Bacteria Total Maximum Daily Load Development for Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek and a Sediment Total Maximum Daily Load Development for Colliers Creek

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Background

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations require states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQSs). TMDLs represent the total pollutant loading a waterbody can receive without violating WQSs.

The Maury River and four of its tributaries and Cedar Creek were listed as impaired on Virginia's 2010 Section 303(d) Report on Impaired Waters due to water quality violations of the *E.* coli standard. These impaired stream segments include Colliers Creek (VAV-I38R_CLL01A00), North Fork Buffalo Creek (VAV-I38R_NBF01A00 & VAV-I38R_NBF02A10), South Fork Buffalo Creek (VAV-I38R_SBF01A00), Buffalo Creek (VAV-I38R_BLDDD03A10, VAV-I38R_BLD02A04, & VAV-I38R_BLD01A00), Maury River (VAV-I37R_MRY01A00 & VAV-I37R_MRY02A00), and Cedar Creek (VAV-I28R_CEC01A00 & VAV-I28R_CEC02A10). The Maury River is approximately 536,255 acres in size and covers portions of Augusta County, Bath County and Rockbridge County, and the City of Lexington and the City of Buena Vista. The Cedar Creek watershed is approximately 10,230 acres in size and located in Rockbridge County.

Colliers Creek was also listed as impaired due to water quality violations of the general aquatic life (benthic) standard in the 2010 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report (VADEQ, 2010). The Virginia Department of Environmental Quality (DEQ) has identified this impairment as Cause Group Code I38R-02-BEN, and delineated the benthic impairment as 13.77 miles on Colliers Creek (stream segment VAV-I38R_CLL01A00). The Colliers Creek impaired segment from the headwaters to its confluence with Buffalo Creek.

This document describes the Total Maximum Daily Loads (TMDL) for bacteria that were developed for Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek watersheds in order to remedy the bacteria water quality impairments. The TMDLs were developed for the water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL.

Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. This document describes the process used to identify the most probable stressor contributing to the impairment of the benthic community in Colliers Creek and the development of the TMDL to address the pollutant. Sediment has been identified as the most probable stressor and a sediment TMDL has been developed to address the Colliers Creek biological impairment.

A glossary of terms used in the development of this TMDL is listed in Appendix A.

Pollutant Sources

Sources of fecal bacteria were identified throughout the watershed defining the entire study area. Multiple permitted point discharges of fecal bacteria were identified in the study watershed. Other potential sources of fecal bacteria in the watershed are characterized as nonpoint sources, including livestock, wildlife, manure application, pets, failing septic systems, and straight pipe discharges.

Based on the stressor analysis, the most probable stressor contributing to the impairment of the benthic community in Colliers Creek is sediment. Spring habitat metric scores for bank vegetative protection have been consistently poor throughout the sampling period. Additionally, historical livestock access to the stream, observed incised stream banks, and historical road and bridge construction just upstream from the downstream monitoring point all point to sediment as the most probable stressor.

Modeling

The Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell *et al.*, 2001) was used to simulate the fate and transport of fecal coliform bacteria in the Maury River and the Cedar Creek study watersheds. HSPF is a continuous model that can represent fate and transport of pollutants on both the land surface and in the stream. As recommended by the Virginia Department of Environmental Quality (VADEQ), water quality modeling was conducted with fecal coliform inputs, and then a translator equation was used to convert the output to *E. coli* for the final TMDLs.

The Generalized Watershed Loading Functions (GWLF) model was used to simulate sediment loads in the Colliers Creek watershed. The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The GWLF model was run in metric units and converted to English units for this report.

Endpoints

The numerical criteria for *E. coli* are a *Geometric Mean* of 126 cfu/100 ml and a *Single Sample Maximum* of 235 counts/100 ml. The endpoints were established based on the designated use of primary contact recreation (i.e., swimming and fishing). The calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) with zero violations is the endpoint for the development of TMDL allocation scenarios. A 10.5% violation rate of the instantaneous *E. coli* water quality criterion (235 cfu/100 mL) served as the endpoint for development of Stage 1 implementation scenarios, which allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection.

Since there are no in-stream water quality criteria for sediment in Virginia, an alternate method was used to establish a reference endpoint that would represent the “non-impaired” condition. For this watershed, the “reference watershed” approach was used to set allowable sediment loading rates in the impaired watershed. Buffalo Creek, whose watershed also encompasses Colliers Creek watershed, was selected as the reference watershed.

The Bacteria TMDLs

Various source reduction scenarios were evaluated to identify implementable scenarios that meet the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) with zero violations. These scenarios were conducted using the same meteorological data used to establish existing conditions. The bacteria loadings used in modeling correspond to anticipated and permitted future conditions for Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and

Cedar Creek. Equation ES.1 was used to calculate the TMDL allocations shown in Table ES.1.

$$TMDL = WLA_{total} + LA + MOS \qquad [ES.1]$$

Where:

WLA_{total} = waste load allocation (point source contributions, including future growth);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

Table ES.1. Annual *E. coli* loadings (cfu/yr) for the TMDLs.

Impairment	WLA_{total}	LA*	MOS**	TMDL
Maury River	2.98×10^{13}	7.74×10^{14}	--	8.04×10^{14}
Buffalo Creek	1.91×10^{12}	9.33×10^{13}	--	9.53×10^{13}
Colliers Creek	4.75×10^{11}	2.29×10^{13}	--	2.34×10^{13}
North Fork Buffalo Creek	6.52×10^{11}	3.19×10^{13}	--	3.25×10^{13}
South Fork Buffalo Creek	2.01×10^{11}	9.87×10^{12}	--	1.01×10^{13}
Cedar Creek	5.01×10^{11}	1.58×10^{13}	--	1.63×10^{13}

*The LA is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value is different from the tables providing nonpoint source load (Tables ES.3 – ES.14) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.
**Implicit MOS

The Sediment TMDL for Colliers Creek

The sediment TMDL for Colliers Creek was also calculated using Equation ES.1. The sediment TMDL load for Colliers Creek watershed was defined as the average annual sediment load from the non-impaired, area-adjusted Buffalo Creek watershed. The Colliers Creek TMDL load and its components are shown in Table ES.2.

Table ES.2. Colliers Creek sediment TMDL.

Colliers Creek; VAV-I38R_CLL01A00; Cause Group Code I38R-02-BEN

TMDL	WLA		LA	MOS
(tons/yr)				
10,321.4	103.4		9,185.9	1,032.1
	general permits aggregate WLA	0.17 tons/yr		
	Future Growth	103.21 tons/yr		

Allocation Scenarios

The proposed scenarios for the bacteria TMDLs require load reductions only for nonpoint sources of *E. coli*. The difference between the TMDL and the existing annual load represents the necessary level of *E. coli* reduction. Details on the loads to be reduced from each source are given in Table ES.3 through Table ES.14.

Table ES.3. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Maury River.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	180	<1	162	10
Pasture	64,265	93	44,986	30
Residential	3,769	5	942	75
Forest	1,077	2	1,077	0
Total	69,291		47,167	32

Table ES.4. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	13	<1	9	30
Pasture	7,084	96	2,479	65
Residential	187	3	131	30
Forest	68	<1	68	0
Total	7,352		2,687	63

Table ES.5. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Colliers Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	14	<1	10	30
Pasture	5,177	96	1,294	75
Residential	107	2	75	30
Forest	67	1	67	0
Total	5,365		1,446	73

Table ES.6. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for North Fork Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	12	<1	8	30
Pasture	4,775	98	2,388	50
Residential	30	1	21	30
Forest	41	1	41	0
Total	4,858		2,458	49

Table ES.7. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for South Fork Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	2	<1	1.5	30
Pasture	2,211	94	553	75
Residential	40	2	28	30
Forest	88	4	88	0
Total	2,342		670	71

Table ES.8. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Cedar Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	8	<1	7	10
Pasture	2,159	95	1,080	50
Residential	56	2	28	50
Forest	49	2	49	0
Total	2,273		1,164	49

Table ES.9. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Maury River.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	232	60	2	99
Wildlife in Streams	145	38	73	50
Straight Pipes	8	2	0	100
Total	386		8.6	81

Table ES.10. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	18.7	60	0.2	99
Wildlife in Streams	10.7	35	2.7	75
Straight Pipes	1.6	5	0	100
Total	30.9		2.9	91

Table ES.11. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Colliers Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	23.8	68	0.2	99
Wildlife in Streams	9.1	26	5.5	40
Straight Pipes	2.0	6	0	100
Total	34.9		5.7	84

Table ES.12. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for North Fork Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	46.1	91	11.5	75
Wildlife in Streams	4.1	8	4.1	0
Straight Pipes	0.7	1	0	100
Total	50.9		15.6	69

Table ES.13. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for South Fork Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	42	81	0.4	99
Wildlife in Streams	8	15	3.1	60
Straight Pipes	2	4	0	100
Total	52		3.5	93

Table ES.14. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Cedar Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	13.1	71	0	100
Wildlife in Streams	3.8	20	1.7	55
Straight Pipes	1.6	9	0	100
Total	18.5		1.7	91

The target sediment load for each watershed allocation scenario is the TMDL minus the MOS. Allocation scenarios were created by applying percent reductions to the various land use/source categories until the target allocation load was achieved. Two allocation scenarios were created based on input from local stakeholders, Table ES. 15.

Table ES.15. Sediment TMDL load allocation scenarios for Colliers Creek.

Land Use/ Source Group	Future Sediment Load (tons/yr)	Scenario 1		Scenario 2	
		Reduction	Load	Reduction	Load
Row Crops	78.3		78.3		78.3
Pasture	8,689.4	27.3%	6,313.8	33.0%	5,818.3
Hay	1,355.2	27.3%	984.7		1,355.2
Forest	1,092.8		1,092.8		1,092.8
Harvested Forest	92.3		92.3		92.3
Developed	755.0	27.3%	548.6	10.0%	679.5
Channel Erosion	103.7	27.3%	75.3	33.0%	69.4
Permitted WLA	103.4		103.4		103.4
Total Load	12,270.1		**9,289.3**		**9,289.3**
Target Allocation Load =	**9,289.3**				
% Reduction Needed =	24.3%				

Margin of Safety

To allocate loads while protecting the aquatic environment, a margin of safety (MOS) needs to be considered. An implicit MOS was included in the bacteria TMDLs for Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek. An explicit 10% MOS was used in the sediment TMDL calculation for Colliers Creek based on best professional judgment and the precedence of other TMDLs developed using the reference watershed approach for biological impairments due to sediment in Virginia.

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in attainment of water quality standards. This report represents the culmination of that effort for the bacteria impairments on Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek and the benthic impairment on Colliers Creek. The second step is to develop a TMDL implementation plan. The final step is to initiate recommendations outlined in the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ and other cooperating agencies.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Technical Advisory Committee (TAC) meetings and public meetings were organized for this purpose. These meetings were held in various locations in Rockbridge County, Buena Vista, and Lexington.

Chapter 1: Introduction

1.1. *Background*

1.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2. Impairment Listing

The purpose of this report is to describe the development of bacteria TMDLs for a segment of the Maury River and four of its tributaries along with a bacteria TMDL for Cedar Creek, a tributary to the James River, and a sediment TMDL for Colliers Creek. These segments were listed as impaired on Virginia's 2010 Section 303(d) Report on Impaired Waters due to water quality violations of the *E.* coli standard. These impaired stream segments include Colliers Creek (VAV-I38R_CLL01A00), North Fork Buffalo Creek (VAV-I38R_NBF01A00 & VAV-I38R_NBF02A10), South Fork Buffalo Creek (VAV-I18R_SBF01A00), Buffalo Creek (VAV-I38R_BLDDD03A10, VAV-I38R_BLD02A04, & VAV-I38R_BLD01A00), Maury River (VAV-I37R_MRY01A00 & VAV-I37R_MRY02A00), and Cedar Creek (VAV-I28R_CEC01A00 & VAV-I28R_CEC02A10). Colliers Creek was also listed as impaired due to water quality violations of the general aquatic life (benthic) standard on Virginia's 2010 Section 303(d) Report on Impaired Waters. The Virginia Department of Environmental Quality (VADEQ) has described the impaired segments as presented in Figure 1.1 and Table 1.1.

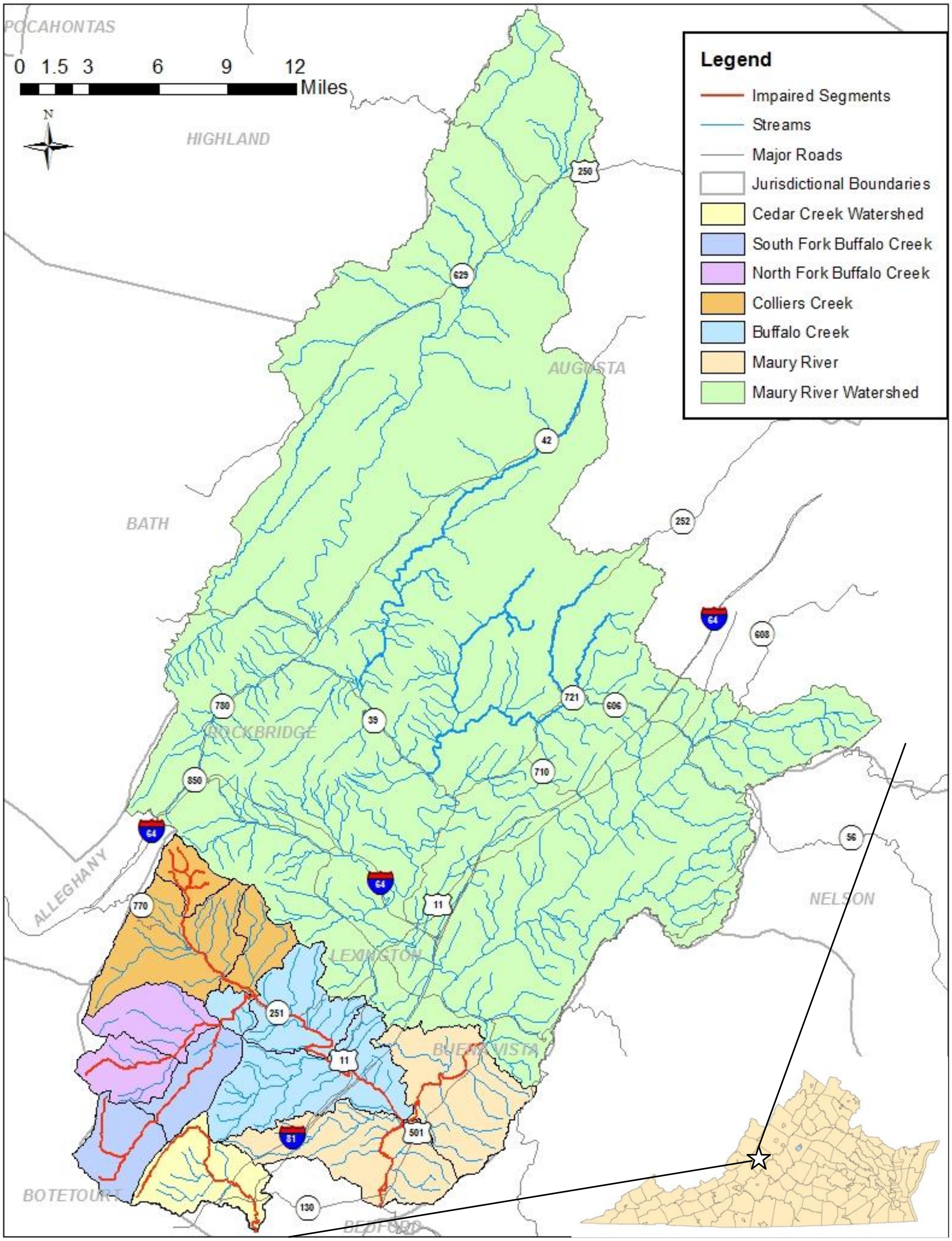

Figure 1.1. Impaired segments in the Maury River and Cedar Creek watersheds.

Table 1.1. Impaired Segments Addressed in this TMDL report.

Impaired Segment	Size	Initial Listing Year	Description
Colliers Creek (VAV-I38R_CLL01A00)	13.77 miles	2006	extending from the headwaters downstream to its confluence with Buffalo Creek
North Fork Buffalo Creek (VAV-I38R_NBF01A00 & VAV-I38R_NBF02A10)	7.28 miles	2012	extending from the headwaters downstream to its confluence with Buffalo Creek
South Fork Buffalo Creek (VAV-I18R_SBF01A00)	13.24 miles	2010	extending from the headwaters downstream to its confluence with Buffalo Creek
Buffalo Creek (VAV-I38R_BLDDD03A10, VAV-I38R_BLD02A04, & VAV-I38R_BLD01A00)	15.51 miles	2004	extending from its confluence with North/South Fork Buffalo Creek downstream to its confluence with the Maury River
Maury River VAV-I37R_MRY01A00 & VAV-I37R_MRY02A00)	12.84 miles	2006	Extending from its confluence with Indian Gap Run downstream to its confluence with the James River
Cedar Creek (VAV-I28R_CEC01A00 & VAV-I28R_CEC02A10)	11.49 miles	2002	extending from the headwaters downstream to its confluence with the James River

1.1.3. **Watershed Location and Description**

The Maury River is approximately 536,255 acres in size and covers portions of Augusta County, Bath County and Rockbridge County, and the City of Lexington and the City of Buena Vista. The Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, and Cedar Creek watersheds are located in Rockbridge County. The watershed sizes are: Colliers Creek, 23,392 acres; North Fork Buffalo Creek, 13,189 acres; South Fork Buffalo Creek, 13,618 acres; Buffalo Creek, 29,027 acres. The Cedar Creek watershed is approximately 10,230 acres in size. The watersheds associated with the individual impaired stream segments in this study are identified in Figure 1.2.

The predominant land uses in the Maury River study area are forest (68.8%) and pasture (22.0%). Less significant land uses are residential (8.2%) and cropland (0.4%). The forest (78.3%) land use in the Cedar Creek study area is predominant with additional areas in agricultural (14.6%) and residential (6.8%) land uses.

The Colliers Creek watershed is predominantly forest (74.4%), with significant pasture (20.4%); and minimal residential (5.0%), and cropland (0.2%). The land use distribution in the North Fork Buffalo Creek watershed consists mainly of forested area (83.5%) and a significant portion in; less significant land uses include pasture (12.8%), residential (3.1%) and cropland (0.4%). The land use distribution in the South Fork Buffalo Creek watershed consists mainly of forested area (88.8%) with less significant area in pasture (8.4%), residential (2.7%) and cropland (0.1%). The land use in the Buffalo Creek watershed consists mainly of forested area (54.8%) and pasture (38.6%) with less significant portion in residential (6.1%) and cropland (0.6%).

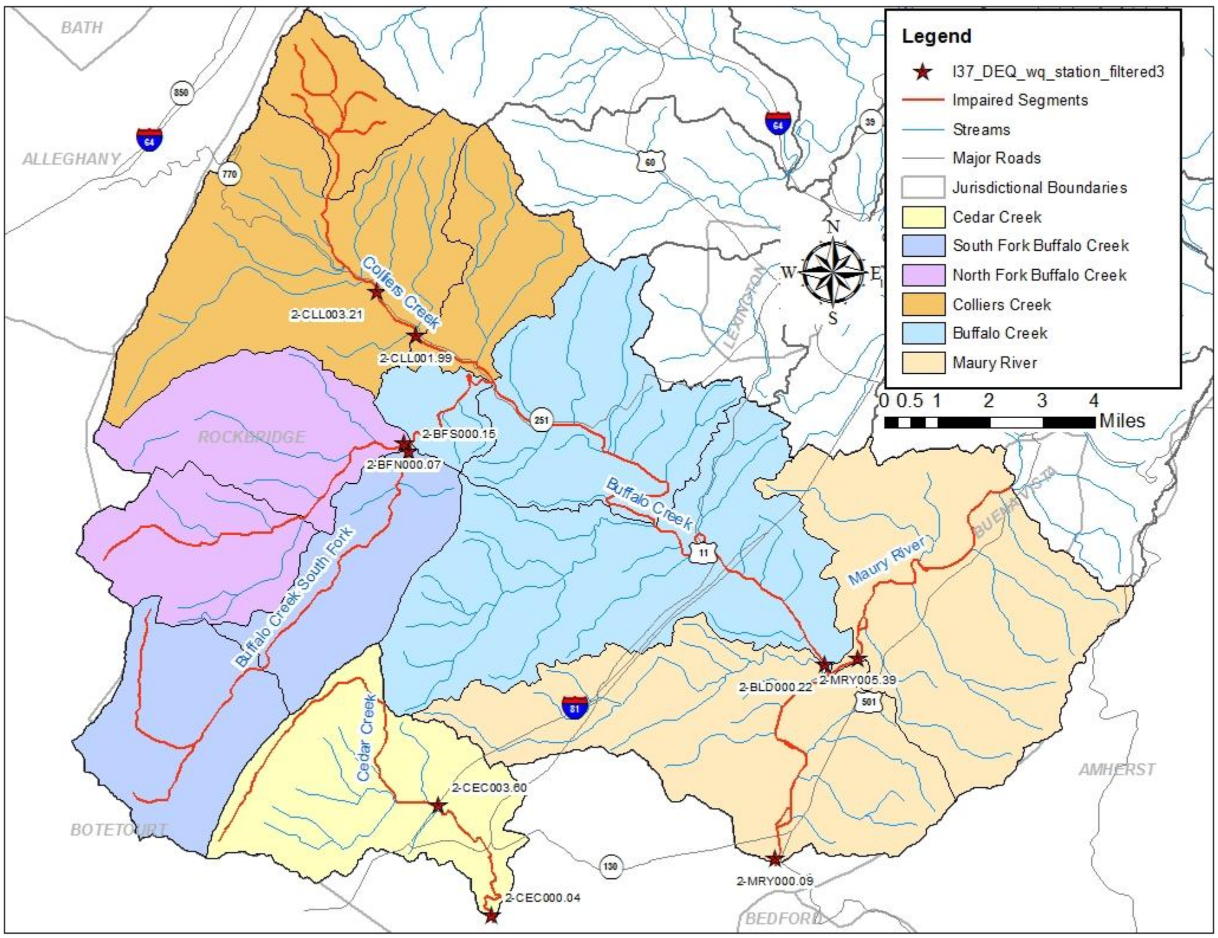

Figure 1.2 Maury River and Cedar Creek TMDL impaired streams

1.1.4. **Pollutants of Concern**

Pollution from both point and nonpoint sources can lead to *E. coli* bacteria contamination of water bodies. *E. coli* bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains *E. coli*. Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with *E. coli* bacteria are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing *E. coli* counts. If the *E. coli* concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state bacteria standard for contact recreational uses.

Pollution from both point and nonpoint sources can lead to a violation of the benthic standard. A violation of this standard is assessed on the basis of measurements of the in-stream benthic macro-invertebrate community. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia's waters.

1.2. *Designated Uses and Applicable Water Quality Standards*

1.2.1. **Designation of Uses (9 VAC 25-260-10)**

> "A. All State waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish." SWCB, 2011.

Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek do not support the recreational (primary contact) designated use due to violations of the bacteria standard. Colliers Creek also does not support the aquatic life designated use based on biological monitoring of the benthic macroinvertebrate community.

1.2.2. **Bacteria Standard (9 VAC 25-260-170)**

EPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a strong correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness. *E. coli* and enterococci are bacteria that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards the following criterion shall apply to protect primary contact recreational uses (SWCB, 2011):

***Escherichia coli* Standard:**

E. coli bacteria concentrations for freshwater shall not exceed a monthly geometric mean of 126 colony forming units (cfu) per 100 mL. During any assessment period, if more than 10.5% of a station's samples exceed 235 *E. coli* cfu/100mL, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. There are six ambient monitoring stations in the impaired Maury River watershed that were used to assess and list the study streams as impaired: two on the Maury River and one on each of the other streams. Two ambient monitoring stations in the impaired Cedar Creek watershed were used to assess and list Cedar Creek as impaired.

For the 2010 assessment period, January 2003 through December 2008, all of the stations had a violation rate greater than 10.5% of the instantaneous target concentration of 235 cfu/100ml, leading to the impaired classification for the Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River and Cedar Creek segments.

The bacteria TMDLs for the impaired segments were developed to meet the *E. coli* standard of a monthly geometric mean not exceeding 126 *E. coli* cfu/100mL. The modeling was conducted with fecal coliform inputs, and then a translator equation provided by VADEQ was used to convert the output to *E. coli* concentrations.

1.2.3. **General Standard (9 VAC 25-260-20)**

The general standard for a water body in Virginia is stated as follows:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." (State Water Control Board, 2011)

The biological monitoring program in Virginia that is used to evaluate compliance with the above standard is administered by the Virginia Department of Environmental Quality (DEQ). Evaluations of monitoring data from this program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment has a benthic impairment. Changes in water quality generally result in alterations to the quantity and diversity of the benthic organisms. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Two types of biological monitoring, both qualitative and semi-quantitative, have been conducted by DEQ since the early 1970's. The U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize a standardized, repeatable assessment methodology (Barbour et al., 1999). For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, benthic samples are typically collected and analyzed twice a year in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring "network" stations to "reference" sites. A reference site is one that has been determined to be representative of a natural, non-impaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different eco-regions. One additional product of the RBP II evaluation is a habitat assessment. This is a stand-alone assessment that describes bank condition and other stream and riparian corridor characteristics and serves as a measure of habitat suitability for the benthic community.

Beginning in 2006, DEQ modified their bioassessment procedures. While the RBP II protocols were still followed for individual metrics, a new index, the Virginia Stream Condition Index (VSCI), was developed based on comparison of observed data to a set of reference conditions, rather than with data from a single reference station. The new index was also calculated for all previous samples in order to better assess trends over time.

Determination of the degree of support for the aquatic life designated use is based on biological monitoring data and the best professional judgment of the DEQ regional biologist, relying primarily on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with a benthic score less than the impairment threshold is placed on the state's 303(d) list of impaired streams (VADEQ, 2012).

Chapter 2: Watershed Characterization

2.1. *Selection of Sub-watersheds*

To account for the spatial distribution of bacteria sources, the Maury River study area was subdivided into 43 sub-watersheds and Cedar Creek was subdivided into 3 sub-watersheds, as shown in Figure 2.1. The Maury River, Cedar Creek, the impaired tributaries, and their corresponding sub-watersheds are shown in Table 2.1. The stream network used to help define the sub-watersheds was obtained from the National Hydrography Dataset. Sub-watersheds were delineated based on a number of factors: continuity of the stream network, similarity of land use distribution, and monitoring station locations. It is preferable to have a sub-watershed outlet at or near monitoring station locations in order to calibrate the model chosen for this study (to be discussed in Chapter 4); the monitoring stations used in modeling are also shown in Figure 2.1.

Table 2.1. Study streams and corresponding sub-watersheds.

Stream Name	Corresponding Sub-watersheds
Maury River	MAU 1; 12 - 43
Colliers Creek	MAU 4 - 6
North Fork Buffalo Creek	MAU 8 - 9
South Fork Buffalo Creek	MAU 10 - 11
Buffalo Creek	MAU 2 – 3; 7
Cedar Creek	CEC 1 - 3

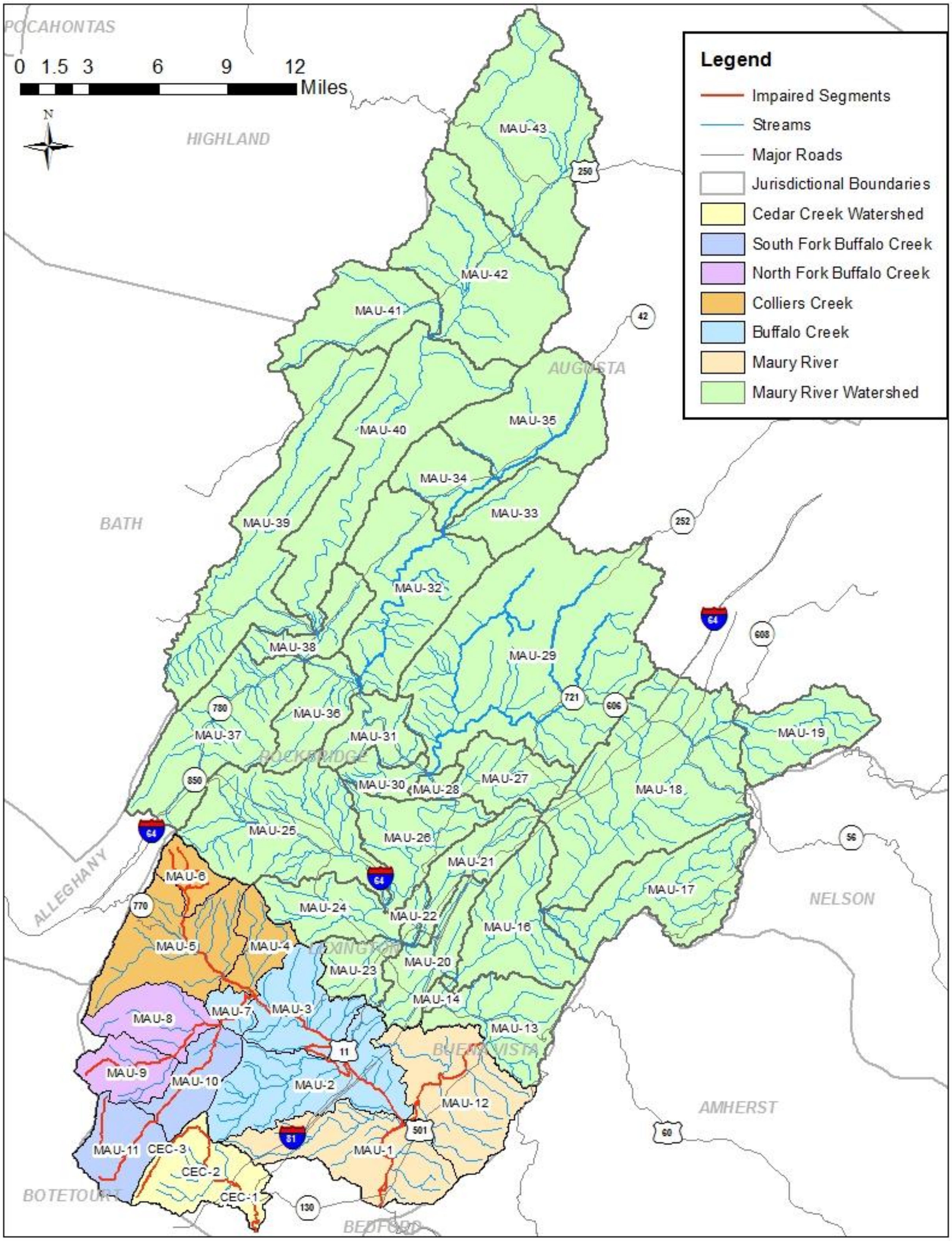

Figure 2.1. Sub-watersheds and water quality modeling stations used for modeling the Maury River and Cedar Creek watersheds.

2.2. *Ecoregion, Soils, and Climate*

2.2.1. Ecoregion

Ecoregions in this section are classified at level IV. The entire study area lies within the Northern Inner Piedmont level IV ecoregion. This level IV ecoregion "is a dissected upland composed of hills, irregular plains, and isolated ridges and mountains" (Woods et al., 1999). The area is characteristically underlain by highly deformed and deeply weathered Cambrian and Proterozoic feldspathic gneiss, schist, and melange (Woods et al., 1999).

2.2.2. Soils

The Soil Survey Geographic (SSURGO) soils data were used for modeling purposes. The dominant soil series in the watershed include Spears Mountain, Tatum, Manteo, Clifford, Littlejoe, and Bugley. All of these dominant soil series are in Hydrologic Soil Groups B and C/D.

Hydrologic soil groups describe soil texture in terms of potential for surface runoff and infiltration rates. For example, soils in hydrologic group "A" pass a larger proportion of rainfall through to ground water than soils in hydrologic group "B." Conversely, soils in hydrologic group "D" inhibit infiltration such that a large proportion of rainfall contributes to surface runoff and therefore a more direct path to stream channels. These processes have consequences for bacteria residing on the land surface in terms of the potential bacteria loads transported to streams during storm events.

2.2.3. Climate

The climate of the watershed was characterized based on the meteorological observations acquired from the National Climatic Data Center (NCDC) for "nearby" weather stations (NCDC, 2013). Meteorological data were obtained primarily from four National Weather Service COOP stations within and near the Maury River watershed; Kerrs Creek (COOP ID 444565), Craigsville (COOP ID 442064), Lexington (COOP ID 444876) and Lynchburg Regional Airport (COOP ID 445120). The Kerrs Creek, Craigsville, and Lexington stations are located within the Maury River watershed and Lynchburg Regional Airport station is located roughly 34 miles south of the watershed.

Data from the Staunton station (COOP ID 448062) were used to supplement for the missing precipitation data. The record summary (1981-2010) at the Lexington station which is located in the middle of the Maury River study watershed shows an average annual precipitation of 40.51 inches, with 31% of the precipitation occurring during the cropping season (May-October). Average annual daily temperature is 54.8°F, with the highest average daily temperature of 75.2°F occurring in July, and the lowest average daily temperature of 34.0°F occurring in January (NCDC, 2013).

2.3. *Land Use*

The National Land Cover Database (NLCD) 2006 land use data were used to characterize land use characterize land use in the watershed. The National Agricultural Statistics Service (NASS) 2009 (NASS) 2009 cropland data layer (CDL) land use map for Virginia was used to verify land use land use characterization and, with stakeholder input and aerial photos, was used to adjust adjust cropland area estimates. The land cover categories in the Maury River and the Cedar Creek Cedar Creek watersheds were grouped into six major categories based on similarities in hydrologic features and waste application/production practices (Table 2.2). The land use categories were assigned pervious and impervious percentages for use in the watershed models. watershed models. Land uses for the Maury River and the Cedar Creek watersheds are presented presented graphically in Figure 2.2 and tabulated in

Table 2.3.

Table 2.2. NASS, NLCD, and land use aggregation.

TMDL Land Use Categories	**Pervious/Impervious (Percentage)**	**NASS Land Use Categories (Class No.)**
Cropland	Pervious (100%)	Corn (1) Sorghum (4) Soybeans (5) Tobacco (11) Winter Wheat (24) Rye (27) Oats (28) Alfalfa (36) Dbl. Crop Barley/Corn (237) Cabbage (243)
Wetland	Pervious (100%)	NLCD – Woody Wetlands (90) NLCD – Emergent Herbaceous (95)
Pasture	Pervious (100%)	Grass/Pasture (62) NLCD - Grassland Herbaceous (171) NLCD - Barren
Residential	Pervious (90%); Impervious (10%) Pervious (65%); Impervious (35%) Pervious (35%); Impervious (65%) Pervious (10%); Impervious (90%) Pervious (100%)	NLCD - Developed/Open Space (121) NLCD - Developed/Low Intensity (122) NLCD- Developed/Medium Intensity (123) NLCD - Developed/High Intensity (124) NLCD – Barren (131)
Forest	Pervious (100%)	Christmas Trees (70) NLCD - Deciduous Forest (141) NLCD - Evergreen Forest (142) NLCD - Mixed Forest (143) NLCD – Shrubland (152)
Water	Pervious (100%)	NLCD - Open Water (111)

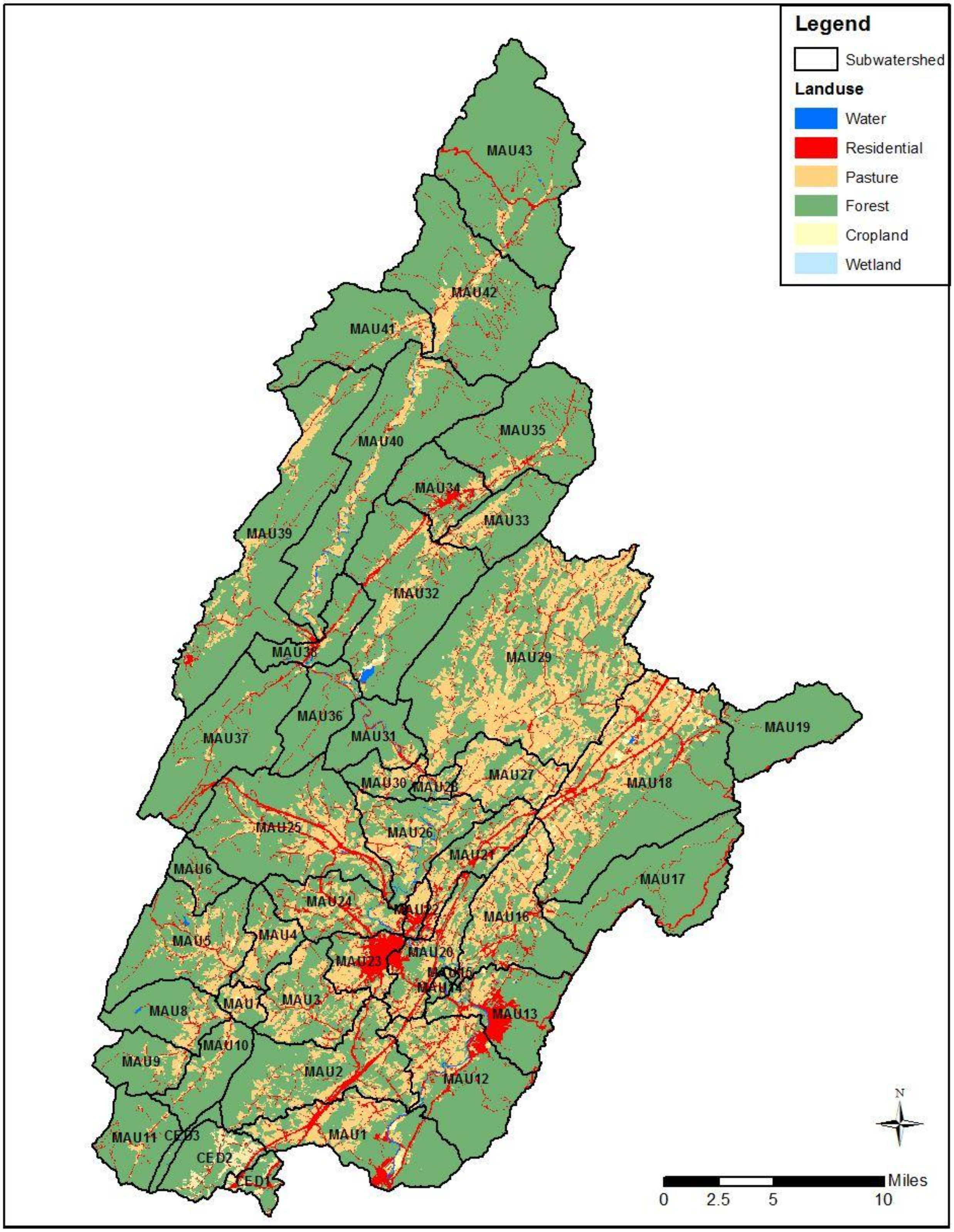

Figure 2.2. Land use in the Maury River and the Cedar Creek watersheds.

Table 2.3. Land use areas in the Maury River and the Cedar Creek watersheds (acres).

Sub-watershed	Forest	Cropland	Pasture	Residential	Wetland	Water	Total
MAU-1	9,220	217	4,292	1,746	0	149	15,624
MAU-2	11,597	14	4,148	1,333	0	3	17,095
MAU-3	5,447	43	3,709	707	0	2	9,908
MAU-4	2,781	5	1,859	293	0	1	4,939
MAU-5	11,431	53	2,829	748	0	32	15,093
MAU-6	3,060	0	162	137	0	0	3,359
MAU-7	842	24	1,092	66	0	0	2,024
MAU-8	5,979	16	1,083	240	0	28	7,346
MAU-9	5,001	34	637	171	0	0	5,843
MAU-10	5,387	12	864	166	1	0	6,430
MAU-11	6,747	0	240	202	0	0	7,189
MAU-12	10,919	16	3,629	1,607	0	166	16,337
MAU-13	7,192	19	1,363	2,112	0	72	10,758
MAU-14	300	0	217	82	0	24	623
MAU-15	113	0	71	13	0	9	206
MAU-16	7,054	117	5,402	1,216	1	19	13,809
MAU-17	15,642	11	269	867	0	1	16,790
MAU-18	20,513	1,044	10,686	2,876	0	65	35,184
MAU-19	9,850	0	28	202	0	0	10,080
MAU-20	3,122	9	2,847	1,581	0	92	7,651
MAU-21	2,921	4	2,899	1,280	0	5	7,109
MAU-22	191	0	757	455	0	12	1,415
MAU-23	1,169	5	1,858	1,936	0	5	4,973
MAU-24	4,749	5	2,610	1,187	0	70	8,621
MAU-25	16,136	42	4,472	2,127	0	13	22,790
MAU-26	5,561	106	3,768	747	0	200	10,382
MAU-27	2,839	146	4,239	463	0	9	7,696
MAU-28	701	11	566	108	0	35	1,421
MAU-29	26,285	503	22,293	2,430	0	2	51,513
MAU-30	2,003	20	1,020	198	0	6	3,247
MAU-31	5,609	0	471	292	0	78	6,450
MAU-32	17,243	164	2,929	1,037	0	188	21,561
MAU-33	6,254	0	1,403	339	0	7	8,003
MAU-34	5,704	8	734	810	0	14	7,270
MAU-35	15,054	21	748	753	0	-	16,576
MAU-36	7,002	0	131	242	0	38	7,413
MAU-37	17,403	22	254	742	1	7	18,429
MAU-38	5,072	25	290	416	0	30	5,833
MAU-39	25,038	36	2,943	1,000	0	7	29,024
MAU-40	21,775	101	2,701	697	0	203	25,477
MAU-41	10,945	24	917	321	0	6	12,213
MAU-42	21,459	80	2,010	860	0	33	24,442

Sub-watershed	Forest	Cropland	Pasture	Residential	Wetland	Water	Total
MAU-43	26,650	26	522	885	1	25	28,109
MAU-total	389,960	2,983	105,962	35,690	4	1,656	536,255
CEC-1	1,557	24	463	374	0	5	2,423
CEC-2	4,630	75	1,416	320	0	0	6,441
CEC-3	1,348	0	8	1	1	8	1,366
CEC-total	7,535	99	1,887	695	1	14	10,230

2.4. *Bacteria Monitoring Data*

VADEQ monitors water quality within the impaired Maury River and the Cedar Creek watersheds at eight stations that were used to evaluate and list the impaired streams. The locations of these stations were shown previously (Figure 2.1); a summary of the bacteria data, including violation rates of the appropriate single-sample standards, is presented in Table 2.4.

Table 2.4. VADEQ monitoring stations within the impaired Maury River and the Cedar Creek watersheds.

Station ID	Stream Name	Station Description	Indicator Organism Measured	Number of Samples	Violation Rate	Period of Record
2-MRY000.09	Maury River	DGIF Boat Launch	*E. coli*	29	10.3%	2003 - 2012
2-MRY005.39	Maury River	Off Rt. 663 Near Old Canal Lock	*E. coli*	29	10.3%	2003 - 2012
2-BFN000.07	North Fork Buffalo Creek	Rt. 611 Bridge	*E. coli*	12	16.7%	2007 - 2008
2-BFS000.15	South Fork Buffalo Creek	Rt. 611 Bridge	*E. coli*	23	47.8%	2007 – 2012
2-BLD000.22	Buffalo Creek	Private Br. off Rt. 700	*E. coli*	29	24.1%	2003 - 2012
2-CLL001.99	Colliers Creek	Rt. 644 Bridge	*E. coli*	23	21.7%	2007 - 2012
2-CEC000.04	Cedar Creek	Rt. 608 Bridge	*E. coli*	47	14.9%	2008 – 2012
2-CEC003.60	Cedar Creek	Rt. 609 Bridge	*E. coli*	47	48.9%	2008 – 2012

Seasonality of *E. coli* concentrations in the streams was evaluated by plotting the mean monthly *E. coli* concentrations observed at station 2-CEC003.60, the station on

Cedar Creek which has the most data available and best temporal distribution (Figure 2.3).

