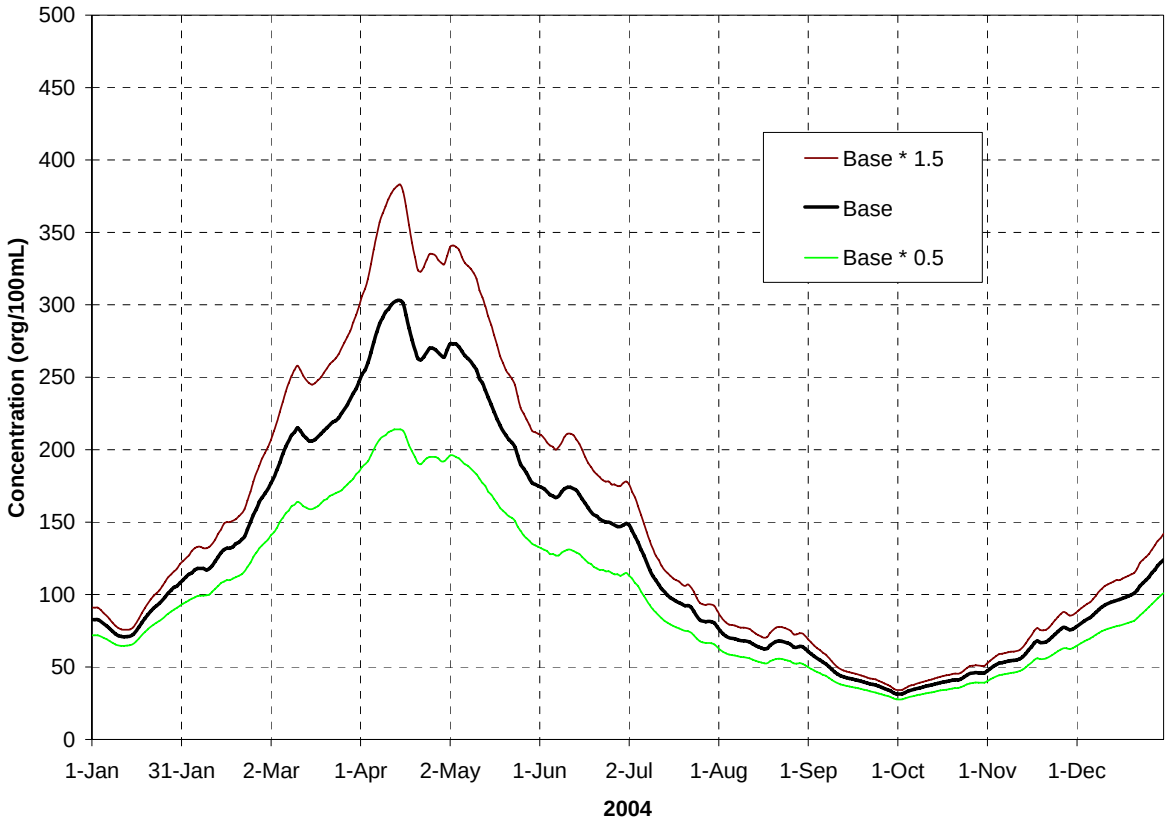

Figure 5-14: SQOLIM Sensitivity Analysis, 91-Day Geometric Mean

The sensitivity analysis on the paired combination of ACQOP and SQOLIM is shown in Figure 5-15. A moderate difference in results was demonstrated by variation of the paired parameters.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
ACQOP & SQOLIM pair	10^6 org/ac/d and 10^6 org/ac	Bacterial areal loading rate and maximum accumulation	ACQOP at 400-9000; SQOLIM at 1200–27000 depending on land use category	Moderate differences in results; simulated instream bacteria concentration change 15-30% on geometric mean	Relates to bacteria washoff during runoff; cumulative loading of bacteria from wildlife, livestock to the land surface and maximum accumulation; +/- 50% change in the paired combination of the loading parameters

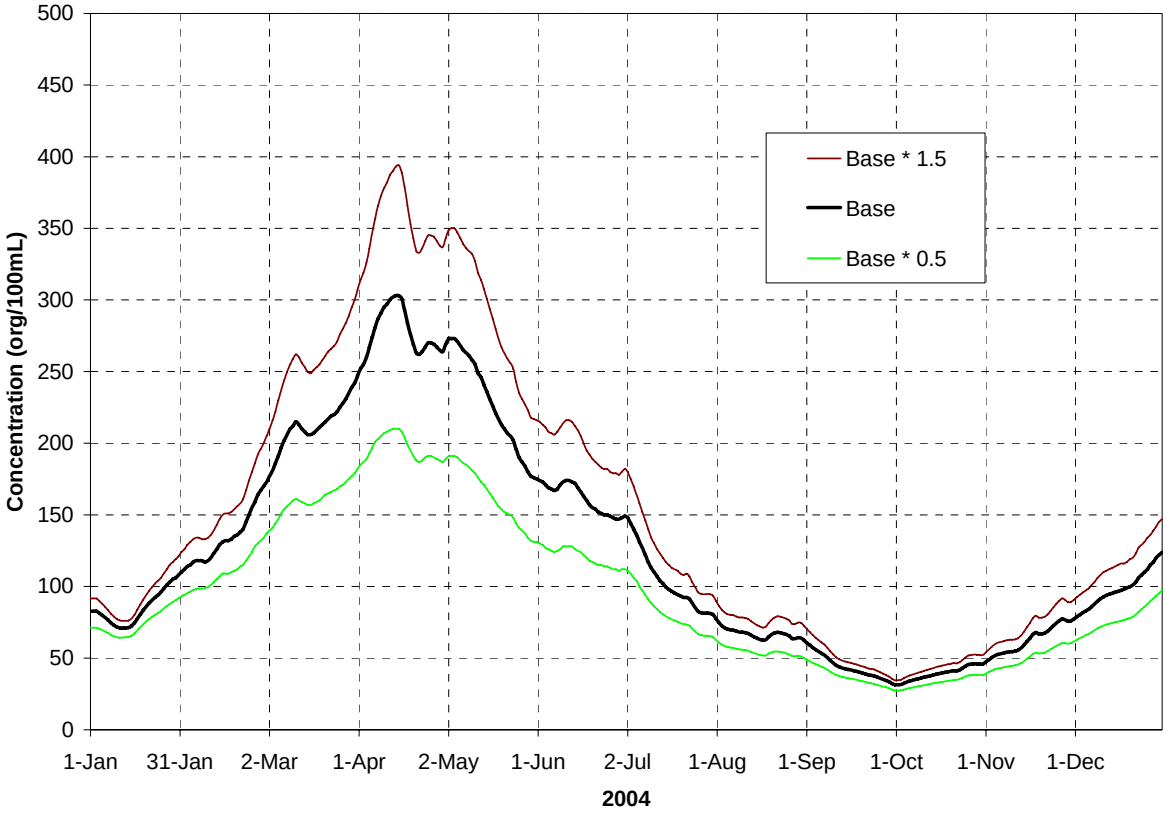

Figure 5-15: ACQOP & SQOLIM Sensitivity Analysis, 91-Day Geometric Mean

In Figure 5-16 are displayed the sensitivity results for FSTDEC. Variation of this parameter over a range of plus or minus 50% had a relatively large effect on the simulation results. The range of plus or minus 50% represents a reasonable range for the first-order decay coefficient in watercourses.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
FSTDEC	1/day	Bacterial decay rate	0.7/day	Large differences in results; simulated instream bacteria concentration change 30-50%on geometric mean	Rate at which bacteria die off in the stream, after they are introduced by point or nonpoint sources; at rate of 0.7/d approx half die in one day

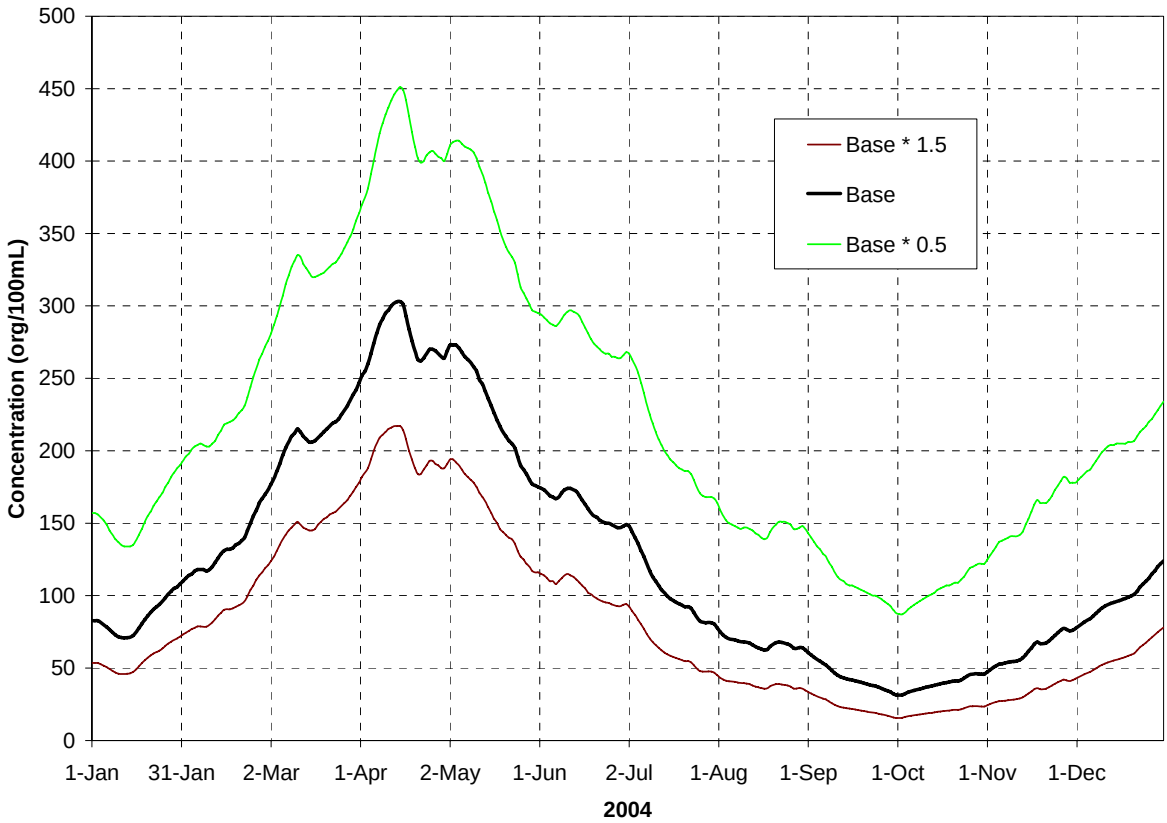

Figure 5-16: FSTDEC Sensitivity Analysis, 91-Day Geometric Mean

Figure 5-17 shows the results of the sensitivity analysis for WQSOP. Differences from variation of this parameter are relatively small to large in magnitude. The range of plus or minus 50% represents a reasonable range for the runoff rate.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
WQSOP	In/hr	Surface runoff rate required to wash off 90% of bacteria mass	1.8 for pervious, 1.0 for impervious surfaces	Small to large differences in results; simulated instream bacteria concentration change 0-40%on geometric mean	Effects washoff of bacteria during runoff; larger WQSOP means that larger runoff rate is needed to wash off bacteria; the runoff rate in the model is usually low

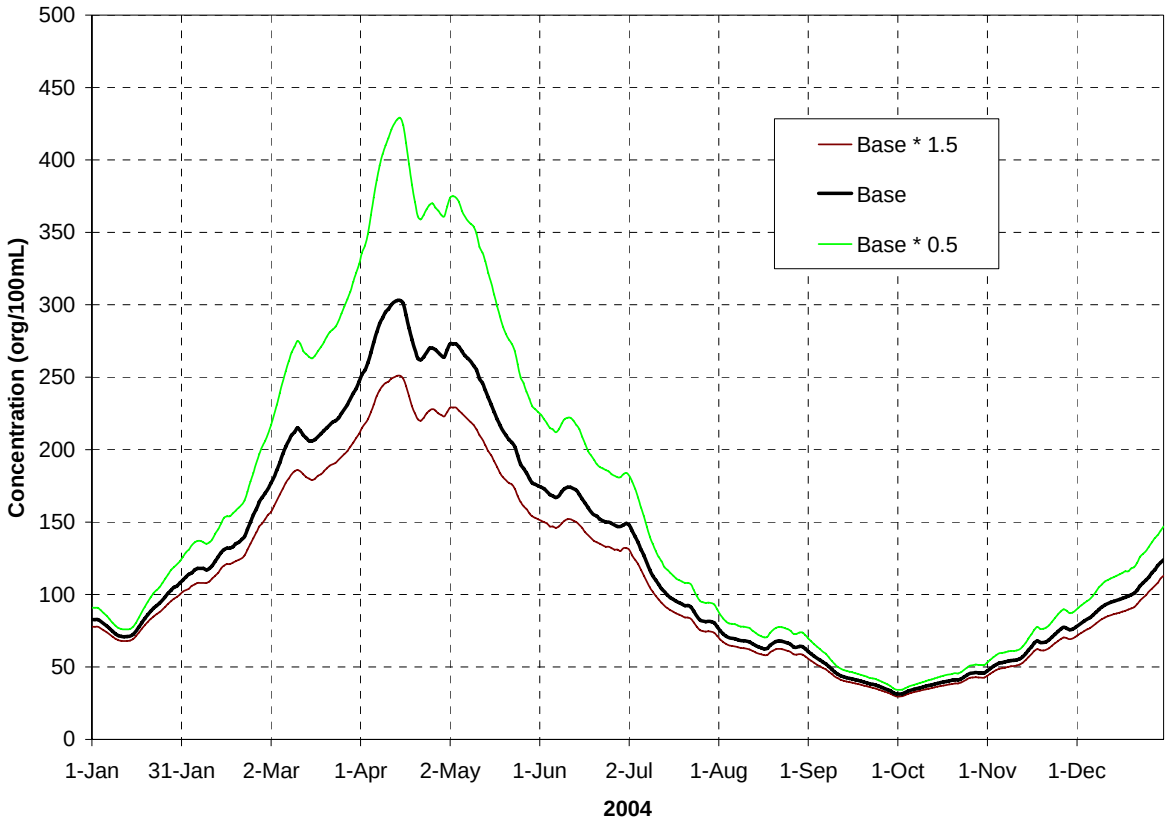

Figure 5-17: WQSOP Sensitivity Analysis, 91-Day Geometric Mean

Sensitivity to variation of direct nonpoint sources is illustrated in Figure 5-18. The observed effects of variation are relatively small. Actual values of direct nonpoint sources could vary by more than the tested range of plus or minus 50%, with potential values much higher.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
Direct nonpoint sources	10^6 org/d	Direct bacteria concentrations to the stream	12000-144000 10^6 org/d, depending on reach	Relatively small differences in results; simulated instream bacteria concentration change 5-10% on geometric mean	Related to direct input of bacteria to stream from wildlife, livestock, septic systems, or sewage collection systems; not related to runoff