Mean monthly *E. coli* concentration was determined as the mean of all values in any given month for the period of record; there were between 3 and 5 samples available for every month. The observed bacteria record shows little seasonality, except perhaps to show that bacteria concentrations observed in March, May, and July are higher than the other months.

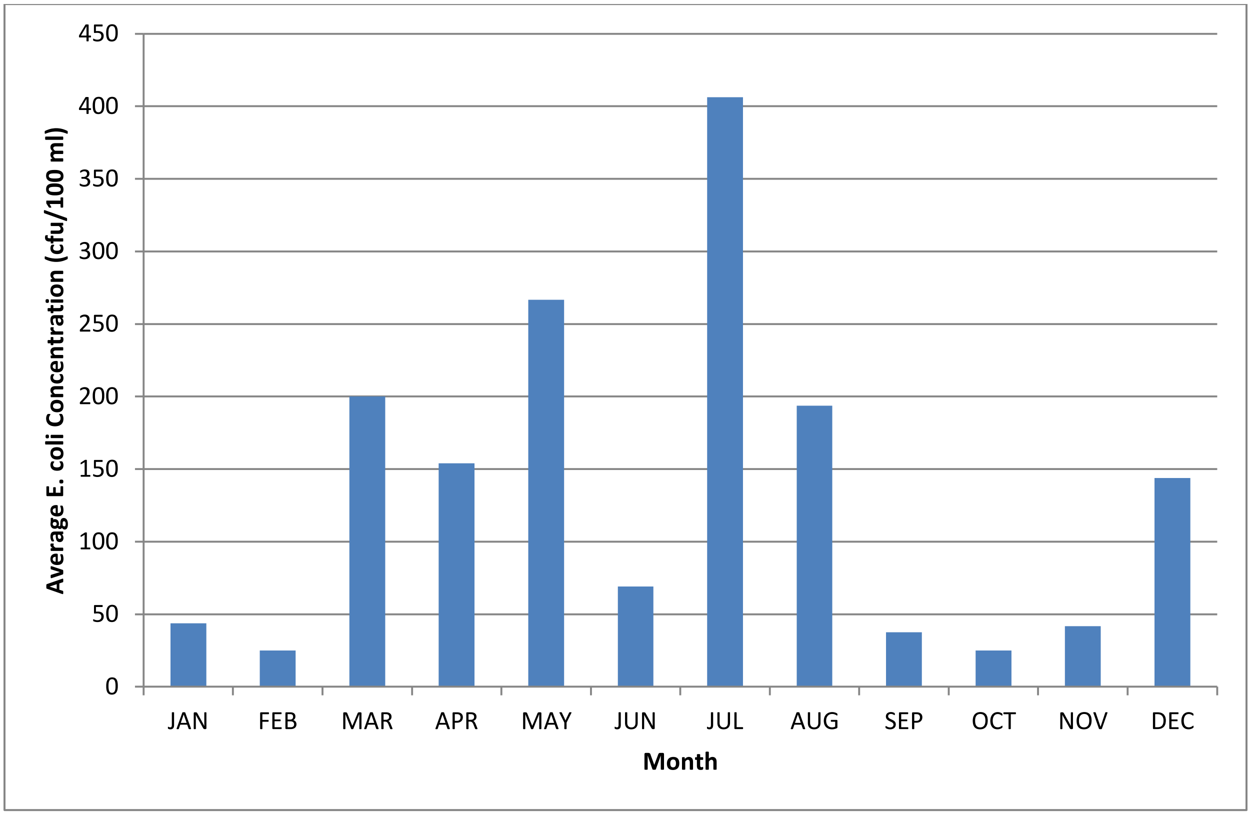

Figure 2.3. Average E. coli concentrations by month for station 2-CEC003.60.

Chapter 3: Benthic Stressor Analysis

3.1. *Introduction*

A TMDL must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for the each of the impaired stream segments in this study. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from DEQ provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, Google Earth aerial imagery (www.google.com/earth/), and visual assessment of conditions in and along the stream corridor provided additional information to investigate specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors included ammonia, hydrologic modifications, nutrients, organic matter, pH, sediment, TDS/conductivity/sulfates, temperature, and toxics. The details of the stressor analyses are included in the Colliers Creek Stressor Analysis Report (Kline et al., 2013), dated July 10, 2013, and the summary is presented in the following section.

3.2. *Biological Monitoring Data – Benthic Macro-invertebrates*

Biological monitoring consisted of sampling the benthic macro-invertebrate community along with corresponding habitat assessments. The data for the bioassessments in Colliers Creek were based on DEQ biological monitoring at one DEQ monitoring site in the watershed. The location of the DEQ biological and an ambient monitoring station are shown in Figure 3.1. Monitoring station 2-CLL003.21was monitored in twice in 2007 twice in 2008.

Biological samples were collected from the best available habitat using riffle or multi-habitat methods. The samples were then preserved and subsorted, and then the organisms were identified to the family and/or genus taxonomic level.

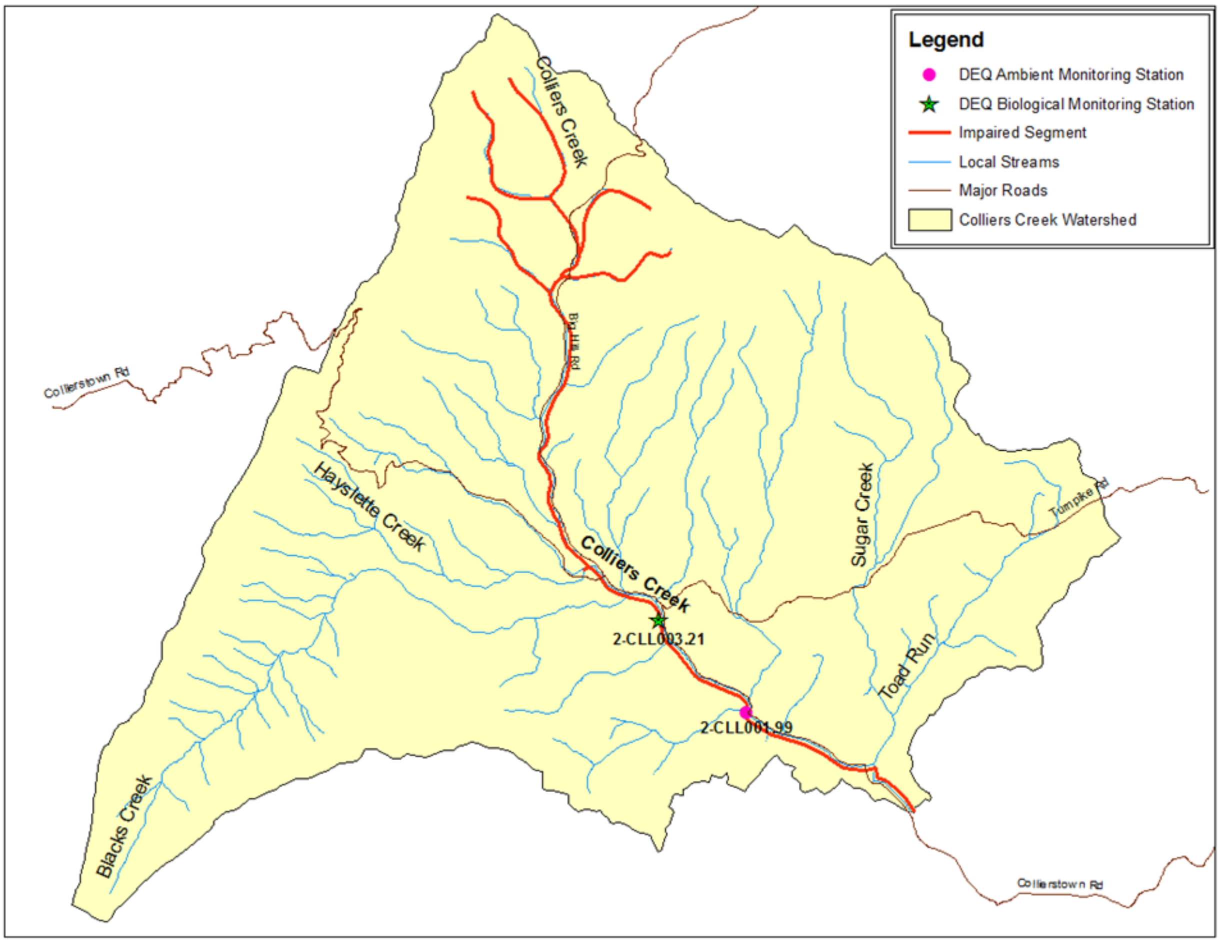

Figure 3.1. Location of DEQ Monitoring Stations in Colliers Creek Watershed

In 2006, DEQ upgraded its biomonitoring and biological assessment methods to those currently recommended by USEPA Region 3 for the mid-Atlantic region. As part of this effort, a study was performed to assist the agency in moving from a paired-network/reference site approach based on the RBP II to a regional reference condition approach, and has led to the development of the Virginia Stream Condition Index (VSCI) for Virginia's non-coastal areas (Tetra Tech, 2003). This multi-metric index is based on 8 biomonitoring metrics, with a scoring range of 0-100, that include some different metrics than those used previously in the RBP II, but are based on the same taxa inventory. A maximum score of 100 represents the best benthic community sites. The current criteria define “non-impaired” sites as those with a VSCI of 60 or above, and “impaired” sites as those with a score below 60 (VADEQ, 2006).

A full listing of the benthic macro-invertebrate taxa inventory or distribution within each Colliers Creek biological sample is given in Table 3.1. Across all samples, the most dominant family of benthic macro-invertebrates is the pollution-tolerant Chironimidae (A), ranked highest in three of the four samples. In the other sample, the dominant family was a more pollution-sensitive family, indicative of better water quality. The percentage of haptobenthos varied from 6.6% to 43.1% during the sampling period. Individual VSCI metrics and scores are given in Table 3.2, and a graph of the VSCI scores over time are displayed in Figure 3.2. The primary biological effects are identified as those metrics scoring in the lowest 20th percentile. The primary biological effects in Colliers Creek, indicative of its relatively minor impairment, are the occasional low scores for sensitive members of the Plecoptera (stoneflies) and Tricoptera (case maker caddisflies) families.

3.3. ***Biological Monitoring Data – Habitat***

A qualitative analysis of various habitat parameters was conducted in conjunction with each benthic macro-invertebrate sampling event. Habitat data collected as part of the biological monitoring were obtained from DEQ through the EDAS database. For each evaluation, ten metrics are scored 0-20 using EPA rapid biosassessment protocols (Barbour et al., 1999). Scores of 0-5 are rated “poor”; 6-10 are “marginal”; 11-15 are “sub-optimal”; and 16-20 are “optimal”, with minor variations for those metrics scored separately for each stream bank. The maximum 10-metric total habitat score is 200; scores <120 are considered sub-optimal, and those >150 are optimal. The 10 metrics evaluated vary based on whether the best available habitat was dominated by riffle or multi-habitat (snags, leaf packs). The former is considered “high gradient” and the latter “low gradient.”

The habitat assessment data for Colliers Creek are shown in Table 3.3. Scores for two of the "riparian vegetative zone width" metrics were rated as "poor". All of the samples are rated as "optimal", again indicative of a minor impairment.

Table 3.1. Taxa Inventory by Sample Date in Colliers Creek (CLL)

Family	Family Functional Group	Tolerance Value	2-CLL003.21			
			4/25/07	9/11/07	4/22/08	10/8/08
Rhyacophilidae	Predator	0				3
Capniidae	Shredder	1	2			
Gomphidae	Predator	1				1
Isonychiidae	Filterer	2	4	13		16
Leptophlebiidae	Collector	2	17	2	2	1
Nemouridae	Shredder	2	2		1	
Philopotamidae	Collector	3		1		1
Tipulidae	Shredder	3	2	2	2	3
Baetidae	Collector	4	4	6	5	3
Caenidae	Collector	4		35		23
Elmidae	Scraper	4		2	2	10
Ephemerellidae	Collector	4	2		21	
Heptageniidae	Scraper	4	3	13	13	34
Psephenidae	Scraper	4			1	2
Cambaridae	Shredder	5		2		
Hydracarina (unknown)	Predator	5				7
Chironomidae (A)	Collector	6	65	7	50	60
Empididae	Predator	6	3		3	2
Hydropsychidae	Filterer	6	1	33	5	37
Simuliidae	Filterer	6	1		1	1
Naididae	Collector	8			3	
VSCI			**42**	**59**	**48**	**55**
No. of species			12	11	13	16
Abundance			106	116	109	204
Additional Benthic Metrics						
Scraper/Filterer-Collector			0.03	0.15	0.18	0.32
%Filterer-Collector			88.7%	83.6%	79.8%	69.6%
%Haptobenthos			6.6%	42.2%	39.4%	43.1%
%Shredder			5.7%	3.4%	2.8%	1.5%

(shaded) - Dominant 2 species in each sample.

VSCI: Optimal >= 60, suboptimal < 50

Table 3.2. Biological Index (VSCI) Scores for Colliers Creek (CLL)

StationID	2-CLL003.21			
CollDate	05/25/07	09/11/07	04/22/08	10/08/08
VSCI Metric Values				
TotTaxa	12	11	13	13
EPTTax	8	7	6	6
%Ephem	28.3	59.5	37.6	37.6
%PT - Hydropsychidae	3.8	0.9	0.9	1.9
%Scrap	2.8	12.9	14.7	22.7
%Chiro	61.3	6.0	45.9	29.7
%2Dom	77.4	58.6	65.1	51.2
HBI	4.8	4.4	5.1	4.8
VSCI Metric Scores				
Richness Score	54.5	50.0	59.1	56.8
EPT Score	72.7	63.6	54.5	54.5
%Ephem Score	46.2	97.0	61.4	61.3
%PT-H Score	10.6	2.4	2.6	5.4
%Chironomidae Score	38.7	94.0	54.1	70.3
%Scraper Score	5.5	25.1	28.4	44.0
%2Dom Score	32.7	59.8	50.4	70.5
%MFBI Score	76.3	82.0	71.8	77.0
VSCI	**42.2**	**59.2**	**47.8**	**55.0**
VSCI Rating	**Stressed**	**Stressed**	**Stressed**	**Stressed**

(shaded) - Primary biological effects.

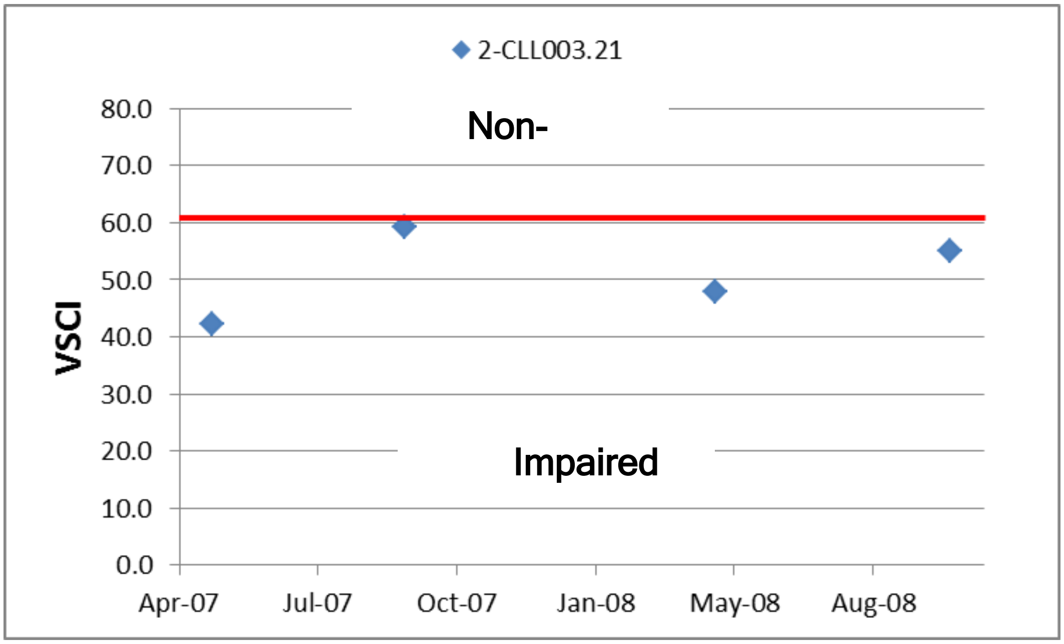

Figure 3.2. VSCI Trend for Colliers Creek (CLL)

Table 3.3. Habitat Metric Scores for Colliers Creek (CLL)

StationID	2-CLL003.21			
Collection Date	04/25/07	09/11/07	04/22/08	10/08/08
Channel Alteration	17	16	16	17
Bank Stability	17	15	16	16
Vegetative Protection	14	16	17	17
Embeddedness	14	15	18	15
Channel Flow Status	19	17	19	16
Frequency of riffles (or bends)	19	19	18	19
Riparian Vegetative Zone Width	4	14	7	10
Sediment Deposition	16	19	17	16
Epifaunal Substrate / Available Cover	18	19	17	18
Velocity / Depth Regime	18	16	16	15
10-Metric Total Habitat Score	**156**	**166**	**161**	**159**

- Marginal or Poor habitat metric rating.

Habitat Score: optimal > 150; suboptimal < 120

3.4. ***Water Quality Data***

3.4.1. **DEQ Ambient Monitoring Data**

Ambient bi-monthly monitoring was performed on the Colliers Creek impaired segment at the 2-CLL001.99 ambient station from August 2001 to June 2003, then again from February 2007 to December 2008. Four samples were collected at the 2-CLL003.21 station, one each in April 2007, September 2007, April 2008, and October 2008. Field physical parameters included temperature, DO, pH, and conductivity. Chemical parameters include: nitrogen (N) species – ammonia-N, nitrate-N, nitrite-N, TKN, and total N; total phosphorus (P); total filterable residue (suspended solids); chloride; bacteria (Escherichia coli); and chlorophyll A.

Average nutrient concentrations from the two stations are summarized in Table 3.4, along with two calculated ratios to assist in assessing nutrient influences in these watersheds.

Table 3.4. Nutrient Concentration Averages and Ratios

Station	Period	TN		NH3-N		NO2-N		NO3-N		TKN		TP		TN:TP	TKN:TN
		No.	Ave.	No.	Ave.	No.	Ave.	No.	Ave.	No.	Ave.	No.	Ave.	Ratio	Ratio
2-CLL001.99	2001 - 2008	12	0.45	18	0.04	12	0.01	12	0.28	12	0.13	24	0.03	16.91	0.30
2-CLL003.21	2007 - 2008	4	0.30	3	0.04	3	0.03	3	0.17	4	0.18	4	0.03	9.83	0.59

Colliers Creek has been listed with a biological impairment at station 2-PLP002.08 in both the 2010 and 2012 Virginia biennial 305(b)/303(d) Combined Reports.

3.4.2. **DEQ Stream Tests for Metals and Organic Compounds**

Two sediment samples were collected in Colliers Creek and analyzed by DEQ for a standard suite of metals.

None of the analytes exceeded any established consensus-based probable effects concentration (PEC) screening criteria, and most of the metals were not detected above their respective minimum detection limit (MDL), Table 3.5.

Table 3.5. DEQ Channel Bottom Sediment Monitoring and Screening Criteria for Metals

Station ID:	2-CLL003.21				Consensus-Based	
Collection Date Time:	4/25/2007		4/22/2008		TEC	PEC
Name	Value	Comment Code	Value	Comment Code	(mg/kg)	(mg/kg)
ALUMINUM IN BOTTOM DEPOSITS (MG/KG AS AL DRY WGT)	7,520		10,200			
ANTIMONY IN BOTTOM DEPOSITS (MG/KG AS SB DRY WGT)	5	U	5	U		
ARSENIC IN BOTTOM DEPOSITS (MG/KG AS AS DRY WGT)	5	U	5	U	9.79	33
BERYLLIUM IN BOTTOM DEPOSITS(MG/KG AS BE DRY WGT)	5	U	5	U		
CADMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	1	U	1	U	0.99	4.98
CHROMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	18.5		16.7		43.4	111
COPPER IN BOTTOM DEPOSITS (MG/KG AS CU DRY WGT)	11.2		15.2		31.6	149
IRON IN BOTTOM DEPOSITS (MG/KG AS FE DRY WGT)	33,700		29,200			
LEAD IN BOTTOM DEPOSITS (MG/KG AS PB DRY WGT)	19.3		17.5		35.8	128
MANGANESE IN BOTTOM DEPOSITS (MG/KG AS MN DRY WGT)	949		982			
MERCURY,TOT. IN BOT. DEPOS. (MG/KG AS HG DRY WGT)	0.1	U	0.1	U	0.18	1.06
NICKEL, TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	15.7		20.0		22.7	48.6
SELENIUM IN BOTTOM DEPOSITS (MG/KG AS SE DRY WGT)	1	U	1	U		
SILVER IN BOTTOM DEPOSITS (MG/KG AS AG DRY WGT)	1	U	1	U		
THALLIUM DRY WGTBOTMG/KG	5	U	5	U		
ZINC IN BOTTOM DEPOSITS (MG/KG AS ZN DRY WGT)	43.4		55.4		121	459

U = parameter analyzed, but not detected.
TEC = Threshold effects concentration
PEC = Probable effects concentration

(shaded) - Minimum detection limit.

Samples analyzed for dissolved metals were taken on the same day as the sediment metals samples. These results are shown in Table 3.6. No samples exceeded any of the applicable aquatic life, human health, or EPA nationally recommended freshwater criteria.

Heavy metals such as mercury, chromium, cadmium, arsenic and lead in streams and rivers can damage aquatic insects at low concentrations. The metals tend to accumulate in the gills and muscles of aquatic organisms. Dissolved metals have been identified as important predictors of stream health. In the context of water quality criteria, dissolved metals are typically treated independently; however there is strong evidence that metals have a cumulative effect (Clements et al., 2000). The Cumulative Criterion Units (CCU) metals index accounts for this additive effect by standardizing each dissolved metal's concentration. The metals are summed together and the result is the CCU Metals Index score. When the CCU Metals Index is above 2, the cumulative effect is considered likely to harm aquatic life (Clements et al., 2000). The CCU score for the set of dissolved metals collected on April 25, 2007 was 0.08, and the CCU score for the sample collected on April 22, 2008 was 0.04, well below the threshold of concern.

Table 3.6. Dissolved Metals Monitoring and Screening Criteria

Station ID:	2-CLL003.21				Consensus-Based	
Collection Date Time:	4/25/2007		4/22/2008		TEC	PEC
Name	Value	Comment Code	Value	Comment Code	(mg/kg)	(mg/kg)
ALUMINUM IN BOTTOM DEPOSITS (MG/KG AS AL DRY WGT)	7,520		10,200			
ANTIMONY IN BOTTOM DEPOSITS (MG/KG AS SB DRY WGT)	5	U	5	U		
ARSENIC IN BOTTOM DEPOSITS (MG/KG AS AS DRY WGT)	5	U	5	U	9.79	33
BERYLLIUM IN BOTTOM DEPOSITS(MG/KG AS BE DRY WGT)	5	U	5	U		
CADMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	1	U	1	U	0.99	4.98
CHROMIUM,TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	18.5		16.7		43.4	111
COPPER IN BOTTOM DEPOSITS (MG/KG AS CU DRY WGT)	11.2		15.2		31.6	149
IRON IN BOTTOM DEPOSITS (MG/KG AS FE DRY WGT)	33,700		29,200			
LEAD IN BOTTOM DEPOSITS (MG/KG AS PB DRY WGT)	19.3		17.5		35.8	128
MANGANESE IN BOTTOM DEPOSITS (MG/KG AS MN DRY WGT)	949		982			
MERCURY,TOT. IN BOT. DEPOS. (MG/KG AS HG DRY WGT)	0.1	U	0.1	U	0.18	1.06
NICKEL, TOTAL IN BOTTOM DEPOSITS (MG/KG,DRY WGT)	15.7		20.0		22.7	48.6
SELENIUM IN BOTTOM DEPOSITS (MG/KG AS SE DRY WGT)	1	U	1	U		
SILVER IN BOTTOM DEPOSITS (MG/KG AS AG DRY WGT)	1	U	1	U		
THALLIUM DRY WGTBOTMG/KG	5	U	5	U		
ZINC IN BOTTOM DEPOSITS (MG/KG AS ZN DRY WGT)	43.4		55.4		121	459

U = parameter analyzed, but not detected.
TEC = Threshold effects concentration
PEC = Probable effects concentration
[shaded cell] - Minimum detection limit.

3.4.3. **DEQ – Other Relevant Monitoring or Reports**

3.4.3.1. Relative Bed Stability (RBS) Analysis

A Log Relative Bank Stability (LRBS) test is a type of siltation index. An LRBS score of negative one (-1) indicates that sediments ten times larger than the median are moving at bankfull, with a medium probability of impairment from sediment. A high percentage of fine sediment in streams would directly contribute to embeddedness, the filling of the interstitial spaces in the channel bottom. LRBS scores < -1 are considered sub-optimal, while scores > -0.5 are considered optimal. Colliers Creek shows a very low percentage of fine sediment in the stream. The LRBS scores of 0.151 in September 2007 and -0.209 in October 2008 are optimal.

3.4.4. **Permitted Point Sources**

There are four general discharge permits for single-family home (SFH) alternative wastewater disposal systems in the Colliers Creek watershed as shown in Table 3.7. There are no VPDES, Industrial Stormwater, or Mixed Concrete permits in the watershed.

Table 3.7. Permitted Discharges

Permit No.	Receiving Stream
VAG408147	Colliers Creek
VAG401984	Colliers Creek, Unnamed Tributary
VAG401347	Colliers Creek
VAG408020	Toad Run

There was one historical land disturbing (construction stormwater) permit issued in the Colliers Creek watershed in 2000, representing a total site area of 14 acres and disturbed area of 9.2 acres. There are currently no active construction stormwater permits in the Colliers Creek watershed.

3.5. *Stressor Analyses Summaries*

Sediment is supported as the most probable stressor contributing to the impairment of the benthic community in Colliers Creek based on the consistently low proportion of haptobenthos organisms, which require clean substrates for habitat, and through the lack of adequate riparian vegetation to buffer surface runoff. Additionally, historical livestock access to the stream, observed incised stream banks and previous road and bridge construction just upstream from the monitoring point all point to sediment as the most probable stressor.

Therefore, a sediment TMDL was developed to address the biological impairments in Colliers Creek.

Chapter 4: Source Assessment of Fecal Coliform

While the bacteria monitoring data were developed to produce *E. coli* concentrations, the watershed model was developed to simulate the transport and fate of fecal coliform due to the greater availability of fecal coliform production data for various sources. Fecal coliform sources and production rates in the Maury River and the Cedar Creek watersheds were assessed using information from the following sources: VADEQ, Virginia Department of Conservation and Recreation (VADCR), Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Cooperative Extension (VCE), Natural Resources Conservation Service (NRCS), the Natural Bridge Soil and Water Conservation District (SWCD), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Potential nonpoint sources of fecal coliform in the Maury River and the Cedar Creek watersheds are summarized in Table 4.1. Additional information regarding the estimation of loads for the various bacteria sources is included in Appendix B.

Table 4.1. Potential fecal coliform sources and daily fecal coliform production by source for existing conditions in the Maury River and the Cedar Creek watersheds.

Potential Source	Population		Fecal coliform produced (x 10^6 cfu/head/day)
	Maury River Watershed	Cedar Creek Watershed	
Humans (permanent)	50,776	506	350[a]
Beef Cattle	12,037	394	8,556[a]
Dairy Cattle	1,450	0	25,000[b]
Goats	1,010	25	12,000[d]
Sheep	2,124	44	12,000[d]
Horses	236	15	420[d]
Pets	17,076	210	450[c]
Deer	9,215	404	350
Raccoons	4,913	158	50
Muskrats	852	19	25[e]
Beavers	395	8	0.2
Ducks	578	11	2400
Geese	372	7	800
Wild Turkeys	1,664	70	93

[a] Source: Geldreich (1978)
[b] Cow-calf pairs
[c] Source: Weiskel *et al*. (1996)
[d] Source: ASAE(1998)
[e] Source: Yagow (2001)

Permitted point sources of fecal coliform bacteria in the Maury River and the Cedar Creek watersheds study area are shown in Table 4.2. Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain an *E. coli* concentration of 126 cfu/100 mL or less in their effluent. In allocation scenarios for bacteria, load for the permitted point source was calculated as the allowable point source discharge concentration of 126 cfu/100 mL at the facility's maximum design flow rate.

Table 4.2. Permitted facilities discharging into impaired streams of the Maury River and the Cedar Creek study area.

Water -shed	Permit Number	Facility Name	Sub water -shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*E. coli* Load (cfu/year)
Maury River	VA0004791	Bontex Inc. (Closed)	MAU-13	0.300	126	5.22×10^{11}
	VA0020991	Buena Vista STP	MAU-12	2.250	126	3.92×10^{12}
	VA0088161	Lexington-Rockbridge Regional WQCF	MAU-22	3.000	126	5.22×10^{12}
	VA0004677	Mohawk Industries Inc.	MAU-1	2.000	126	3.48×10^{12}
	VA0086967	Rockbridge Alum Springs STP	MAU-37	0.040	126	6.96×10^{10}
	VA0089885	Fairfield Square	MAU-18	0.013	126	2.26×10^{10}
	VA0091821	Craigsville STP	MAU-33	0.435	126	7.57×10^{11}
	VA0021148	Rockbridge Middle School	MAU-27	0.0088	126	1.53×10^{10}
	VA0024074	White's Truck Stop Inc. (closed)	MAU-18	0.050	126	8.70×10^{10}
	VA0088960	Kerrs Creek LLC	MAU-25	0.020	126	3.48×10^{10}
	VA0073156	Millboro STP	MAU-39	0.050	126	8.70×10^{10}
	VAG408015	Single Family Home	MAU-3	0.001	126	1.74×10^{9}
	VAG408016	Single Family Home	MAU-3	0.001	126	1.74×10^{9}
	VAG401858	Single Family Home	MAU-18	0.001	126	1.74×10^{9}
	VAG408088	Single Family Home	MAU-18	0.001	126	1.74×10^{9}
	VAG408147	Single Family Home	MAU-6	0.001	126	1.74×10^{9}

	VAG401067	Single Family Home	MAU-23	0.001	126	1.74×10^9
	VAG401811	Single Family Home	MAU-39	0.001	126	1.74×10^9
	VAG401984	Single Family Home	MAU-6	0.001	126	1.74×10^9
	VAG408002	Single Family Home	MAU-38	0.001	126	1.74×10^9
	VAG401085	Single Family Home	MAU-20	0.001	126	1.74×10^9
	VAG401347	Single Family Home	MAU-5	0.001	126	1.74×10^9
	VAG401976	Single Family Home	MAU-34	0.001	126	1.74×10^9
	VAG408153	Single Family Home	MAU-2	0.001	126	1.74×10^9
	VAG408220	Single Family Home	MAU-2	0.001	126	1.74×10^9
	VAG408020	Single Family Home	MAU-4	0.001	126	1.74×10^9
Cedar Creek	VA0024101	Natural Bridge of Virginia	CEC-3	0.099	126	1.72×10^{11}
	VAG401974	Single Family Home	CEC-2	0.001	126	1.74×10^9

*million gallons per day

4.1. ***Summary: Contributions from All Sources***

Based on the inventory of sources discussed in this chapter and Appendix B, an estimate of the contributions by the different direct nonpoint sources to the annual fecal coliform loading to the streams is summarized in Table 4.3 and Table 4.4. The estimated distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also included in Table 4.3 and Table 4.4. From Table 4.3 and Table 4.4, it is clear that nonpoint source loadings to the land surface are greater than direct nonpoint source loadings to the stream. Pastures receive the greatest portion of this load, at 93.0% in the Maury River watershed and at 94.2% in the Cedar Creek watershed. However, factors such as precipitation amount and pattern, die-off rates, manure application activities, type of waste, and proximity to the streams impact the amount of fecal coliform from upland areas that reaches the streams. Due to their nature, direct nonpoint source loadings to streams are not modified before transmission to the stream. The HSPF model discussed in Chapter 4 considers these factors when estimating fecal coliform loadings in the receiving waters.

Table 4.3. Estimated annual fecal coliform loadings to the stream and the various land use categories for the Maury River watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/yr)	Percent of total loading
Direct loading to streams		
Livestock in stream	363	0.4%
Wildlife in stream	155	0.2%
Straight pipes	24	<0.1%
Point Sources	7	<0.1%
Loading to land surfaces		
Cropland	220	0.2%
Pasture	83,497	93.2%
Residential	4,117	4.6%
Forest	1,203	1.3%
Total	**89,586**	

Table 4.4. Estimated annual fecal coliform loadings to the stream and the various land use categories for the Cedar Creek watershed.

Source	Fecal coliform loading ($x10^{11}$ cfu/yr)	Percent of total loading
Direct loading to streams		
Livestock in stream	131	0.6%
Wildlife in stream	38	0.2%
Straight pipes	16	0.1%
Point Sources	0.4	<0.1%
Loading to land surfaces		
Cropland	80	0.4%
Pasture	21,592	94.2%
Residential	563	2.5%
Forest	493	2.2%
Total	**22,913**	

Chapter 5: Setting Reference TMDL Loads for Sediment

Since there are no in-stream WQC for sediment in Virginia, an alternate method was used to establish a reference endpoint that would represent the "non-impaired" condition. For this watershed, the "reference watershed" approach was used to set allowable sediment loading rates in the impaired watershed.

The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. The reference watershed is selected on the basis of similarity of land use, topography, ecology, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

After an appropriate reference watershed is selected, models of both the reference and TMDL watersheds are created, the TMDL endpoint is defined as the simulated load from the area-adjusted reference watershed, and alternative TMDL reduction (allocation) scenarios are developed (Yagow, 2004).

5.1. *TMDL Reference Watershed Selection*

The initial list of potential reference watersheds was composed of watersheds in the vicinity (approximately a 30-mile radius) of Colliers Creek that were listed as reference sites from DEQ's probabilistic monitoring program or had been used previously as reference watersheds by Tetra Tech for the development of the VSCI. Because sediment was identified as the primary pollutant responsible for the benthic impairment, the comparison of watershed characteristics focused not only on geological and ecological similarities, but also on sediment-generating characteristics. Figure 5.1 illustrates the proximity of the potential reference watersheds to the impaired Colliers Creek segment.

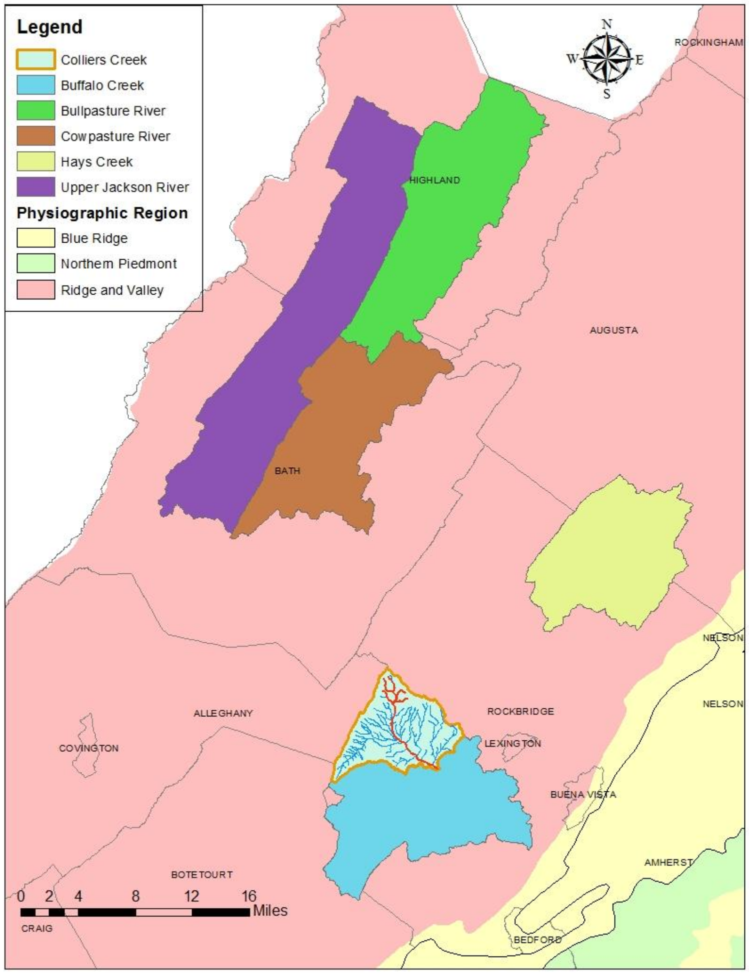

Figure 5.1. Location of Colliers Creek and Potential Reference Watersheds

Table 5.1 compares the various physical and sediment-related characteristics of the potential reference watersheds to the characteristics of the impaired watershed. All of the potential watersheds are in the same river basin (James River) as Colliers Creek. All of the potential reference watersheds also lie within the Northern Limestone/Dolomite Valleys (67a) sub-ecoregion. The characteristics chosen to be most representative of sediment generation were land use distribution, non-forested average soil erodibility (SSURGO K-factor), and non-forested average % slope.

Table 5.1. Comparison of Potential Reference Watershed Characteristics

			Landuse Distribution			Non-Forested			Latest SCI			
Station ID	Stream Name	Area (ha)	Urban (%)	Forest (%)	Agr (%)	SSURGO K-factor	Slope (%)	Elevation (meters)	Score	Date	SubEco Region	River Basin
				Impaired Watershed								
2-CLL-003.21	Colliers Creek	9,466	5%	74%	21%	0.266	14.89	353.0	56.00	Oct-08	67a/67c	James
				Potential TMDL Reference Watersheds								
2-BLD000.22	Buffalo Creek	32,062	5%	74%	21%	0.273	12.82	225.3	67.18	Oct-08	67a	James
2-BLP000.79	Bullpasture River	28,495	0%	82%	18%	0.25**	7.73	794.6	70.30	Mar-08	67a	James
2-CWP050.66	Cowpasture River	56,604	0%	86%	14%	0.26**	13.81	748.4	71.78	Mar-08	67a	James
2-HYS001.41	Hays Creek	20,801	0%	52%	48%	0.310	12.53	526.2	60.18	Mar-08	67a	James
2-JKS067.00	Jackson River	31,429	0%	81%	19%	0.26**	13.93	848.7	65.52	Oct-08	67a	James

(green) - Impaired watershed
(tan) - Closest matches
** STATSGO soils

Based on the above comparisons, Buffalo Creek was selected as the most appropriate reference watershed with the greatest similarity of land use distribution and other sediment generating characteristics with Colliers Creek watershed.

5.2. *TMDL Modeling Target Loads*

The reference watershed approach for this TMDL used the area-adjusted sediment load from the non-impaired Buffalo Creek watershed as the TMDL sediment load endpoint for Colliers Creek. Reductions from various sources are specified in the alternative TMDL scenarios that will achieve the TMDL target within the Colliers Creek watershed. Since Colliers Creek watershed is also a part of the larger non-impaired Buffalo Creek watershed, area-adjusted loads from the entire watershed should serve as a reasonable target to allow remediation of the upstream benthic impairment in Colliers Creek.

Although sediment is used as a surrogate for benthic health in the development of this TMDL, attainment of a healthy benthic community will ultimately be based on biological monitoring of the benthic macro-invertebrate community, in accordance with established DEQ protocols. If a future review should find that the reductions called for in these TMDLs based on current modeling are found to be insufficiently protective of local water quality, then revision(s) will be made as necessary to provide reasonable assurance that water quality goals will be achieved.

Chapter 6: Modeling Process for Bacteria TMDL Development

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, the modeling process, input data requirements, and model calibration procedure and results are discussed.

6.1. *Model Description*

The TMDL development process requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) version 12 (Bicknell et al., 2005; Duda et al., 2001) was used to model fecal coliform transport and fate in the Maury River and the Cedar Creek watersheds. The ArcGIS 10 GIS software was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes. HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget, on pervious areas (e.g., agricultural land). Runoff from impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the general constituent pollutant (GQUAL) sub-module within the RCHRES module. Fecal coliform bacteria are simulated as dissolved pollutants in the GQUAL sub-module.

Two models were developed: one for the Maury River watershed, and one for the Cedar Creek study watershed. These models were calibrated for hydrology and water quality.

The Maury River study watershed includes the Hays Creek study area for which existing TMDLs have been developed. Therefore, output from existing TMDL models were used as inputs to the model used for this study during model calibration, existing conditions simulation, and allocation as appropriate.

6.2. *Model Calibration and Validation*

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. In this section, the procedures followed for calibrating the hydrology and water quality components of the Hydrological Simulation Program-FORTRAN (HSPF) model are discussed.

6.2.1. Hydrology

The Hydrology Statistics Calculator (HSC) decision support system developed by the Center for Watershed Studies, Biological Systems Engineering, Virginia Tech was used to calibrate the hydrologic portion of HSC for Maury River and Cedar Creek. The default HSC criteria for evaluating the accuracy of the flow simulation were used in the calibration for Maury River and Cedar Creek. These criteria are listed in Table 6.1. After calibration, all criteria listed in Table 6.1 were met.

Table 6.1. Default criteria for HSC.

Variable	Percent Error Criteria
Total Volume	10%
50% Lowest Flows	10%
10% Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

6.2.1.1. Hydrologic Calibration for Maury River watershed

Four flow gaging station data were used to calibrate the Maury River watershed. Three stations are located on the main stem of the Maury River at the outlets of sub-watersheds #15 (Station ID 02024000), #31(Station ID 02021500) and #40 (Station ID 02020500). The fourth station is located on Kerrs Creek (sub-watershed #25; Station ID 02022500), a tributary of the Maury River.

The hydrologic calibration period for Maury River watershed was January 1, 2000 to December 31, 2005. The hydrologic validation period was from January 1, 2006 to December 31, 2009. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range (USEPA, 2000).

Hydrologic Calibration for sub-watershed #15 gaging station

The calibration for flow gage at sub-watershed #15 met all HSC model performance criteria for both the calibration and the validation periods. This indicates that the developed hydrologic model provides an acceptable prediction of Maury River flows at this station.

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figure 6.1 and Figure 6.2. The agreement with observed flows is further illustrated in Appendix C.