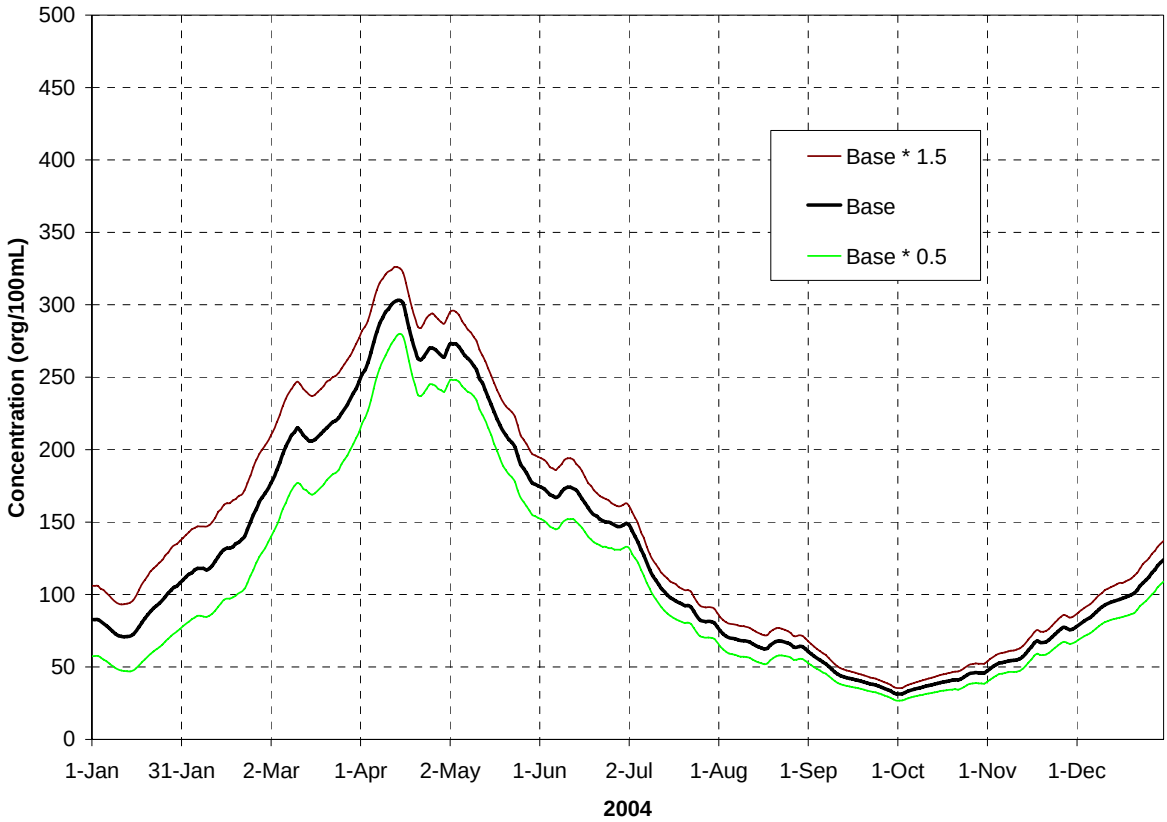

Figure 5-18: Direct NPS Sensitivity Analysis, 91-Day Geometric Mean

Effects of variation of the bacteria loading from Proctor Lake are shown in Figure 5-19. Variation of this parameter demonstrated a relatively small difference in results. The range of plus or minus 50% is probably a reasonable range for this source, though for short term releases values could be substantially higher.

PARAMETER	UNITS	DEFINITION	VALUE IN CALIBRATION	RESULTS OF +/- 50% SENSITIVITY	INTERPRETATION
Proctor Lake input	10^6 org/d	Bacteria contribution from lake releases	Average 260000 10^6 org/d	Relatively small differences in results; simulated instream bacteria concentration change 0-15% on geometric mean	Bacteria in releases from lake; +/- 50% has relatively small effect; input directly into stream

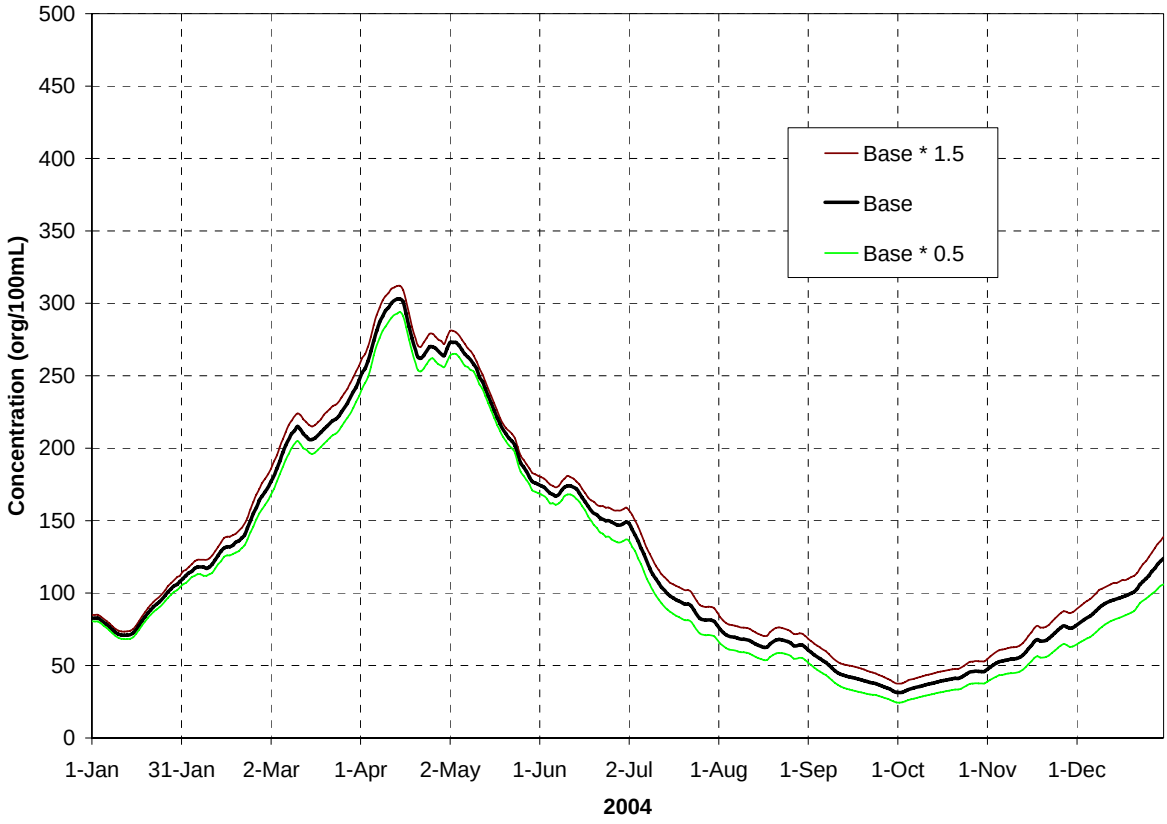

Figure 5-19: Proctor Lake Loading Sensitivity Analysis, 91-Day Geometric Mean

6.0 TMDL METHODOLOGY

6.1 TMDL CALCULATION

Total maximum daily loads (TMDLs) are the sum of the individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background conditions, and a margin of safety (MOS). The TMDL equation is written as follows:

TMDL = WLA + LA + MOS

The TMDL defines the total amount of a pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards. For fecal coliform bacteria, TMDLs are expressed in terms of bacteria counts or resulting concentration. The WLA portion of this equation is the total loading assigned to traditional point sources, such as domestic wastewater treatment plants. The LA portion of this equation represents the loading assigned to nonpoint sources, which would include washoff from land surfaces, direct deposition from animals, and leaking septic systems or collection system mains. The MOS is the portion of the loading that is assigned to represent any uncertainty in the data and the modeling process.

The TMDL target was established as a fecal coliform geometric mean value of 200 org/100 mL, based on the bacteria criteria specified in the Texas Water Quality Standards. An explicit MOS of 5 percent was employed in the TMDL calculations. This 5 percent MOS amounts to 10 org/100 mL, referencing the geometric mean criterion. Application of the model to the TMDL determination then was based on achievement of compliance with an instream geometric mean of 190 org/100 mL. In addition to the explicit MOS, implicit MOS factors were also incorporated into the TMDL development process through the use of conservative model assumptions and source load estimates.

The HSPF model was developed for the study area and was employed to simulate instream bacterial counts for the period 2001 through 2004. For TMDL determinations, the model was applied to simulate various allocation scenarios that could result in partial attainment or full attainment of water quality standards.

6.2 WASTELOAD ALLOCATIONS

In the Leon River study segment, there are several significant point source discharges in existence. In the upper reaches of the study segment, there exist three domestic wastewater treatment point sources that contribute loadings to the impaired reach. Two of the municipal treatment plants (Cities of Comanche and Gustine) are mechanical plants that include disinfection unit processes prior to discharge, which would ordinarily be expected to reduce bacteria concentrations to negligible amounts. However, plants with disinfection facilities may still have problems due to equipment malfunctions, operational errors, or insufficient design. Generally, problems are most likely to occur under conditions of high inflow, which put the greatest demands on the treatment system. These plants also have occasional to frequent overflows and bypasses from their sewage collection systems, as documented in TCEQ data files.

The Dublin treatment facility consists of facultative lagoons. This treatment facility does not include a chemical disinfection unit process. Substantial reduction in bacteria numbers is achieved via provision of 21 days of detention time within the pond system, during which bacteria are eliminated by solar radiation and other natural processes. These types of treatment facilities may not be able to provide sufficient hydraulic retention time under conditions of rainfall-induced peak flows, therefore, there is no mechanism to control the concentration of bacteria that might be discharged. Self-reporting monitoring data for this facility does indicate that fecal coliform bacteria are discharged.

The present analysis indicates that substantial reduction in fecal coliform loading to Leon River from a variety of sources is necessary in order to achieve compliance with stream criteria. Therefore, it is prudent to impose a WLA reduction for the three domestic wastewater treatment plants that are located above or within the impaired zone in order to meet the overall wasteload allocation. A 70% reduction in existing load has been assigned to the domestic wastewater point sources, based upon consideration of several loading control scenarios described subsequently in this section. This reduction would theoretically apply to both routine discharges from the facilities and to any periodic overflows from the plant or collection system. The WLAs determined for the study area are displayed in Table 6-1.

Table 6-1 WLAs for Point Source Fecal Coliform Loads in Impaired Reach

Point Source	Routine FC Load (org/yr)	Overflow FC Load (org/yr)	Total FC Load (org/yr)	% Reduction	FC WLA (org/yr)
City of Dublin WWTP	1.54E+11	8.60E+12	8.75E+12	70	2.63E+12
City of Comanche WWTP	2.75E+09	4.30E+12	4.30E+12	70	1.29E+12
City of Gustine WWTP	1.38E+10	4.05E+11	4.19E+11	70	1.26E+11
Totals:	1.71E+11	1.33E+13	1.35E+13		4.04E+12

While the magnitude of the bacteria loads from point sources may be small relative to the land-based washoff bacteria loads, their contribution is important particularly under baseflow conditions in the impaired reach of the Leon River.

A logical question would be to define the nature and scope of potential improvements that point sources might have to initiate in order to achieve the WLA objectives. The details of potential improvements or control measures will be developed in the implementation phase of the TMDL with stakeholder participation. But at this point in time, it would appear that the municipal point sources would be required to maintain compliance with disinfection requirements at the permitted treatment facilities, and possibly implement improvements to make the disinfection processes more reliable. In addition, it is likely that an evaluation of the sanitary collection system would be needed, that would identify the condition of sewer lines, potential problem areas, and steps that could be implemented to minimize overflows and bypasses.

6.3 LOAD ALLOCATIONS

Load allocations for nonpoint sources include land-based washoff loadings and direct discharge nonpoint source loadings. The land-based loadings originate via washoff of bacteria from land surfaces in the watersheds of the impaired reach under rainfall runoff conditions. The direct

discharge nonpoint source loadings represent direct deposition from animals (including wildlife, livestock, and pets), and potentially leaking wastewater collection mains. In the modeling analysis, the category of direct sources includes the animal deposition directly into the stream, along with any other unspecified bacterial loadings that may exist. The category of septic loads is modeled separately from the direct source category, but they are both similar in that they represent known and unknown sources of bacteria that are discharged continuously to the stream and that are not associated with rainfall runoff.

The load allocation component of the TMDL incorporates background loadings within the impaired reach, which include aspects of both the land-based source loadings and the direct source loadings. Specifically, the background load from wildlife is included as deposition of bacteria onto land surfaces that is subject to subsequent washoff under rainfall runoff conditions, and as direct deposition into receiving streams. Another background loading included in the modeling analysis is the incoming bacteria load associated with releases from Proctor Lake into the headwater of the impaired reach.

The existing average annual bacterial loads that were estimated for the impaired reach of the Leon River through the model calibration exercises are displayed in Table 6-2. Loads, presented as organisms per year, are tabulated for each land use category and for each stream reach. The reach of the Leon River that has been designated as impaired by the TCEQ includes generally the reaches 30, 41, 50, and 70. Inclusion of headwater reaches and tributary reaches brings in reaches 10, 20, 40, and 60 into the impaired zone analysis. Therefore, complete analysis of the impaired zone requires examination of reaches 10 through 70. The loads presented are the total annual average loads that are simulated by the model to enter the impaired stream. The loads do not account for decay that occurs as the bacteria travel downstream.