Selected diagnostic output from the HSC program is listed in Table 6.2 and Table 6.3. The total winter runoff and total summer runoff errors are considered in the HSC term ‘seasonal volume error’ (see Table 6.1). The resulting seasonal volume error was -0.67% for the calibration period of the sub-watershed #15. The seasonal volume error for the validation period was 3.96%. Both are within the required range of ±10%

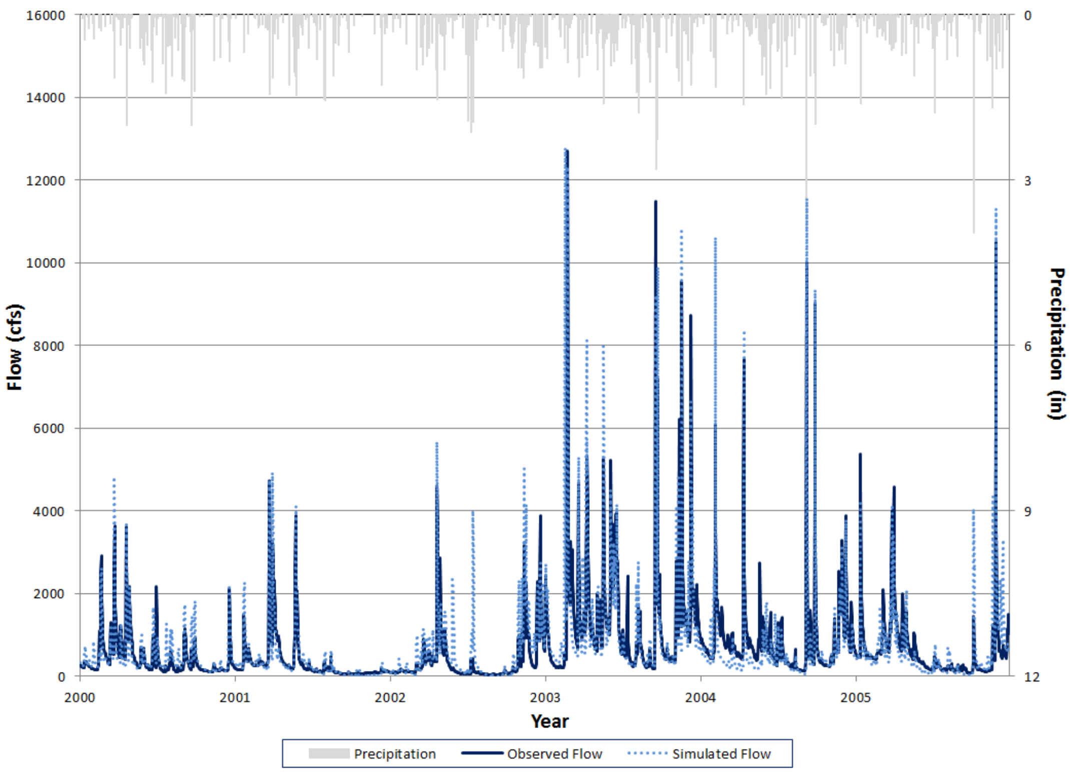

Figure 6.1. Comparison of observed and simulated flow at sub-watershed #15 in Maury River watershed for the calibration period

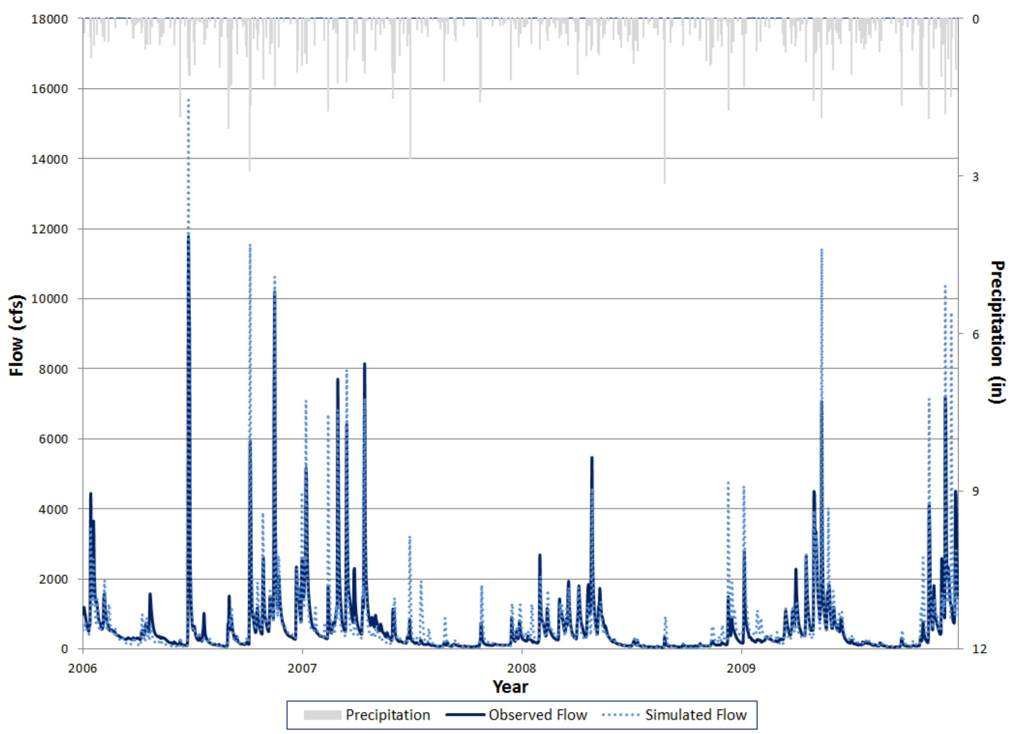

Figure 6.2. Comparison of observed and simulated flows at sub-watershed #15 in Maury River watershed for the validation period

Table 6.2. Summary statistics for the calibration for Maury River at sub-watershed #15

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	88.507	85.893	3.0	10%
Average Annual Total Runoff (in)	14.751	14.316	3.0	10%
Total of Highest 10% of flows (in)	40.100	37.206	7.8	15%
Total of Lowest 50% of flows (in)	11.562	10.883	6.2	10%
Total Winter Runoff (in)	25.975	23.543	10.3	na
Total Summer Runoff (in)	14.025	12.790	9.7	na
Coefficient of Determination, r^2	0.750			

na = not applicable; these are not criteria directly considered by HSC

Table 6.3. Summary statistics for the validation period for Maury River at sub-watershed #15

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	54.662	50.541	8.2	10%
Average Annual Total Runoff (in)	13.666	12.635	8.2	10%
Total of Highest 10% of flows (in)	25.532	23.145	10.3	15%
Total of Lowest 50% of flows (in)	6.621	6.030	9.8	10%
Total Winter Runoff (in)	19.477	15.985	21.8	na
Total Summer Runoff (in)	8.096	6.435	25.8	na
Coefficient of Determination, r^2	0.760			

na = not applicable; these are not criteria directly considered by HSC

Hydrologic Calibration for sub-watershed #25 gaging station

The simulated flow for both the calibration and validation period matched the observed flow well, as shown in Figure 6.3 and Figure 6.4. The agreement with observed flows is further illustrated in Appendix C.

Selected diagnostic output from the HSC program is listed in Table 6.4 and Table 6.5. The total winter runoff and total summer runoff errors are considered in the HSC term ‘seasonal volume error’ (see Table 6.1). The seasonal volume error was -6.24% for the calibration period at sub-watershed #25. The seasonal volume error for the validation period of the sub-watershed #25 was -1.86%. Both are within the required range of ±10%.

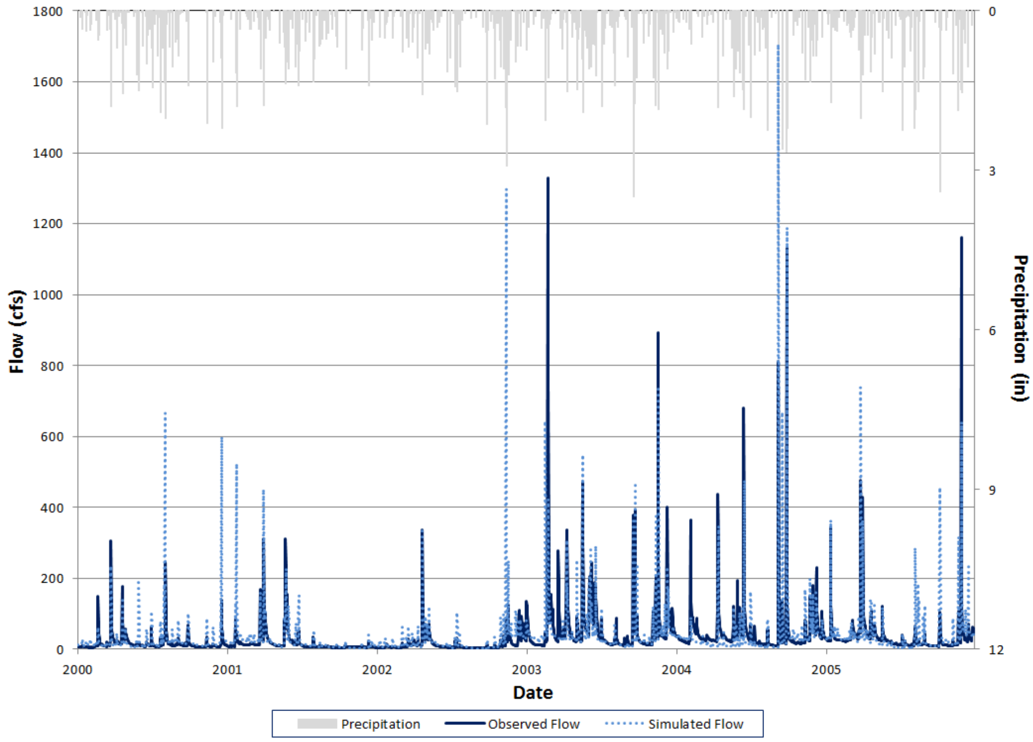

Figure 6.3. Comparison of observed and simulated flow at sub-watershed #25 in Maury River watershed for the calibration period

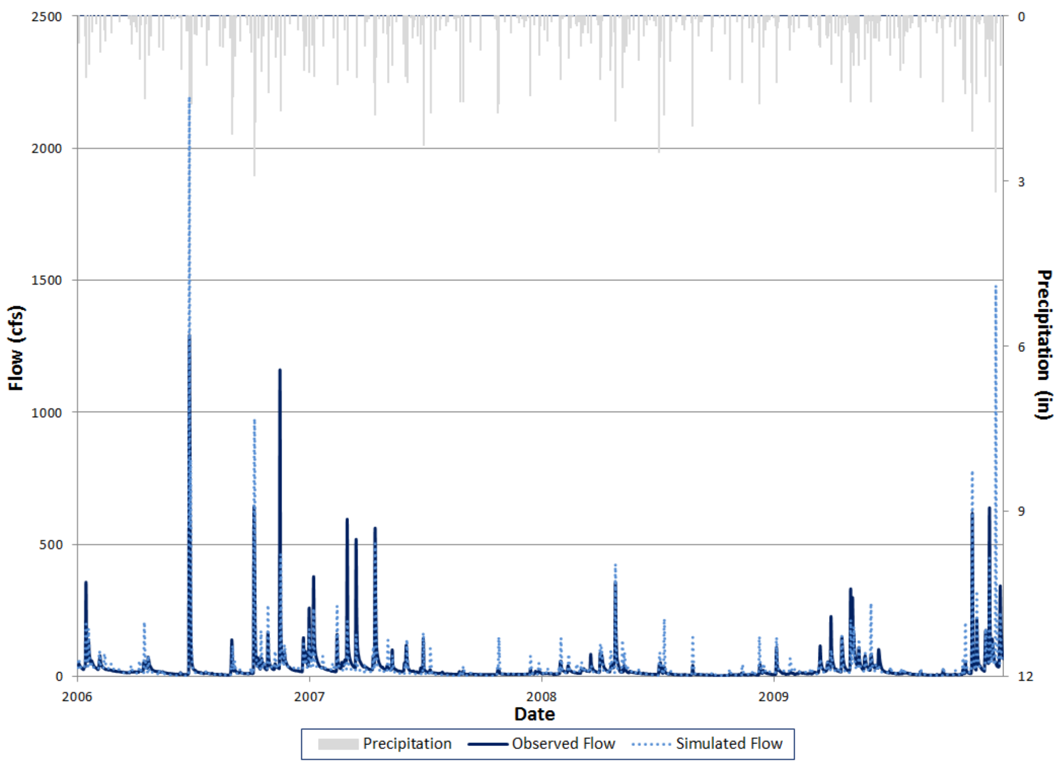

Figure 6.4. Comparison of observed and simulated flows at sub-watershed #25 in Maury River watershed for the validation period

Table 6.4. Summary statistics for the calibration for Maury River at sub-watershed #25

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	82.770	76.023	8.9	10%
Average Annual Total Runoff (in)	13.795	12.671	8.9	10%
Total of Highest 10% of flows (in)	41.270	37.069	11.3	15%
Total of Lowest 50% of flows (in)	11.425	10.406	9.8	10%
Total Winter Runoff (in)	22.143	20.020	10.6	na
Total Summer Runoff (in)	14.325	13.726	4.4	na
Coefficient of Determination, r^2	0.228			

na = not applicable; these are not criteria directly considered by HSC

Table 6.5. Summary statistics for the validation period for Maury River at sub-watershed #25

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	51.324	48.868	5.0	10%
Average Annual Total Runoff (in)	12.831	12.217	5.0	10%
Total of Highest 10% of flows (in)	26.420	23.750	11.2	15%
Total of Lowest 50% of flows (in)	6.757	7.140	- 5.4	10%
Total Winter Runoff (in)	16.534	13.959	18.4	na
Total Summer Runoff (in)	9.964	8.546	16.6	na
Coefficient of Determination, r^2	0.341			

na = not applicable; these are not criteria directly considered by HSC

Hydrologic Calibration for sub-watershed #31 gaging station

The simulated flow for both the calibration and validation period matched the observed flow well, as shown in Figure 6.5 and Figure 6.6. The agreement with observed flows is further illustrated in Appendix C.

Selected diagnostic output from the HSC program is listed in Table 6.6 and Table 6.7. The total winter runoff and total summer runoff errors are considered in the HSC term 'seasonal volume error' (see Table 6.1). The seasonal volume error was -8.93% for the calibration period of the sub-watershed #31, and 2.04% for the validation period. Both are within the required range of ±10%.

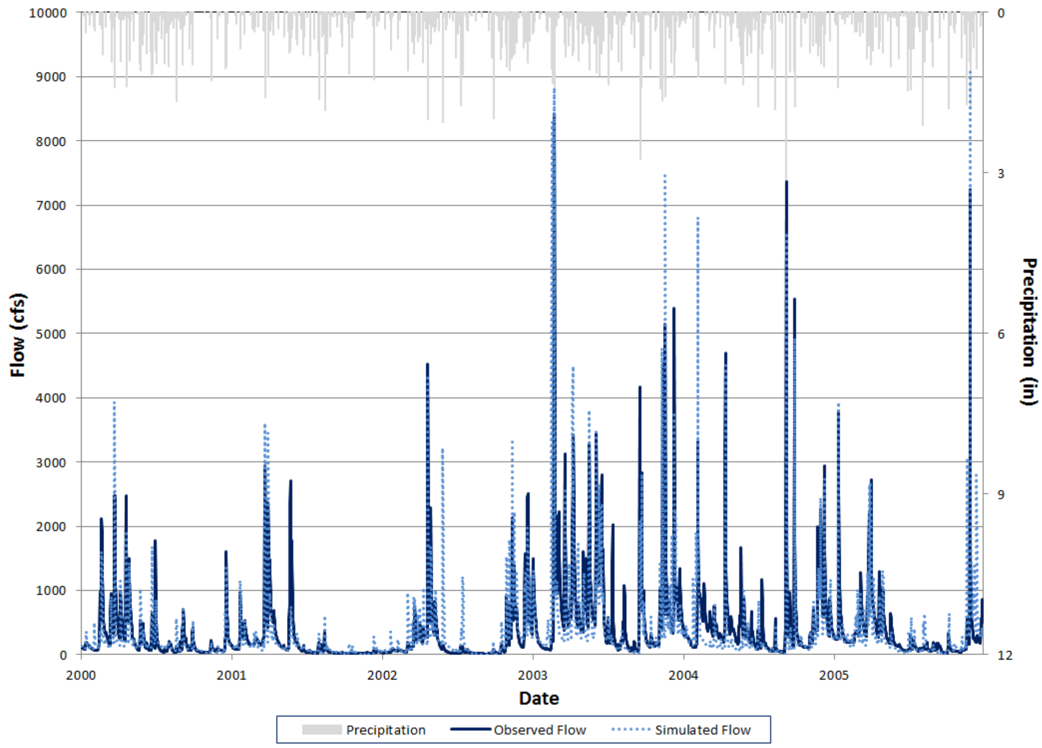

Figure 6.5. Comparison of observed and simulated flow at sub-watershed #31 in Maury River watershed for the calibration period

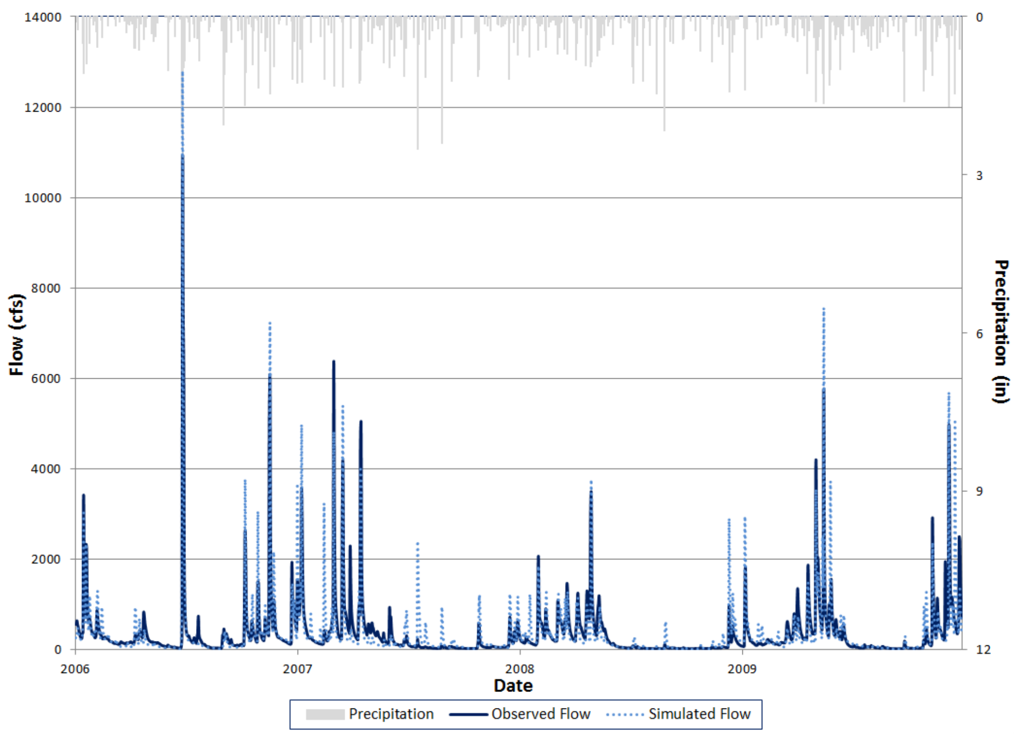

Figure 6.6. Comparison of observed and simulated flows at sub-watershed #31 in Maury River watershed for the validation period

Table 6.6. Summary statistics for the calibration for Maury River at sub-watershed #31

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	86.840	95.120	- 8.7	10%
Average Annual Total Runoff (in)	14.473	15.853	- 8.7	10%
Total of Highest 10% of flows (in)	44.931	45.361	- 0.9	15%
Total of Lowest 50% of flows (in)	9.320	9.265	0.6	10%
Total Winter Runoff (in)	27.076	25.763	5.1	na
Total Summer Runoff (in)	11.985	12.464	- 3.8	na
Coefficient of Determination, r^2	0.656			

na = not applicable; these are not criteria directly considered by HSC

Table 6.7. Summary statistics for the validation period for Maury River at sub-watershed #31

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	57.712	57.736	0.0	10%
Average Annual Total Runoff (in)	14.428	14.434	0.0	10%
Total of Highest 10% of flows (in)	30.211	28.921	4.5	15%
Total of Lowest 50% of flows (in)	5.797	5.350	8.4	10%
Total Winter Runoff (in)	20.761	17.888	16.1	na
Total Summer Runoff (in)	8.674	7.345	18.1	na
Coefficient of Determination, r^2	0.788			

na = not applicable; these are not criteria directly considered by HSC

Hydrologic Calibration for sub-watershed #40 gaging station

The simulated flow for both the calibration and validation period matched the observed flow well, as shown in Figure 6.7 and Figure 6.8. The agreement with observed flows is further illustrated in Appendix C.

Selected diagnostic output from the HSC program is listed in Table 6.8 and Table 6.9. The total winter runoff and total summer runoff errors are considered in the HSC term ‘seasonal volume error’ (see Table 6.1). The seasonal volume error was -9.52% for the calibration period of sub-watershed #40 and was within the required range of ±10%. The seasonal volume error for the validation period of sub-watershed #40 was calculated as 11.48%, which was a little bit over the criterion.

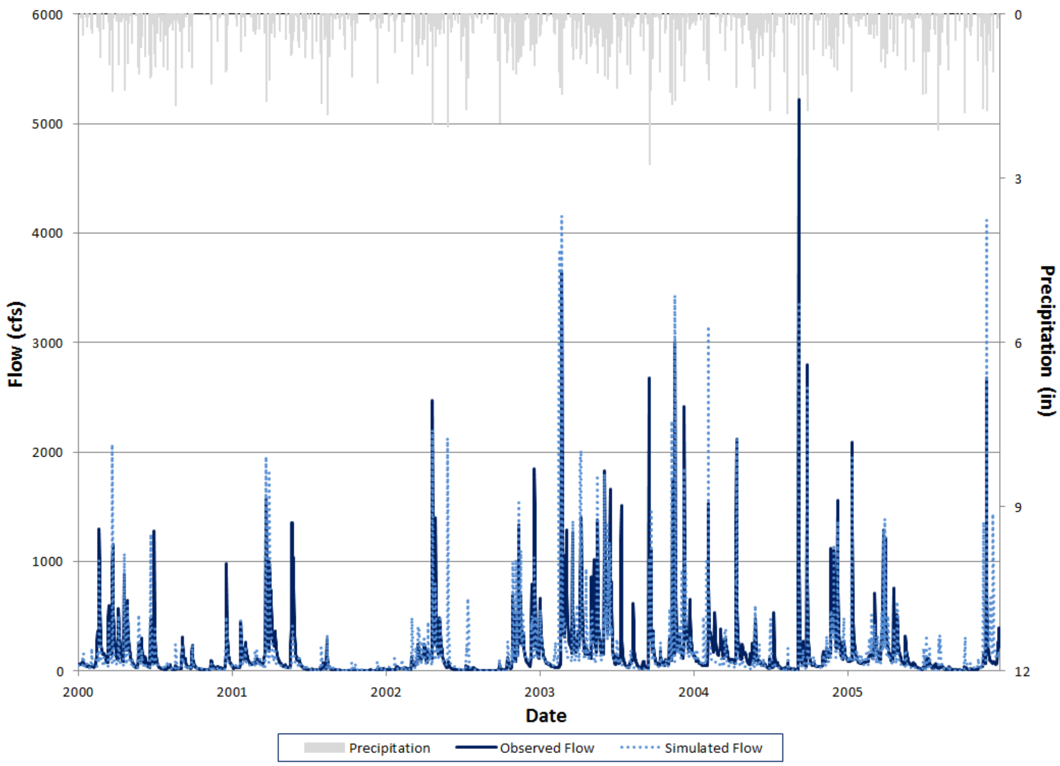

Figure 6.7. Comparison of observed and simulated flow at sub-watershed #40 in Maury River watershed for the calibration period

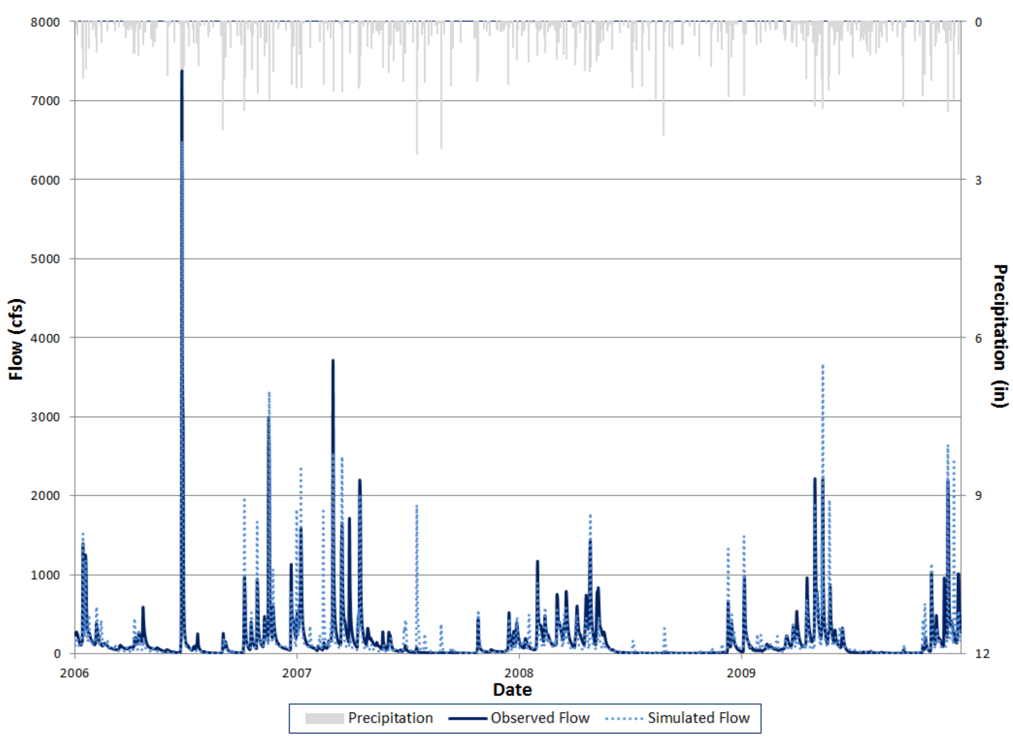

Figure 6.8. Comparison of observed and simulated flows at sub-watershed #40 in Maury River watershed for the validation period

Table 6.8. Summary statistics for the calibration for Maury River at sub-watershed #40

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	86.781	96.282	- 9.9	10%
Average Annual Total Runoff (in)	14.464	16.047	- 9.9	10%
Total of Highest 10% of flows (in)	86.781	96.282	- 6.3	15%
Total of Lowest 50% of flows (in)	7.752	8.234	- 5.9	10%
Total Winter Runoff (in)	26.642	25.643	3.9	na
Total Summer Runoff (in)	11.860	12.566	- 5.6	na
Coefficient of Determination, r^2	0.600			

na = not applicable; these are not criteria directly considered by HSC

Table 6.9. Summary statistics for the validation period for Maury River at sub-watershed #40

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	57.843	62.193	- 7.0	10%
Average Annual Total Runoff (in)	14.461	15.548	- 7.0	10%
Total of Highest 10% of flows (in)	32.059	32.483	- 1.3	15%
Total of Lowest 50% of flows (in)	4.714	4.332	8.8	10%
Total Winter Runoff (in)	20.481	19.526	4.9	na
Total Summer Runoff (in)	8.752	7.521	16.4	na
Coefficient of Determination, r^2	0.746			

na = not applicable; these are not criteria directly considered by HSC

6.2.1.2. Hydrologic Calibration for Cedar Creek watershed

Hydrologic model calibration could not be conducted on Cedar Creek watershed due to the lack of continuous observed flow data. However, hydrological parameters in HSPF had to be set to “reasonable” values because the output of the hydrological component of HSPF impacts on fecal coliform predictions. Some of those parameters were estimated based on watershed characteristics, while others were based on the parameters which were calibrated in the Maury River watershed. Parameters from the sub-watershed #31 calibrated model in the Maury River watershed was shown the best match with the observed flow data and were selected for the Cedar Creek model.

USGS (U.S. Geological Survey) collected monthly flow samples at ambient monitoring station 02020139 from September 2008 to February 2012. To ensure that the model parameters were appropriate for the Cedar Creek watershed, observed flows at the monitoring location were compared to simulated flows at the corresponding sub-watershed outlet. The observed and simulated flows for the observation period are shown in Figure 6.9. As can be seen from the Figure 6.9, the simulated flows match the few observed points. Thus, the adapted parameters are acceptable for use in the Cedar Creek watershed.

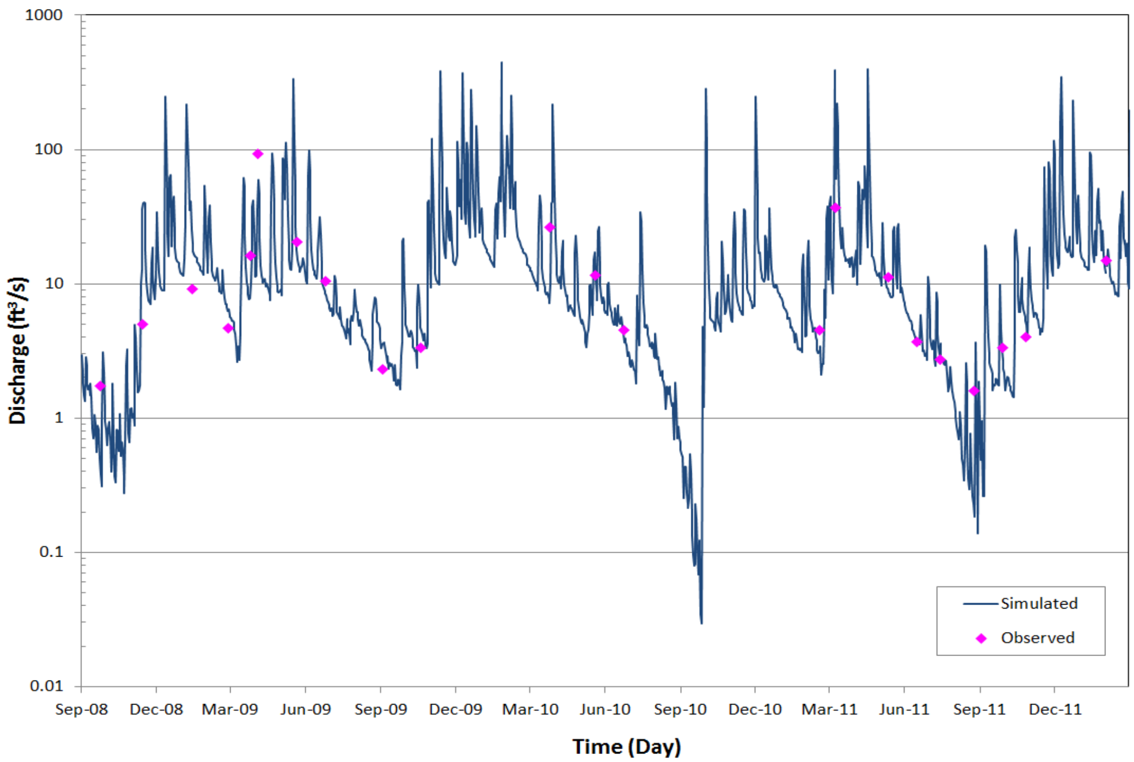

Figure 6.9 Comparison of observed and simulated flow in Cedar Creek

6.2.2. **Water Quality**

The water quality model calibration and validation for the Maury River and Cedar Creek watersheds were performed at an hourly time step using the HSPF model. Limited observations of bacterial water quality were available for some stations in the watershed, while other stations had more suitable quantities of data available for use. The water quality stations identified for use in developing the water quality model are identified in Table 6.10. All data used for calibration and validation were observed *E. coli* concentration data. VADEQ's *E. coli* translator regression equation was used to translate the fecal coliform model results to *E. coli* concentrations for comparison to observed *E. coli* concentration data.

Table 6.10 shows stations used for the water quality calibration and validation for the Maury River and Cedar Creek. Data from the following VADEQ monitoring stations were used for the calibration and/or validation for Maury River: 2-CFP004.67 (Calfpasture River), 2-CFP024.20 (Calfpasture River), 2-MIT000.04 (Mill Creek), MRY000.09 (Maury River), MRY005.39 (Maury River), MRY014.78 (Maury River), MRY016.62 (Maury River), MRY020.82 (Maury River), MRY038.29 (Maury River), 2-STH000.21 (South River), 2-ISH000.02 (Irish Creek), 2-MIS000.04 (Mill Creek), 2AWDS000.10 (Woods Creek), 2-BFN000.07 (North Fork Buffalo Creek), 2-BFS000.15 (South Fork Buffalo Creek), 2-BLD000.22 (Buffalo Creek) and 2-CLL001.99 (Colliers Creeks). Stations 2-CFP004.67 (Calfpasture River), 2-MRY000.09 (Maury River), 2-MRY005.39 (Maury River), 2-MRY014.78 (Maury River), 2-MRY016.62 (Maury River), 2-MRY038.29 (Maury River), 2-STH000.21 (South River), 2-BFS000.15 (South Fork Buffalo Creek), 2-BLD000.22 (Buffalo Creek) and 2-CLL001.99 (Colliers Creeks) had sufficient data for both calibration and validation. Stations 2-MIT000.04, 2-MIS000.04 and 2-BFN000.07 only had sufficient data to allow for calibration. Stations 2-CFP024.20, 2-MRY020.82, 2-ISH000.02 and 2AWDS000.10 only had limited data to allow for validation. Data from stations 2-CEC000.04 and 2-CEC003.60 were used for both calibration and validation for Cedar Creek.

Output from the HSPF model was generated as an hourly time series and daily average time series of *E. coli* concentration at the sub-watershed outlets that correspond to the locations of the water quality model calibration stations. The VADEQ *E. coli* translator (Eqn. 4.1) was implemented using the GENER block in HSPF to calculate instream *E. coli* concentration data compared to observed data during calibration, validation, and later during existing conditions modeling and allocation. The geometric mean of *E. coli* concentrations was calculated on a monthly basis.

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad [4.1]$$

Observed data in the study watersheds were typically collected through grab samples collected on a monthly or bimonthly basis (at best). Because it is not practical to expect such data to exactly match an average simulated value on a specific day, other methods of comparison are needed. The strongest method of comparison is the use of the minimum and maximum simulated values – the observed data should fall roughly within the range of values simulated near the date of observed data collection. Other parameters to consider are violation rate, averages, medians, geometric means, etc.

Table 6.10. Water quality stations in the Maury River and the Cedar Creek watersheds

Station ID	Stream Name	Station Description	Indicator Organism Measured	Number of Samples	Violation Rate	Period of Record
2-CFP004.67	Calfpasture River	77 feet downstream of Rt. 42 bridge	E. coli	105	7.6%	2003 - 2012
2-CFP024.20	Calfpasture River	-	E. coli	12	25.0%	2007 - 2008
2-MIT000.04	Mill Creek	-	E. coli	18	11.1%	2004 - 2008
2-MRY000.09	Maury River	DGIF Boat Launch	E. coli	29	10.3%	2003 - 2012
2-MRY005.39	Maury River	Off Rt. 663 Near Old Canal Lock	E. coli	29	10.3%	2003 - 2012
2-MRY014.78	Maury River	Rt. 60 at Ben Salem Wayside	E. coli	111	8.5%	2002 - 2012
2-MRY016.62	Maury River	-	E. coli	21	9.5%	2005 – 2012
2-MRY020.82	Maury River	-	E. coli	12	0.0%	2007 – 2008
2-MRY038.29	Maury River	Rt. 39 Bridge	E. coli	62	14.5%	2002 – 2012
2-STH000.21	South River	-	E. coli	21	0.0%	2005 – 2012
2-ISH000.02	Irish Creek	Rt. 608 Bridge at Cornwall	E. coli	12	0.0%	2005 – 2012
2-MIS000.04	Mill Creek	-	E. coli	12	16.7%	2007 – 2008
2AWDS000.10	Woods Creek	-	E. coli	12	25.0%	2008 – 2009
2-BFN000.07	North Fork Buffalo Creek	-	E. coli	12	16.7%	2007 - 2008
2-BFS000.15	South Fork Buffalo Creek	Rt. 611 Bridge	E. coli	23	47.8%	2007 – 2012
2-BLD000.22	Buffalo Creek	Private Br. off Rt. 700	E. coli	29	24.1%	2003 - 2012
2-CLL001.99	Colliers Creek	Rt. 644 Bridge	E. coli	23	21.7%	2007 - 2012
2-CEC000.04	Cedar Creek	Rt. 608 Bridge	E. coli	47	14.9%	2008 – 2012
2-CEC003.60	Cedar Creek	Rt. 609 Bridge	E. coli	47	48.9%	2008 – 2012

6.2.2.1. Water Quality Calibration for Maury River watershed

Calibration

Initial model predictions of *E. coli* concentrations were slightly high for Calfpasture River following watershed-wide model adjustments made while calibrating other impairments. Such parameters included livestock stream access and fecal coliform production rates for beef cattle and humans. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.11. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.11. Water quality calibration statistics for the Calfpasture Creek at station 2-CFP004.67.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	42	104	35	5
Simulated	52	84	64	8

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* concentration were slightly high for Mill Creek. Cattle direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.12. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.12. Water quality calibration statistics for Mill Creek at station 2-MIT000.04.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	48	208	25	11
Simulated	55	89	49	11

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for Maury River. Multiple parameters were adjusted during calibration, these included the first order decay rate (FSTDEC) and livestock direct deposition. Once these adjustments were made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.13. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.13. Water quality calibration statistics for Maury River at stations 2-MRY000.09, 2-MRY005.39, 2-MRY014.78, 2-MRY016.62 and 2-MRY038.29.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
2-MRY000.09	Observed	37	49	25	0
	Simulated	66	80	77	6
2-MRY005.39	Observed	30	32	25	0
	Simulated	60	74	76	6
2-MRY014.78	Observed	37	59	30	3
	Simulated	77	131	93	13
2-MRY016.62	Observed	32	48	25	8
	Simulated	71	88	78	7
2-MRY038.29	Observed	48	144	25	14
	Simulated	63	112	87	13

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were high for South River following watershed-wide model adjustments made while calibrating other impairments. Such parameters included livestock stream access and fecal coliform production rates for beef cattle and humans. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.14. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.14. Water quality calibration statistics for South River at station 2-STH000.21

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	26	27	25	0
Simulated	74	91	56	8

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* concentration were slightly high for Mill Creek. Livestock direct deposition was adjusted during the calibration process, adjusted fecal coliform production rates for beef cattle, and waterfowl population peaks were removed throughout the watershed. Once these adjustments were made, the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.15. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.15. Water quality calibration statistics for Mill Creek at station 2-MIS000.04.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	85	119	75	17
Simulated	61	126	115	10

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were high for North Fork Buffalo Creek. Livestock direct deposition was adjusted during calibration. Once these adjustments were made, the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.16. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.16. Water quality calibration statistics for North Fork Buffalo Creek at station 2-BFN000.07.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	73	202	63	17
Simulated	136	170	160	22

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for South Fork Buffalo Creek. Livestock direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.17. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.17. Water quality calibration statistics for South Fork Buffalo Creek at station 2-BFS000.15.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	248	330	250	64
Simulated	218	298	244	54

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for Buffalo Creek. Livestock direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.18. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.18. Water quality calibration statistics for Buffalo Creek at station 2-BLD000.22.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	96	165	100	29
Simulated	128	219	121	39

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Initial model predictions of *E. coli* were slightly high for Colliers Creek. Livestock direct deposition was adjusted during the calibration process. Once this adjustment was made the bacteria predictions from HSPF acceptably matched the simulated data. The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.19. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.19. Water quality calibration statistics for Colliers Creek at station 2-CLL001.99.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	129	305	75	27
Simulated	120	171	134	20

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Validation

After the calibration of Calfpasture River at VADEQ monitoring station 2-CFP004.67, the model output was compared to *E. coli* data from station 2-CFP004.67 and 2-CFP024.20 for two periods (August 15, 2003 to December 31, 2007 and February 15, 2007 to December 15, 2008, respectively) as a validation to confirm the calibrated input parameters were appropriate. Similarly, validation was performed for Maury River at stations 2-MRY000.09 (August 1, 2003 to June 30, 2005), 2-MRY005.39 (August 1, 2003 to June 30, 2005), 2-MRY0014.78 (August 15, 2002 to December 31, 2007), 2-MRY016.62 (July 1, 2005 to November 15, 2006), 2-MRY020.82 (February 1, 2007 to December 15, 2008) and 2-MRY038.29 (August 15, 2002 to December 31, 2007). Also validation was conducted for the South River, the Irish River, the Woods Creek, the South Buffalo Creek, the Buffalo Creek and the Colliers Creek at stations 2-STH000.21 (July 1, 2005 to November 15, 2006), 2-ISH000.02 (February 1, 2007 to December 15, 2008), 2AWDS000.07 (January 15, 2008 to January 15, 2010), 2-BFS000.15 (February 1, 2007 to December 15, 2008), 2-BLD000.22 (August 1, 2003 to June 30, 2005) and 2-CLL001.99 (February 1, 2007 to December 15, 2008), respectively. The goodness-of-fit statistics for the validation runs are listed in Table 6.20 through Table 6.27. Based on the goodness-of-fit parameter values and the visual comparisons, validations for Calfpasture River, Maury River, South River, Irish Creek, Woods Creek, South Buffalo Creek, Buffalo Creek and Colliers Creek were considered acceptable. Graphical comparisons are included in Appendix C.

Table 6.20. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Calfpasture at stations 2-CFP004.67 and 2-CFP024.20.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
2-CFP004.67	Observed	46	149	25	11
	Simulated	44	84	73	8
2-CFP024.20	Observed	150	276	165	25
	Simulated	59	82	62	9

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.21. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period at stations 2-MRY000.09, 2-MRY005.39, 2-MRY014.78, 2-MRY016.62, 2-MRY020.82 and 2-MRY038.29.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
2-MRY000.09	Observed	81	273	50	25
	Simulated	44	71	57	8
2-MRY005.39	Observed	62	250	25	25
	Simulated	43	78	61	9
2-MRY014.78	Observed	53	168	25	15
	Simulated	56	115	75	12
2-MRY016.62	Observed	50	77	50	11
	Simulated	63	119	106	10
2-MRY020.82	Observed	29	31	25	0
	Simulated	74	132	98	16
2-MRY038.29	Observed	38	112	25	15
	Simulated	39	76	53	6

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.22. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for South River at station 2-STH000.21.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	29	33	25	0
Simulated	55	71	50	13

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.23. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Irish Creek at station 2-ISH000.02.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	56	75	63	0
Simulated	26	40	28	0

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.24. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Woods Creek at station 2AWDS000.10.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	91	138	110	25
Simulated	69	158	171	17

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.25. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for South Fork Buffalo Creek at station 2-BFS000.15.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	162	383	140	33
Simulated	128	215	144	40

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.26. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Buffalo Creek at station 2-BLD000.22.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	93	253	88	17
Simulated	66	89	55	12

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Table 6.27. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Colliers Creek at station 2-CLL001.99.

	Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
Observed	80	170	75	17
Simulated	60	111	82	15

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

6.2.2.2. Water Quality Calibration for Cedar Creek watershed

Calibration

Two water quality monitoring stations are located in the Cedar Creek watershed. While Cedar Creek has a relatively small watershed and sampling at those stations have occurred at the same dates. Observed data from two stations shows a noticeable difference in results between stations. To model this difference, continuous hydrologic monitoring data and precise geomorphic data are needed. Cedar Creek has been listed as impaired on Virginia's 2010 Section 303(d) Report based on the data from station 2-CEC003.60. Given this listing basis and to provide a conservative modeling approach, the water quality calibration for the Cedar Creek watershed was focused on the data from station 2-CEC003.60

The final goodness-of-fit measures for the calibration at the monitoring station are listed in Table 6.28. Based on the goodness-of-fit parameter values and the visual comparison (Appendix C), the water quality calibration was considered acceptable.