Table 6-2 Existing Fecal Coliform Loads for Impaired Reach

RCHRES	Name	Washoff Pervious Categories (org/yr)						
		Forest	Crop/ Pasture	Rangeland	Residential	Commercial /Industrial	WAF1	WAF2
RCHRES 10	Leon River	6.57E+11	1.67E+12	6.68E+12	2.06E+12	9.08E+11	0.00E+00	0.00E+00
RCHRES 20	Walnut Creek	2.10E+12	4.19E+12	3.08E+13	3.22E+11	9.05E+11	2.19E+12	1.61E+13
RCHRES 30	Leon River	9.99E+12	3.56E+13	1.65E+14	1.98E+13	5.62E+12	7.16E+12	1.75E+13
RCHRES 40	South Leon River	1.15E+13	2.03E+13	3.09E+14	3.78E+09	1.88E+12	2.45E+12	3.50E+12
RCHRES 41	Leon River	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RCHRES 50	Leon River	4.50E+12	9.14E+12	7.82E+13	0.00E+00	1.17E+12	9.91E+12	2.32E+12
RCHRES 60	Resley Creek	8.63E+12	1.23E+13	1.31E+14	1.56E+13	5.83E+12	2.31E+13	2.61E+13
RCHRES 70	Leon River	1.05E+13	1.25E+13	2.46E+14	1.79E+12	1.86E+12	7.85E+12	3.20E+12
Totals		4.78E+13	9.57E+13	9.67E+14	3.96E+13	1.82E+13	5.27E+13	6.87E+13

RCHRES	Name	Washoff Impervious Categories (org/yr)		Discharge Categories (org/yr)			
		Residential	Commercial/ Industrial	Direct Sources	Septic Load	Upstream Releases	Point Sources
RCHRES 10	Leon River	2.76E+12	4.48E+12	8.71E+12	5.05E+09	5.00E+12	0.00E+00
RCHRES 20	Walnut Creek	3.51E+11	3.61E+12	1.03E+13	2.32E+09	0.00E+00	0.00E+00
RCHRES 30	Leon River	2.64E+13	2.77E+13	2.84E+13	4.96E+10	0.00E+00	4.29E+12
RCHRES 40	South Leon River	5.06E+09	9.27E+12	3.31E+13	1.63E+10	0.00E+00	0.00E+00
RCHRES 41	Leon River	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.18E+11
RCHRES 50	Leon River	0.00E+00	4.66E+12	1.39E+13	4.65E+09	0.00E+00	0.00E+00
RCHRES 60	Resley Creek	1.70E+13	2.32E+13	2.34E+13	2.32E+10	0.00E+00	8.74E+12
RCHRES 70	Leon River	1.94E+12	7.53E+12	1.18E+13	2.09E+10	0.00E+00	0.00E+00
Totals		4.85E+13	8.05E+13	1.30E+14	1.22E+11	5.00E+12	1.35E+13

Several scenarios for best management practices (BMP) application were examined in order to assess options for loading allocation scenarios for the watershed. The scenarios constitute various combinations of percent removals applied as BMPs to the bacteria loads that emanate from the watersheds that contribute to the impaired reach of the Leon River. In the model, this was accomplished for washoff-based loadings by application of a module that allows specification of a percent of load removal by land use category. Other direct sources of loadings were adjusted in the model with appropriate multipliers to effect reductions. The percent removals are in terms of the load that emanates from the source and that subsequently reaches the stream. For example, Scenario 1 includes a 30% reduction in bacterial loads originating from the forest land use category, in combination with other reductions specified for loads originating from other land uses. Multiple scenarios were formulated, resulting in various degrees of compliance with the existing bacteria criterion target. Table 6-3 summarizes the various scenarios examined.

In Table 6-3 are also displayed the number of days of exceedance of the 91-day criteria associated with each control scenario. Columns are provided for the number of days that a concentration of 190 org/100mL is exceeded (the criterion with the MOS), as well as the number of days of exceedance of the actual fecal coliform criterion of 200 org/100mL. Recall that the total simulation period was 2001 through 2004 for the BMP control scenarios. The number of days of exceedance provides an indication of the extent of time that the criteria are not met with each scenario.

Based upon the results shown in Table 6-3, any of the control scenarios where exceedances of the geometric mean are limited to the range between 190 and 200 org/100mL should be considered to achieve compliance with the objectives of the TMDL. Recall that the value of 190 org/100 mL was postulated as the target criterion including a margin of safety. Therefore, if it is determined that a geometric mean value falls between 190 and 200 org/100 mL, it is not rigorously an exceedance per se, but instead is an indication that the explicit (and arbitrary) MOS has been intruded upon. In such cases, the analysis simply has, in effect, a lower MOS applied for those days. This should be an acceptable outcome, given the numerous assumptions and uncertainties embedded within the analysis.

The results of the various BMP application scenarios can also be viewed graphically. Model output can be plotted to display differences between existing conditions and the allocation conditions. For this purpose, the daily calculation of the 91-day geometric mean bacteria concentration is employed. The corresponding time series of geometric mean fecal coliform for existing and selected BMP application scenarios are shown in Figure 6-1 through Figure 6-4 for the key water quality station at Hwy 281 (Reach 70 in the model). Plots are presented for scenarios number 1, 3, 4, and 10 from Table 6-3. These cases are sufficient to display the patterns of the 91-day geometric means.

Table 6-3 Percent Reduction Applied in Different Allocation Scenarios

Scenario	Land Washoff Categories							Discharge Categories			91-Day Mean Excursions* (4-year period)			
	Forest	Crop / Pasture	Range land	Res-idential	Comm / Industrial	WAF1	WAF2	Point Source	Septic Source	Direct Source	190 org/100mL #days	190 org/100mL %days	200 org/100mL #days	200 org/100mL %days
Base	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	654	45%	618	42%
1	30%	30%	30%	30%	30%	30%	30%	50%	50%	50%	92	6%	68	5%
2	30%	30%	30%	30%	30%	30%	30%	90%	50%	50%	84	6%	66	5%
3	30%	30%	30%	30%	30%	30%	30%	50%	20%	20%	345	24%	267	18%
4	10%	10%	10%	30%	30%	30%	30%	50%	20%	20%	419	29%	354	24%
5	10%	10%	10%	30%	30%	30%	30%	50%	50%	50%	189	13%	141	10%
6	10%	10%	10%	80%	80%	30%	30%	90%	50%	50%	57	4%	33	2%
7	20%	20%	20%	80%	80%	30%	30%	90%	50%	50%	30	2%	0	0%
8	20%	20%	20%	80%	80%	30%	30%	90%	50%	60%	1	0%	0	0%
9	10%	10%	10%	80%	80%	30%	30%	90%	50%	70%	19	1%	0	0%
10	10%	10%	10%	80%	80%	30%	30%	70%	70%	70%	19	1%	0	0%

*Based on simulated results for Hwy 281

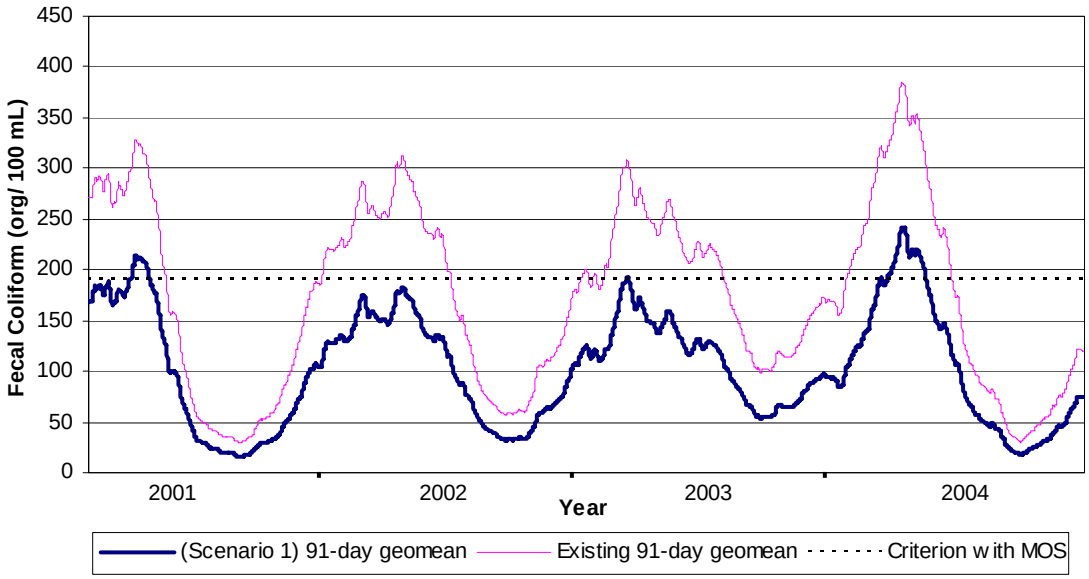

Figure 6-1 Fecal Coliform Results for BMP Scenario 1, Leon River at Hwy 281

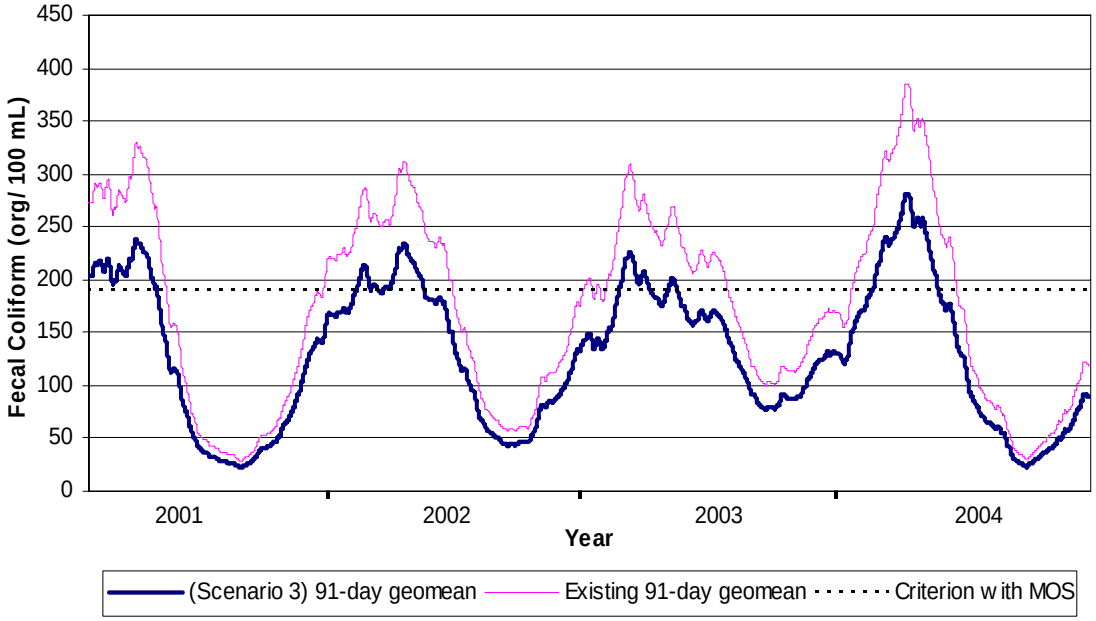

Figure 6-2 Fecal Coliform Results for BMP Scenario 3, Leon River at Hwy 281

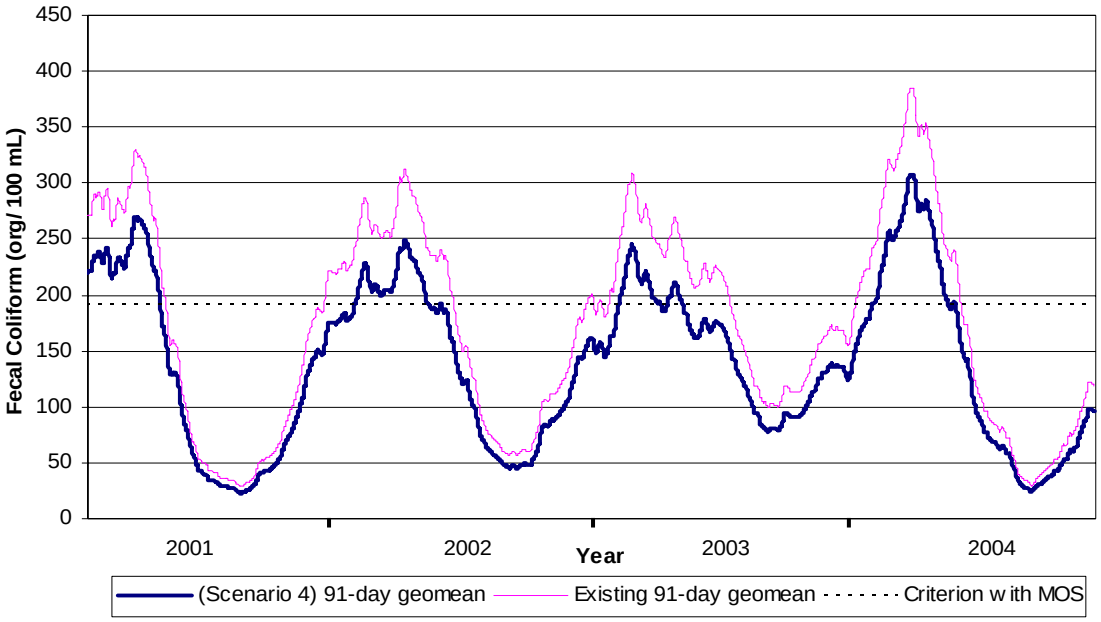

Figure 6-3 Fecal Coliform Results for BMP Scenario 4, Leon River at Hwy 281

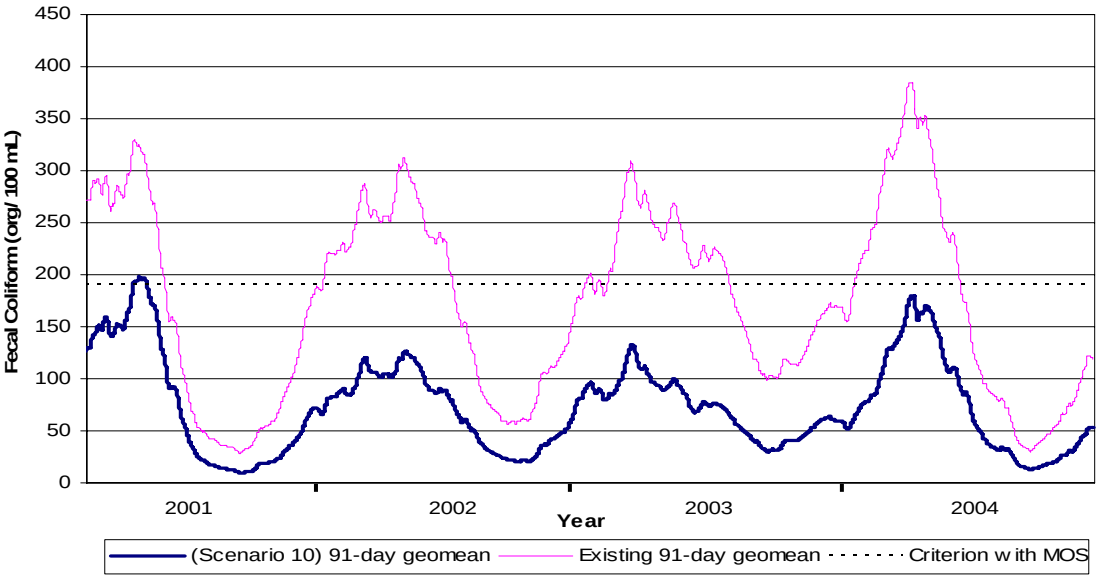

Figure 6-4 Fecal Coliform Results for BMP Scenario 10, Leon River at Hwy 281

For the present analysis, the scenario that will be selected for calculation of the TMDL is scenario number 10. This scenario includes reductions in bacterial loadings from nonpoint source land-based washoff sources and from nonpoint source direct discharging sources. Point sources are also required to achieve reductions in this scenario. The exact removals employed in the modeling analysis for each specific land use category should be interpreted only as guidance and a demonstration that reductions in washoff-based loadings are necessary. The present breakdown by land use serves only to illustrate that hypothetical removals can accomplish the objective of achievement of compliance with the bacterial criteria. As the LA for the TMDL is developed below, it will be based upon the overall percent reduction in loading required from all of the washoff-based loadings as a composite source, not upon the hypothetical assignment of a removal rate specific to any one category of land use. This outcome is a reflection of the degree of uncertainty regarding the magnitude of any of the specific bacterial sources. Instead, it will be more appropriate for these more specific nonpoint source-based removals to be developed during the TMDL implementation phase in concert with the affected stakeholders in the watershed.

The LA is determined as shown in Table 6-4. Here, existing loads and allocated loads are inventoried. The total load allocation (LA) for nonpoint sources is shown in the table. This total load allocation was the result of summation of the various individual load allocations, with hypothetical removals applied to corresponding existing loads. Then, the overall composite nonpoint source load reduction is calculated, which is applicable to the total nonpoint source load. During implementation, the TCEQ and stakeholders can assign removals to specific sources such that the overall removal objectives are achieved.

Table 6-4 Load Allocation for Impaired Reach

NPS Load Categories	Washoff Pervious Categories (org/yr)						
	Forest	Crop/ Pasture	Rangeland	Residential	Commercial/ Industrial	WAF1	WAF2
Existing	4.78E+13	9.57E+13	9.67E+14	3.96E+13	1.82E+13	5.27E+13	6.87E+13
Reductions (%)	10	10	10	80	80	30	30
Allocated	4.30E+13	8.62E+13	8.70E+14	7.92E+12	3.63E+12	3.69E+13	4.81E+13

NPS Load Categories (continued)	Washoff Impervious Categories (org/yr)		NPS Discharge Categories (org/yr)		
	Residential	Commercial/ Industrial	Direct Sources	Septic Load	Upstream Releases
Existing	4.85E+13	8.05E+13	1.30E+14	1.22E+11	5.00E+12
Reductions (%)	80	80	70	70	0
Allocated	9.70E+12	1.61E+13	3.89E+13	3.66E+10	5.00E+12

NPS TMDL Summary (org/yr)	
Total NPS Load Existing:	1.55E+15
Overall NPS Load Reduction (%):	25
Total Load Allocation (LA):	1.17E+15