Table 6.28. Water quality calibration statistics for Cedar Creek at station 2-CEC000.04 and 2-CEC003.60.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
2-CEC000.04	Observed	53	89	25	9
	Simulated	212	418	298	48
2-CEC003.60	Observed	214	307	225	43
	Simulated	247	495	302	50

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Validation

After the calibration of Cedar Creek at VADEQ monitoring stations 2-CEC000.04 and 2-CEC002.60, the model output was compared to *E. coli* data from same stations for validation period (January 15, 2008 to December 31, 2010) to confirm the calibrated input parameters were appropriate. The goodness-of-fit statistics for the validation runs are listed in Table 6.29. Based on the goodness-of-fit parameter values and the visual comparisons, the validation for Cedar Creek was considered acceptable. Graphical comparisons are included in Appendix C.

Table 6.29. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Colliers Creek at stations 2-CEC000.04 and 2-CEC003.60.

Station		Geometric Mean cfu/100ml	Average* cfu/100ml	Median* cfu/100ml	Single Sample Criterion Violation Rate (%)
2-CEC000.04	Observed	**65**	**170**	**38**	**21**
	Simulated	**159**	**503**	**202**	**40**
2-CEC003.60	Observed	**210**	**404**	**250**	**52**
	Simulated	**199**	**654**	**240**	**45**

* Simulated values for these parameters were calculated from the average daily predictions in the 5 days surrounding each observed data collection day; this provides a more detailed comparison with the actual observations, as it targets the specific meteorological and hydrologic conditions at the time of data collection.

Chapter 7: Modeling Process for Sediment TMDL Development

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutant that caused the impairment. Pollutant transport to water bodies is evaluated using a variety of tools, including watershed modeling. The modeling process, input data requirements, and TMDL load calculation procedures used in developing the Colliers Creek sediment TMDL are discussed in this chapter.

7.1. *Model Selection*

The model selected for development of the sediment TMDL in the Colliers Creek watershed was the Generalized Watershed Loading Functions (GWLF) model, originally developed by Haith et al. (1992), with modifications by Evans et al. (2001), Yagow et al. (2002), and Yagow and Hession (2007). The model was run in metric units and converted to English units for this report.

The loading functions upon which the GWLF model is based are compromises between the empiricism of export coefficients and the complexity of process-based simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater. The hydrology in the model is simulated with a daily water balance procedure that considers different types of storages within the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986).

GWLF uses three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation.

The transport file contains input data primarily related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Penn State Visual Basic™ version of GWLF with modifications for use with ArcView was the starting point for additional modifications (Evans et al., 2001). The following modifications related to sediment were made to the Penn State version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Urban sediment buildup was added as a variable input.
- Urban sediment washoff from impervious areas was added to total sediment load.
- Formulas for calculating monthly sediment yield by land use were corrected.
- Mean channel depth was added as a variable to the streambank erosion calculation.

The current Virginia Tech (VT) modified version of GWLF (Yagow and Hession, 2007) was used in this study. The VT version includes a correction to the flow accumulation calculation in the channel erosion routine that was implemented in December 2005 (VADEQ, 2005). This version also includes modifications from Schneiderman et al. (2002) to include an unsaturated zone leakage coefficient, and to add in missing bounds for the calculation of erosivity using Richardson equations which were intended to have minimum and maximum bounds on daily calculations. These minimum and maximum bounds were not included in GWLF 2.0, and have been added to keep calculations within physically expected bounds.

Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (VADEQ, 2005).

7.2. *GWLF Model Development for Sediment*

Model development for both the reference and impaired watersheds was performed by assessing the sources of sediment in the watershed, evaluating the necessary parameters for modeling loads, and applying the model and procedures for calculating loads.

7.3. *Input Data Requirements*

7.3.1. **Climate Data**

Climate in Colliers Creek and Buffalo Creek watersheds were characterized by meteorological observations from the National Weather Service Cooperative Station 444565 at Kerrs Creek, Virginia. Data from Station 444876 at Lexington were used to patch missing data. The period of record used for TMDL modeling was a nineteen-year period from January 1992 through December 2010, with the preceding 9 months of data used to initialize storage parameters. The locations of the various NCDC stations are shown in relationship to the Colliers Creek and Buffalo Creek in Figure 7.1.

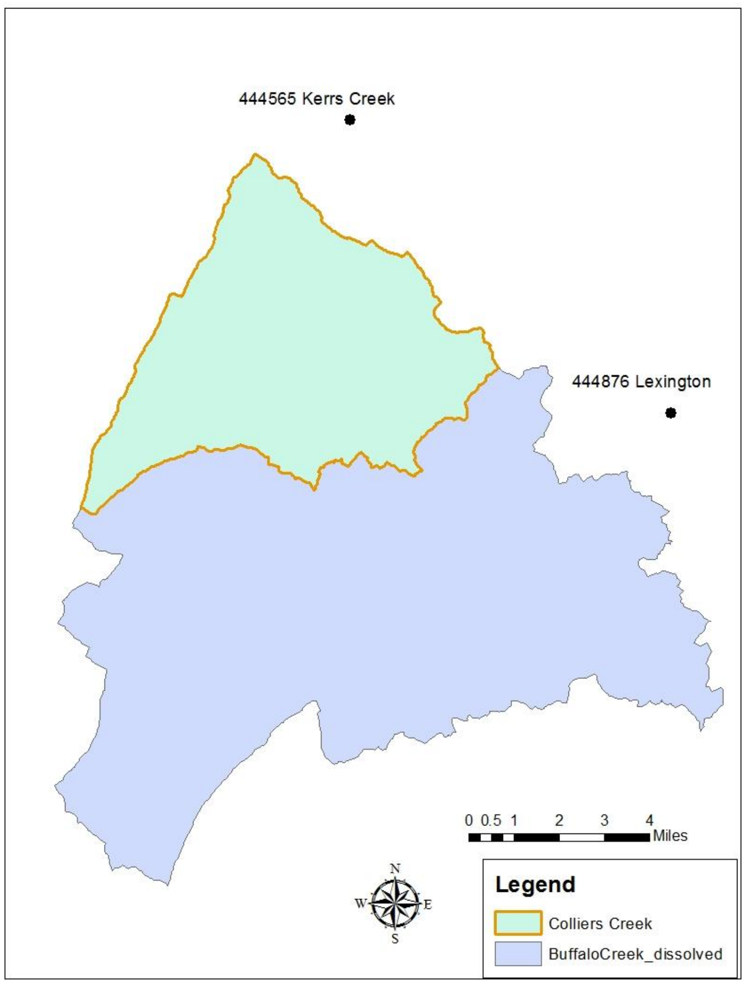

Figure 7.1. Location of Watersheds and NCDC Weather Stations

7.3.2. **Existing Land Use**

Modeled land uses for the Colliers Creek and Buffalo Creek watersheds were derived from the 2006 NLCD, as discussed in Section 2.5. The Row Crop category was subdivided into hi-till and low-till categories based on Conservation Tillage Information Center (CTIC) data as incorporated in the 2006 Virginia Statewide NPS Watershed Assessment (Yagow and Hession, 2007). The Hay and Pasture acreages were combined and reassigned based on percent distribution by VAHU6, also as used in the Yagow and Hession study (2007). From the Pasture category, the "riparian", and "animal feeding operation" land uses were calculated as 0.0498 and 0.0041 times the total Pasture area, respectively, as estimated from proportions within the Chesapeake Bay Watershed Model (CBWM) land-river segment JU1_6880_7260. The remaining Pasture area was sub-divided into 10% "good", 80% "fair", and 10% "poor" pasture land uses, based on an assessment by local conservation personnel. A "harvested forest" land use was created as 1% of the Forest category, similar to procedures used in the CBWM (USEPA, 2010). The "barren" category was re-assessed as 2% of all the developed land use categories for Colliers Creek, and subtracted from the "Urban Open Space" land use. The "developed" categories were sub-divided into pervious and impervious portions, with "urban open space" assigned to the pervious portion of the "low intensity developed" land use. Impervious percentages of 20%, 50%, and 80% were used, respectively, for the low intensity, medium intensity and high intensity developed areas. The simulated land uses and their derivations are summarized in Table 7.1.

Each land use within a sub-watershed formed a hydrologic response unit (HRU). Model parameters were then calculated for each HRU using GIS analysis to reflect the variability in topographic and soil characteristics across the watershed.

Table 7.1. Modeled Land Use Categories

NASS Land Uses	NASS Groups	% Impervious	Modeled Land Use Categories
Corn, sorghum, soybeans, winter wheat, etc.	Row Crop	0	Hi-till cropland
			Lo-till cropland
Alfalfa, other hays	Hay	0	Hay
Pasture/grass, shrubland, grassland herbaceous	Pasture	0	Good pasture
			Fair pasture
			Poor Pasture
			Riparian pasture
			Animal feeding operation
Deciduous forest, evergreen forest, mixed forest,	Forest	0	Forest
			Harvested forest
Barren	Barren	0	Barren
Urban open space	Open Space	0	Pervious LDI
Developed, low intensity	LDI	20	Impervious LDI
			Pervious LDI
Developed, medium intensity	MDI	50	Impervious MDI
			Pervious MDI
Developed, high intensity	HDI	80	Impervious HDI
			Pervious HDI

7.4. *Future Land Use*

A future land use scenario was created using the same land use categories as for the existing scenario. Future land use was assessed from a combination of the Rockbridge County Comprehensive Plan, the U.S. Census Bureau data for the area in both 2000 and 2010 (http://www.census.gov), and an assessment of growth potential from local stakeholders. As no major changes are envisioned for the watersheds, future land use in the watershed was represented as the existing conditions. Detailed land use distributions for Existing conditions in both Colliers Creek and the area-adjusted Buffalo Creek watersheds, are given below in Table 7.2.

7.5. *GWLF Parameter Evaluation*

All parameters were evaluated in a consistent manner for both watersheds in order to ensure their comparability. All GWLF parameter values were evaluated using a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures

(Evans et al., 2001), procedures developed during the 2006 statewide NPS pollution assessment (Yagow and Hession, 2007), and best professional judgment.

Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file. Descriptions of each of the hydrologic and sediment parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses. The GWLF parameter values used for both the Colliers Creek and Buffalo Creek watersheds are detailed in Appendix D.

Table 7.2. Existing and Future Land Use Distributions

Modeled Land Use Categories	**Colliers Creek**	**Buffalo Creek - area adjusted**
	(area in acres)	
HiTill Rowcrop	2.0	2.1
LoTill Rowcrop	56.6	57.0
Pasture	3,600.3	3,638.2
Animal feeding operations	9.7	15.9
Hay	1,236.0	1,251.1
Forest	17,099.8	17,018.9
Harvested forest (hvf)	172.7	171.9
Transitional (barren)	59.1	60.2
Pervious Low Intensity Developed (pur_LDI)	1,107.3	1,117.3
Pervious Med Intensity Developed (pur_MDI)	-	1.6
Pervious High Intensity Developed (pur_HDI)	0.4	0.1
Impervious LDI (imp_LDI)	13.5	22.4
Impervious MDI (imp_MDI)	-	1.6
Impervious HDI (imp_HDI)	1.6	0.5
Total Simulated Area	**23,358.9**	**23,358.9**
Water	33.2	19.5
Total Area	**23,392.1**	**23,378.4**

7.5.1. **Hydrology Parameters**

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC, cm): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.

- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. This parameter was evaluated using the following relationship from Lee et al. (2000): RecCoeff = 0.045+1.13/(0.306+Area in square kilometers)
- Seepage coefficient: The seepage coefficient represents the fraction of flow lost as seepage to deep storage.
- Leakage coefficient: The leakage coefficient represents the fraction of infiltration that bypasses the unsaturated zone through macro-pore flow. An increase in this coefficient, initially set to zero, decreases ET losses and increases baseflow.

The following parameters were initialized by running the model for a 9-month period prior to the period used for load calculation:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the current day.

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model.
- ET_CV: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.
- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance.

7.5.2. **Sediment Parameters**

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997); and then adjusted after consultation with local NRCS personnel.
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans et al., 2003)

- % Developed land: percentage of the watershed with urban-related land uses – defined as all land in MDR and HDR land uses, as well as the impervious portions of LDR.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Curve Number: area-weighted average value for the watershed.
- K Factor: area-weighted USLE soil erodibility factor for the watershed.
- Slope: mean percent slope for the watershed.
- Stream length: calculated as the total stream length of natural perennial stream channels, in meters. Excludes any non-erosive hardened and piped sections of the stream.
- Mean channel depth (m): calculated from relationships developed either by the Chesapeake Bay Program or by USDA-NRCS by physiographic region, of the general form – $y = a * A^b$, where y = mean channel depth in ft, and A = drainage area in square miles (USDA-NRCS, 2005).

7.6. *Supplemental Post-Model Processing*

After modeling was performed on individual and cumulative sub-watersheds, model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of BMPs already implemented within each watershed.

Sediment BMPs are required on harvested forest lands and on disturbed lands subject to Erosion and Sediment (E&S) regulations. The harvested forest land use areas were simulated as if they had BMPs performing at 50% of their potential efficiency, while the disturbed lands were simulated without BMPs. Potential sediment reduction efficiencies for both types of BMPs were obtained from the Chesapeake Bay Watershed Model (USEPA, 2010), where maximum sediment reduction efficiencies of 60% are expected from harvested forest land and 40% reductions from construction areas. For the allocation scenarios, loads from both of these land uses were simulated as operating at their respective full potential efficiencies.

The extent and effect of existing agricultural BMPs in both the Colliers Creek and the reference Buffalo Creek watersheds were based on spatial data provided by Virginia's Department of Conservation and Recreation from their Agricultural BMP Cost-Share Database for the JU84 sixth-order watershed.

Load reductions and corresponding pass-through fractions of the sediment load from each land use were calculated based on BMP efficiencies and credits for upland filtering by buffers, as used in the Chesapeake Bay Watershed Model (USEPA, 2010). Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs. BMPs represented as land use changes were assumed to have already been reflected in the land use data.

7.7. ***Representation of Sediment Sources***

Sediment is generated in the Colliers Creek and Buffalo Creek watersheds through the processes of surface runoff, in-channel disturbances, and streambank and channel erosion, as well as from natural background contributions and permitted sources. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses.

Permitted sediment dischargers in the Colliers Creek watershed include general permit facilities. Stormwater discharges include urban stormwater runoff from MS4, municipal, and industrial permits, while construction permits regulated through Virginia's Erosion and Sediment Control Program and single-family household alternative onsite wastewater disposal systems fall under broader aggregate General Permits.

7.7.1. **Surface Runoff**

During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Pervious area sediment loads were modeled using a modified USLE erosion detachment algorithm, monthly transport capacity calculations, and a sediment delivery ratio in the GWLF model to calculate loads at the watershed outlet. Impervious area sediment loads were modeled in the GWLF model using an exponential buildup-washoff algorithm.

7.7.2. **Channel and Streambank Erosion**

Streambank erosion was modeled within the GWLF model using a modification of the routine included in the AVGWLF version of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of percent developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, average slope, streamflow volume, mean channel depth, and total stream length in the watershed. Livestock population, which figures into animal density, was estimated based on a stocking density of 4.5 acres of available pasture per animal unit (1 animal unit = 1,000 lbs of live weight).

7.7.3. **Industrial Stormwater**

Currently, there are no active Industrial Storm Water General Permits (ISWGPs) in the Colliers Creek watershed.

7.7.4. **Construction Stormwater**

Currently, there are no active Construction General Permits in the Colliers Creek watershed.

7.7.5. **Other Permitted Sources (VPDES and General Permits)**

In the Colliers Creek watershed, there are four general discharge permits for single-family homes.

7.8. ***Accounting for Critical Conditions and Seasonal Variations***

7.8.1. **Selection of Representative Modeling Period**

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed. A long period of weather inputs was selected to represent long-term variability in the watershed. The model was run using a weather time series from April 1991 through December 2010, with the first 9 months used as an initialization period for internal storages within the model. The remaining 19-year period was used to calculate average annual sediment loads in all watersheds.

7.8.2. **Critical Conditions**

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

7.8.3. **Seasonal Variability**

The GWLF model used for this analysis considered seasonal variation through a number of mechanisms. Daily time steps were used for weather data and water balance calculations. The model also used monthly-variable parameter inputs for evapotranspiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

7.9. *Existing and Future Sediment Loads*

Sediment loads were simulated for all individual land uses with the GWLF model, calculated for point sources, and then summed in both the Colliers Creek and the reference Buffalo Creek watersheds for Existing conditions.

Sediment loads for permitted sources were calculated for the Colliers Creek watershed. To allow for future growth in the watershed, a sediment load value for future growth was calculated as 1% of the TMDL load. The sediment loads for permitted sources and future growth were incorporated into the waste load allocation (WLA). Table 7.3 includes sediment loads by land use from Future conditions for the Colliers Creek watershed and the area-adjusted existing load for the reference watershed, Buffalo Creek.

Table 7.3. Future Sediment Loads in Colliers Creek Watershed and Existing Sediment Loads in the Reference Watershed

Land Use/Source Categories	Future	Reference
	Colliers Creek	Buffalo Creek-adj
	Sediment Load (tons/yr)	
HiTill Rowcrop	10.2	7.3
LoTill Rowcrop	68.1	48.9
Pasture	8,689.4	7,223.0
Hay	1,355.2	1,250.8
Forest	1,092.8	914.8
Harvested forest	92.3	77.4
Transitional (barren)	443.9	395.8
Pervious LDI (pur_LDI)	308.4	322.0
Pervious MDI (pur_MDI)	0.0	0.6
Pervious HDI (pur_HDI)	0.0	0.0
Impervious LDI (imp_LDI)	2.1	3.4
Impervious MDI (imp_MDI)	0.0	1.0
Impervious HDI (imp_HDI)	0.6	0.2
Channel Erosion	103.7	76.3
Permitted WLA	103.4	0.0
Total Sediment Load	**12,270.1**	**10,321.4**

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Chapter 8: TMDL Allocations

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

8.1. *Bacteria*

The objective of the bacteria TMDLs for the Maury River and the Cedar Creek watersheds were to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standard for *E. coli* used in the development of the TMDL was a calendar-month geometric mean of 126 cfu/100 mL. The TMDL considers all significant sources contributing *E. coli* to the impaired streams. The sources can be separated into nonpoint and point sources. The different sources in the TMDL are defined in the following equation:

$$TMDL = WLA_{total} + LA + MOS \qquad [8.1]$$

Where:

WLA_{total} = waste load allocation (point source contributions, including future growth);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

A TMDL accounts for critical conditions, seasonal variations and must include a margin of safety (MOS).

8.1.1. **Accounting for Critical Conditions and Seasonal Variations**

Current EPA regulations [40 CFR 130.7(c)(1)] require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. Such an approach ensures that TMDLs, when implemented, will not result in violations of the water quality criteria under a wide variety of flow regimes that affect *E. coli* concentrations.

A period of four years was used for allocation modeling. Observed meteorological data from the NCDC Cooperative Weather Stations at the Lexington, Kerrs Creek, Craigsville and Lynchburg Airport were extracted for 2009, 2010, 2011 and 2012 and used in the allocation simulations. These particular rainfall years were selected because they incorporate average rainfall, low rainfall, and high rainfall; and the climate during these years caused a wide range of hydrologic events including both low and high flow conditions. The bacteria loading in the model for allocation scenarios was representative of anticipated future conditions.

The continuous simulation model developed for these TMDLs explicitly incorporates the seasonal variations of rainfall and other meteorological parameters, in addition to monthly estimates of fecal coliform loads. By using an hourly time-step in the model, these measures account for the seasonal effects in fecal coliform loading within the watershed.

When developing a bacterial TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria running off the land surface that reach the stream or decreasing the amount of bacteria directly deposited in the stream; these reductions are presented in the tables in the following sections. The reductions called for in the following sections indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in these sections are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (livestock direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, eliminating sewage spills, and other appropriate measures included in the TMDL Implementation Plan.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, the arithmetic mean of the hourly values was computed on a daily basis, and then the geometric mean was calculated from these average daily values.

8.1.2. **Margin of Safety**

A MOS is factored into a TMDL to account for model uncertainty. The MOS can be either explicit, as an additional load reduction requirement, or implicit, which incorporates conservative assumptions within the application of the TMDL model. An implicit MOS was used in these bacteria TMDLs by using conservative estimations of all factors that would affect bacteria loadings in the watershed (e.g., animal numbers, production rates, contributions to the stream). These factors were estimated in such a way as to represent the worst-case scenario; i.e., they describe the worst stream conditions that could exist in the watersheds. Creating TMDLs with conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

8.1.3. **Existing Conditions**

Analysis of the simulation results for the existing conditions in the watershed (Table 8.1) shows that contributions from wildlife direct deposits are the primary source of *E. coli* to Colliers Creek. Contributions from pervious land sources are the primary source of *E. coli* to Maury River. Contributions from livestock direct deposits are the primary source of *E. coli* to Buffalo Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, and Cedar Creek. The results in this table were taken as the average daily contributions for the allocation simulation period, irrespective of the magnitude of the concentration or the flow rate (factors that were considered in the earlier section detailing the source breakdown used in the calibration).

Table 8.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in the Maury River and the Cedar Creek watersheds.

Source	Relative Daily Contribution by Source					
	Maury River	Buffalo Creek	Colliers Creek	North Fork Buffalo Creek	South Fork Buffalo Creek	Cedar Creek
Nonpoint source loadings from cropland	10%	<1%	<1%	<1%	<1%	<1%
Nonpoint source loadings from forest	2%	<1%	<1%	<1%	<1%	<1%
Nonpoint source loadings from pasture	31%	20%	16%	26%	9%	9%
Nonpoint source loadings from residential	3%	1%	<1%	<1%	<1%	<1%
Direct nonpoint source loadings to the stream from livestock	28%	40%	21%	56%	46%	63%
Direct nonpoint source loadings to the stream from wildlife	19%	29%	36%	13%	33%	17%
Interflow and groundwater contribution	<1%	<1%	<1%	<1%	<1%	<1%
Straight-pipe discharges to stream	3%	9%	24%	3%	10%	8%
Permitted point source loadings	5%	<1%	<1%	<1%	<1%	2%

8.1.4. **Future Conditions**

The Rockbridge County Comprehensive Plan adopted June 23, 2003 outlines potential growth in the study watershed, but this potential growth was minimal. Similarly, modest potential growth is identified in the Comprehensive Plans for Augusta County (adopted January 28, 2009), Lexington City (adopted May, 2006), and Buena Vista City (adopted November, 2011). Therefore, allocation scenarios were developed using existing conditions in the watershed.

8.1.5. **Allocation Scenarios**

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean concentration less than 126 cfu/100 mL. The scenarios and results are summarized in Tables 8.2 – 8.7 for Maury River, Buffalo Creek, Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, and Cedar

Creek, respectively. Recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. The recommended scenarios are highlighted in yellow in Tables 8.2 – 8.7.

Scenarios labeled "1" are shown in Tables 8.2 – 8.7 to illustrate that there is a need for reductions in directly deposited wildlife loads in Maury River, Buffalo Creek, Colliers Creek, South Fork Buffalo Creek, and Cedar Creek to meet the water quality standard. Successful scenarios labeled "2" show the minimum modeled reductions needed to attain compliance with the *E. coli* standard. However, the true measure of water quality improvement in this watershed will not be based on modeled results, but rather on the results of in-stream monitoring.

Table 8.2. Bacteria allocation scenarios for the Maury River watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	15
1	100	100	100	100	100	0	2
Successful Scenario							
2	99	30	10	100	0	50	0

* does not include loads from failing septic systems

Table 8.3. Bacteria allocation scenarios for the Buffalo Creek watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	37
1	100	100	100	100	100	0	12
Successful Scenario							
2	99	65	30	100	10	75	0

* does not include loads from failing septic systems

Table 8.4. Bacteria allocation scenarios for the Colliers Creek watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	38
1	100	100	100	100	100	0	15
Successful Scenario							
2	99	75	30	100	10	40	0

* does not include loads from failing septic systems

Table 8.5. Bacteria allocation scenarios for the North Fork Buffalo Creek watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	47
1	100	100	100	100	100	0	0
Successful Scenario							
2	75	50	30	100	10	0	0

* does not include loads from failing septic systems

Table 8.6. Bacteria allocation scenarios for the South Fork Buffalo Creek watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	47
1	100	100	100	100	100	0	17
Successful Scenario							
2	99	75	30	100	10	60	0

* does not include loads from failing septic systems

Table 8.7. Bacteria allocation scenarios for the Cedar Creek watershed.

Scenario Number	Required *E. coli* Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard
	Livestock Direct Deposit	Loads from Pasture	Loads from Cropland	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Geo. Mean
Unsuccessful Scenarios							
Baseline Conditions	0	0	0	0	0	0	57
1	100	100	100	100	100	0	17
Successful Scenario							
2	99	50	10	100	0	55	0

* does not include loads from failing septic systems

As a general rule, direct deposit sources (livestock, wildlife, and straight pipes) control violations of the calendar-month geometric mean standard. These sources control the constant inputs to the water body, and thus control the geometric mean of the daily average predictions over the entire month.

Loadings for the existing conditions and the chosen successful TMDL allocation scenario (2) are presented for nonpoint sources by land use in Table 8.8 – Table 8.13 and for direct nonpoint sources in Table 8.14 – Table 8.19.

The fecal coliform allocation scenario loads presented in Tables 8.8 – 8.19 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF-predicted mean daily fecal coliform concentrations.

Table 8.8. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Maury River.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	180	<1	162	10
Pasture	64,265	93	44,986	30
Residential	3,769	5	942	75
Forest	1,077	2	1,077	0
Total	69,291		47,167	32

Table 8.9. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	13	<1	9	30
Pasture	7,084	96	2,479	65
Residential	187	3	131	30
Forest	68	<1	68	0
Total	7,352		2,687	63

Table 8.10. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Colliers Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	14	<1	10	30
Pasture	5,177	96	1,294	75
Residential	107	2	75	30
Forest	67	1	67	0
Total	5,365		1,446	73

Table 8.11. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for North Fork Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	12	<1	8	30
Pasture	4,775	98	2,388	50
Residential	30	1	21	30
Forest	41	1	41	0
Total	4,858		2,458	49

Table 8.12. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for South Fork Buffalo Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	2	<1	1.5	30
Pasture	2,211	94	553	75
Residential	40	2	28	30
Forest	88	4	88	0
Total	2,342		670	71

Table 8.13. Estimated annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Cedar Creek.

Land use category	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Cropland	8	<1	8	0
Pasture	2,159	95	1,080	50
Residential	56	2	28	50
Forest	49	2	49	0
Total	2,273		1,165	49

Table 8.14. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Maury River.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	232	60	2	99
Wildlife in Streams	145	38	73	50
Straight Pipes	8	2	0	100
Total	386		8.6	81

Table 8.15. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	18.7	60	0.2	99
Wildlife in Streams	10.7	35	2.7	75
Straight Pipes	1.6	5	0	100
Total	30.9		2.9	91

Table 8.16. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Colliers Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	23.8	68	0.2	99
Wildlife in Streams	9.1	26	5.5	40
Straight Pipes	2.0	6	0	100
Total	34.9		5.7	84

Table 8.17. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for North Fork Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	46.1	91	11.5	75
Wildlife in Streams	4.1	8	4.1	0
Straight Pipes	0.7	1	0	100
Total	50.9		15.6	69

Table 8.18. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for South Fork Buffalo Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	42	81	0.4	99
Wildlife in Streams	8	15	3.1	60
Straight Pipes	2	4	0	100
Total	52		3.5	93

Table 8.19. Estimated annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario 2 for Cedar Creek.

Source	Existing Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Existing Load
Livestock in Streams	13.1	71	0	100
Wildlife in Streams	3.8	20	1.7	55
Straight Pipes	1.6	9	0	100
Total	18.5		1.7	91

8.1.6. **Waste Load Allocation**

A Total Waste Load Allocation (WLA_{Total}) was developed for each impaired segment. The WLA_{Total} is the sum of the WLA for each permitted point source facility, a WLA for any applicable MS4 permits in the watershed, and a WLA to account for future growth.

Twenty-four point source facilities are located in the Maury River watershed and two point source facilities are located in Cedar Creek (Table 4.2). Fifteen of these are general permit coverage for a single family home, and the load from these source were considered small (<10%) relative to the load allocation. A WLA was assigned to the permitted point source facilities in the Maury River, Buffalo Creek, Colliers Creek, and Cedar Creek watersheds. There are no permitted point source facilities in the North Fork Buffalo Creek or South Fork Buffalo Creek watersheds.

The existing WLA in each watershed represented ≤ 10% of the TMDL. Therefore, a scenario to account for future growth was set at 2% of the TMDL for permitted operations in each of the study watersheds. This future growth allocation may be allocated to new or expanding dischargers as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. Any permit issued for bacteria control will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Inclusion of the future growth WLA results in no violations of geometric mean standard. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 126 cfu/100 mL *E. coli* will not cause additional violations of the water quality standards. The calculation of WLA_{Total} for each impairment is presented in Tables 8.20 through 8.25.

Table 8.20. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Maury River bacteria TMDL.

Permit Number	WLA
VA0020991	*3.92×10^{12}*
VA0088161	*5.22×10^{12}*
VA0004677	*3.55×10^{12}*
VA0086967	*6.96×10^{10}*
VA0089885	*2.26×10^{10}*
VA0091821	*7.57×10^{11}*
VA0021148	*1.53×10^{10}*
VA0088960	*3.48×10^{10}*
VA0073156	*8.70×10^{10}*
7 domestic Sewage General Permit	*1.22×10^{10}*
Future Growth	*1.61×10^{13}*
WLA_{Total}	*2.98×10^{13}*

Table 8.21. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Buffalo Creek bacteria TMDL.

Permit Number	WLA
4 domestic Sewage General Permit	*6.97×10^{9}*
Future Growth	*1.91×10^{12}*
WLA_{Total}	*1.91×10^{12}*

Table 8.22. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Colliers Creek bacteria TMDL.

Permit Number	WLA
4 domestic Sewage General Permit	6.97×10^{9}
Future Growth	4.68×10^{11}
WLA_{Total}	4.75×10^{11}

Table 8.23. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the North Fork Buffalo Creek bacteria TMDL.

Permit Number	WLA
Future Growth	6.52×10^{11}
WLA_{Total}	6.52×10^{11}

Table 8.24. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the South Fork Buffalo Creek bacteria TMDL.

Permit Number	WLA
Future Growth	2.01×10^{11}
WLA_{Total}	2.01×10^{11}

Table 8.25. Estimated annual WLA for *E. coli* loadings (cfu/yr) at the watershed outlet used for the Cedar Creek bacteria TMDL.

Permit Number	WLA
VA0024101	1.72×10^{11}
1 domestic Sewage General Permit	1.74×10^{9}
Future Growth	3.26×10^{11}
WLA_{Total}	5.01×10^{11}

8.1.7. **Summary of the TMDL Allocation Scenarios for Bacteria**

TMDLs for *E. coli* have been developed for Maury River, Buffalo Creek, Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, and Cedar Creek. The TMDLs address the following issues:

1. The TMDLs meet the calendar-month geometric mean water quality standard.
2. Because *E. coli* loading data were not available to quantify nonpoint source bacterial loads, available fecal coliform loading data were used as input to the HSPF model. This input of fecal coliform loads from indirect sources (land applied) and direct in-stream sources are listed in Tables 8.8 – 8.19. HSPF uses processes to model land surface build-up, wash-off, and instream die-off to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator equation was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations.

3. The TMDLs were developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDLs. In the Maury River and Cedar Creek study area, violations of the water quality standard were caused during both low stream flow and high stream flow; because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.
6. Both the flow regime and bacteria loading to the streams are seasonal. The TMDLs account for these seasonal effects.

Using equation 8.1, the summary of the bacteria TMDLs for Maury River, Buffalo Creek, Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, and Cedar Creek for the selected allocation scenarios are given in Table 8.26. The LAs in the TMDL equations are the corresponding in-stream annual *E. coli* loads resulting from the allocated nonpoint source fecal coliform loads listed in Tables 8.8 – 8.19.

Table 8.26. Maximum annual *E. coli* loadings (cfu/yr) at the impaired watershed outlets in the Maury River and the Cedar Creek watersheds.

Impairment	WLA_{total}	LA*	MOS**	TMDL
Maury River	2.98×10^{13}	7.74×10^{14}	--	8.04×10^{14}
Buffalo Creek	1.91×10^{12}	9.33×10^{13}	--	9.53×10^{13}
Colliers Creek	4.75×10^{11}	2.29×10^{13}	--	2.34×10^{13}
North Fork Buffalo Creek	6.52×10^{11}	3.19×10^{13}	--	3.25×10^{13}
South Fork Buffalo Creek	2.01×10^{11}	9.87×10^{12}	--	1.01×10^{13}
Cedar Creek	5.01×10^{11}	1.58×10^{13}	--	1.63×10^{13}

*The LA is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value is different from the tables providing nonpoint source load (Tables 8.8 – 8.19) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.
**Implicit MOS

Daily *E. coli* TMDL

The USEPA has mandated that TMDL studies completed in 2007 and later include a daily maximum load as well as the average annual load shown in the previous section. The daily load was determined as the product of a representative flow rate from the watershed and the appropriate concentration criterion from the water quality standard. This section summarizes the daily maximum loads for Maury River, Buffalo Creek, Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, and Cedar Creek.

Hydrologic Considerations

According to guidance from EPA (USEPA, 2006) it is necessary to assess the flow duration curve to determine an appropriate flow rate to use in the load calculation. EPA guidance suggests that the flow duration curve should be plotted using observed continuous flow data. Flow data from the USGS gage used in the hydrologic calibration were used to calculate the daily load. As is specified in the EPA guidance, the observed flows from the Maury River were multiplied by the ratio of each impaired segment's watershed area to the drainage area above the USGS gage. The flow rate corresponding to the 99^{th} percentile flow (that is, the flow rate exceeded by only 1% of the observed flows) was identified for the Maury River at the USGS gage 02024000 as 5,514 cfs.

Daily Load

Setting a *maximum daily* load will help ensure that the annual loads given in Table 8.27 are appropriately distributed such that on any given day the single sample component of the bacteria water quality standard will be met. The loadings in the annual load tables, being of a long-term nature, will more directly assure compliance with the geometric mean component of the standard. Thus, the maximum daily load was computed as the product of the critical flow condition and the geometric mean criterion (126 cfu/100 mL). Since the annual WLA_{total} is already based on a maximum daily permitted flow and a maximum daily permitted concentration the daily WLA_{total} is calculated as the annual WLA_{total} divided by 365; the daily LA is then the TMDL less the

WLA_{total}. The resulting daily maximum loadings are shown in Table 8.27. The actual maximum daily load is dependent upon flow conditions, and progress toward water quality improvement will be assessed against the numeric water quality criteria (126 cfu *E. coli*/100 mL for a calendar month geometric mean, and 235 cfu *E. coli*/100 mL for a single sample).

Table 8.27. Maximum daily *E. coli* loadings (cfu/day) at the watershed outlets.

Watershed	WLA_{total} †	LA	MOS*	TMDL
Maury River	8.16×10^{10}	4.10×10^{13}	-	4.11×10^{13}
Buffalo Creek	5.23×10^{9}	6.07×10^{12}	-	6.07×10^{12}
Colliers Creek	1.30×10^{9}	1.79×10^{12}	-	1.79×10^{12}
North Fork Buffalo Creek	1.79×10^{9}	1.01×10^{12}	-	1.01×10^{12}
South Fork Buffalo Creek	5.51×10^{8}	1.04×10^{12}	-	1.04×10^{12}
Cedar Creek	1.37×10^{9}	7.83×10^{11}	-	7.84×10^{11}

†the WLA will be implemented in accordance with permitting regulations
*Implicit MOS

8.2. *Colliers Creek Sediment TMDL*

8.2.1. **TMDL Components**

The sediment TMDL for Colliers Creek watershed was calculated using equation 8.1. The sediment TMDL load for Colliers Creek watershed was defined as the average annual sediment load from the area-adjusted Buffalo Creek watershed.

8.2.1.1. Waste Load Allocation

The WLA is comprised of sediment loads from general permits and future growth. The WLA loads for the SFH permits were calculated as the septic tank design flow of 1,000 gallons/day and the permitted effluent TSS concentration of 30 mg/L, as shown in Table 8.28. A Future Growth WLA was estimated as 1% of the TMDL. The future growth WLA of 103.2 tons/yr is included in the Colliers Creek sediment TMDL.

Table 8.28. SFH Alternative Wastewater Treatment General Permit WLA

VPDES Permit Number	Source Type	Receiving Stream	Annual Flow (MGD)	Permitted Average TSS Concentration	TSS WLA (tons/yr)
VAG408147	SFH	Colliers Creek	0.001	30	0.04
VAG401984	SFH	Colliers Creek, UT	0.001	30	0.04
VAG401347	SFH	Colliers Creek	0.001	30	0.04
VAG408020	SFH	Toad Run	0.001	30	0.04

SFH Load = .001 MGD * 30 mg/L * 1.382 = 0.041 t/yr

8.2.1.2. Margin of Safety

A margin of safety (MOS) is factored into a TMDL to account for model uncertainty. The MOS can be either explicit, as an additional load reduction requirement, or implicit, which incorporates conservative assumptions within the application of the TMDL model. An explicit MOS was used in this sediment TMDL. An explicit 10% MOS was used in the TMDL calculation based on best professional judgment and the precedence of other TMDLs developed using the reference watershed approach for biological impairments due to sediment in Virginia. A MOS of 1,032.1 tons/yr is included in the Colliers Creek sediment TMDL.

8.2.1.3. Load Allocation

The load allocation (LA) represents the contributions from nonpoint sources. The LA was calculated as the TMDL minus the sum of WLA and MOS. The TMDL load and its components for each TMDL watershed are shown in Table 8.29.

Table 8.29. The Colliers Creek Sediment TMDL

Colliers Creek; VAV-I38R_CLL01A00; Cause Group Code I38R-02-BEN

TMDL	WLA		LA	MOS
(tons/yr)				
10,321.4	103.4		9,185.9	1,032.1
	general permits aggregate WLA	0.17 tons/yr		
	Future Growth	103.21 tons/yr		

8.2.2. **Maximum Daily Loads**

The USEPA (2006a) has mandated that TMDL studies submitted since 2007 include a maximum “daily” load (MDL), in addition to the average annual loads shown in Section 6.2.1. The approach used to develop these MDLs was provided in Appendix B of a related USEPA guidance document (USEPA, 2006b). The appendix to this USEPA document, entitled "Approaches for developing a Daily Load Expression for TMDLs computed for Longer Term Averages" is dated December 15, 2006. This guidance provides a procedure for calculating an MDL (tons/day) from the long-term average (LTA) annual TMDL load (tons/yr) and a coefficient of variation (CV) based on annual loads over a period of time. The "LTA to MDL multipliers" for Colliers Creek watershed was calculated from the 1992-2010 simulated output of annual sediment loads using the calibrated GWLF model.

Annual simulated sediment loads for Colliers Creek watershed ranged from 1,686 to 21,199 t/yr, producing a coefficient of variation (CV) = 0.4543. The "LTA to MDL" multiplier was then interpolated from the USEPA guidance and calculated as 3.060. The MDL was calculated as the TMDL divided by 365 days/yr and multiplied by 3.060.

Since the WLA represents permitted loads, no multiplier was applied to these loads. Therefore the daily WLA and components were converted to daily loads by dividing by 365 days/yr. The daily LA was calculated as the MDL minus the daily WLA minus the daily MOS. The resulting sediment MDL and associated components for the impaired Colliers Creek stream segment is shown in Table 8.30 in units of tons/day.

Expressing the TMDL as a daily load does not interfere with a permit writer's authority under the regulations to translate that daily load into the appropriate permit limitation, which in turn could be expressed as an hourly, weekly, monthly or other measure (USEPA, 2006a).

Table 8.30. Colliers Creek Maximum "Daily" Sediment Loads

MDL	WLA	LA	MOS
(tons/day)			
86.54	0.28	77.60	8.65

8.3. ***Allocation Scenarios***

The target allocation sediment load for each watershed allocation scenario is the TMDL minus the MOS (10,321.4 – 1,032.1 = 9,289.3). Allocation scenarios were created by applying percent reductions to the various land use/source categories until the target allocation load was achieved for the Colliers Creek watershed.

Two allocation scenarios were created, Table 8.31. Harvested Forest BMPs are typically required for all commercially harvested areas, but are not always implemented in small-lot harvests. Scenario 1 applies equal percent reductions from all land uses and sources, except row crops, forest, harvested forest, and permitted sources. Scenario 2 applies equal percent reductions from the largest source (pasture and hayland) and the channel erosion, along with a 10% reduction on the "developed" land use. These scenarios represent two strategies that can be refined by a local TMDL Implementation Planning committee, as they consider applicable BMPs, costs, and available funding sources for site-specific implementation.

Table 8.31. Sediment TMDL Load Allocation Scenario, Colliers Creek

Land Use/ Source Group	Future Sediment Load (tons/yr)	Scenario 1		Scenario 2	
		Reduction	Load	Reduction	Load
Row Crops	78.3		78.3		78.3
Pasture	8,689.4	27.3%	6,313.8	33.0%	5,818.3
Hay	1,355.2	27.3%	984.7		1,355.2
Forest	1,092.8		1,092.8		1,092.8
Harvested Forest	92.3		92.3		92.3
Developed	755.0	27.3%	548.6	10.0%	679.5
Channel Erosion	103.7	27.3%	75.3	33.0%	69.4
Permitted WLA	103.4		103.4		103.4
Total Load	12,270.1		**9,289.3**		**9,289.3**
Target Allocation Load =	**9,289.3**				
% Reduction Needed =	24.3%				

Chapter 9: TMDL Implementation and Reasonable Assurance

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and non-point sources in the stream (see Section 9.4.2). For point sources, all new or revised VPDES/NPDES permits must be consistent with the TMDL WLA_{total} pursuant to 40 CFR §122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. The measures for non-point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

9.1. ***Staged Implementation***

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from straight pipe discharges and failing septic systems should be a primary implementation focus because of their health implications. These components could be implemented through education on septic tank pump-outs, a septic system installation/repair/replacement program, and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines and sewage spillage could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

9.2. *Stage 1 Scenarios*

The goal of the Stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the instantaneous criterion (235 cfu/100mL) are less than 10.5 percent while requiring no reductions from wildlife sources. The Stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. One successful scenario was selected for each of the impaired watersheds (Table 9.1).

Table 9.1. Allocation scenario for Stage 1 TMDL implementation for the Maury River and the Cedar Creek watersheds.

Impaired Segment	Required Fecal Coliform Loading Reductions to Meet the Stage 1 Goal, %							% Violation of *E. coli* Single Sample Standard
	Livestock Direct Deposit	Loads from Cropland	Loads from Pasture	Straight Pipes and Failing Septic Systems	Loads from Residential Areas*	Wildlife Direct Deposit	Loads from Forested Areas	
Maury River	99	10	30	100	0	0	0	6.4
Buffalo Creek	50	10	50	100	0	0	0	10.1
Colliers Creek	70	10	50	100	0	0	0	9.9
North Fork Buffalo Creek	35	10	35	100	0	0	0	10.3
South Fork Buffalo Creek	99	10	50	100	0	0	0	10.5
Cedar Creek	99	10	50	100	0	0	0	10.2

9.3. *Link to Ongoing Restoration Efforts*

Implementation of these TMDLs will contribute to on-going water quality improvement efforts in Maury River and Cedar Creek and efforts aimed at restoring water quality. Implementation of BMPs to address the benthic impairment in Colliers Creek will be coordinated with BMPs required to meet bacteria water quality standards.