As with the point source control measures, the selection of BMP control measures to address reductions in loading from nonpoint sources will be developed during the implementation phase of the TMDL with participation from stakeholders. In general, for land-based washoff loadings, a suite of potential BMPs are available, including buffer strips, detention basins, sand filters, infiltration basins, and biolfiltration basins**.** The different types of sources from various land use categories will dictate the most promising BMPs for both urban and non-urban areas. Potential septic system problems can be addressed with inspection and maintenance under the purview of local management agencies. Implementation of controls to address the direct source category of loadings will require some innovative approaches, and will require stakeholder input.

6.4 CRITICAL CONDITIONS

The HSPF model is a continuous simulation model that has been successfully applied to bacteria TMDLs throughout the country. For the present analysis, simulations were conducted for the period 2001 - 2004. Through simulation of this multi-year period, all potential flow conditions are explicitly considered in development of the TMDL. The modeling period includes typical high flow and low flow periods throughout the study area watersheds, which encompasses any critical conditions that must be accounted for.

6.5 SEASONALITY

Seasonal variation was explicitly included in the modeling approach for TMDL determination. Application of the continuous simulation model over a multi-year period ensured that all potential seasonal effects were considered.

6.6 FUTURE GROWTH

In many cases, future growth can conceivably impact TMDL allocation scenarios if associated with increased point source loads or increased nonpoint source loads. Point source loads can change if existing point sources are expanded, for example, a municipal wastewater treatment plant is expanded to handle increased wastewater flows. Point source loads can also change from addition of new point sources, such as new wastewater treatment plants. In the present analysis, future growth in point sources is not expected to have a deleterious effect upon bacterial concentrations because of the assumption that disinfection will be required prior to discharge and the resulting loads will be too small to be significant.

Future growth can also conceivably affect nonpoint sources as land use coverages change in the watersheds. For example, forest land may be converted to residential land. Such changes are expected to have minimal or no impact in the present study area due to the largely rural character of the watershed. The watershed is expected to retain its rural characteristic for a long term planning period.

6.7 TMDL SUMMARY

The TMDL was developed to achieve compliance with the Texas Water Quality standard for fecal coliform of 200 org/100 mL as a geometric mean value. Table 6-5 summarizes the allocations of the TMDL for fecal coliform for the impaired reach of the Leon River. The WLA includes all of the

allocated point source discharges. The LA is comprised of the allocated washoff sources, direct nonpoint sources, and various background sources. The MOS is calculated as 5 percent of the TMDL.

Table 6-5 Summary of Fecal Coliform TMDL for Impaired Reach

	TMDL (org/yr)	WLA (org/yr)	LA (org/yr)	MOS (org/yr)
Leon River	1.23E+15	4.04E+12	1.17E+15	6.16E+13

In order to achieve the bacteria TMDL for the impaired reach of the Leon River, reductions in washoff loadings from land use areas will be required, along with reductions in direct nonpoint sources and point sources, as described in detail in Section 6.3.