9.4. *Reasonable Assurance for Implementation*

9.4.1. **Follow-up Monitoring**

Following the development of the TMDLs, the Department of Environmental Quality (DEQ) will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with VADEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s). At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

DEQ will continue to monitor benthic macro-invertebrates and habitat in accordance with its biological monitoring program at station 2-CLL003.21 on Colliers Creek. DEQ will continue to use data from this monitoring station to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

DEQ staff, in cooperation with the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the Implementation Plan), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

9.4.2. **Regulatory Framework**

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. EPA also requires that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the Virginia NPDES (VPDES) program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan. Regional and local offices of VADEQ and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate WQMP, in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the State Water Control Board (SWCB) adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under

http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/TMDL/Regulation.aspx.

9.4.3. **Stormwater Permits**

VADEQ coordinates the State program that regulates the management of pollutants carried by storm water runoff. VADEQ regulates storm water discharges associated with "industrial activities", from construction sites, and from municipal separate storm sewer systems (MS4s).

It is the intent of the Commonwealth that TMDLs implement existing regulations and programs where they apply. However, since there are no MS4s permitted in the Colliers Creek, North Fork Buffalo Creek, South Fork Buffalo Creek, Buffalo Creek, Maury River, and Cedar Creek watersheds at the time of this TMDL, they are not included in this study. More information is available on VADEQ's web site through the following link: http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/VSMPPermits/MS4Permits.aspx.

Additional information on Virginia's Stormwater Management program can be found at

http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx.

9.4.4. **Implementation Funding Sources**

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

9.4.5. **Attainability of Primary Contact Recreation Use**

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. These streams may not be able to attain standards without some reduction in wildlife load.

With respect to these potential reductions in bacteria loads attributed to wildlife, Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. However, if bacteria levels remain high and localized overabundant populations of wildlife are identified as the source, then measures to reduce such populations may be an option if undertaken in consultation with the Department of Game and Inland Fisheries (DGIF) or the United States Fish and Wildlife Service (USFWS). Additional information on DGIF's wildlife programs can be found at http://www.dgif.virginia.gov/wildlife/game/. While managing such overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address the overall issue of attainability of the primary contact criteria, Virginia proposed during its latest triennial water quality standards review a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityStandards/WQS_eff_6JAN2011.pdf.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process.

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of nuisance populations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 9.1 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable best management practices can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

Chapter 10: Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made.

A preliminary Technical Advisory Committee (TAC) Meeting for all biological and benthic impairments on the Maury River (including Colliers Creek) was held on January 10, 2013 at the Natural Bridge Soil and Water Conservation District (SWCD) office in Lexington, Virginia. The purpose of that meeting was to introduce agency stakeholders to the TMDL process and to discuss the impairments identified on stream segments in these watersheds. The meeting was attended by 26 people.

The first Public Meetings were held on February 26, 2013 and March 12, 2013 at the Effinger Fire Hall in Buena Vista and the Natural Bridge Fire Hall in Natural Bridge, respectively. The purpose of the meetings was to introduce the public to the TMDL process and to discuss the impairments identified on stream segments in these watersheds. The public meetings were attended by 110 and 23 people, respectively.

The first TAC meetings were held on March 20, 2013 at the Buena Vista Library in Buena Vista and the Natural Bridge Elementary School in Natural Bridge to discuss bacteria source loads. The meetings were attended by 24 and 12 people, respectively. TAC meetings were held on June 26, 2013 at the Natural Bridge SWCE office in Lexington and the Palmer Community Center in Natural Bridge to present modeling procedures, draft modeling results, and to solicit feedback on the proposed TMDL strategy. Attendances at these meetings were 15 and 13, respectively. The results of the TMDL modeling were presented to members of the TAC at meetings held on July 17, 2013 at the Natural Bridge SWCD office in Lexington, attended by 18 people, and the Natural Bridge Fire Hall in Natural Bridge, attended by 6 people.

Final Public Meetings to present the draft bacteria and sediment TMDL report for the Maury River and the Cedar Creek watersheds were held on August 6, 2013 and August 7, 2013 at the Buena Vista City Council Chambers in Buena Vista and the Effinger Fire Hall in Natural Bridge. Those final TMDL public meetings had 37 and 20 attendees, respectively. The public comment period ended on September 6, 2013.

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Appendix A: Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms. *E. coli* bacteria are a subset of this group found to more closely correlate with human health problems.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous or Single Sample criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for *E. coli* is 235 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models).

Model

Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation. This follows the calibration of the model and ensures that the calibrated values adequately represent the watershed.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

Appendix B: Source Assessment

Humans and Pets

The Maury River watershed has an estimated permanent population of 50,776 (21,140 households with an average of 2.40 people per household). Permanent population in the Cedar Creek watershed is estimated as 506 (210 households with an average of 2.41 people per household). The number of households and the number of people per household for the watershed was determined from addressable structures data supplied by Augusta County and Rockbridge County governments and the 2010 Census of Population and Housing for Virginia. Fecal coliform from humans can be transported to streams from failing septic systems, via straight pipes discharging directly into streams, sewage spills, or through leaky sewer lines. Although leaky sewer lines are not explicitly accounted for in modeling for this TMDL, they are considered to be part of the residential load, and should be addressed where found during implementation. Professional judgment was used to specify one pet per household for the Maury River watershed and the Cedar Creek watershed.

Failing Septic Systems

Septic system failure can result in the rise of effluent to the soil surface. Surface runoff can transport the effluent, containing fecal coliform, to receiving waters. The number of failing septic systems in each sub-watershed was determined by analyzing the ages of the structures in the watershed and applying a failure rate based on the age category. The U.S. Census (2010) provides an estimate of house ages in its summary file 3. An estimate was made for each Census block group of the fraction of houses in old (pre-1970), middle (1970-1989), and new (post-1989) age categories. This fraction was applied to the total number of houses in each block group to obtain an estimate of the number of houses in each age group in each sub-watershed. Forty percent of old houses, 20% of middle-aged houses, and 3% of new houses were assumed to have failing septic systems.

Daily total fecal coliform load to the land from a failing septic system in each sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate of houses ranged from 1.67 to 2.91 persons per household (Census Bureau, 2010)) by the per capita fecal coliform production rate of 3.6×10^{8}

cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1 person/household is $3.6x10^8$ cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The estimated number of failing septic systems in the watershed is given in Table B.1.

Straight Pipes

Bacteria discharged from straight pipes enter the stream directly, without treatment or die-off. Straight pipe numbers and possible sub-watershed locations were estimated in consultation with stakeholders in the Maury River and the Cedar Creek watersheds. Based on this criterion, it was projected that 76 and 5 houses with straight pipes exist in the Maury River and the Cedar Creek watersheds, respectively. The number of straight pipes in watersheds is given in Table B.1.

Daily total fecal coliform load to the stream from a straight pipe in each sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed by the per capita fecal coliform production rate of $3.6x10^8$ cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the stream from a single straight pipe in a sub-watershed with an occupancy rate of 1 person/household is $3.6x10^8$ cfu/day.

Pets

The American Pet Products Manufacturers Association conducts biannual pet owner surveys in the United States. The Humane Society of the United States reports a summary of these findings: for the 2011-2012 survey: 39% of American households owned an average of 1.7 dogs, and 33% of American households owned an average of 2.2 cats (HSUS, 2012). Assuming that a unit pet is one dog or two cats, this yields (0.39*1.7 + (0.33*2.2)/2) = 1.026 unit pets per household. Therefore, the pet population in the Cedar Creek watershed was calculated at a rate of one unit pet per permanent household. But for the Maury River watershed pet population multiplier was adjusted to 0.8 unit pet per household in the course of bacteria source load calculation to account for the relative magnitude of the resulting load from pets compared to loads from wildlife, with the exception of sub-watersheds 2, 3 and 4 where 1 unit pet per household was applied based on the presence of hunt clubs. Given this assumption, there are an estimated 17,055 pets in the Maury River watershed and 210 pets in the Cedar Creek watershed.

A dog produces fecal coliform at a rate of 4.5 x 10^8 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table B.1. Pet waste is generated in residential areas; surface runoff can transport bacteria in pet waste from these areas to the stream.

Table B.1. Estimated Household and Pet Population Breakdown by Sub-watershed for the Maury River and the Cedar Creek watersheds.

Sub-Watershed	Sewered Houses	Houses with Septic Systems in each age category			Failing Septic Systems	Straight Pipes	Pet Population
		Old	Mid-age	New			
MAU-1	446	227	101	67	112	0	673
MAU-2	0	184	113	98	98	2	397
MAU-3	0	129	107	81	75	2	319
MAU-4	0	38	23	27	19	1	89
MAU-5	0	145	76	72	75	2	236
MAU-6	0	33	20	22	17	3	62
MAU-7	0	14	7	6	7	1	22
MAU-8	0	35	19	16	17	1	57
MAU-9	0	28	15	13	14	1	46
MAU-10	0	28	16	14	15	3	49
MAU-11	0	54	27	24	27	3	86
MAU-12	465	215	148	115	118	1	755
MAU-13	2,472	174	91	79	89	1	2254
MAU-14	0	5	3	2	2	0	8
MAU-15	0	0	0	0	0	0	0
MAU-16	0	317	200	167	170	2	548
MAU-17	0	47	37	30	26	2	92
MAU-18	0	1185	775	686	642	6	2121
MAU-19	0	19	16	14	11	1	39
MAU-20	249	201	104	96	103	1	521
MAU-21	0	218	196	113	128	1	422
MAU-22	0	91	119	46	61	0	205
MAU-23	2,552	62	67	49	39	1	2185
MAU-24	136	227	179	154	129	2	558
MAU-25	37	221	181	141	127	3	466
MAU-26	0	98	80	58	56	1	190
MAU-27	0	118	70	63	62	0	201
MAU-28	0	27	17	13	14	0	46
MAU-29*	-	-	-	-	-	-	
MAU-30	0	42	33	22	23	0	78
MAU-31	0	42	30	21	23	1	74
MAU-32	0	357	196	127	184	3	546
MAU-33	0	237	140	98	124	2	382

Sub-Watershed	Sewered Houses	Houses with Septic Systems in each age category			Failing Septic Systems	Straight Pipes	Pet Population
		Old	Mid-age	New			
MAU-34	0	682	277	154	331	5	894
MAU-35	0	243	140	172	128	2	446
MAU-36	0	12	8	6	6	1	21
MAU-37	20	60	56	32	35	2	135
MAU-38	0	89	72	45	50	1	166
MAU-39	0	190	149	79	107	5	338
MAU-40	0	163	135	35	92	5	270
MAU-41	0	224	194	26	128	3	358
MAU-42	0	228	196	26	130	3	362
MAU-43	0	212	183	25	121	2	338
Total	**6,377**	**6,921**	**4,616**	**3,134**	**3,735**	**76**	**17,055**
CEC-1	0	64	23	17	29	1	105
CEC-2	0	50	26	23	25	2	101
CEC-3	0	0	1	1	0	2	4
Total	**0**	**114**	**50**	**41**	**54**	**5**	**210**

* model developed for Hays Creek TMDL used as input for the Maury River model

Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream via surface runoff from animal waste deposited on pastures or applied to crops or pasture.

Distribution of Dairy and Beef Cattle

There are currently five dairy farms in the Maury River watershed. The number of dairy farms was initially estimated from information from the Virginia Department of Agriculture and Consumer Services (VDACS) and was further refined using information provided by the dairy farmer when contacted to determine the number of cows the farm.

The population of beef cattle in the Maury River and the Cedar Creek watersheds was initially estimated from the 2007 Agricultural Census. The total number of beef cows modeled throughout the year varied due to the presence or absences of calves and their weights relative to the adult cattle. The estimated number of beef cattle and the distribution of animals among the sub-watersheds for the Maury River and the Cedar Creek watersheds are shown in Table B.2.

Beef cattle spend varying amounts of time streams, and pastures depending on the time of year. Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Stream access for all beef cattle farms was estimated based on watershed visits and pasture proximity to the stream.

Because there are not many dairy operations in this watershed, it is impossible to report the dairy cows on a sub-watershed basis without allowing the reader to tie the numbers to a specific farm. Therefore, to preserve the confidentiality of the dairy farmer personally contacted, the populations for all cattle are reported on the basis of the impaired watersheds. The estimated number of beef and dairy cattle are listed in Table B.2 for the Maury River and the Cedar Creek watersheds.

Table B.2. Beef and Dairy Cattle Populations in the Maury River and the Cedar Creek watersheds.

Sub-watershed	Cattle*	Sub-watershed	Cattle*	Sub-watershed	Cattle*
MAU-1	710	MAU-17	28	MAU-33	229
MAU-2	503	MAU-18	1525	MAU-34	120
MAU-3	450	MAU-19	3	MAU-35	122
MAU-4	246	MAU-20	470	MAU-36	22
MAU-5	575	MAU-21	520	MAU-37	42
MAU-6	22	MAU-22	119	MAU-38	48
MAU-7	133	MAU-23	298	MAU-39	380
MAU-8	238	MAU-24	417	MAU-40	295
MAU-9	640	MAU-25	740	MAU-41	99
MAU-10	382	MAU-26	622	MAU-42	219
MAU-11	106	MAU-27	701	MAU-43	57
MAU-12	553	MAU-28	94	MAU-Total	**13,487**
MAU-13	188	MAU-29	0	CEC-1	96
MAU-14	36	MAU-30	169	CEC-2	296
MAU-15	11	MAU-31	78	CEC-3	2
MAU-16	796	MAU-32	481	CEC-Total	**394**

* Cow-calf pairs

The following assumptions and procedures were used to estimate the distribution of cattle (and thus, fecal coliform produced by cattle) among different land use types and in streams:

a) Cattle are only confined as detailed in the table below. This table reflects the communications with farmers and agency personnel.
b) All other cattle are on pasture.
c) Cattle with stream access (determined as described earlier) will spend varying amounts of time in the stream during different seasons (Table B.3). Cattle spend

more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.

d) Thirty percent of cattle in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the feces is deposited on pastures.

The resulting numbers of cattle in pastures and streams for all sub-watersheds are given in Table B.4.

Table B.3. Time spent by cattle in confinement and in the stream.

Month	Fraction of time spent in confinement			Time spent in the stream (hours/day)
	Milk Cows (range; typical)	Dry Cows and Heifers (range; typical)	Beef Cattle (range; typical)	
January	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5
February	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5
March	25%-100%; 40%	0%-15%; 0%	0%-0.7%; 0%	0.75
April	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1
May	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1.5
June	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
July	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
August	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	3.5
September	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1.5
October	25%-100%; 30%	0%-15%; 0%	0%-0.7%; 0%	1
November	25%-100%; 40%	0%-15%; 0%	0%-0.7%; 0%	0.75
December	25%-100%; 75%	17%-40%; 40%	0%-40%; 20%	0.5

Table B.4. Distribution of the cattle population among land use types and stream in the Maury River and the Cedar Creek watersheds

Month	Confinement (Maury/Cedar)	Pasture (Maury/Cedar)	Streams* (Maury/Cedar)
January	3285/79	10183/314	19/1
February	3285/79	10183/314	19/1
March	340/0	13111/393	36/1
April	255/0	13183/392	49/2
May	255/0	13158/391	74/3
June	255/0	13060/387	172/7
July	255/0	13060/387	172/7
August	255/0	13060/387	172/7
September	255/0	13158/391	74/3
October	255/0	13183/392	49/2
November	340/0	13111/393	36/1
December	3285/79	10183/314	19/1

*Number of bovine equivalent defecations in the stream

Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (see above) defecating in the stream. Manure loading increases during the warmer months, when cattle spend more time in water. The potential average annual manure loadings directly deposited by cattle in the stream for the Maury River and Cedar Creek watersheds, based on estimates listed in Table B.4, are 2.38×10^6 and 9.17×10^4 pounds, respectively. The associated average daily fecal coliform loading to the stream for Maury River and Cedar Creek are 9.94×10^{11} and 3.58×10^{10} cfu, respectively. Part of the fecal coliform deposited in the stream stays suspended, while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

Direct Manure Deposition on Pastures

Cattle that graze on pastures (see above) but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of cattle changes with season: loading on pasture also changes with season.

Pasture has average annual cattle manure loadings of 4,287 and 5,594 lb/ac for the Maury River and the Cedar Creek watersheds, respectively. The associated fecal coliform loading from cattle to pasture on a daily basis averaged over the year is 2.73×10^9 cfu/ac/day for the Maury River watershed and is 3.14×10^9 cfu/ac/day for the Cedar Creek watershed. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gal of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (above) and the number of lactating cows, annual liquid dairy manure production in the Maury River watershed is 1.45×10^6 gal. Based on the per capita fecal coliform production of lactating cows, the fecal coliform concentration in fresh liquid manure is 2.17×10^8 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) when applied to land. Based on input from the dairy farmer, a liquid dairy manure application rate 6,600 gal/ac-year to cropland land use category was used. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 219 acres (8.8%) of cropland.

For modeling purposes, a seven-year crop rotation in the watershed with three years of corn-rye and four years of rotational hay was assumed. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure is given in Table B.5. Dry cows and heifers were assumed to produce only solid manure.

Table B.5. Schedule of cattle manure application on the Maury River and the Cedar Creek watersheds.

Month	Solid cattle manure applied (%)*	Liquid dairy manure applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	5	10
July	5	0
August	5	5
September	10	15
October	10	5
November	10	10
December	0	0

* As percent of annual production

Land Application of Solid Manure

Solid manure produced by beef cattle during confinement is collected for land application. The application schedule for solid manure is given in Table B.5. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are listed in Table B.6. Solid manure is last on the priority list for application to land (it falls behind liquid manure). The amount of solid manure produced in each sub-watershed was estimated based on the populations of beef cattle in the sub-watershed (Table B.2) and their confinement schedules (Table B.3).

Table B.6. Estimated solid manure production characteristics.

Type of cattle	Population (Maury/Cedar)	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure (x 10^6 cfu/lb)
Dry cow	300/0	1,400†	115‡	217§
Heifer	300/0	640††	40.7†	281§
Beef*	12,887/394	1000†	60†	143§

†Source: ASAE (1998)
‡Source: MWPS (1993)
§Based on per capita fecal coliform production per day (Table 4.1) and manure production
††Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993)

Solid cattle manure is applied at the rate of 12 tons/ac-year to cropland and hay land, with priority given to cropland. Solid manure is applied to cropland from February through May, and October through November. Solid manure can be applied to hay land anytime of the year. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 868 acres (35%) of cropland and 501 acres (<1%) of pasture in the Maury River watershed. And 42 acres (43%) of cropland and 0.2 acres (<1%) of pasture in the Cedar Creek watershed was estimated to be applied solid cattle manure.

Sheep and Goats

The sheep and goat populations (Table 4.1) were estimated from population numbers in the 2007 Agricultural Census for Augusta County, Bath County, Rockbridge County, Lexington County, Buena Vista and Botetourt County. The populations were area-weighted according to pasture areas in each sub-watershed of Maury River and Cedar Creek. The sheep and goats were kept on pasture at all times. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was represented as being deposited directly on pasture.

Pasture in the Maury River and the Cedar Creek watersheds has average annual sheep and goat manure loadings of 209.3 and 4.6 lb/ac-year, respectively. Fecal coliform loadings to the pasture in the Maury River and the Cedar Creek watersheds from sheep and goats on a daily basis averaged over the year are 2.9×10^9 and 6.3×10^7 cfu/ac-day, respectively.

Horses

Horse populations for the watershed were estimated from population numbers in the 2007 Agricultural Census for Augusta County, Bath County, Rockbridge County, Lexington County, Buena Vista and Botetourt County. The populations were area-weighted according to pasture areas in each sub-watershed of Maury River and Cedar Creek (Table B.7). The fecal coliform originating from horses contributes to the pasture load. Fecal coliform loadings from horses on a daily basis averaged over the year and over all pastures in the Maury River and the Cedar Creek watershed are estimated as 3.59×10^6 and 2.28×10^5 cfu/ac-day, respectively.

Table B.7. Horse Population in the Maury River and the Cedar Creek watersheds.

Sub-watershed	Horse	Sub-watershed	Horse	Sub-watershed	Horse
MAU-1	12	MAU-17	1	MAU-33	4
MAU-2	120	MAU-18	31	MAU-34	2
MAU-3	20	MAU-19	0	MAU-35	2
MAU-4	10	MAU-20	8	MAU-36	0
MAU-5	8	MAU-21	8	MAU-37	1
MAU-6	0	MAU-22	2	MAU-38	1
MAU-7	3	MAU-23	5	MAU-39	9
MAU-8	3	MAU-24	7	MAU-40	8
MAU-9	2	MAU-25	13	MAU-41	3
MAU-10	2	MAU-26	11	MAU-42	6
MAU-11	1	MAU-27	12	MAU-43	2
MAU-12	9	MAU-28	2	MAU-Total	359
MAU-13	3	MAU-29	0	CEC-1	1
MAU-14	1	MAU-30	3	CEC-2	14
MAU-15	0	MAU-31	1	CEC-3	0
MAU-16	15	MAU-32	8	CEC-Total	15

Poultry

The only large poultry operations in the Maury River watershed are located within the Hays Creek watershed. The bacteria loads from these operations are addressed in the Hays Creek TMDLs. There are currently no poultry operations reported in the Cedar Creek watershed.

Wildlife

Wildlife fecal coliform contributions can come from excretion of waste on land and from excretion directly into streams. Information gleaned from the literature and provided by VADGIF and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined along with preferred habitat and habitat area.

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, by considering each habitat area occupied (Table B.8). Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas muskrat and raccoons had variable population densities based on land use and proximity to a water source. Therefore, a sub-watershed with more stream length and impoundments and more area in crop land use would have more muskrats than a sub-watershed with shorter stream length, fewer impoundments, and less area in crop land use. Estimated distribution of wildlife among sub-watersheds for the Maury River and the Cedar Creek watersheds is given in Table B. 9.

Table B.8. Wildlife habitat, population density, and direct fecal deposition in streams.

Wildlife type	Habitat and Estimation Method	Population Density (animal / mi² - habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	30	1%
Raccoon	low density on forests not in high density area; high density on forest within 600 ft of a permanent water source or 0.5 mile of cropland; highest density in residential areas	Low density: 10 High density: 30 Highest density: 50	10%
Muskrat	16/mile of ditch or medium sized stream intersecting cropland; 8/mile of ditch or medium sized stream intersecting pasture; 10/mile of pond or lake edge; 50/mile of slow-moving river edge	-see habitat column-	25%
Beaver	300 ft buffer of main streams and impoundments on forest and pasture	10	50%
Geese	300 ft buffer around main streams and impoundments	50 – off season 70 – peak season	25%
Wood Duck	300 ft buffer around main streams and impoundments	40 – off season 60 – peak season	25%
Wild Turkey	Forest; based on kill rate per square mile of forest for Nelson county, assuming the killed birds are 10% of the total population	4	1%

Table B. 9. Wildlife populations in the Maury River and the Cedar Creek watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Goose	Duck	Wild Turkey
MAU-1	261	118	44	15	14	22	45
MAU-2	299	131	15	8	10	16	57
MAU-3	174	75	19	5	8	12	27
MAU-4	93	39	11	3	5	8	14
MAU-5	287	135	41	9	12	19	60
MAU-6	65	33	2	2	1	2	16
MAU-7	37	11	4	0	1	2	4
MAU-8	135	66	11	7	4	7	29
MAU-9	108	59	10	4	2	4	25
MAU-10	251	83	18	7	10	15	38
MAU-11	292	88	2	5	6	9	49
MAU-12	249	141	15	16	14	22	48
MAU-13	120	83	9	9	8	13	26
MAU-14	9	5	0	0	0	0	1
MAU-15	3	1	0	0	0	0	0
MAU-16	238	108	47	10	15	23	35
MAU-17	302	197	6	10	9	16	78
MAU-18	588	296	66	19	27	43	94
MAU-19	145	119	0	6	5	8	27
MAU-20	110	45	22	9	9	13	15
MAU-21	110	39	31	9	9	16	14
MAU-22	17	3	9	3	2	4	0
MAU-23	41	13	6	2	3	6	4
MAU-24	135	57	14	8	9	13	22
MAU-25	392	173	52	15	16	25	80
MAU-26	179	84	19	9	12	18	27
MAU-27	137	50	17	5	6	9	14
MAU-28	24	11	0	1	0	1	3
MAU-29	0	0	0	0	0	0	0
MAU-30	57	20	14	2	3	5	9
MAU-31	115	62	2	4	4	7	27
MAU-32	368	208	96	27	24	37	78
MAU-33	113	64	18	5	4	7	17
MAU-34	95	72	6	7	7	10	16
MAU-35	234	176	9	15	6	9	42
MAU-36	135	75	0	3	3	6	35
MAU-37	335	179	6	8	4	6	86
MAU-38	102	57	9	4	4	6	25
MAU-39	653	275	23	18	8	12	63
MAU-40	398	248	24	13	9	14	77
MAU-41	175	122	12	6	4	6	30
MAU-42	348	261	36	15	10	16	59
MAU-43	401	341	11	19	13	20	73
MAU-total	**8,330**	**4,423**	**756**	**342**	**320**	**507**	**1,489**
CEC-1	86	38	1	2	2	4	14
CEC-2	260	82	18	2	3	4	43
CEC-3	58	38	0	4	2	3	13
CEC-total	**404**	**158**	**19**	**8**	**7**	**11**	**70**

Other Animals

The Virginia Safari Park is located in Maury River sub-watershed #1. It is a 180-acre park with three species of large birds and over 25 species of mammals which roam the park, all herbivores ranging from rheas (flightless birds weighing approximately 70 pounds) to white rhinos (over 4,000 pounds). The animals get their water supply from water troughs and ponds, and do not have direct access to any free flowing streams. The park also includes the "Safari Village" that houses confined animals. Manure from the confined animals is bagged and removed from the watershed. After an inspection of the Park, it was decided to model the fecal waste from the free-range animals using an equivalent beef-cattle density on pasture.

Biosolids and Poultry Litter

There are numerous fields in the Maury River watersheds that are permitted to receive biosolids or poultry litter applications. Fields associated with permits obtained by Glasgow STP, Lexington-Rockbridge Regional WQCF, Houff's Feed & Fertilizer Co., Inc have been actively applied to since 2002. The fields for biosolid application are located in sub-watersheds 1, 16, and 18. The litter application fields are located in sub-watersheds 1, 13, 16, 18, 21, 24, 25, 29, 34, 39, 40, 41, 42, and 43. There are no fields reportedly receiving biosolids or poultry litter in the Cedar Creek watershed.

During calibration, the applications were represented in the model based on the application rates and times from the available records, and permitted bacteria concentrations (2,000,000 cfu/dry g). During the allocation period, applications to all fields at worst case scenario application rates and permitted bacteria concentrations (2,000,000 cfu/dry g) were represented in the model to ensure that applications at the 'worst case' permitted limits would be allowable in the watershed. 'Worst case' conditions were assumed, such that all available fields would be applied to each year. This methodology represents a conservative assumption in support of the implicit margin of safety for the TMDL because most fields are not applied to each year, application rates are typically lower than those assumed for allocation scenarios, and typical bacteria concentrations in treated biosolids are much lower than 2,000,000 cfu/g.

Appendix C: Model Development

Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDLs for the Maury River and the Cedar Creek watersheds are discussed below.

Climatological Data

Hourly precipitation data were disaggregated from the daily precipitation data using NRCS type III distribution method. Daily precipitation data from three NCDC's National Weather Service stations, which are Lexington, Kerrs Creek and Craigsville, within the Maury River watershed were used for the Maury River watershed TMDL development. For some of missing data, the Staunton stations were used to patch the recorded precipitation. For the Cedar Creek, daily precipitation data from Lexington was used.

Model Parameters

The hydrology parameters required by HSPF were defined for every land use category. Required hydrology parameters are listed in the HSPF Version 12 User's Manual (Bicknell et al., 2005). Initial estimates for required hydrology parameters for Maury River watershed were generated based on guidance in BASINS Technical Note 6 (USEPA, 2000); these parameters were refined during calibration. Each reach requires a function table (FTABLE) to describe the relationship between water depth, surface area, volume, and discharge (Bicknell et al., 2005). Stream lengths and slopes were determined using GIS data. The procedures described in Staley et al. (2006) were used to characterize the reaches in the Maury River and the Cedar Creek watersheds using NRCS bankfull equations and digital elevation models. Information on the calculated stream geometry for each sub-watershed is presented in Table C.1 for the bankfull conditions.

Table C.1. Reach characteristics for the Maury River and the Cedar Creek watersheds

Sub-watershed	Stream length (mile)	Average bankfull width (ft)	Average bankfull channel depth (ft)	Slope (ft/ft)
MAU-1	4.81	123.75	9.72	0.0024
MAU-2	6.04	62.17	5.48	0.0048
MAU-3	6.97	56.96	5.09	0.0043
MAU-4	1.89	40.07	3.80	0.0103
MAU-5	3.63	36.79	3.54	0.0105
MAU-6	2.26	19.93	2.12	0.0236
MAU-7	2.96	43.20	4.04	0.0065
MAU-8	3.04	32.60	3.20	0.0097
MAU-9	3.00	24.32	2.50	0.0223
MAU-10	6.09	32.98	3.23	0.0087
MAU-11	3.39	26.20	2.67	0.0282
MAU-12	6.54	115.38	9.17	0.0030
MAU-13	3.24	113.82	9.06	0.0007
MAU-14	0.81	112.78	8.99	0.0008
MAU-15	0.52	112.72	8.99	0.0001
MAU-16	5.69	61.21	5.40	0.0050
MAU-17	14.01	35.56	3.44	0.0209
MAU-18	13.82	50.82	4.63	0.0081
MAU-19	7.02	29.60	2.95	0.0311
MAU-20	3.88	104.76	8.46	0.0018
MAU-21	9.11	26.10	2.66	0.0161
MAU-22	0.72	103.09	8.35	0.0035
MAU-23	3.47	22.95	2.39	0.0103
MAU-24	3.21	102.35	8.30	0.0004
MAU-25	10.21	39.70	3.77	0.0116
MAU-26	10.57	98.57	8.04	0.0020
MAU-27	5.79	26.86	2.72	0.0189
MAU-28	2.13	96.27	7.88	0.0042
MAU-29	19.90	53.24	4.81	0.0068
MAU-30	0.85	88.91	7.38	0.0047
MAU-31	5.40	88.42	7.34	0.0082
MAU-32	11.27	53.94	4.86	0.0019
MAU-33	5.89	27.24	2.75	0.0076
MAU-34	3.94	40.35	3.82	0.0040
MAU-35	6.55	35.40	3.42	0.0140
MAU-36	3.05	78.41	6.64	0.0024
MAU-37	9.24	36.78	3.53	0.0091
MAU-38	1.49	73.28	6.28	0.0013
MAU-39	21.89	43.31	4.05	0.0063
MAU-40	19.82	65.15	5.69	0.0024
MAU-41	9.21	31.71	3.12	0.0178
MAU-42	6.97	53.63	4.84	0.0045
MAU-43	12.35	42.81	4.01	0.0257
CEC-1	3.77	29.75	2.96	0.0228
CEC-2	2.93	26.99	2.73	0.0198
CEC-3	4.17	14.41	1.62	0.0492

Required water quality parameters are also given in the HSPF User's Manual (Bicknell et al., 2005). Initial estimates for bacteria loading parameters in the Maury River and the Cedar Creek watersheds were based on estimates of bacteria production in the watershed; estimates of die-off rates and subsurface bacteria concentrations were based on values commonly used in previous TMDLs.

Accounting for Pollutant Sources

Overview

There is one single family domestic sewage discharge. During calibration and validation, reported bacteria concentrations discharged by these facilities were used as input to the model. During future conditions, loads from the facilities were modeled at their design flows and bacteria concentrations at their permitted limits (126 cfu/100 mL) (Table 3.2).

Bacteria loads that are deposited by cattle, wildlife, and straight pipes directly into streams were treated as direct nonpoint sources in the model. Direct nonpoint source loadings were applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in their permits.

Bacteria that were deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. The nonpoint source loading was applied in the model in the form of fecal coliform counts to individual land use categories by sub-watershed. Bacterial die-off on the land surface and in the stream was simulated within the model. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences in bacteria production and deposition characteristics, such as migratory behavior, management practices, and cattle time in streams.

The Bacteria Source Load Calculator (Zeckoski et al., 2005) was used to generate nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. The BSLC allows direct deposition in the stream by cattle and waterfowl to occur only during daylight hours.

Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_o 10^{-kt}$$

Where: C_t = concentration or load at time t;

C_o = starting concentration or load;

k = decay rate (day^{-1});

and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the James River watershed (Table C.2).

Table C.2. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy Manure	Pile (not covered)	0.066	Crane and Moore (1986)
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Crane and Moore (1986)
Poultry litter	Soil surface	0.035	Giddens *et al*. (1973)
		0.342	Crane *et al*. (1980)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.
- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used, assuming that a majority of manure piles are not covered.

Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A base-10 decay rate of 0.05 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.05 day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. In-stream decay rates of 0.45 day^{-1} and 1.15 day^{-1} were used for the James River main stem and tributaries, respectively.

Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land, and hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 3. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland and Hay land: Liquid and solid manure is applied to cropland and hay land as described in Chapter 3. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land application. Wildlife contributions were also added to the cropland and hay land areas. For modeling, the monthly fecal coliform loading assigned to

cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of solid manure as described in Chapter 3. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, the monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.
3. Residential: Fecal coliform loading on rural residential land uses came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were assumed to be uniformly applied to the residential pervious land use areas in each sub-watershed. Pet loads varied by sub-watershed but were constant throughout the year. Impervious areas received constant loads of 1.0 x 10^7 cfu/acre/day.
4. Forest: Wildlife not defecating in streams, cropland, or pastures provided fecal coliform loading to the forested land use. These loadings varied by month (to account for migration and hibernation) and by sub-watershed.

Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences and sewage spills. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 3. Contributions of fecal coliform from interflow and groundwater were modeled with a constant concentration of 8 cfu/100mL for interflow and 4 cfu/100mL for groundwater for most of the watershed.

Hydrology Results: Calibration and Validation

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Section 4.2.1. The agreement with observed flows is further illustrated as follows for a representative year and a representative storm event. The agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves.

1) Hydrologic Calibration for sub-watershed #15 gaging station

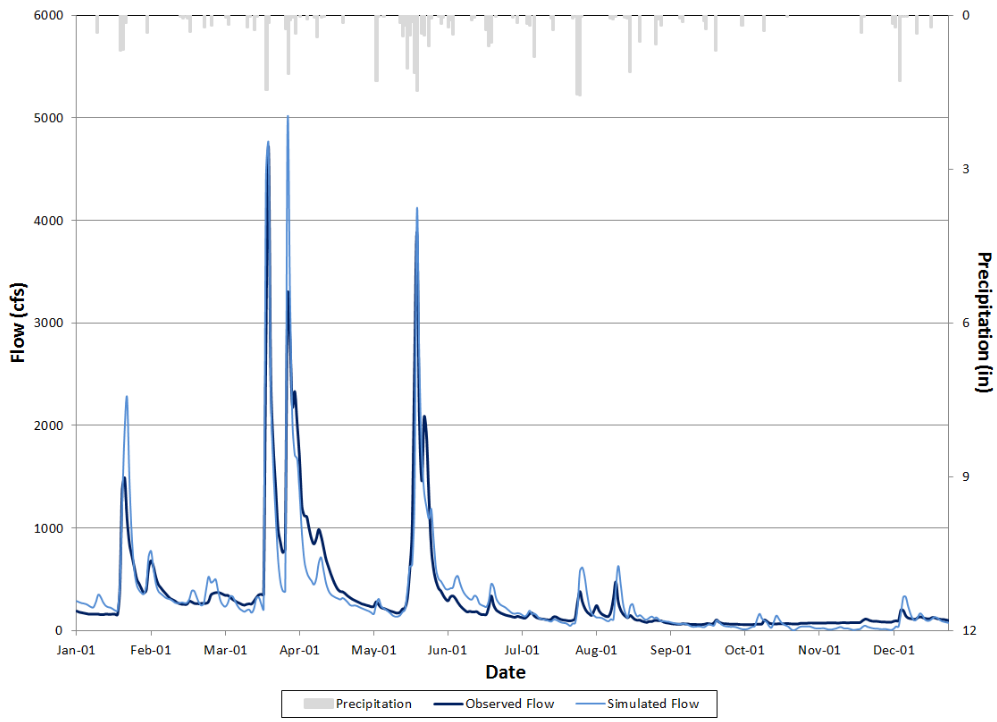

Figure C.1. Observed and simulated flows and precipitation for the representative year in the calibration period for Maury River sub-watershed #15

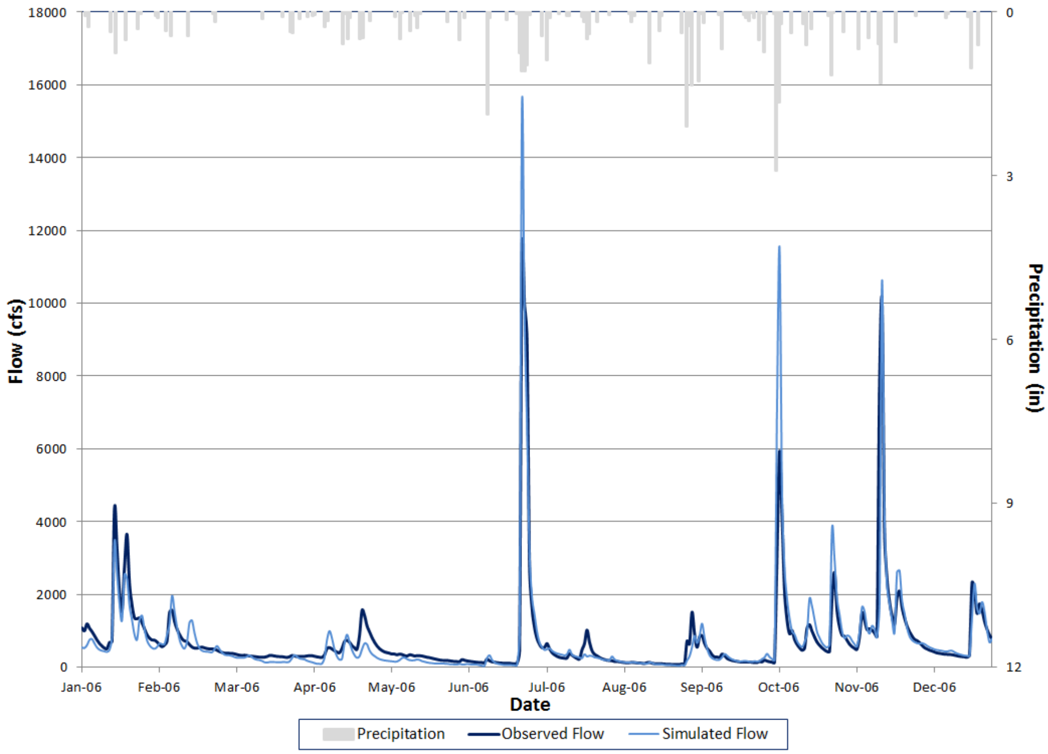

Figure C.2. Observed and simulated flows and precipitation for the representative year in the validation period for Maury River sub-watershed #15

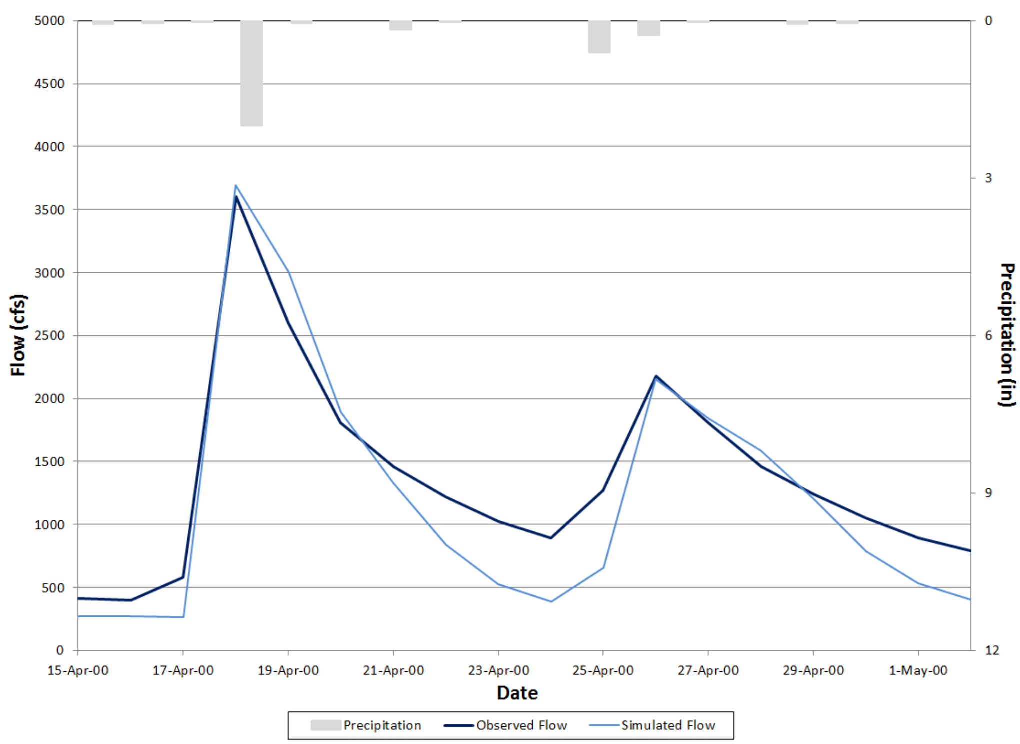

Figure C.3. Observed and simulated flows and precipitation at Maury River sub-watershed #15 for a representative storm in the calibration period

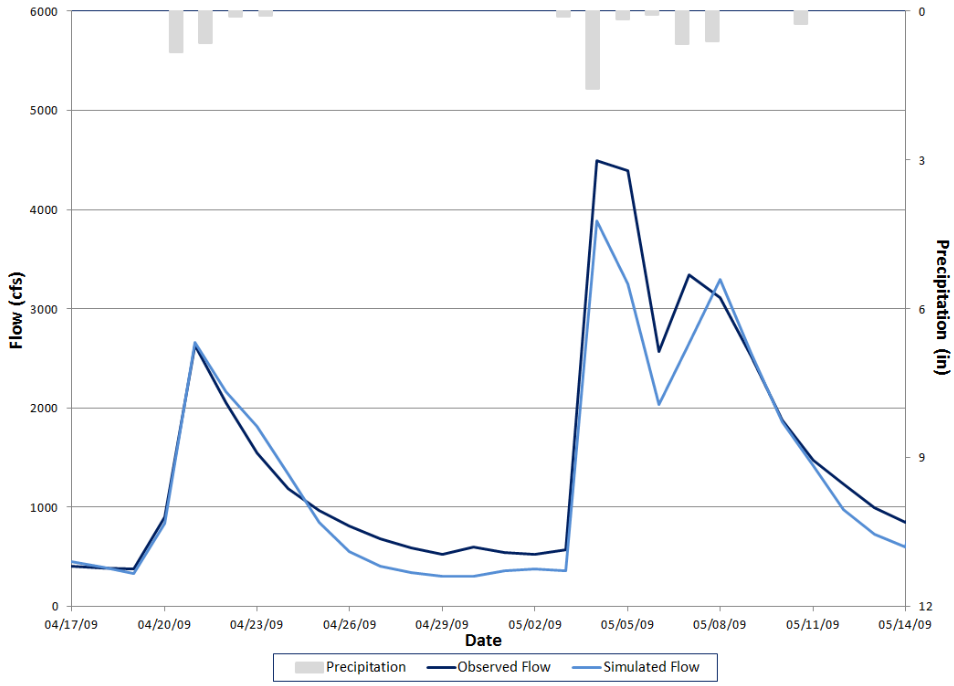

Figure C.4. Observed and simulated flows and precipitation at Maury River sub-watershed #15 for a representative storm in the validation period

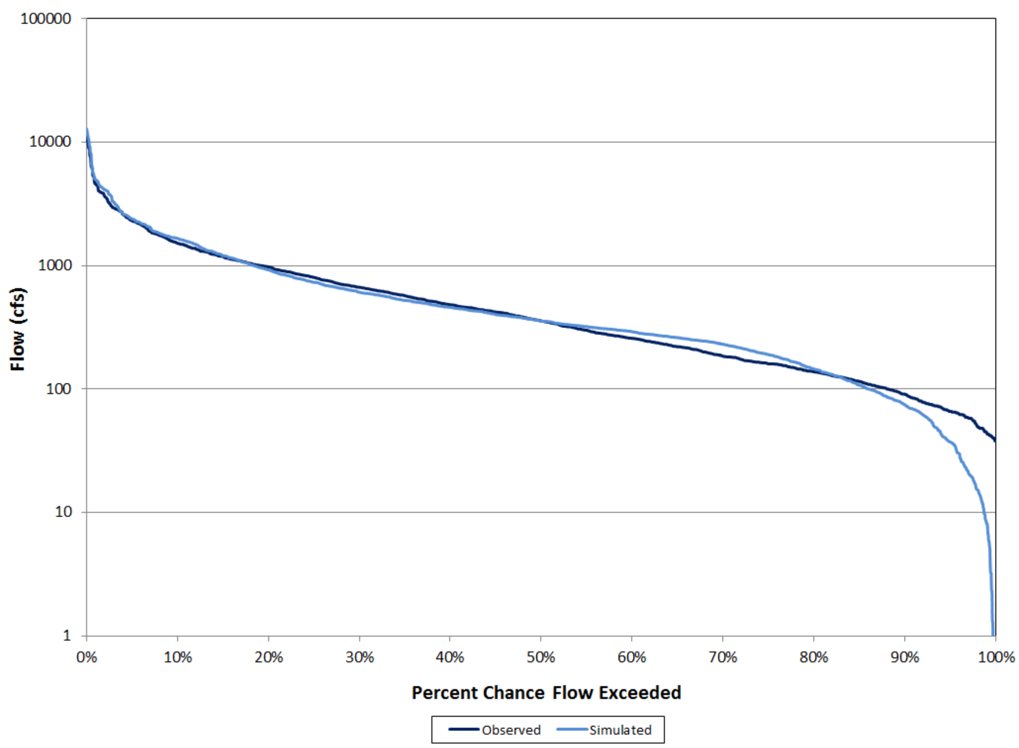

Figure C.5 Cumulative frequency curves at Maury River sub-watershed #15 for calibration period

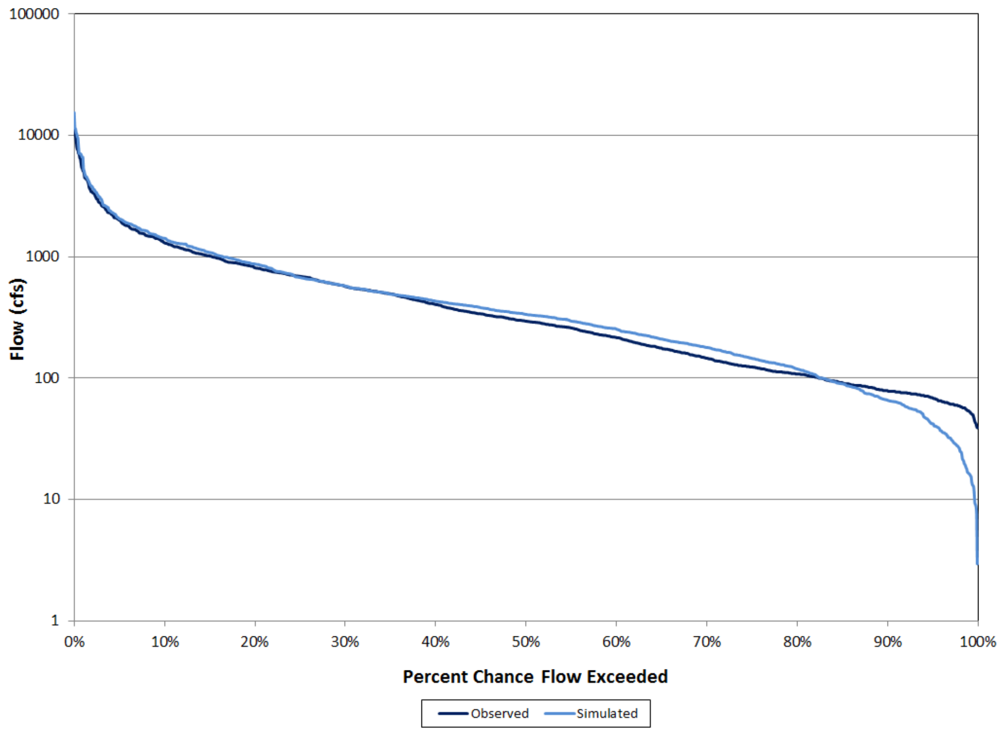

Figure C.6. Cumulative frequency curves at Maury River sub-watershed #15 for validation period

Flow partitioning for the Maury River hydrologic model calibration and validation is shown in the Table C.3. When the observed flow data were evaluated using Baseflow Program (Arnold, 1999), the baseflow target indices for the calibration and validation periods were 0.51 and 0.48 respectively, and the target range of baseflow indices were 0.44 - 0.66 and 0.41 – 0.63 for the calibration and validation periods respectively. The simulated baseflow indices are within the observed value range.

Table C. 3 Flow partitioning for the calibration and validation periods for Maury River at sub-watershed #15

Flow gaging station	Average Annual Flow	Calibration		Validation	
Sub-watershed #15	Total Runoff (in)	14.75		13.67	
	Total Surface Runoff (in)	3.96	(26.85%)	3.92	(28.68%)
	Total Interflow (in)	3.73	(25.29%)	3.49	(25.53%)
	Total Baseflow (in)	7.06	(47.86%)	6.26	(45.79%)
	Baseflow Index (Range)	0.51	(0.44 - 0.66)	0.48	(0.41 - 0.63)

2) Hydrologic Calibration for sub-watershed #25 gaging station

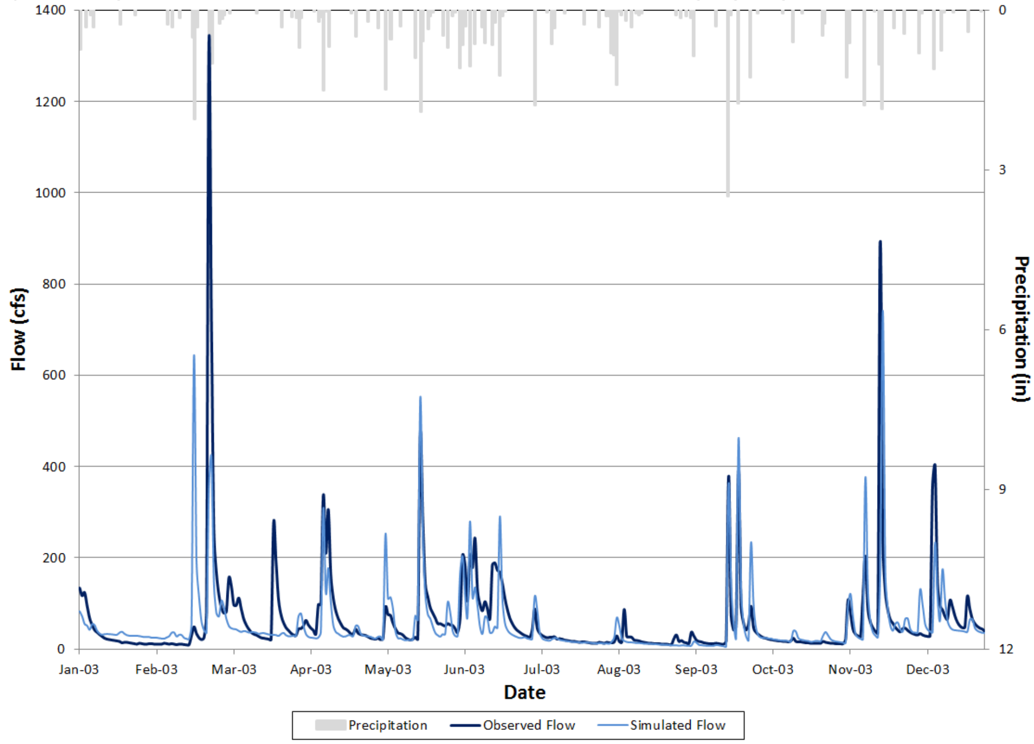

Figure C.7. Observed and simulated flows and precipitation for the representative year in the calibration period for Maury River sub-watershed #25

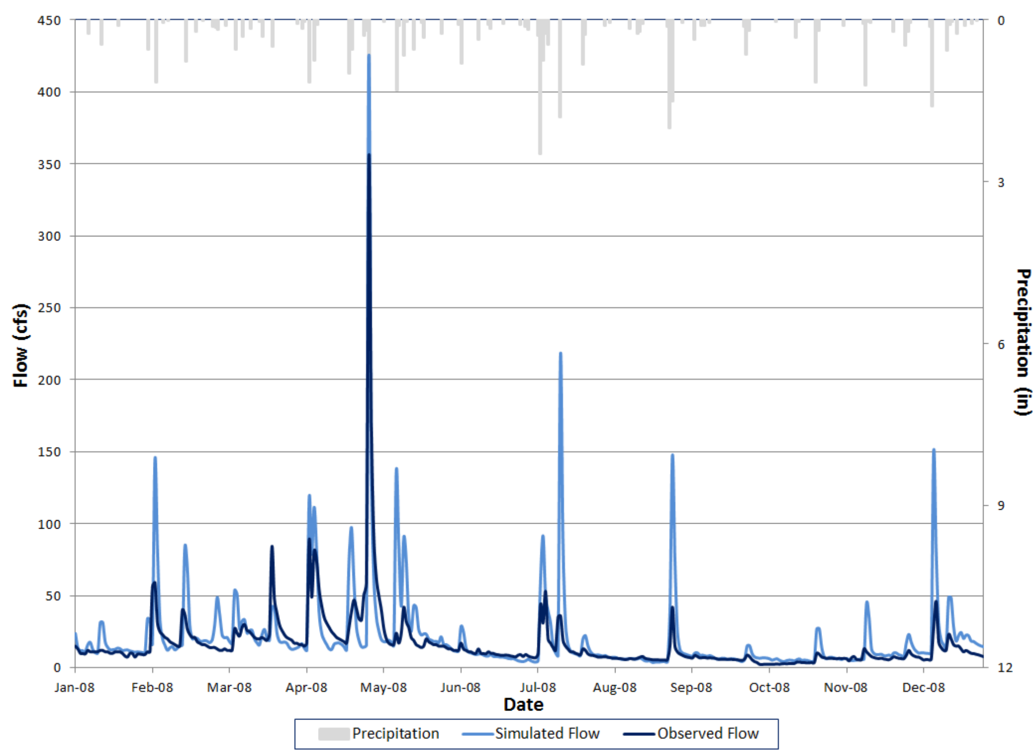

Figure C.8. Observed and simulated flows and precipitation for the representative year in the validation period for Maury River sub-watershed #25

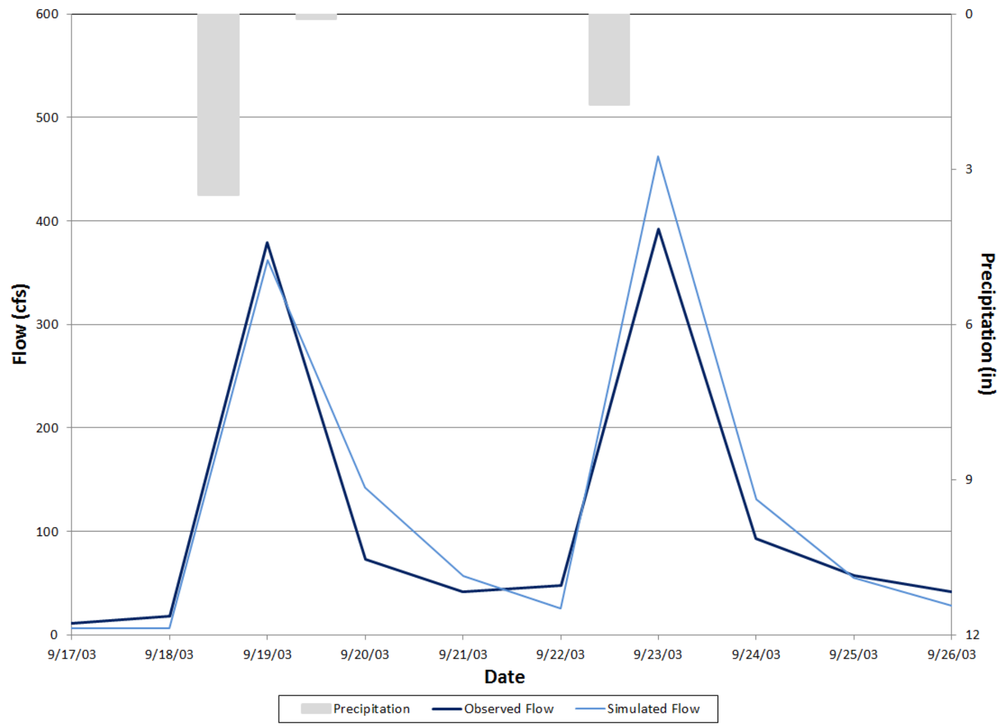

Figure C.9. Observed and simulated flows and precipitation at Maury River sub-watershed #25 for a representative storm in the calibration period

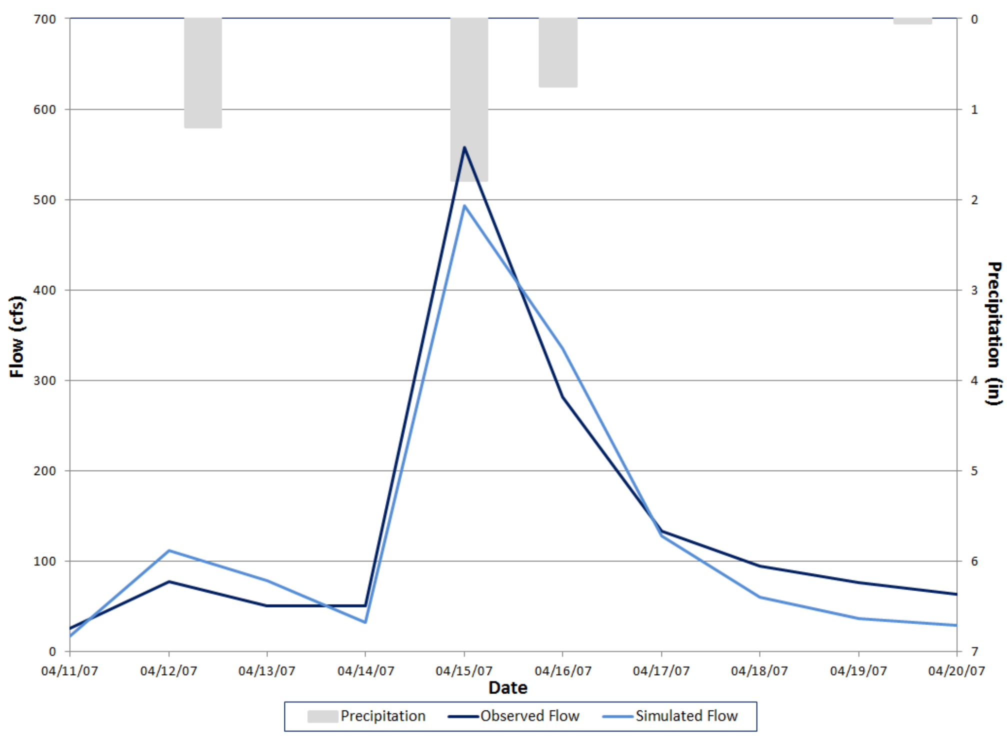

Figure C.10. Observed and simulated flows and precipitation at Maury River sub-watershed #25 for a representative storm in the validation period

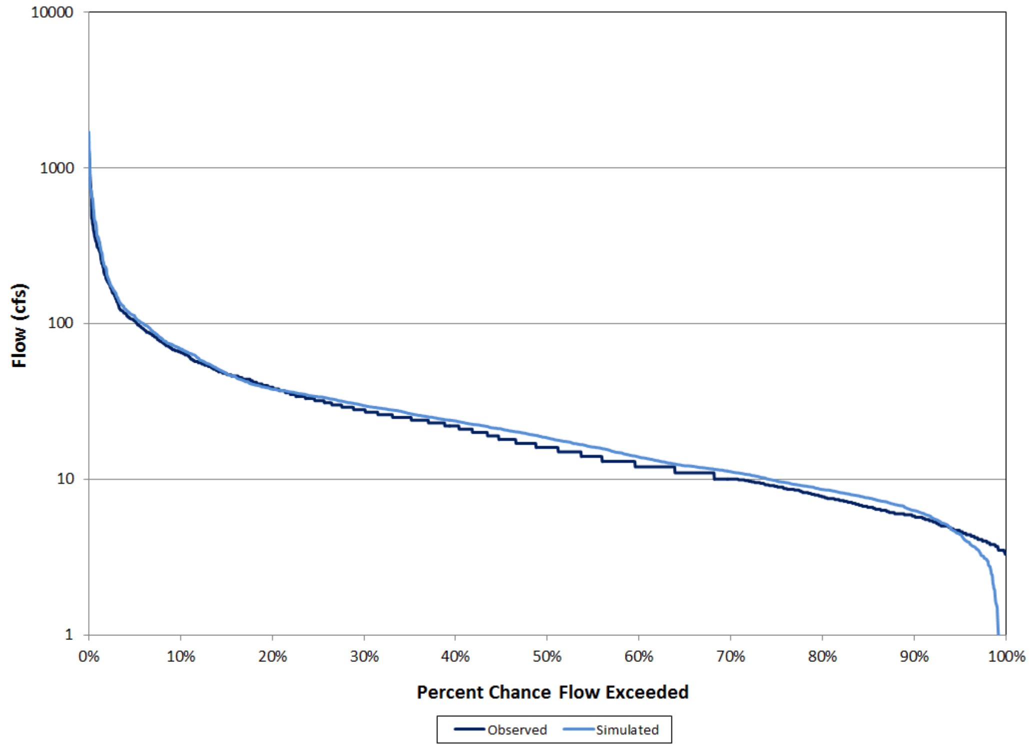

Figure C.11 Cumulative frequency curves at Maury River sub-watershed #25 for calibration period

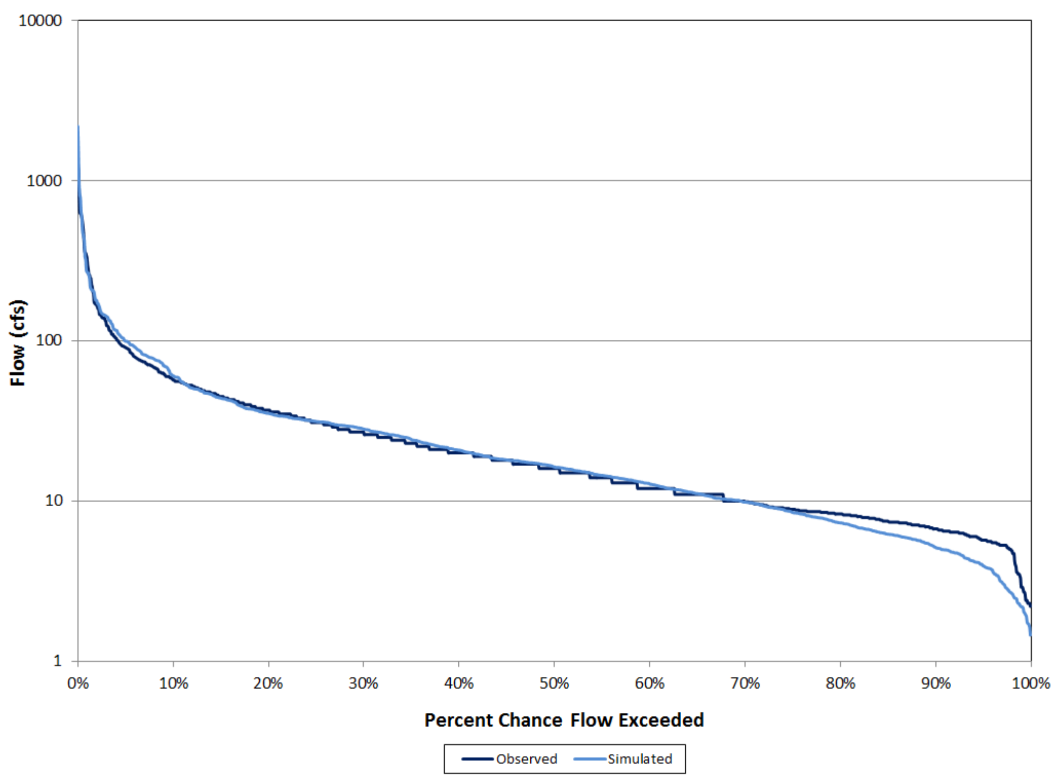

Figure C.12 Cumulative frequency curves at Maury River sub-watershed #25 for validation period

3) Hydrologic Calibration for sub-watershed #31 gaging station

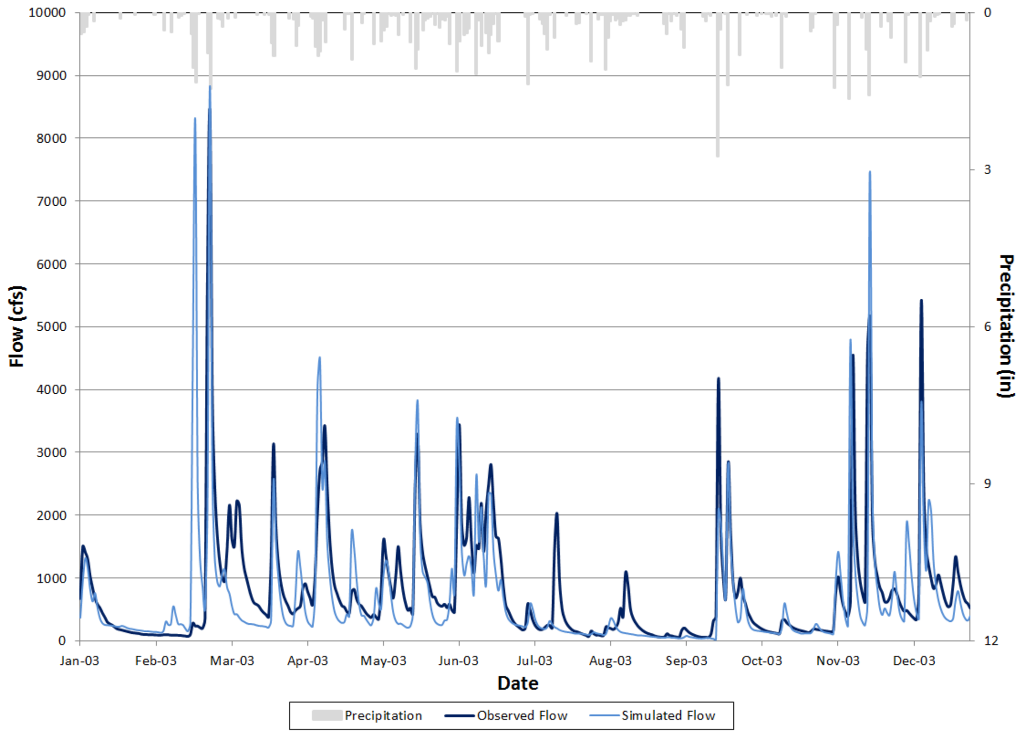

Figure C.13. Observed and simulated flows and precipitation for the representative year in the calibration period for Maury River sub-watershed #31

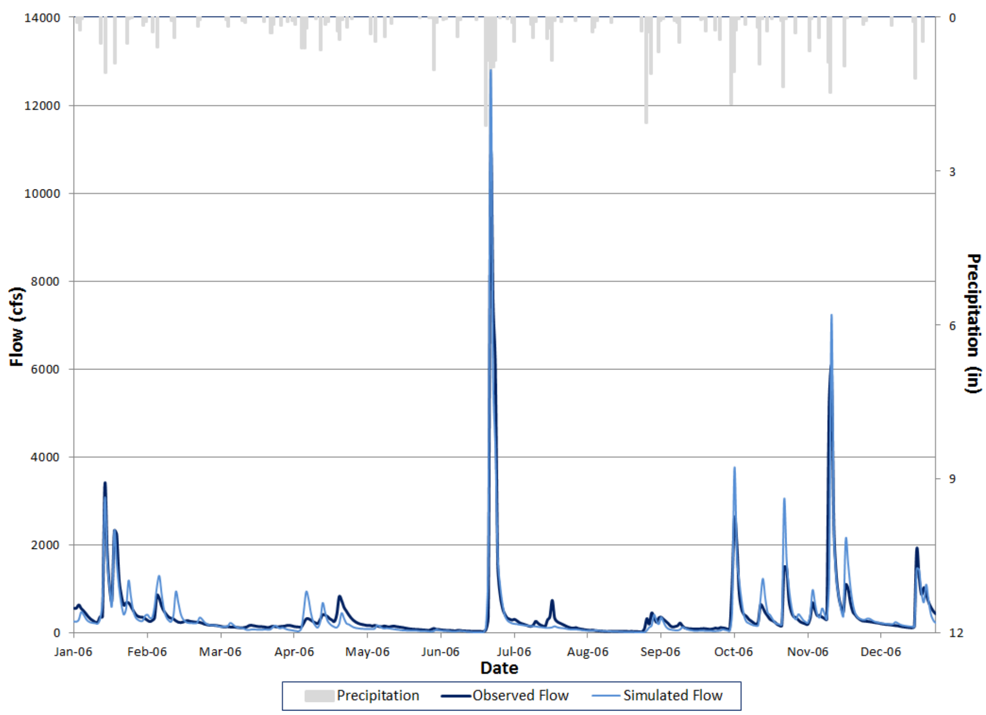

Figure C.14. Observed and simulated flows and precipitation for the representative year in the validation period for Maury River sub-watershed #31

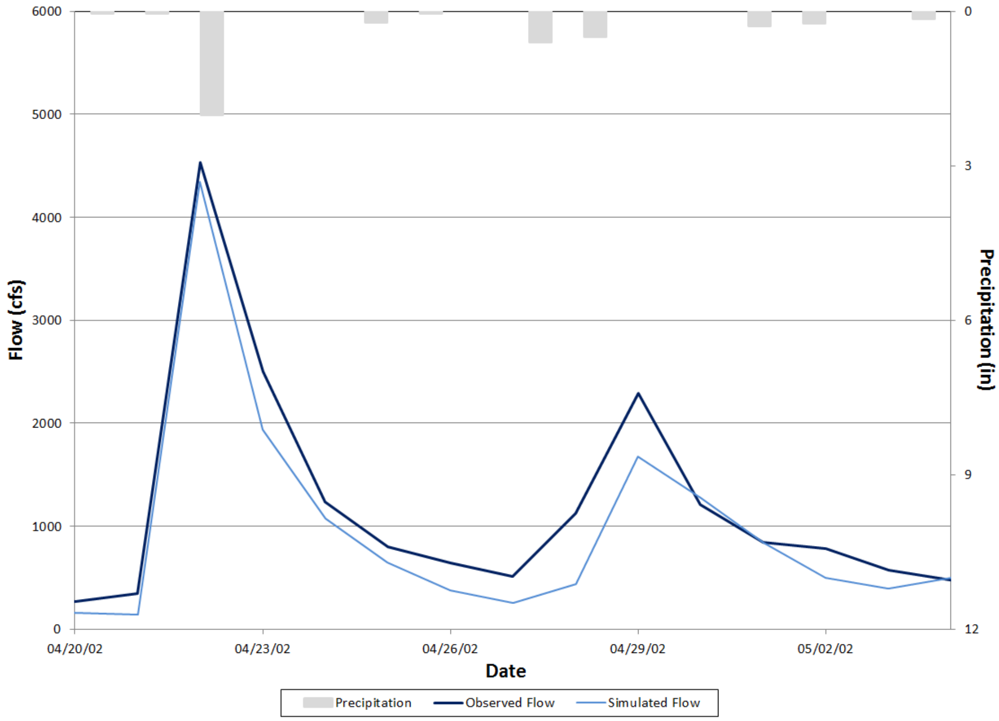

Figure C.15. Observed and simulated flows and precipitation at Maury River sub-watershed #31 for a representative storm in the calibration period

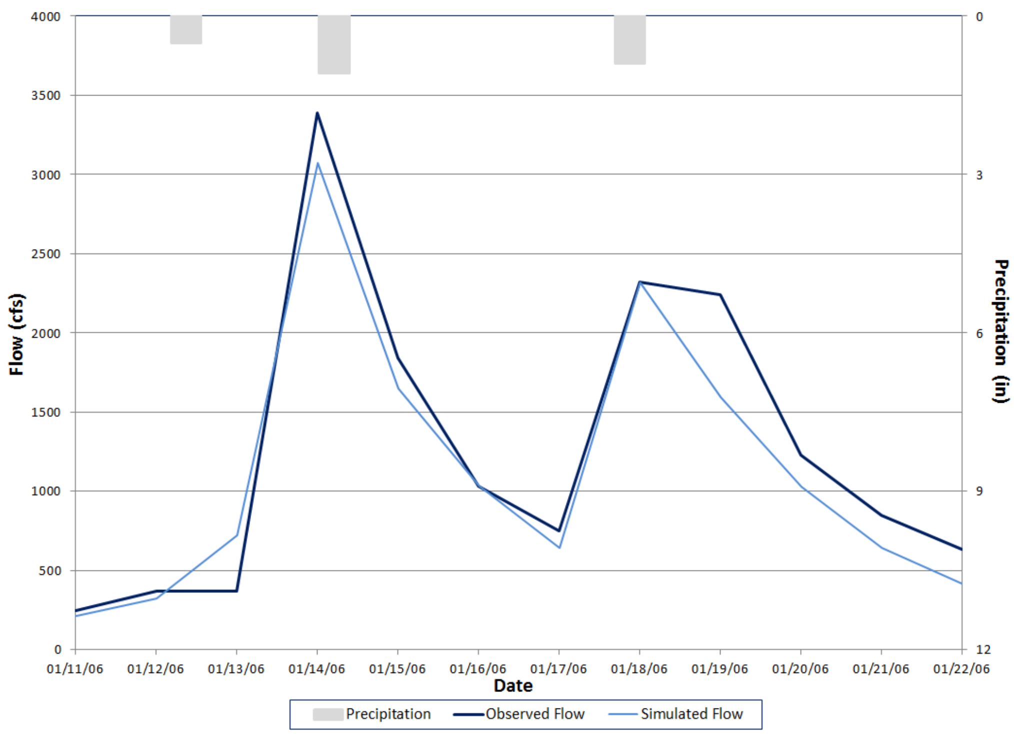

Figure C.16. Observed and simulated flows and precipitation at Maury River sub-watershed #31 for a representative storm in the validation period

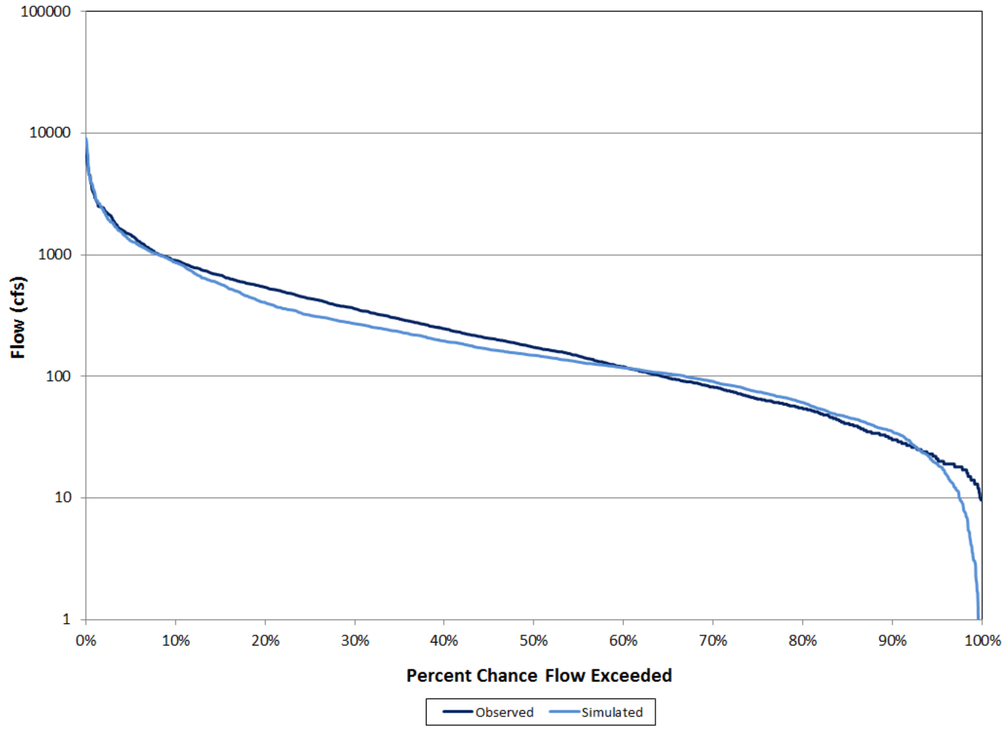

Figure C.17 Cumulative frequency curves at Maury River sub-watershed #31 for calibration period

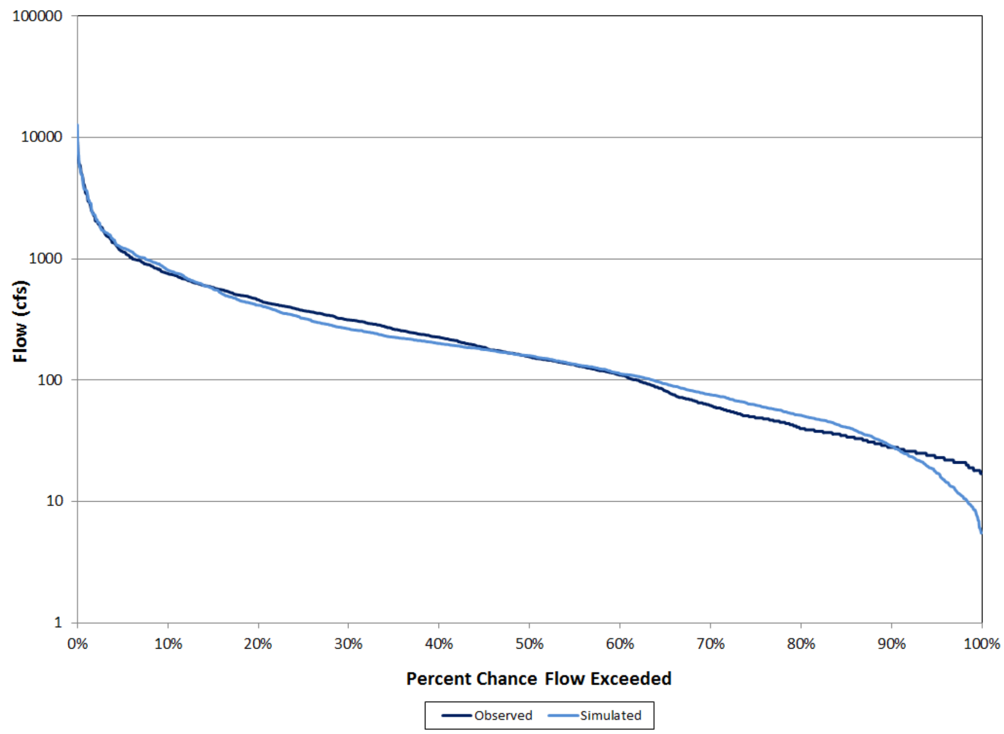

Figure C.18. Cumulative frequency curves at Maury River sub-watershed #31 for validation period

Flow partitioning for the Maury River hydrologic model calibration and validation is shown in Table C.4. When the observed flow data were evaluated using Baseflow Program

(Arnold, 1999), the baseflow target indices for the calibration and validation periods were 0.44 and 0.43 respectively, and the target range of baseflow indices were 0.36 - 0.60 and 0.36 – 0.59 for the calibration and validation periods respectively. The simulated baseflow indices are within the observed value range.