The proposed TMDL for fecal coliform is also expected to be protective for Texas water quality criteria for *E. coli*. The historical database available for the Leon River monitoring stations was insufficient to enable direct comparison of the ratio of *E. coli* to fecal coliform. Therefore, an assumed ratio of 0.63 was applied in the present study to convert fecal coliform to E. coli. This ratio is based on comparison of the criteria for *E. coli* compared to the criteria for fecal coliform (126/200 = 0.63). Similar ratios have been reported in other studies. Therefore, development of a TMDL to achieve compliance with a fecal coliform concentration of 190 org/100 mL should be protective down to an *E. coli* concentration of 190 times 0.63, or, 120 org/100 mL. This is below the corresponding *E. coli* of 126 org/100 mL as a geometric mean. In Table 6-6 is presented the corresponding TMDL summary written in terms of E. coli bacteria loadings.

Table 6-6 Summary of *E. coli* TMDL for Impaired Reach

	TMDL (org/yr)	WLA (org/yr)	LA (org/yr)	MOS (org/yr)
Leon River	7.76E+14	2.55E+12	7.34E+14	3.88E+13

7.0 REFERENCES

ASAE. 2003. Manure Production and Characteristics. D384.1.

Baxter-Potter, W.R. and M.W.Gilliland. 1988. Bacterial Pollution in Runoff from Agricultural Lands. J.of the Am Water Res Assoc. Vol 17, No. 1

Brazos River Watershed Information Center. http://wqweb.brazos.org/ Retrieved January 2006.

Buckhouse, J.C. and G.F. Gifford. 1976. Water Quality Implications of Cattle Grazing on Semiarid Watershed in Southeastern Utah. J. Of Rangeland Man. Vol. 29, No. 2

Cain, A. 2004. Personal communication, District Biologist, TPWD

Davis, W.B. and D.J. Schmidly. 1994. The Mammals of Texas. TPWD Nongame and Urban Program

Doran, J.W. and D.M. Linn. 1979. Bacteriological Quality of Runoff Water from Pastureland. Applied and Envir. Microb. May.

Drapcho, C.M and A.K.B. Hubbs. 2003. Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure. La Water Resources Inst.

Edwards, D.R., B.T.Larson, and T.T.Lim. 2000. Runoff Nutrient and Fecal Coliform Content from Cattle Manure Application to Fescue Plots. J.of the Am Water Res Assoc. Vol 36, No. 4

Edwards, D.R., M.S.Coyne, P.F.Vendrell, T.C.Daniel, P.A.Moore, and J.F. Murdoch. 1997. Fecal Coliform and Streptococcus concentrations in Runoff from Grazed Pastures in Northwest Arkansas. J.of the Am Water Res. Assoc, Vol. 32, No. 2

EPA. 1986. Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality, EPA 440/5-87-001

EPA. 1997. TMDL Regional Guidance. Region 6, 9 Sep 1997. Dallas, TX.

EPA. 2000. Bacterial Indicator Tool: User's Guide. EPA-823-B-01-003. Office of Water. Washington, D.C.

EPA. 2004. Better Assessment Science Integrating Point and Nonpoint Sources. BASINS v.3.1. EPA-823-C-04-004. Office of Water. Washington, D.C.

Frazier, B. 2005. Personal Communication. TCEQ Load Application Team.

Glick. R. 2005. City of Austin Stormwater Data, 1984-2004, unpublished data. COA Watershed Protection Dept.

Inamdar, S.P., S. Mostaghimi, M.N. Cook, K.M. Brannan, and P.W. McClellan. 2002. A Long-Term, Watershed-Scale, Evaluation of the Impacts of Animal Waste BMPs. J.of the Am.Water Res Assoc, Vol.38, No.3.

JMA and PES. 2002a. Historical Water Quality Data Assessment, Project Area 2 - Basins Groups D &E Bacteria Impairments. Report to TNRCC TMDL Strategic Assessment Division

JMA and PES. 2002b. Supplemental Report, Historical Water Quality Data Assessment, Project Area 2 - Basins Groups D & E Bacteria Impairments. Report to TNRCC TMDL Strategic Assessment Division

Kress, M. And G.F. Gifford. 1984. Fecal Coliform Release from Cattle Fecal Deposits. Wat. Res. Bull. Vol. 20, No. 1.

Mau, D.P, and L.M. Pope. 1999. Occurrence of Fecal Coliform Bacteria in the Cheney Reservoir Watershed, South-Central Kansas, 1996-1998. USGS, Fact Sheet 170-99

Miller, M. 2005. City of San Antonio Stormwater Data, 2000-2004. Unpublished data. SAWS

Moore, J.A., J.D. Smyth, E.S. Baker, J.R. Miner, and D.C. Moffitt. 1989. Modeling Bacteria Movement in Livestock Manure Systems. ASAE. Vol. 32, No. 3.

Ockerman, D.J. 2002. Hydrologic Conditions and Quality of Rainfall and Storm Runoff in Agricultural and Rangeland Areas in San Patricio County, Texas, 2000-2001. USGS, Open File Report 02-291

Perciasepe, Robert. 1997. Memorandum: New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs). Office of Water, Washington, D.C.

Reed Stowe and Yanke. 2001. Study to determine the magnitude of, and reasons for, chronically malfunctioning on-site sewage facility systems in Texas. Austin, Texas.

Robbins, J.W.D., D.H. Howells, and G.J. Kriz. 1972. Stream Pollution from Animal Production Units. J.WPCF. Vol. 44, No.8

Selvakumar, A. And M. Borst. 2004. Land Use and Seasonal Effects on Urban Stormwater Runoff Microorganism Concentrations. ASCE, World Water Congress

Smith, J.H. and C.L. Douglas. 1973. Microbiological Quality of Surface Drainage Water from Three Small Irrigated Watersheds in southern Idaho. J.of Env.Qual. Vol 2, No. 1

Thelin, R. And G.F. Gifford. 1983. Fecal Coliform Release Patterns from Fecal Material of Cattle. J.of Env. Qual., Vol. 12, No. 1

TNRCC. 1999. TMDL Guidance Document. TMDL Team, Water Quality Division.

TNRCC. 2000a. Draft 2000 303(d) list.

TNRCC. 2000b. Texas Surface Water Quality Standards. 30 TAC 307.1-307.10.

TNRCC. 2001. Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data

TPWD. 2004. Online white-tailed deer population data.

US Census Bureau. 2006. Online census data for 1990, 2000.

USDA. 2002. Census of Agriculture, County Data.

Weidner, R.B., A.G. Christianson, S.R. Weibel, and G.G. Robeck. 1969. Rural Runoff as a Factor in Stream Pollution. J.WPCF, Vol. 41, No.3, Part 1

Weiskel, Peter K., B. L. Howes, G. R. Heufelder. 1996. Coliform Contamination of a Coastal Embayment: Sources and Transport Patheways. *Environmental Science and Technolog*y. 30:1872-1881.

Wendt, A. 2005. Personal Communication. Texas State Soil and Water Conservation Board, Temple, Texas.