Table C. 4. Flow partitioning for the calibration and validation periods for Maury River

Flow gaging station	Average Annual Flow	Calibration		Validation	
Sub-watershed #31	Total Runoff (in)	14.47		14.43	
	Total Surface Runoff (in)	5.26	(36.35%)	5.44	(37.70%)
	Total Interflow (in)	3.90	(26.95%)	3.84	(26.61%)
	Total Baseflow (in)	5.31	(36.70%)	5.15	(35.69%)
	Baseflow Index	0.44		0.43	

4) Hydrologic Calibration for sub-watershed #40 gaging station

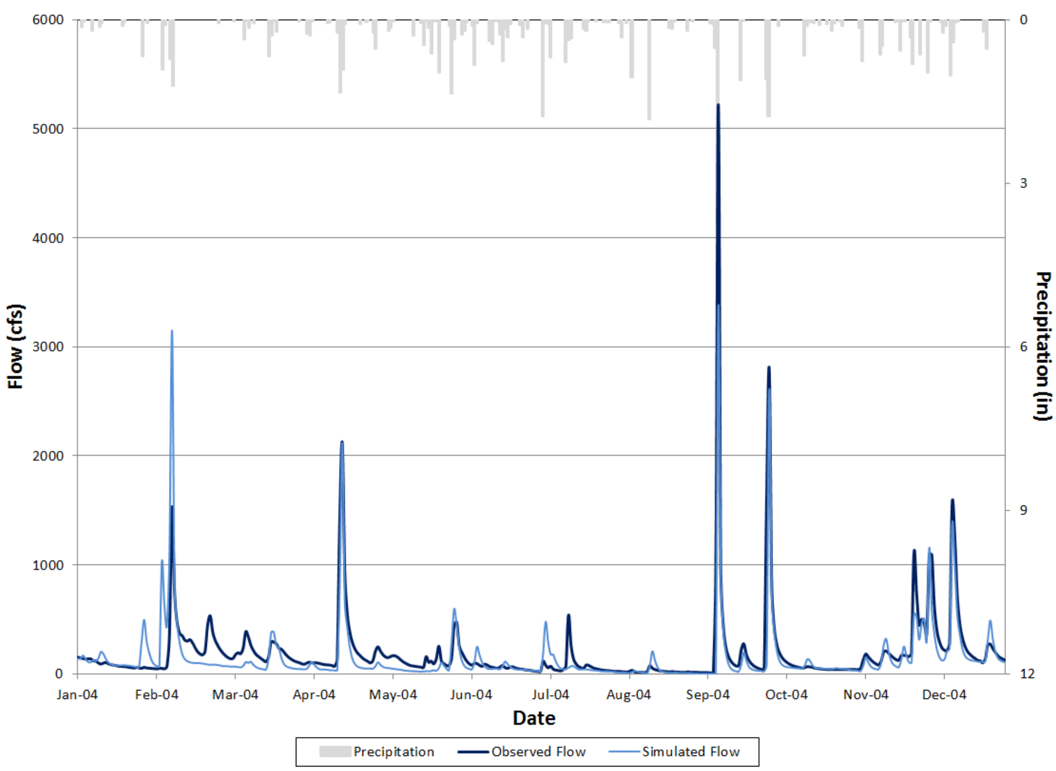

Figure C.19. Observed and simulated flows and precipitation for the representative year in the calibration period for Maury River sub-watershed #40

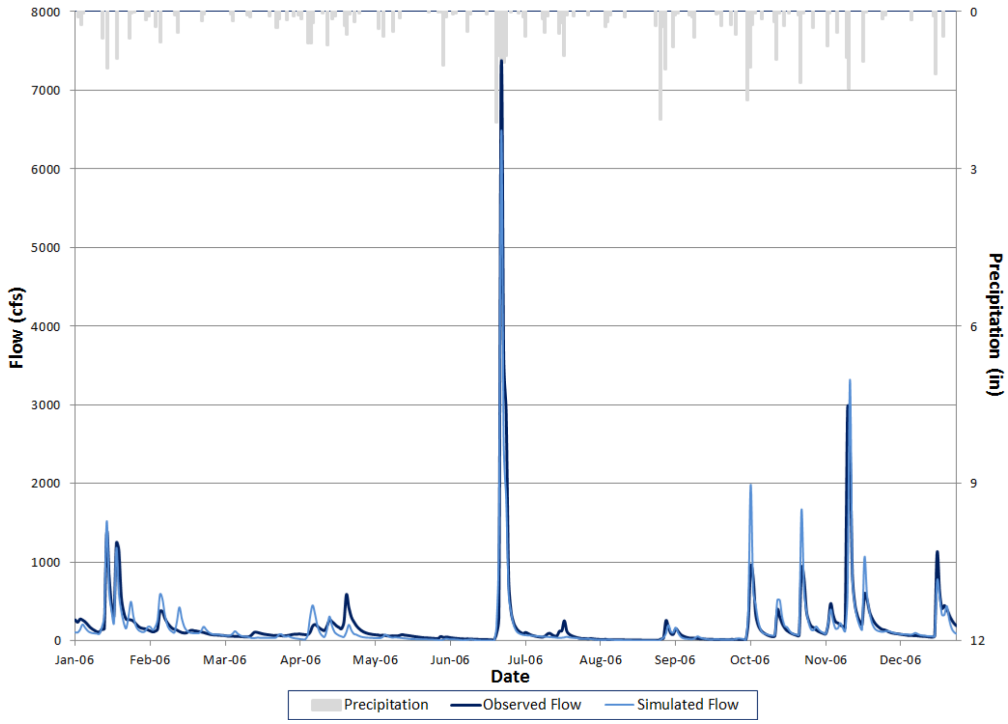

Figure C.20. Observed and simulated flows and precipitation for the representative year in the validation period for Maury River sub-watershed #40

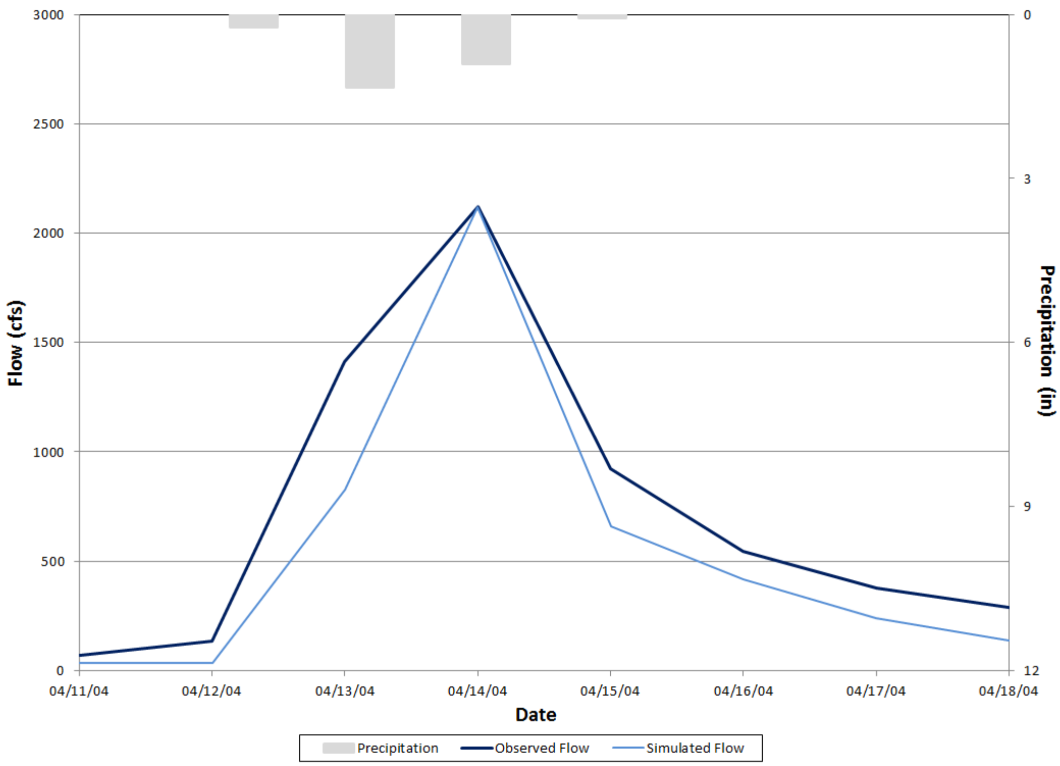

Figure C.21. Observed and simulated flows and precipitation at Maury River sub-watershed #40 for a representative storm in the calibration period

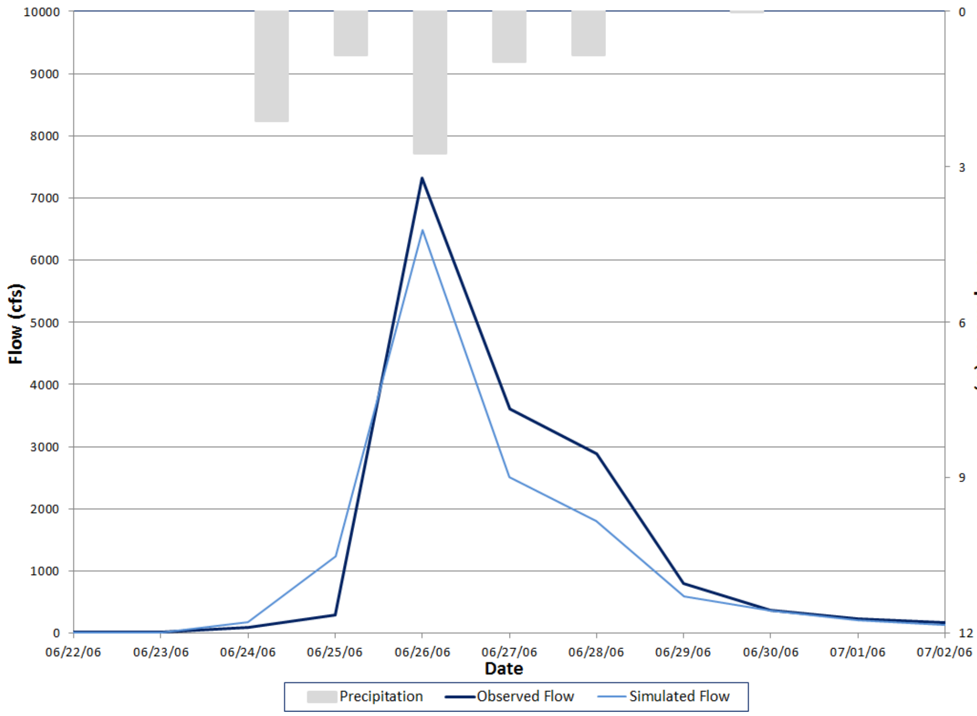

Figure C.22. Observed and simulated flows and precipitation at Maury River sub-watershed #40 for a representative storm in the validation period

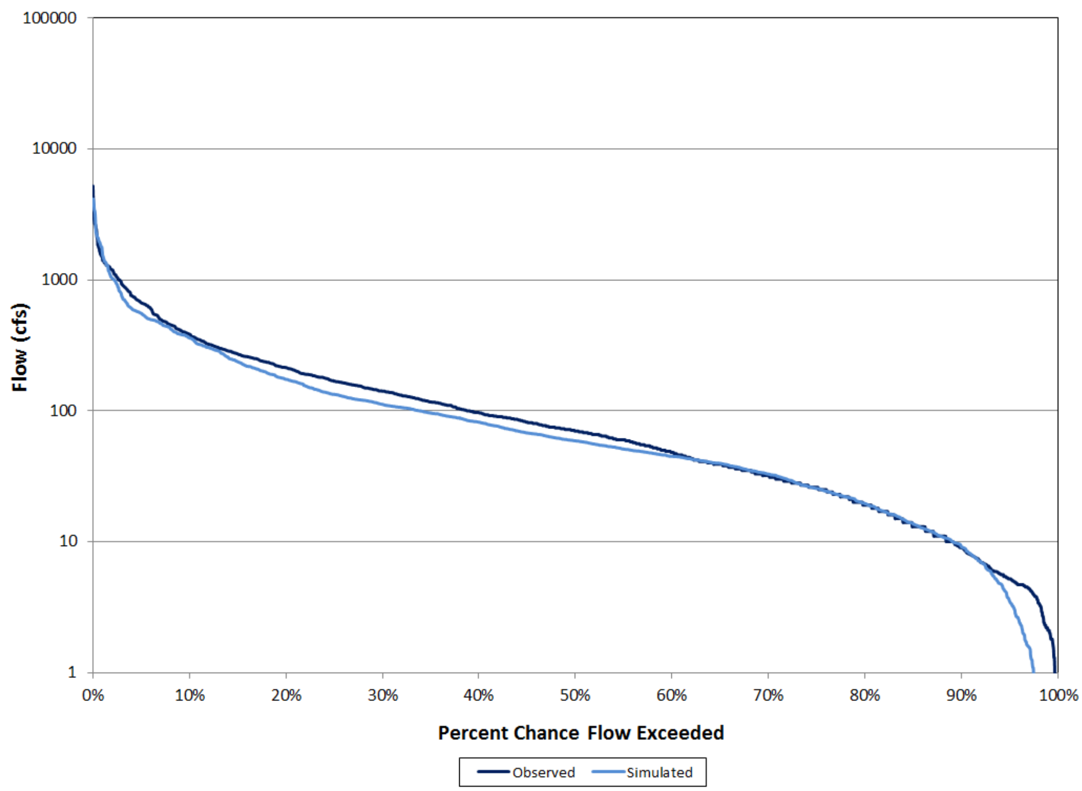

Figure C.23 Cumulative frequency curves at Maury River sub-watershed #40 for calibration period

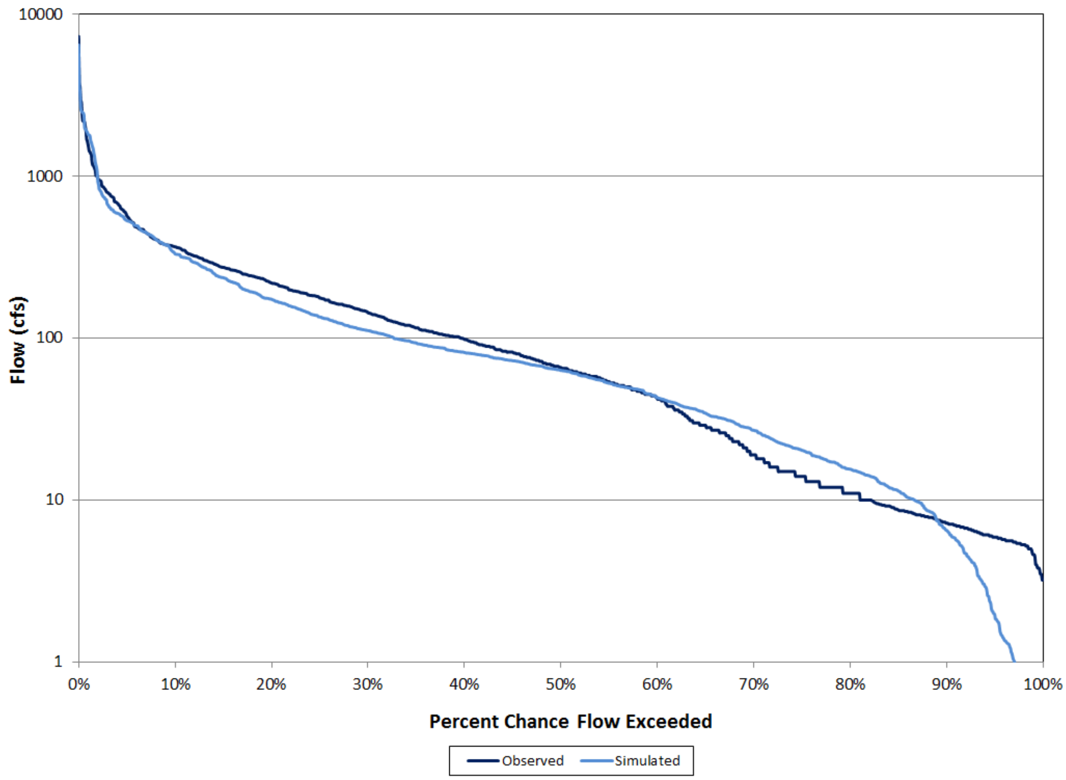

Figure C.24 Cumulative frequency curves at Maury River sub-watershed #40 for validation period

Flow partitioning for the Maury River hydrologic model calibration and validation is shown in Table C.5. When the observed flow data were evaluated using Baseflow Program (Arnold, 1999), the baseflow target indices for the calibration and validation periods were 0.38 and 0.39 respectively, and the target range of baseflow indices were 0.32 - 0.54 and 0.32 – 0.55 for the calibration and validation periods respectively. The simulated baseflow indices are within the observed value range.

Table C. 5. Flow partitioning for the calibration and validation periods for Maury River

Flow gaging station	Average Annual Flow	Calibration		Validation	
Sub-watershed #40	Total Runoff (in)	14.46		14.46	
	Total Surface Runoff (in)	7.38	(51.04%)	7.63	(52.77%)
	Total Interflow (in)	2.36	(16.32%)	2.26	(15.63%)
	Total Baseflow (in)	4.72	(32.64%)	4.57	(31.60%)
	Baseflow Index	0.40		0.39	

Table C. 6. Hydrology parameters for Maury River watershed

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix C Table (if applicable)
PERLND					
			PWAT-PARM2		
FOREST	Fraction forest cover	none	1.0	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	3.0 for subshed #1 – #24 and #26 – #39; 14 for subshed #25; 2.5 for subshed #40 – #43	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.004 – 0.076	Soil and cover conditions	
LSUR	Length of overland flow	feet	14.48 – 369.29	Topography	
SLSUR	Slope of overland flowplane	none	0.0105 – 0.4117	Topography	
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.957 for subshed #1 – #24 and #26 – #30; 0.981 for subshed #25; 0.963 for subshed #31 – #39 0.965 for subshed #40 – #43	Calibrate	
			PWAT-PARM3		
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.05 for subshed #1 – #24, #26 – #30 and #40 – #43; 0.20 for subshed #25; 0.02 for subshed #31 – #39	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0.01 for subshed #1 – #24, #26 – #30 and #40 – #43; 0.00 for subshed #31 – #39; 0.10 for subshed #25	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0.01 for subshed #1 – #24 and #26 – #30; 0.00 for subshed #31 – #39; 0.02 for subshed #40 – #43; 0.10 for subshed #25	Marsh/wetlands ET	
			PWAT-PARM4		
CEPSC	Interception storage capacity	inches	monthly[a]	Vegetation	1
UZSN	Upper zone nominal soil moisture storage	inches	monthly[a]	Soil properties	2
NSUR	Mannings' n (roughness)	none	0.15 forest; 0.35 residential; 0.20 pasture and cropland; 0.10 water	Land use, surface condition	

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix C Table (if applicable)
INTFW	Interflow/surface runoff partition parameter	none	3.0 for subshed #1 – #24 and #26 – #39; 1.0 for subshed #25 and #40 – #43	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.30	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[a]	Vegetation	3
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	150	Topography	
SLSUR	Slope of overland flowplane	none	0.140	Topography	
NSUR	Mannings' n (roughness)	none	0.3	Land use, surface condition	
RETSC	Retention/inter-ception storage capacity	inches	0.070	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		

[a]Varies by month and with land use
[a]Values varied by soil type (available on request).
[b]Values varied by month and with land use (available on request).

Bacteria Results: Calibration and Validation

Figures C.25 through C.37 show the daily maxima, minima, and averages of simulated values for the final calibration runs for the *E. coli* data at stations 2-CFP004.67, 2-MIT000.04, 2-MRY000.09, 2-MRY005.39, 2-MRY014.78, MRY016.62, 2-MRY038.29, 2-STH000.21, 2-MIS000.04, 2-BFN000.07, 2-BFS000.15, 2-BLD000.22, and 2-CLL001.99, respectively. Figures C.38 through C.51 show the daily maxima, minima, and averages of simulated values for the final validation runs for the *E. coli* data at stations 2-CFP004.67, 2-CFP024.20, 2-MRY000.09, 2-MRY005.39, 2-MRY014.78, 2-MRY016.62, 2- MRY020.82, 2-MRY038.29, 2-STH000.21, 2-ISH000.02, 2AWDS000.10, 2-BFS000.15, 2-BLD000.22, and 2-CLL001.99, respectively. The final calibrated water quality parameters are given in Table C.7.

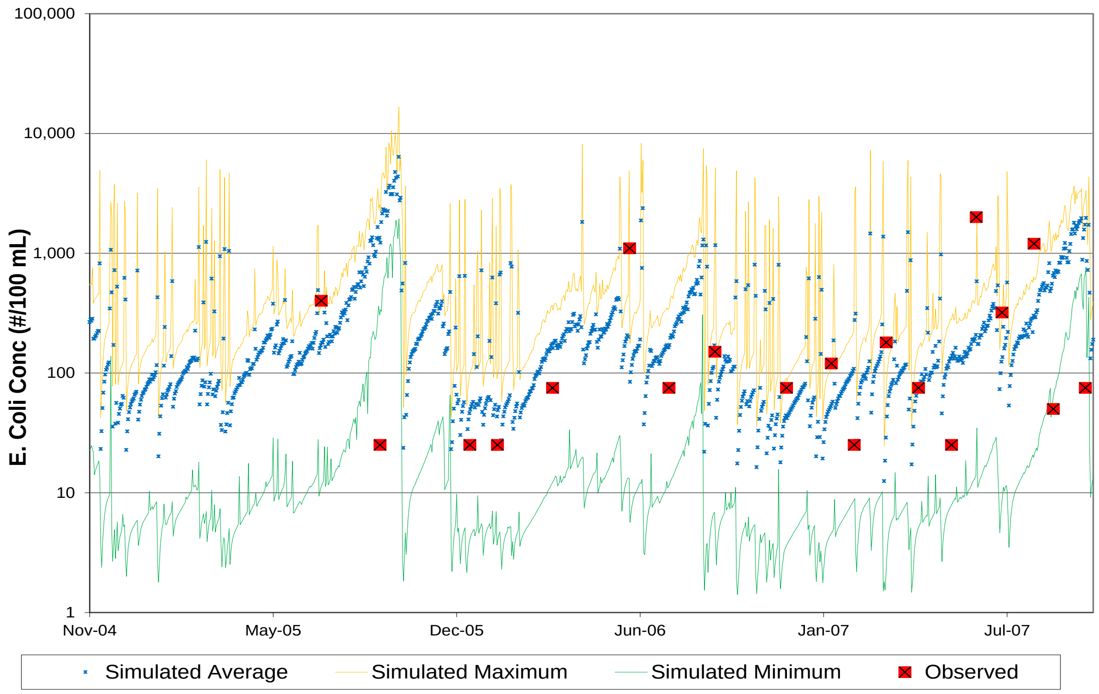

Figure C.25. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Calfpasture Creek at station 2-CFP004.67 for the calibration period (January 1, 2008 – November 30, 2012).

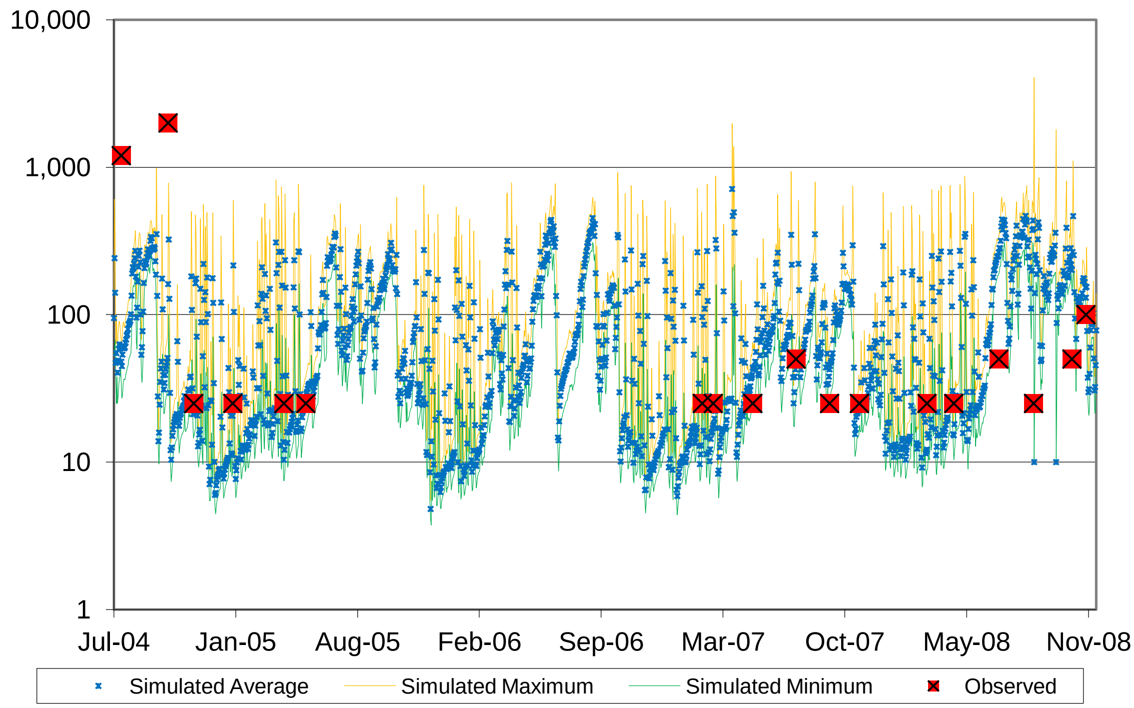

Figure C.26. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Mill Creek at station 2-MIT000.04 for the calibration period (July 1, 2004 – November 30, 2008).

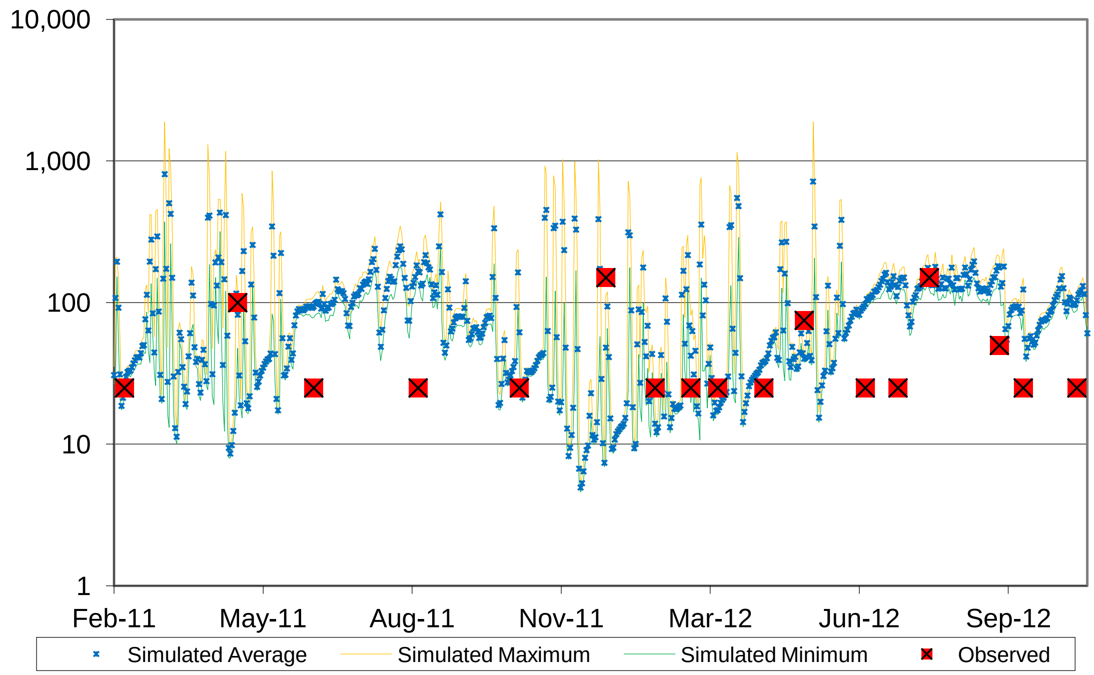

Figure C.27. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY000.09 for the calibration period (February 1, 2011 – November 15, 2012).

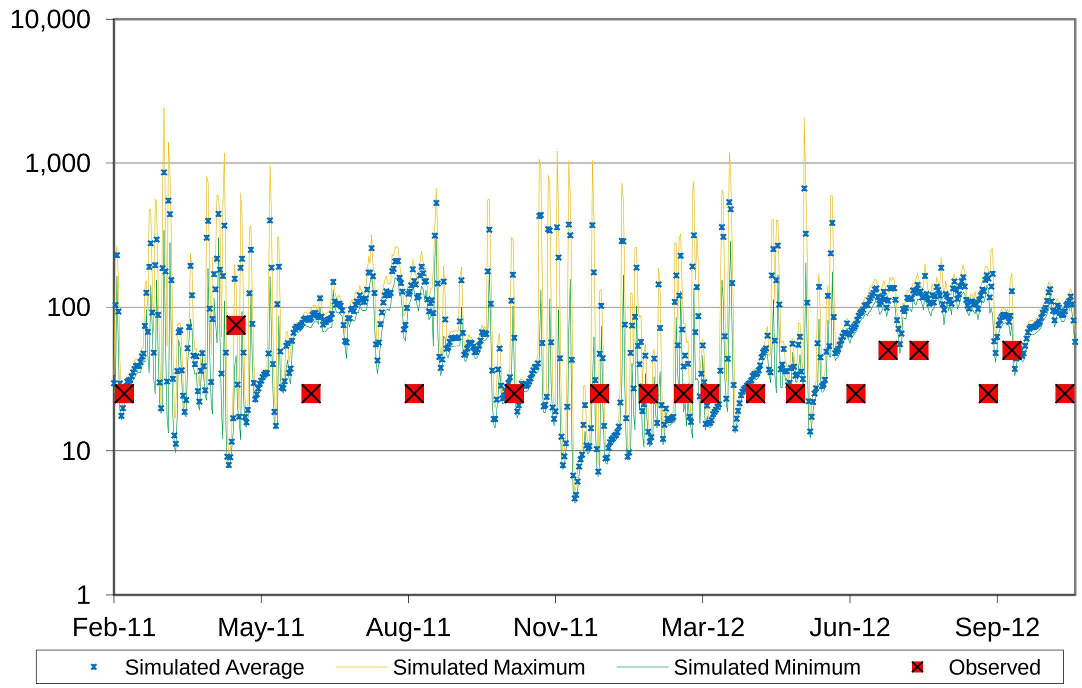

Figure C.28. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY005.39 for the calibration period (February 1, 2011 – November 15, 2012).

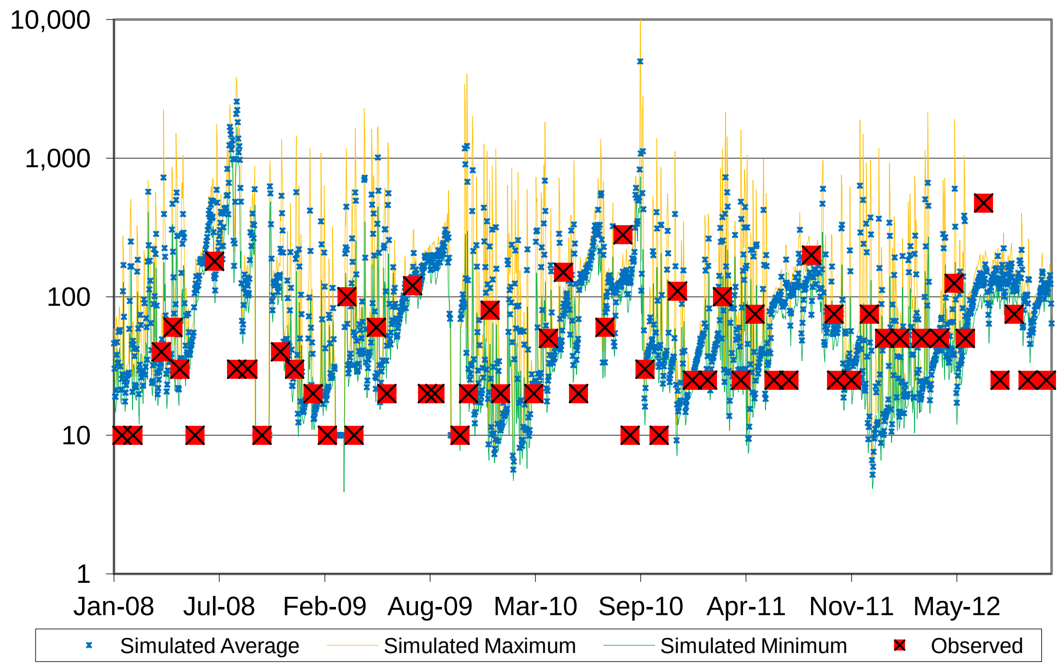

Figure C.29. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY014.78 for the calibration period (January 1, 2008 – November 15, 2012).

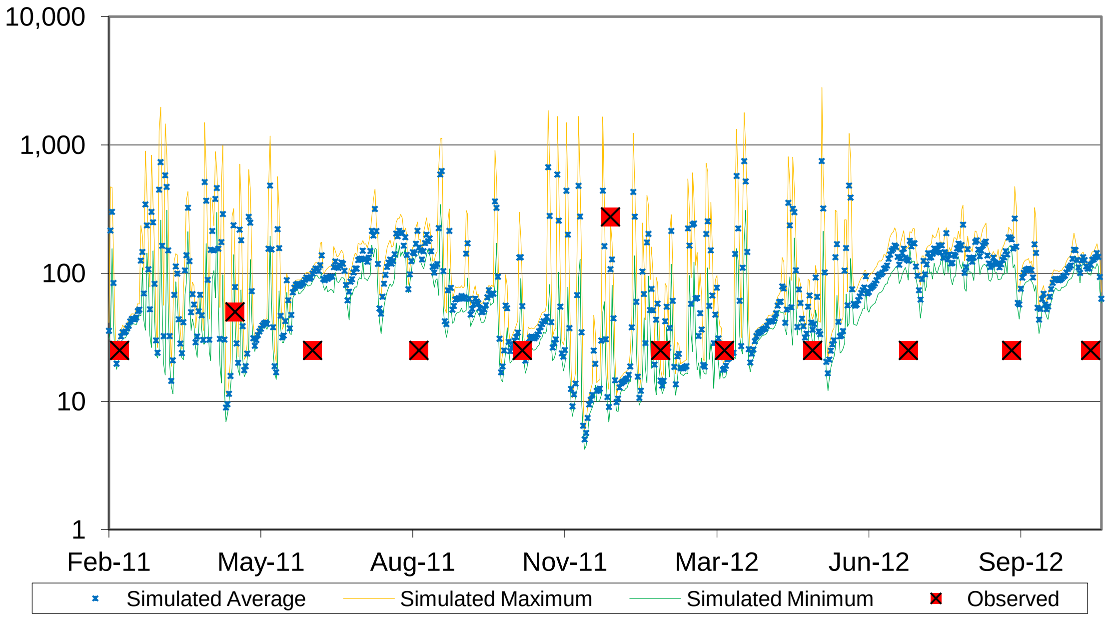

Figure C.30. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY016.62 for the calibration period (February 1, 2011 – November 15, 2012).

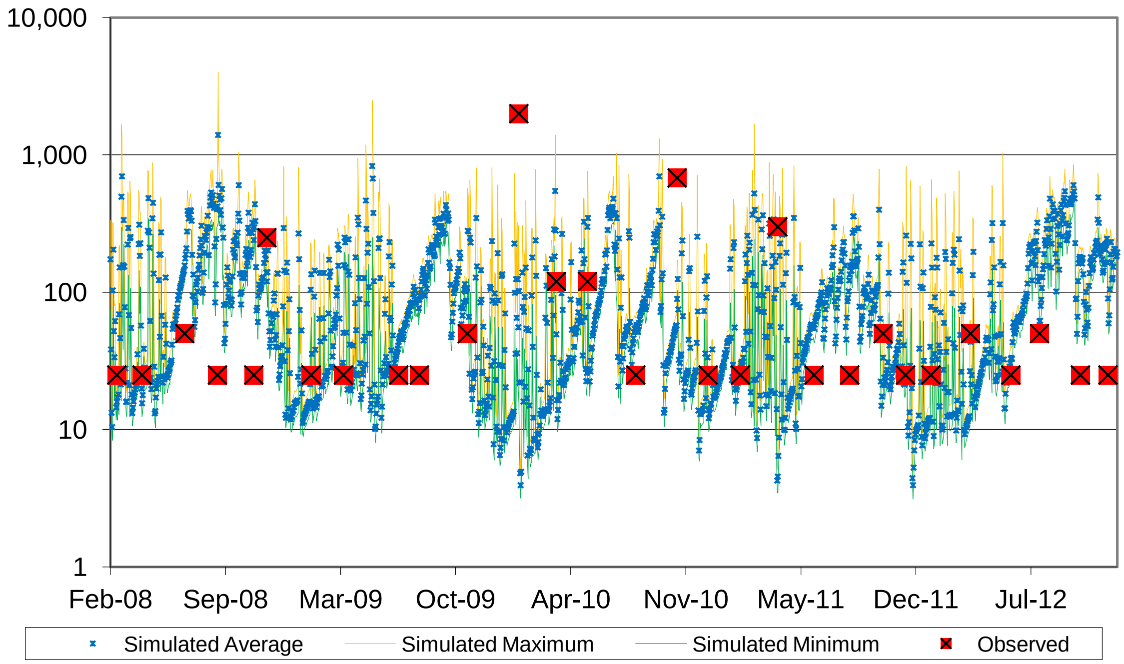

Figure C.31. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY038.29 for the calibration period (February 15, 2008 – November 30, 2012).

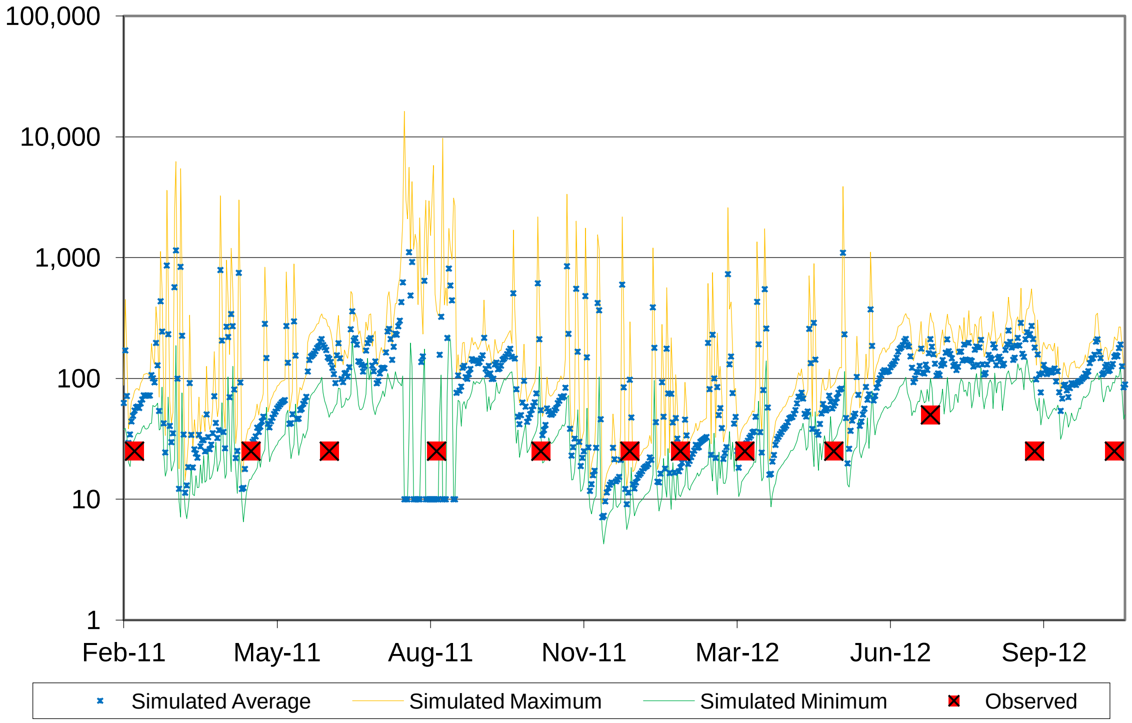

Figure C.32. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for South River at station 2-STH000.21 for the calibration period (February 1, 2011 – November 15, 2012).

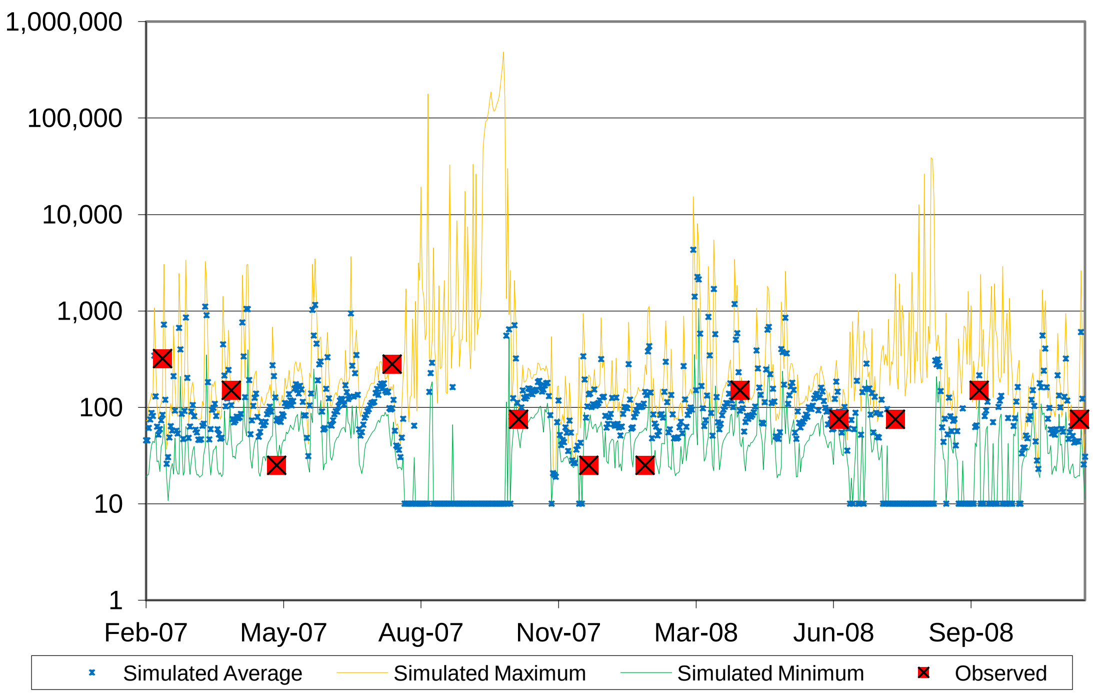

Figure C.33. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Mill Creek at station 2-MIS000.04 for the calibration period (February 1, 2007 – December 15, 2008).

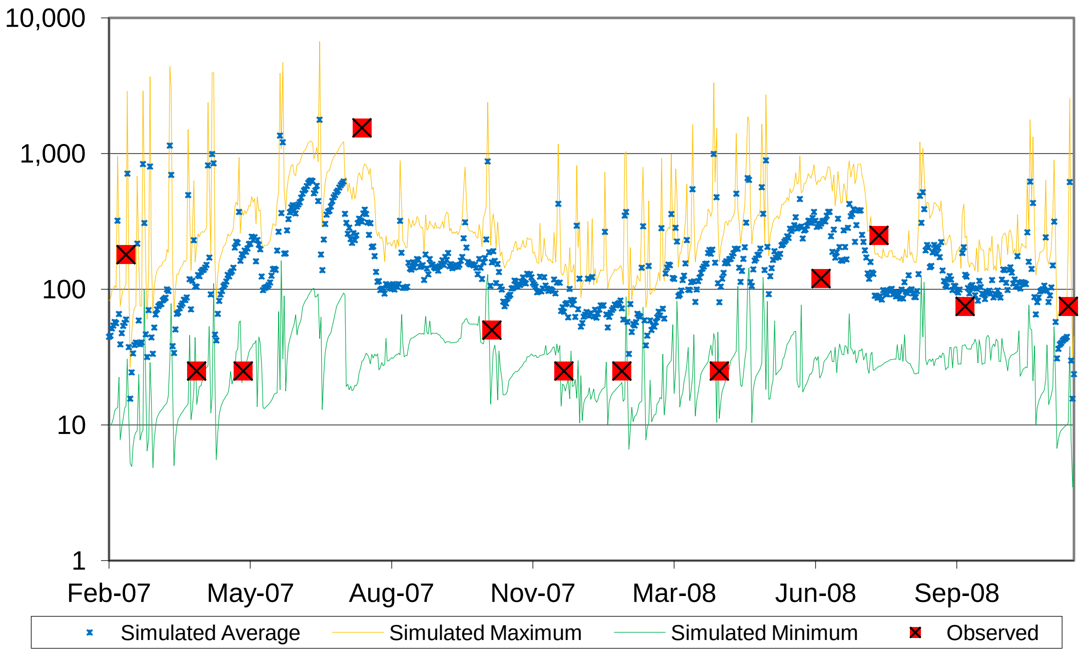

Figure C.34. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for North Fork Buffalo Creek at station 2-BFN000.07 for the calibration period (February 1, 2007 – December 15, 2008).

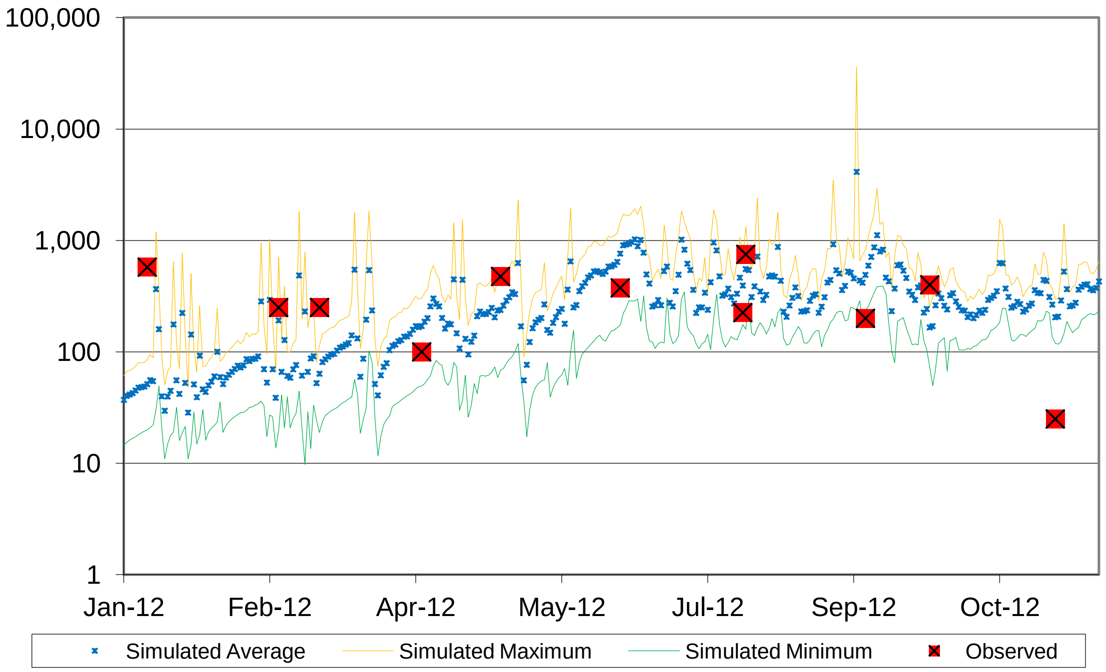

Figure C.35. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for South Fork Buffalo Creek at station 2-BFS000.15 for the calibration period (January 1, 2012 – November 30, 2012).

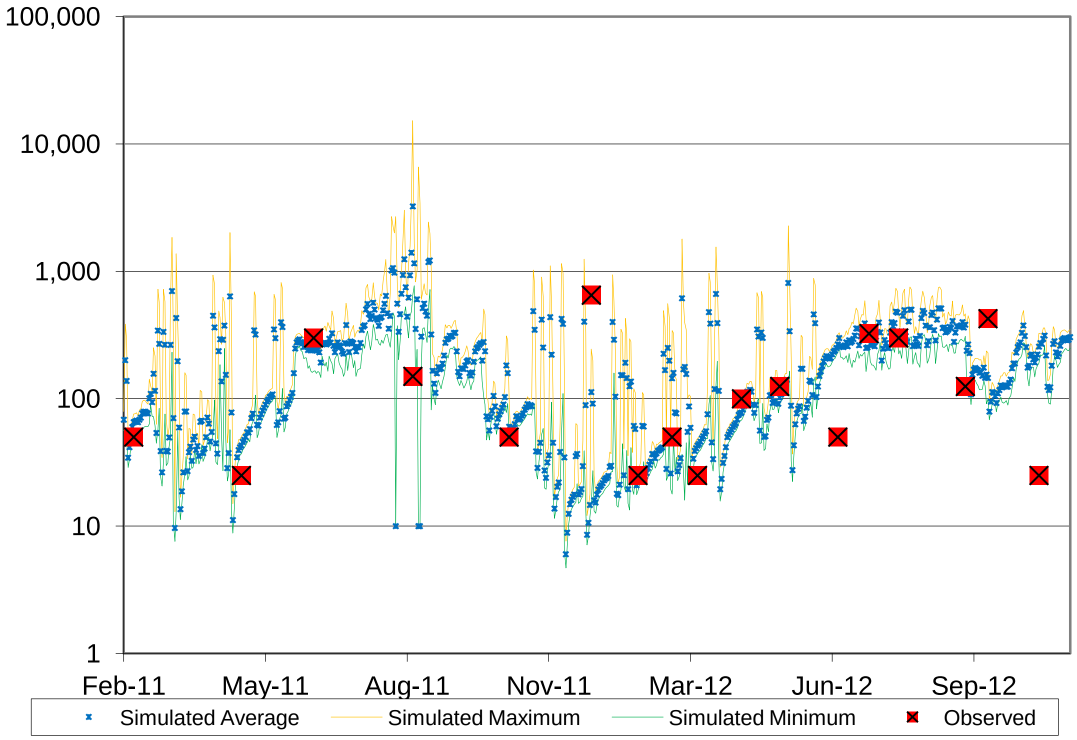

Figure C.36. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Buffalo Creek at station 2-BLD000.22 for the calibration period (February 1, 2011 – November 30, 2012).

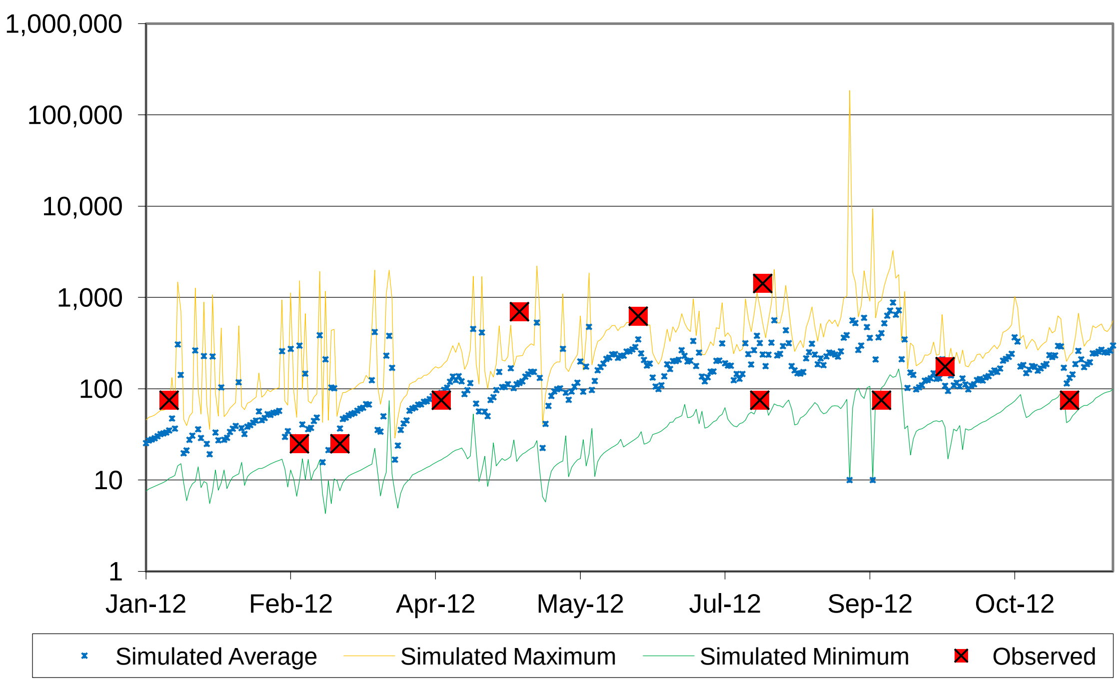

Figure C.37. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Colliers Creek at station 2-CLL001.99 for the calibration period (January 1, 2012 – November 30, 2012).

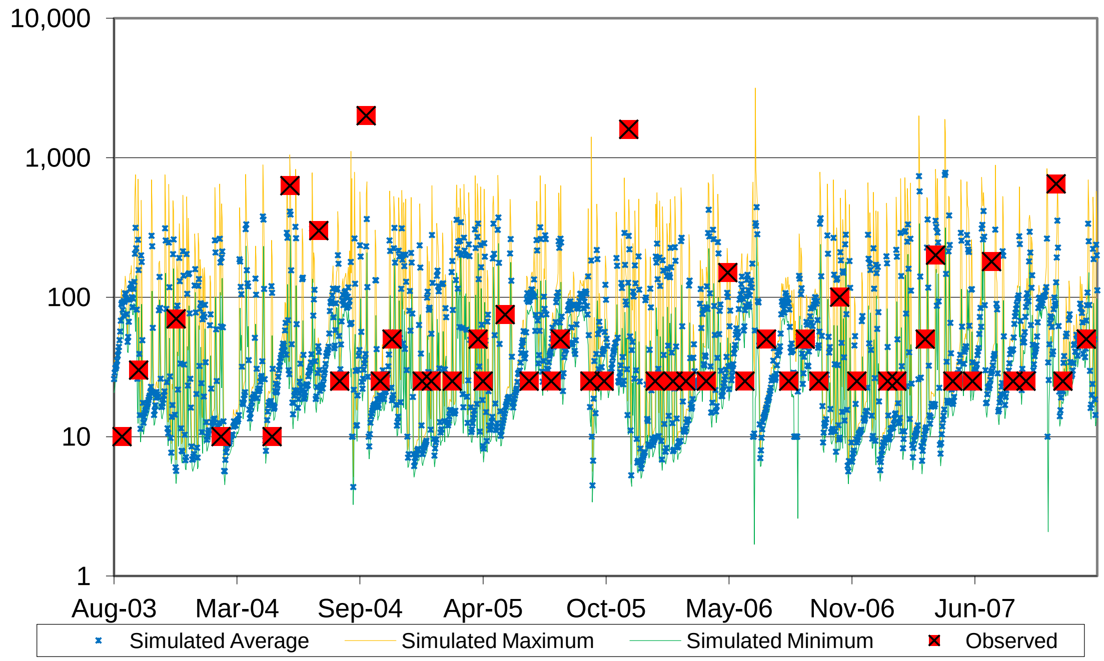

Figure C.38. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Calfpasture Creek at station 2-CFP004.67 for the validation period (August 15, 2003 – December 31, 2007).

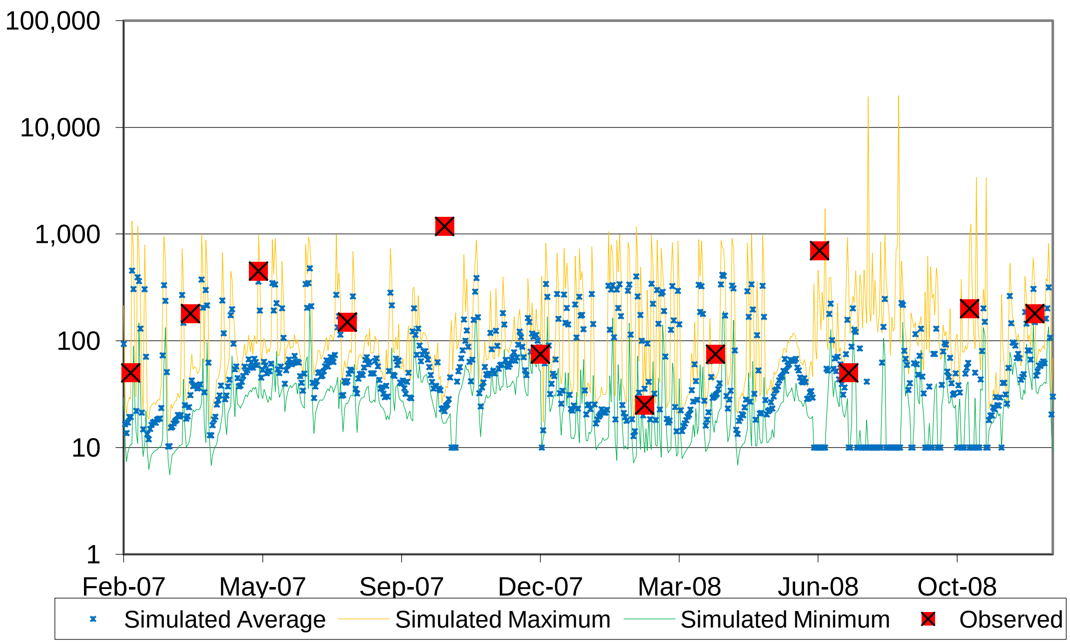

Figure C.39. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Calfpasture Creek at station 2-CFP024.20 for the validation period (February 15, 2003 – December 15, 2008).

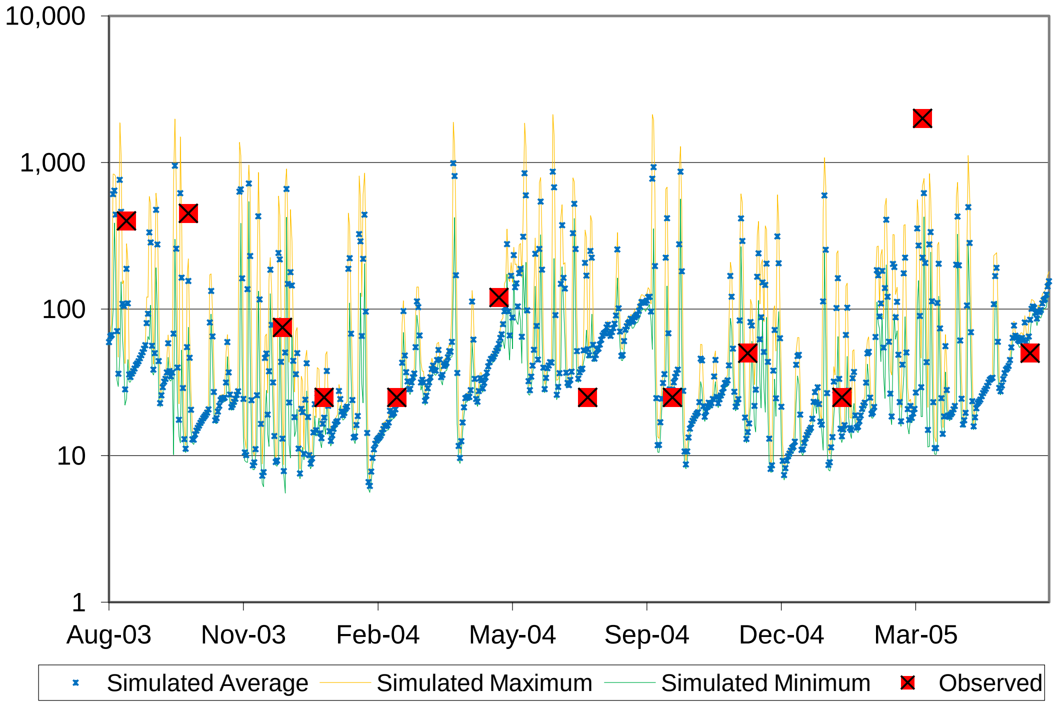

Figure C.40. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY000.09 for the validation period (August 1, 2003 – June 30, 2005).

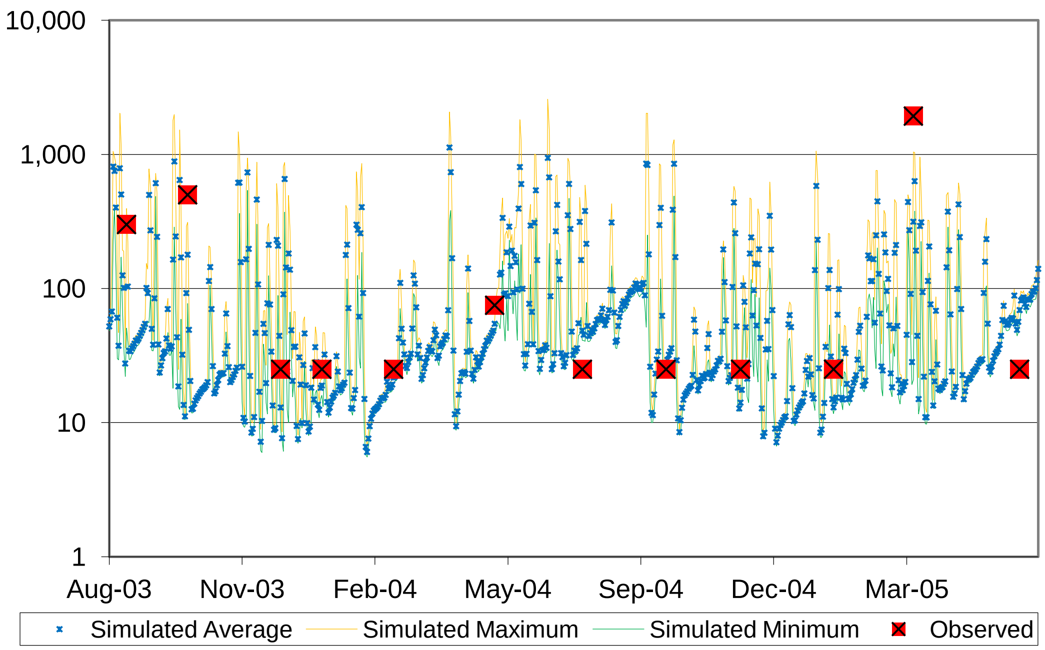

Figure C.41. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY005.39 for the validation period (August 1, 2003 – June 30, 2005).

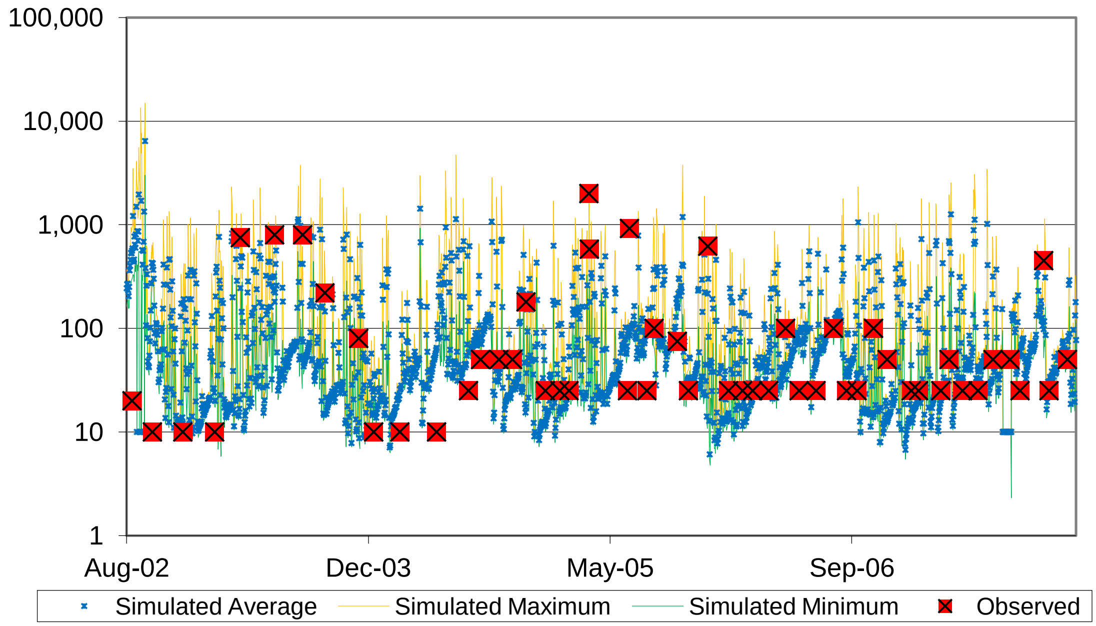

Figure C.42. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY014.78 for the validation period (August 15, 2002 – December 31, 2007).

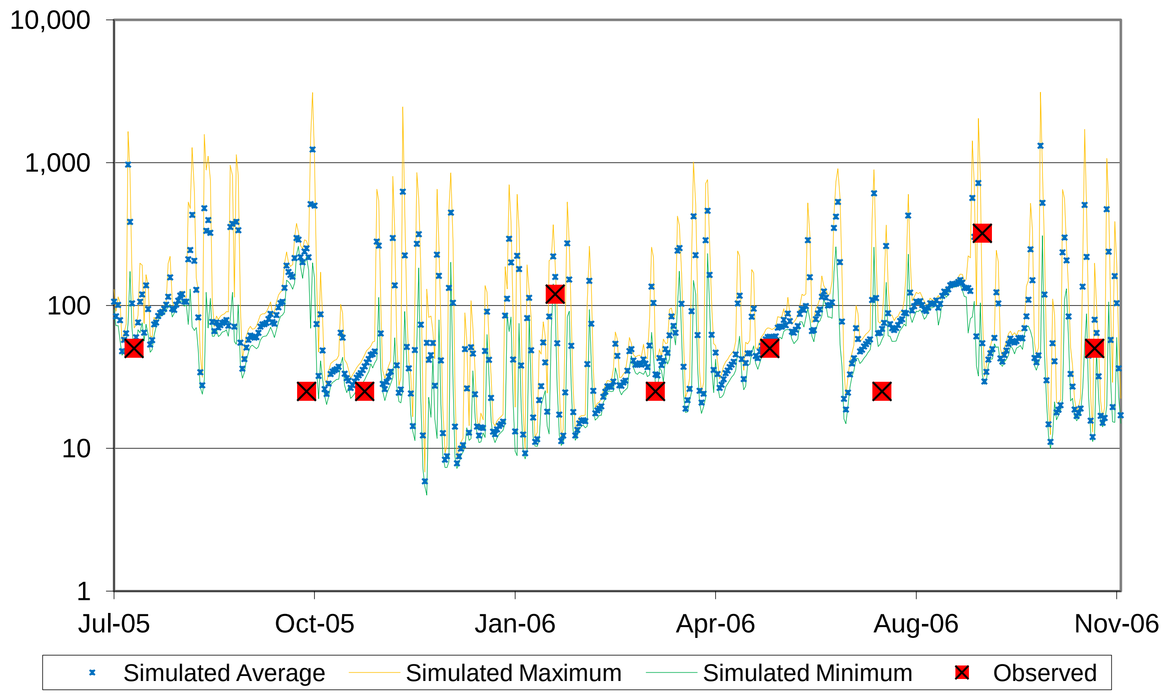

Figure C.43. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY016.62 for the validation period (July 1, 2005 – November 15, 2006).

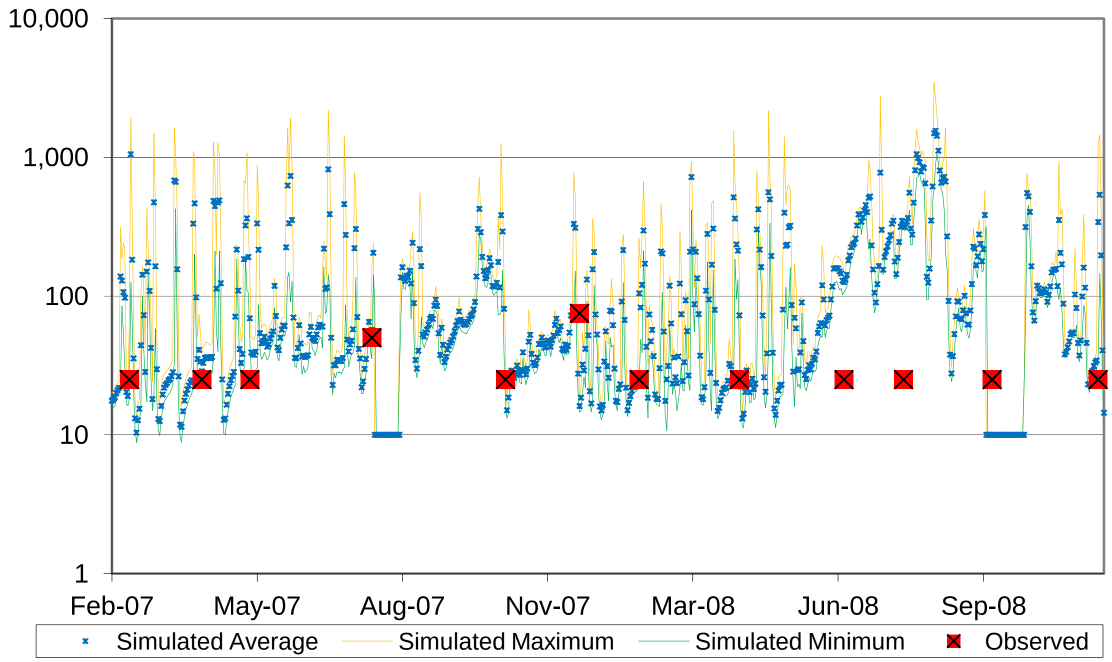

Figure C.44. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY020.82 for the validation period (February 1, 2007 – December 15, 2008).

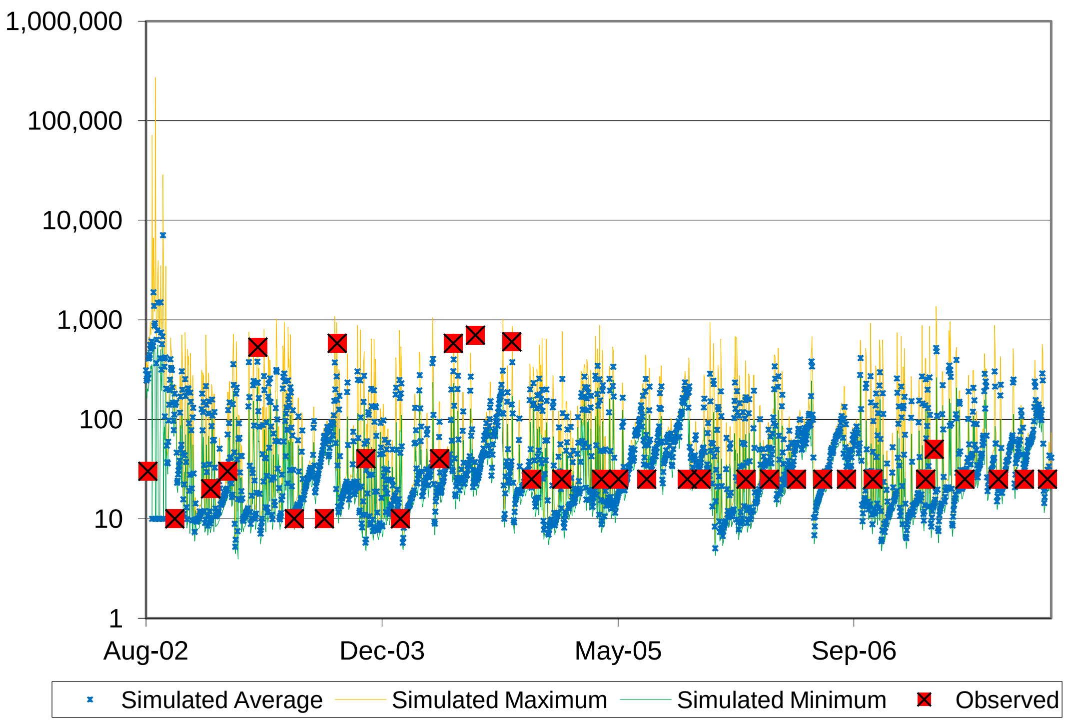

Figure C.45. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Maury River at station 2-MRY038.29 for the validation period (August 15, 2002 – November 15, 2007).

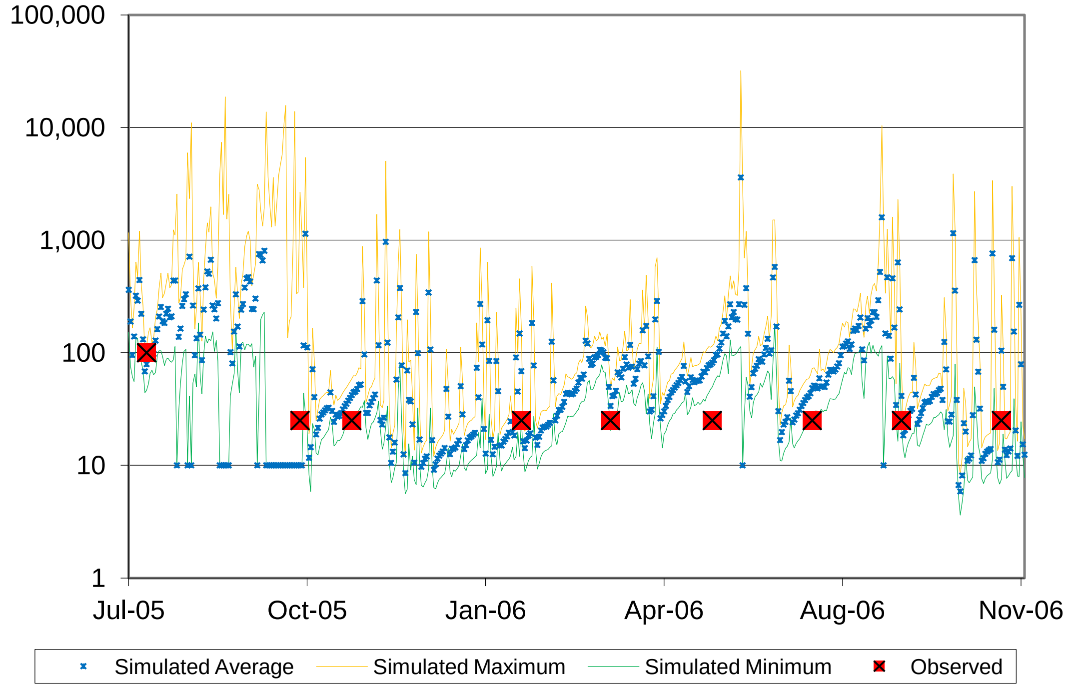

Figure C.46. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for South River at station 2-STH000.21 for the validation period (July 1, 2005 – November 15, 2006).

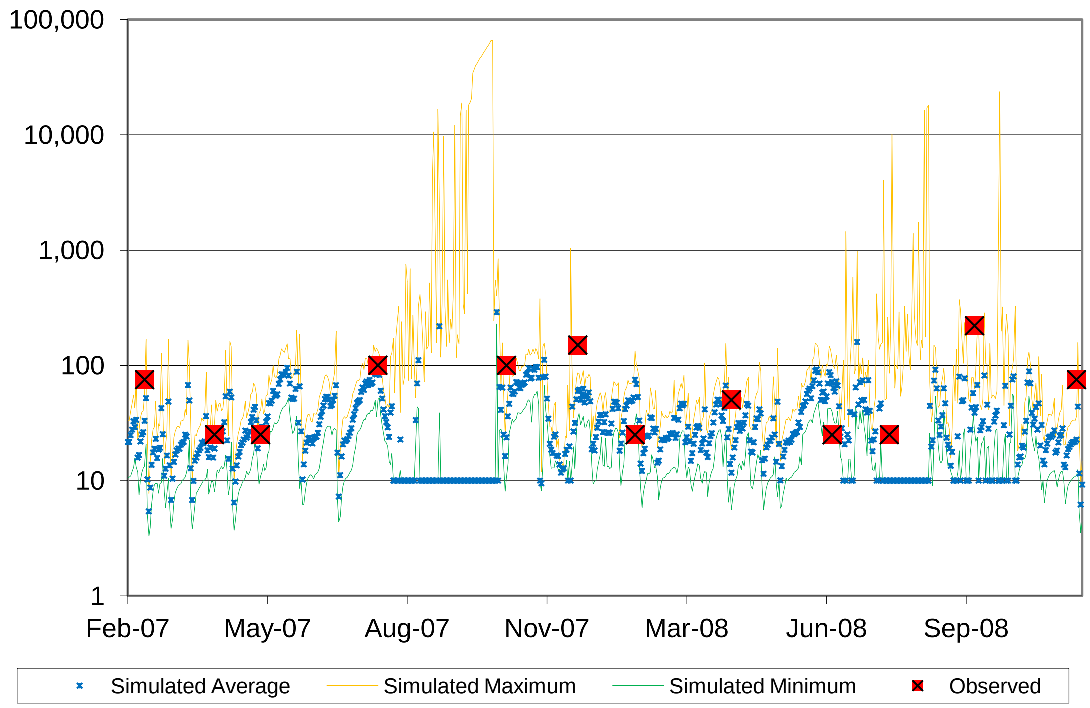

Figure C.47. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Irish Creek at station 2-ISH000.02 for the validation period (February 1, 2007 – December 15, 2008).

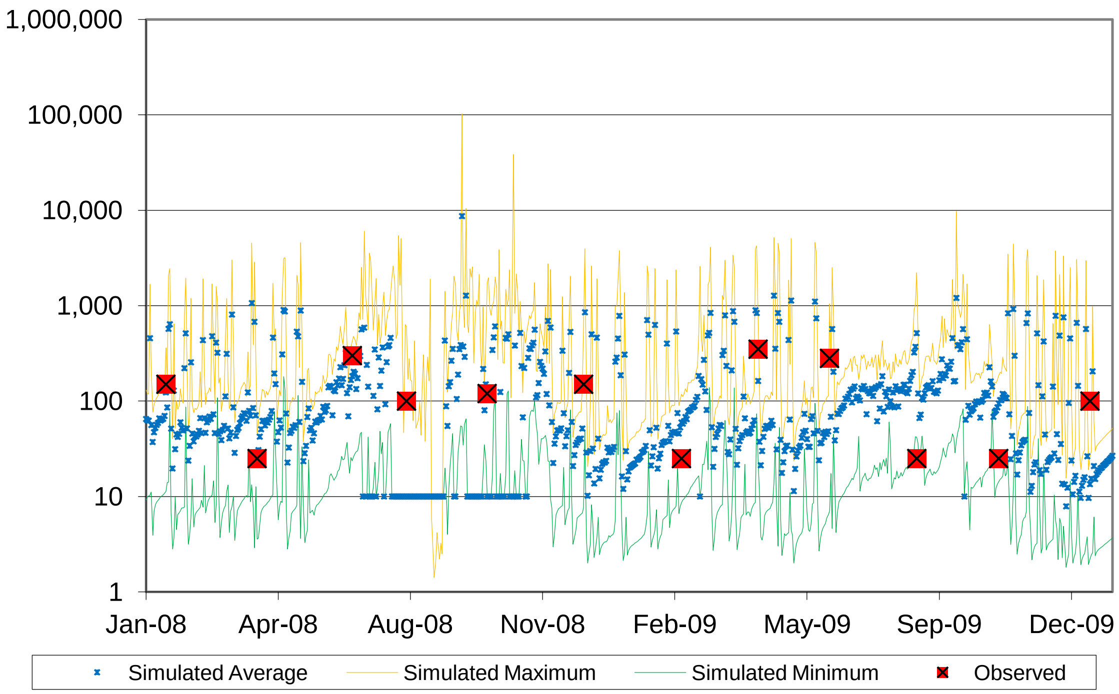

Figure C.48. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Woods Creek at station 2AWDS000.10 for the validation period (January 1, 2008 – January 15, 2010).

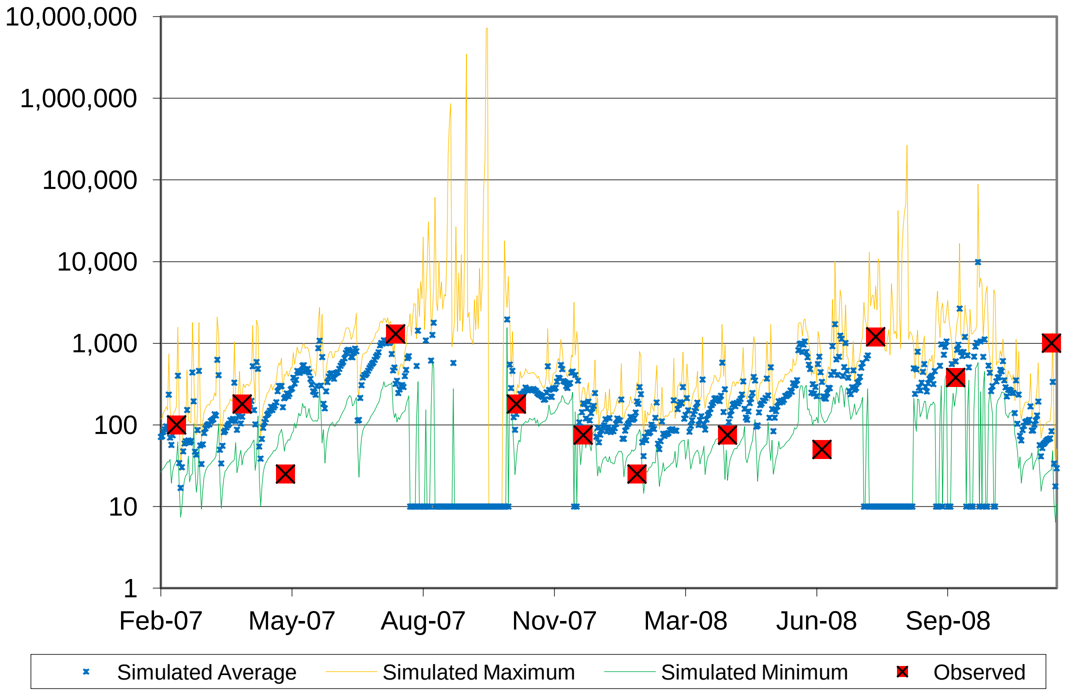

Figure C.49. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for South Fork Buffalo Creek at station 2-BFS000.15 for the validation period (February 1, 2007 – December 15, 2008).

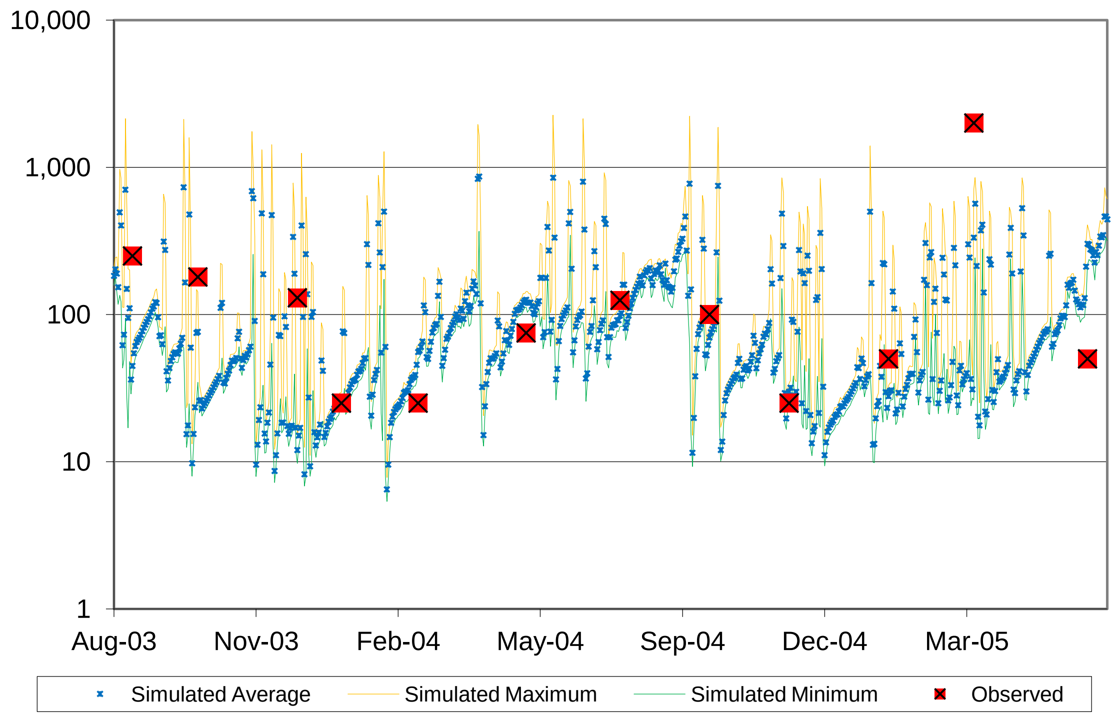

Figure C.50. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Buffalo Creek at station 2-BLD000.22 for the validation period (August 1, 2003 – June 30, 2005).

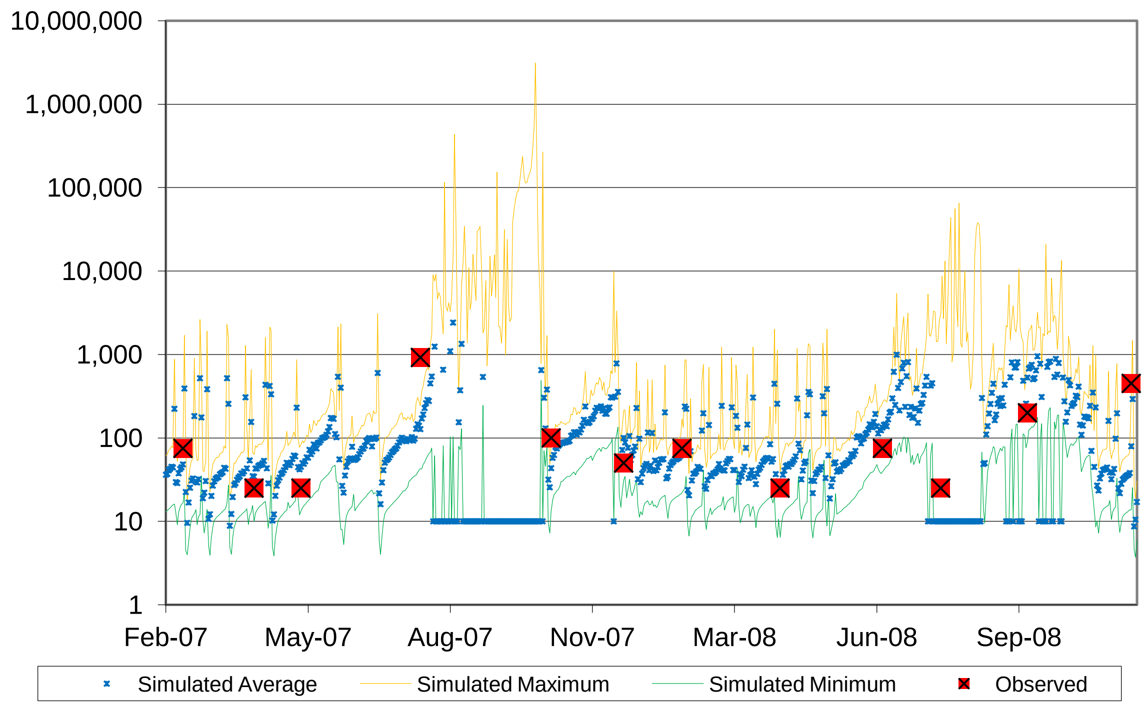

Figure C.51. Observed *E. coli* data plotted with the daily maximum, minimum, and average simulated fecal coliform values for Colliers Creek at station 2-CLL001.99 for the validation period (February 1, 2007 – December 15, 2008).

Table C. 7. Calibrated bacteria water quality parameters for the Maury River and the Cedar Creek watersheds

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…
PQUAL				
SQO	Initial storage of constituent	#/ac	0	Land use
POTFW	Washoff potency factor	#/ton	0	
POTFS	Scour potency factor	#/ton	0	
ACQOP	Rate of accumulation of constituent	#/day	Monthly[a]	Land use
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP[a]	Land use
WSQOP	Wash-off rate	in/hr	0.1	Land use
IOQC	Constituent conc. in interflow	$\#/ft^3$	177 & 531	
AOQC	Constituent conc. in active groundwater	$\#/ft^3$	118 & 354	
IQUAL				
SQO	Initial storage of constituent	#/ac	$1x10^7$	
POTFW	Washoff potency factor	#/ton	0	
ACQOP	Rate of accumulation of constituent	#/day	$1x10^7$	Land use
SQOLIM	Maximum accumulation of constituent	#	$3x10^7$	Land use
WSQOP	Wash-off rate	in/hr	2.0	Land use
GQUAL				
FSTDEC	First order decay rate of the constituent	1/day	1.15 for tributaries; 0.45 for mainstream	
THFST	Temperature correction coeff. for FSTDEC		1.05	

[a]Values varied by month and with land use (available on request)

Appendix D: GWLF Model Parameters

The GWLF parameter values used for the Colliers Creek and Buffalo Creek watershed simulations for Existing conditions are shown in Table D.1 through Table D.3. Table D.1 lists the various watershed-wide parameters and their values, Table D.2 displays the monthly variable evapo-transpiration cover coefficients, and Table D.3 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP product - used for erosion modeling. Since the modeling was performed in metric units, note that all of the input parameters are in metric units, even though the simulated results shown in this report are presented in English units.

Table D. 1. GWLF Watershed Parameters

GWLF Watershed Parameters	units	Colliers Creek TMDL		
		Colliers Creek	Buffalo Creek	Buffalo Creek -
recession coefficient	(day^{-1})	0.0569	0.0485	0.0569
seepage coefficient		0.0020	0.0020	0.0020
leakage coefficient		0.0000	0.0000	0.0000
sediment delivery ratio		0.1165	0.0810	0.1165
unsaturated water capacity	(cm)	14.72	15.74	15.74
erosivity coefficient (Nov - Apr)		0.108	0.130	0.130
erosivity coefficient (growing season)		0.180	0.221	0.221
% developed land	(%)	0.1	0.1	0.1
no. of livestock	(AU)	1,444	4,953	1,462
area-weighted runoff curve number		73.83	71.47	71.47
area-weighted soil erodibility		0.277	0.265	0.265
area-weighted slope	(%)	29.27	26.15	26.15
aFactor		0.0000707	0.0000610	0.0000610
total stream length	(m)	51,592.0	149,171.0	44,018.4
Mean Channel Depth	(m)	1.216	1.705	1.216

* Buffalo Creek was area-adjusted to the land area in Colliers Creek.

Table D. 2 GWLF Monthly ET Cover Coefficients

Watershed	ID	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Colliers Creek	CLL1x	0.984	0.992	0.995	**0.995**	0.969	0.943	0.917	0.866	0.840	**0.823**	0.909	0.967
Buffalo Creek	BDD	0.984	0.991	0.994	**0.994**	0.968	0.942	0.917	0.865	0.840	**0.823**	0.908	0.966
Buffalo Creek - adjusted	BDDadj	0.984	0.991	0.994	**0.994**	0.968	0.942	0.917	0.865	0.840	**0.823**	0.908	0.966

* July values represent the maximum composite ET coefficients during the growing season.

** Jan values represent the minimum composite ET coefficients during the dormant season.

Table D. 3. GWLF Land Use Parameters

Landuse	Colliers Creek		Buffalo Creek		Buffalo Creek - adjusted	
	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.6863	84.4	0.4950	83.0	0.4950	83.0
LoTill Rowcrop (lot)	0.1667	83.7	0.1202	82.2	0.1202	82.2
Pasture (pas_g)	0.0439	72.4	0.0419	70.2	0.0419	70.2
Pasture (pas_f)	0.1754	78.9	0.1678	77.2	0.1678	77.2
Pasture (pas_p)	0.3118	87.4	0.2978	86.2	0.2978	86.2
Riparian pasture (trp)	2.5708	87.4	2.4789	86.2	2.4789	86.2
Hay (hay)	0.1630	78.3	0.1527	76.8	0.1527	76.8
Forest (for)	0.0110	71.4	0.0097	69.2	0.0097	69.2
Harvested forest (hvf)	0.1099	76.5	0.0966	74.6	0.0966	74.6
Transitional (barren)	2.4672	93.6	2.1607	92.7	2.1607	92.7
Pervious LDI (pur_LDI)	0.0397	78.9	0.0423	77.2	0.0423	77.2
Pervious MDI (pur_MDI)	0.0000	78.9	0.0512	77.2	0.0512	77.2
Pervious HDI (pur_HDI)	0.0038	78.9	0.0389	77.2	0.0389	77.2
Impervious LDI (imp_LDI)	0.0000	95.3	0.0000	94.8	0.0000	94.8
Impervious MDI (imp_MDI)	0.0000	100.0	0.0000	100.0	0.0000	100.0
Impervious HDI (imp_HDI)	0.0000	100.0	0.0000	100.0	0.0000	100.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed