Development of Bacterial TMDLs for the Chowan Study Area

Prepared for:
Virginia Department of Environmental Quality
Submitted December 14, 2004
Re-submitted April 25, 2005

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ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ, Piedmont Regional Office

VADEQ, South Central Regional Office

Virginia Department of Conservation and Recreation (VADCR)

Appomattox River Soil and Water Conservation District (SWCD)

J.R. Horsley SWCD

Peanut SWCD

Piedmont SWCD

Southside SWCD

Natural Resources Conservation Service

Virginia Cooperative Extension Service

MapTech, Inc. of Blacksburg, Virginia, supported this study through funding provided by the Virginia Department of Environmental Quality contract #9992

EXECUTIVE SUMMARY

Background and Applicable Standards

The Chowan Study Area includes portions of the following U.S.G.S. hydrologic units:

1. Blackwater River (03010202)
2. Nottoway River (03010201)

The Upper Blackwater River watershed contains the impaired segments of Rattlesnake (Creek) Swamp, Mill Swamp, and Cypress Swamp, which include portions of Virginia's Isle of Wight and Surry Counties (Figure 1.1). The Upper Nottoway River watershed contains the impaired segments of the Nottoway River, Little Nottoway River, Big Hounds Creek, Beaverpond Creek, Sappony Creek, and Raccoon Creek, which include portions of Virginia's Dinwiddie, Lunenburg, Nottoway, Prince Edward, Southampton, and Sussex counties (Figure 1.2).

Stream segments within the Chowan Study Area were placed on the *Virginia 1998 303(d) Total Maximum Daily Load Priority List and Report* and the *Virginia 2002 Section 303(d) Report on Impaired Waters*. All segments remained on the *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report*, except Sappony Creek was submitted as a de-list candidate with the 2004 assessment report and has been subsequently de-listed by EPA.

Prior to 2003, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

EPA has since recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criterion for marine waters by 2003. Virginia's new standard went into effect January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
>
> *2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3] *E. coli*	*126*	*235*
Saltwater and Transition Zone[3] *Enterococci*	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDLs included in this study.

TMDL Endpoint and Water Quality Assessment

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife; grazing livestock; land application of manure; land application of biosolids; urban/suburban runoff; failed and malfunctioning septic systems; and uncontrolled discharges (*i.e.*, dairy parlor waste, etc.). There are five

individual VPDES permitted discharges in the Chowan Study Area that are expected to contain measurable amounts of fecal coliform; Surry County WWTF (VA0088463), Surry County High School (currently offline - VA0029025), Victoria East STP (VA0020184), DOC – Nottoway Correctional Center (VA0066869), and Nottoway County Schools – Nottoway High School (VA0061158).

The *E. coli* bacteria standard specifies that the number of *E. coli* bacteria shall not exceed a maximum allowable level of 235-cfu/100 ml. Similarly, the *enterococci* standard states that no single sample shall exceed 104-cfu/100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 126-cfu/100 ml *E. coli*, or 35-cfu/100 ml *enterococci* in estuarine waters. In TMDL development, the in-stream *E. coli* and *enterococci* targets were a geometric mean not exceeding 126-cfu/100 ml and a single sample maximum of 235-cfu/100 ml for *E. coli*, or a geometric mean not exceeding 35-cfu/100 ml and a single sample maximum of 104-cfu/100 ml for *enterococci*. Translator equations developed by VADEQ were used to convert fecal coliform values to *E. coli* and *enterococci* values.

Water Quality Modeling

The U.S. Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and perform TMDL allocations in the Chowan Study Area. Due to the requirements of HSPF, the Chowan Study Area was subdivided into 155 subwatersheds for the hydrology analysis. The flow period used for hydrologic calibration depended on the data available. A hydrology calibration period of October 1990 through September 1995 was used. The validation period for the Upper Nottoway and Blackwater impairments was October 1997 through September 2002. For the Raccoon Creek impairment, a validation period of October 1982 through September 1987 was used. The water quality calibration period was conducted using monitored data collected at VADEQ monitoring stations between October 1998 and August 2003. The validation period was October 1993 through September 1998.

Existing Conditions

Wildlife populations and ranges; biosolids application rates and practices; rates of failure, locations, and number of septic systems; domestic pet populations; numbers of cattle and other livestock; and information on livestock and manure management practices for the Chowan Study Area watershed were used to calculate fecal coliform loads from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock.

Contributions from all of these sources were updated to 2004 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record covering the period October 1998 to September 2003. Under existing conditions (2004), the HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

Load Allocation Scenarios

The next step in the TMDL process was to determine how to proceed from existing watershed conditions in order to reduce the various source loads to levels that would result in attainment of the water quality standards. Because USEPA requires a zero percent violation load allocation in TMDLs, modeling was conducted for a target value of 0% exceedance of the 126-cfu/100 ml geometric mean standard and 0% exceedance of the sample maximum *E. coli* standard of-235 cfu/100. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. The reductions in percentages in loading from existing conditions are given in Tables ES1 through ES8. Scenario three (four for Rattlesnake (Creek) Swamp) would generally be adopted as the targets for a Stage I

implementation goal. The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the impaired segments to less than 10%. The last scenario, either six or seven, shows the reductions necessary to achieve zero percent violation compliance.

Table ES.1 Allocation scenarios for bacterial concentration with current loading estimates in the Little Nottoway River.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	36.67	21.60
2	0	0	100	100	100	100	3.33	3.29
3[1]	0	0	90	50	100	50	10.00	12.94
4	0	0	100	90	100	90	6.67	6.25
5	0	0	100	99	100	99	3.33	3.73
6	0	0	95	60	100	60	8.33	11.40
7[2]	67	95	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.2 Allocation scenarios for bacterial concentration with current loading estimates in Big Hounds Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	8.33	13.60
2	0	0	100	100	100	100	0.00	3.78
3[1]	0	0	90	50	100	50	0.00	7.41
4	0	0	100	90	100	90	0.00	4.39
5	0	0	100	99	100	99	0.00	3.84
6	0	0	50	25	100	25	0.00	10.20
7[2]	0	81	100	99	100	91	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.3 Allocation scenarios for bacterial concentration with current loading estimates in the Nottoway River.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	15.00	14.25
2	0	0	100	100	100	100	0.00	3.23
3[1]	0	0	90	50	100	50	3.33	9.70
4	0	0	100	90	100	90	0.00	4.71
5	0	0	100	99	100	99	0.00	3.51
6[2]	21	86	100	99.9	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table.ES.4 Allocation scenarios for bacterial concentration with current loading estimates in Beaverpond Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	83.33	28.13
2	0	0	100	100	100	100	23.33	10.14
3[1]	0	0	100	60	100	60	20.11	17.70
4	0	0	100	90	100	90	26.67	13.82
5	0	0	100	99	100	99	23.33	10.58
6[2]	99.4	67	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.5 Allocation scenarios for bacterial concentration with current loading estimates in Raccoon Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	11.67	14.54
2	0	0	100	100	100	100	1.67	5.87
3[1]	0	0	90	50	100	50	5.00	10.53
4	0	0	100	90	100	90	3.33	6.80
5	0	0	100	99	100	99	1.67	6.03
6[2]	0	95	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.6 Allocation scenarios for bacterial concentration with current loading estimates in Cypress Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	21.67	18.82
2	0	0	100	100	100	100	18.33	15.25
3[1]	0	0	100	50	100	50	18.33	15.80
4	0	0	100	90	100	90	18.33	15.41
5	0	0	100	99	100	99	18.33	15.25
6	25	25	100	99	100	99	13.33	10.59
7[2]	73	90	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.7 Allocation scenarios for bacterial concentration with current loading estimates in Mill Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	18.33	14.70
2	0	0	100	100	100	100	0.00	2.80
3[1]	0	0	100	50	100	50	1.67	10.20
4	0	0	100	90	100	90	0.00	3.95
5	0	0	100	99	100	99	0.00	2.80
6[2]	28	86	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

Table ES.8 Allocation scenarios for bacterial concentration with current loading estimates in Rattlesnake (Creek) Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	0.00	5.10
2	0	0	100	0	0	0	0.00	3.07
3	0	0	100	100	100	100	0.00	2.25
4[1]	0	0	100	50	100	50	0.00	2.52
5	0	0	100	90	100	90	0.00	2.30
6	0	0	100	99	100	99	0.00	2.25
7[2]	65	84	100	99	100	99	0.00	0.00

[1]Stage I implementation scenario.
[2]Final 0% TMDL allocation.

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 meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the Chowan Study Area. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once EPA has approved a TMDL, measures must be taken to reduce pollution levels in the stream. These measures, 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 recent *Guidance Manual for Total Maximum Daily Load Implementation Plans*, published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an

approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

In general, Virginia intends that the required reductions 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 management practice to control bacteria and minimize stream bank erosion 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 failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

Watershed stakeholders will have the 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 Stage I scenarios are targeted at controllable, anthropogenic bacteria.

Public Participation

During development of the TMDL for the Chowan Study Area watershed, public involvement was encouraged through 6 meetings.

Table ES.9 Public Meetings for the Chowan Study Area

Impairment	Date	Location
Upper Blackwater River Basin		
1st Public meeting	10/25/2004	Surry Community Center Surry, VA
Final Public meeting	3/3/2005	Airfield 4-H Center Spain Conference Lodge Wakefield, VA
Upper Nottoway River Basin		
1st Public meeting	10/28/2004	Town Office Building Blackstone, VA
Final Public meeting	1/12/2005	Southern Piedmont Agricultural Research and Extension Center Blackstone, VA
Raccoon/Sappony Creek		
1st Public meeting	10/18/2004	Sussex Judicial Center General District Courtroom 15098 Courthouse Rd. Sussex, VA
Final Public meeting	3/3/2005	Airfield 4-H Center Spain Conference Lodge Wakefield, VA

1. INTRODUCTION

1.1 Background

The need for TMDLs to be conducted in the Chowan River watershed is based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA, 1999), states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Blackwater River (contained in USGS Hydrologic Unit Code 03010202) (Figure 1.1) and Nottoway River (contained in USGS Hydrologic Unit Code 03010201) (Figure 1.2) watersheds drain to the Chowan River basin. The Upper Blackwater River watershed contains impaired segments of Rattlesnake (Creek) Swamp, Mill Swamp, and Cypress Swamp, which include portions of Virginia's Isle of Wight and Surry counties (Figure 1.3). The Upper Nottoway River watershed contains impaired segments of the Nottoway River, Little Nottoway River, Big Hounds Creek, Beaverpond Creek, Sappony Creek, and Raccoon Creek, which include portions of Virginia’s Dinwiddie, Lunenburg, Nottoway, Prince Edward, Southampton, and Sussex counties (Figure 1.4). The Virginia Department of Environmental Quality (VADEQ) has identified all of these segments as impaired with regard to fecal coliform. For the purposes of this report, all of these watersheds shall be referred to as the Chowan Study Area.

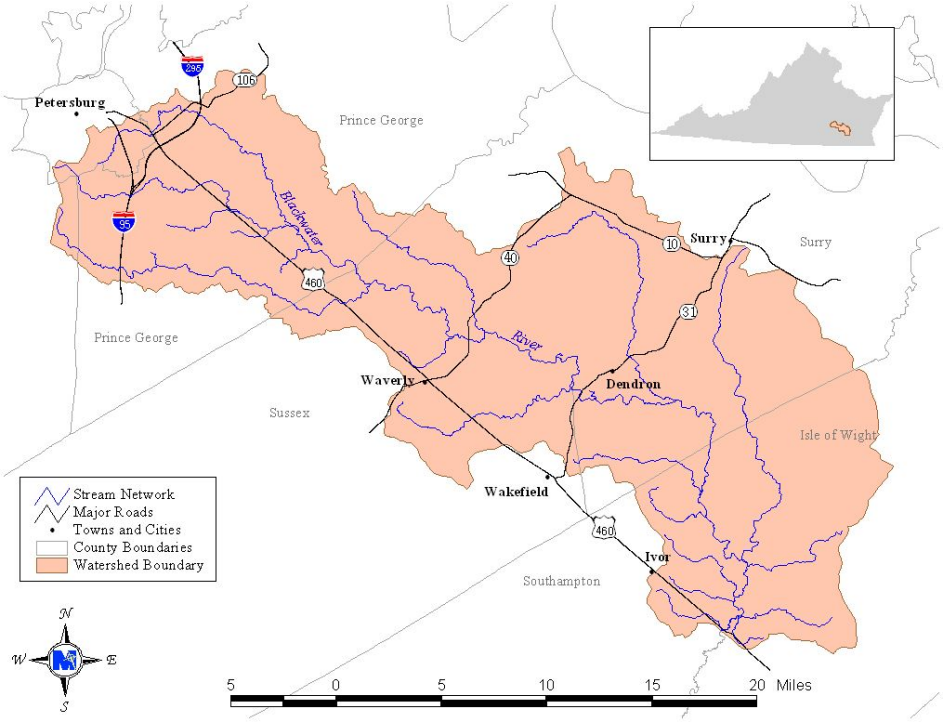

Figure 1.1 Location of the Upper Blackwater River watershed.

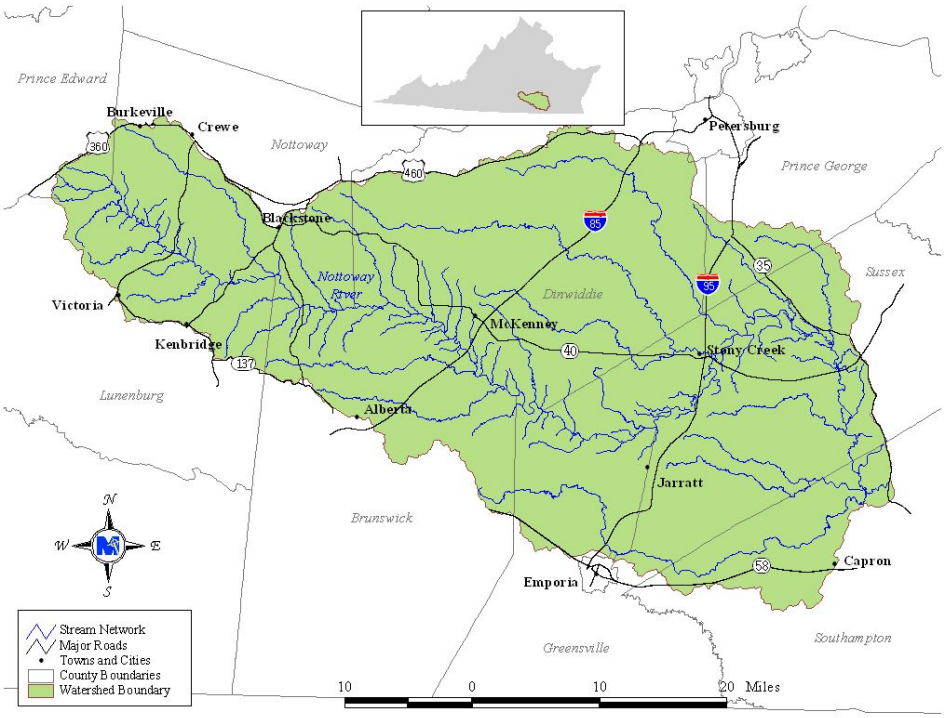

Figure 1.2 Location of the Upper Nottoway River watershed.

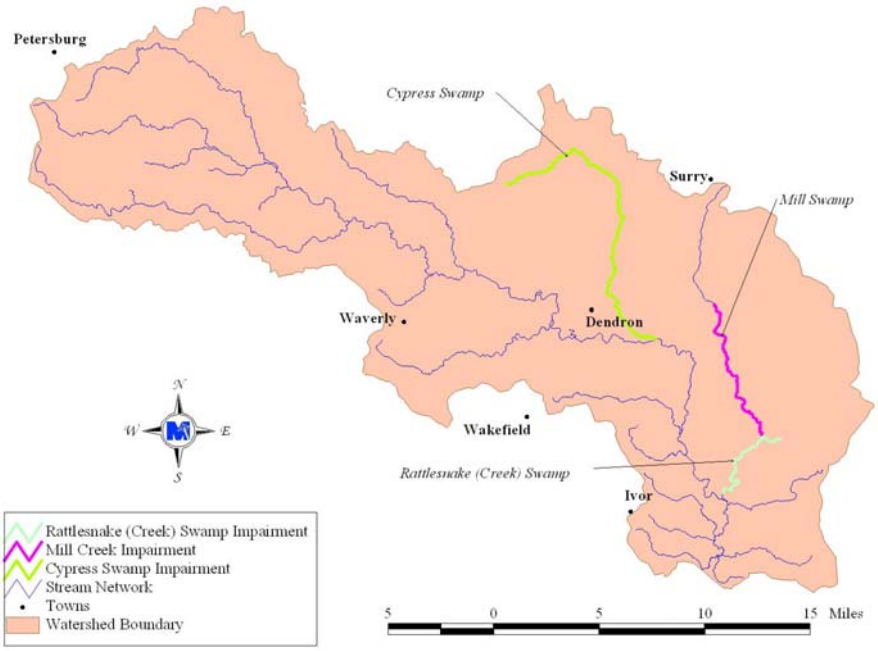

Figure 1.3 Impaired stream segments in the Upper Blackwater River watershed.

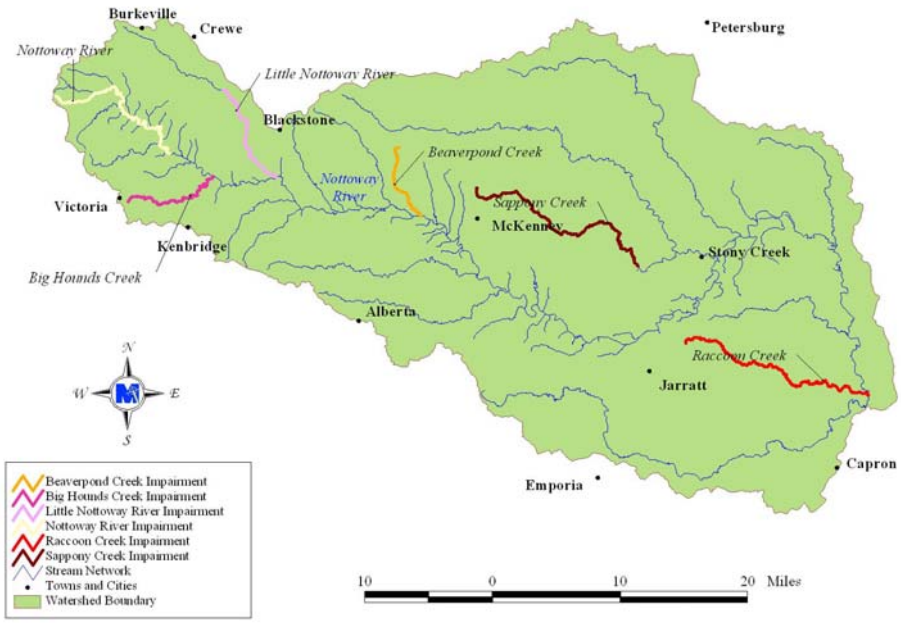

Figure 1.4 Impaired stream segments in the Upper Nottoway River watershed.

Table 1.1 lists, for each impairment, the VADEQ water quality monitoring station used for impaired waters assessment, initial year the segment was listed in the Section 303(d) list, current miles affected in the 2004 listing, fecal coliform violation rates in the *Virginia 2002 Section 303(d) Report on Impaired Waters* and the *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report*, and location of listing.

Table 1.1 Fecal coliform impairments on 2004 Section 305(b)/303(d) Water Quality Integrated Report within the Chowan Study Area.

Stream Name, HUP	Listing Station ID	Initial Listing	Miles Affected	2002 303(d) List FC Violation Rate	2004 303(d) List FC Violation Rate	Location
Upper Blackwater River Basin						
Cypress Swamp, K32	5ACPP003.20	2002	17.1	4/25	N/A	Headwaters to the confluence with Blackwater River
Cypress Swamp, K32	5A-PL-SCP1B	2004	N/A	1/9	N/A	Headwaters to the confluence with Blackwater River
Mill Swamp, K34	5AMSW006.77	2002	16.78	3/24	1/10	From confluence with Moores Swamp to the confluence with Rattlesnake Swamp
Rattlesnake (Creek) Swamp, K34	5ARKN006.40	2002	8.16	7/59	2/18	From confluence with Pouches Swamp to the confluence with Blackwater River
Upper Nottoway River Basin						
Beaverpond Creek	5ABPC000.12	1998	7.17	9/16	9/19	Headwaters to the confluence with Nottoway River
Big Hounds Creek, K14	5ABHC003.73	2002	10.35	5/27	5/28	Headwaters to the confluence with Nottoway River
Little Nottoway River, K15	5ALNT004.68	2002	9.85	6/27	12/28	From Lazaretto Creek to the confluence with Nottoway River
Nottoway River, K14	5ANTW155.06	1998	17.76	1/6	N/A	Headwaters to the backwaters of Nottoway Falls Lake
Raccoon Creek, K25	5ARCN003.36	2002	19.3	4/21	6/29	The entire mainstem of Raccoon Creek
Sappony Creek, K22	5ASAP013.69	2002	20.19	3/27	2/20	Headwaters to Spiers Pond

The Beaverpond Creek and Upper Nottoway River segments were placed on the *Virginia 1998 Section 303(d) Total Maximum Daily Load Priority List and Report* and additional stream segments were successively placed on the *Virginia 2002 Section 303(d) Report on Impaired Waters* (Table 1.1). All segments remained on the *Virginia 2004 Section 305(b)/303(d) Water Quality Integrated Report*, although Sappony Creek was proposed for delisting in 2004. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that these Chowan Study Area stream segments do not support the primary contact recreation use.

The impaired segment of Sappony Creek was listed in the *Virginia 1998 Section 303(d) Total Maximum Daily Load Priority List and Report* as fully supporting but threatened. The segment was downgraded and extended during the 2002 assessment cycle. During the year 2004 cycle, the fecal coliform violation rate was 2/20, and Sappony Creek was proposed for delisting.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *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.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Section 9 VAC 25-260-170 is the applicable water quality criteria for fecal coliform impairments in the Upper Blackwater and Nottoway watersheds.

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

If the waterbody had an exceedance rate > 10.5% and had at least 2 exceedances, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The EPA has since recommended that all states adopt an *E coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard went into effect January 15, 2003 in Virginia.

The new criteria, used in developing the bacteria TMDL in this study, is outlined in 9 VAC 25-260-170 and reads as follows

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.
[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.
[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

2.2 Selection of a TMDL Endpoint.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Chowan Study Area TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Table 2.1). In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals, assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 ml and the instantaneous standard of 235 cfu/100 ml. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 ml and a single sample not exceeding 235 cfu/100 ml.

Table 2.1 Listing Criteria and TMDL Endpoints for the impairments in the Chowan Study Area.

Stream Name	Listing Criterion	TMDL Endpoint
Upper Blackwater River Basin		
Cypress Swamp	Fecal coliform	*E. coli*
Mill Swamp	Fecal coliform	*E. coli*
Rattlesnake (Creek) Swamp	Fecal coliform	*E. coli*
Upper Nottoway River Basin		
Big Hounds Creek	Fecal coliform	*E. coli*
Nottoway River	Fecal coliform	*E. coli*
Little Nottoway River	Fecal coliform	*E. coli*
Beaverpond Creek	Fecal coliform, *E. coli*	*E. coli*
Raccoon Creek	Fecal coliform	*E. coli*
Sappony Creek	Fecal coliform	*E. coli*

2.3 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the Chowan Study Area is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the Chowan Study Area are attributed to both point and non-point sources. Critical conditions for waters impacted by land-based non-point sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include non-point sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and flow duration interval showed that there was no obvious critical flow level (Figures 2.1 through 2.9). A description of the data used in this analysis is shown in Table 2.2. That is, the analysis showed no obvious dominance of either non-point sources or point sources. High concentrations were recorded in all flow regimes at monitoring stations where data were collected during

all flow regimes. In the case of Raccoon Creek, Sappony Creek and Cypress Swamp (5ARCN003.36, 5ASAP013.69, 5ACPP006.04 and 5ACPP003.20), a majority of the data were collected during dry and low flow conditions, making it difficult to conclude that violations occurred during dry times only. Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area. The resulting periods for calibration and validation for each impaired stream are presented in Chapter 4.

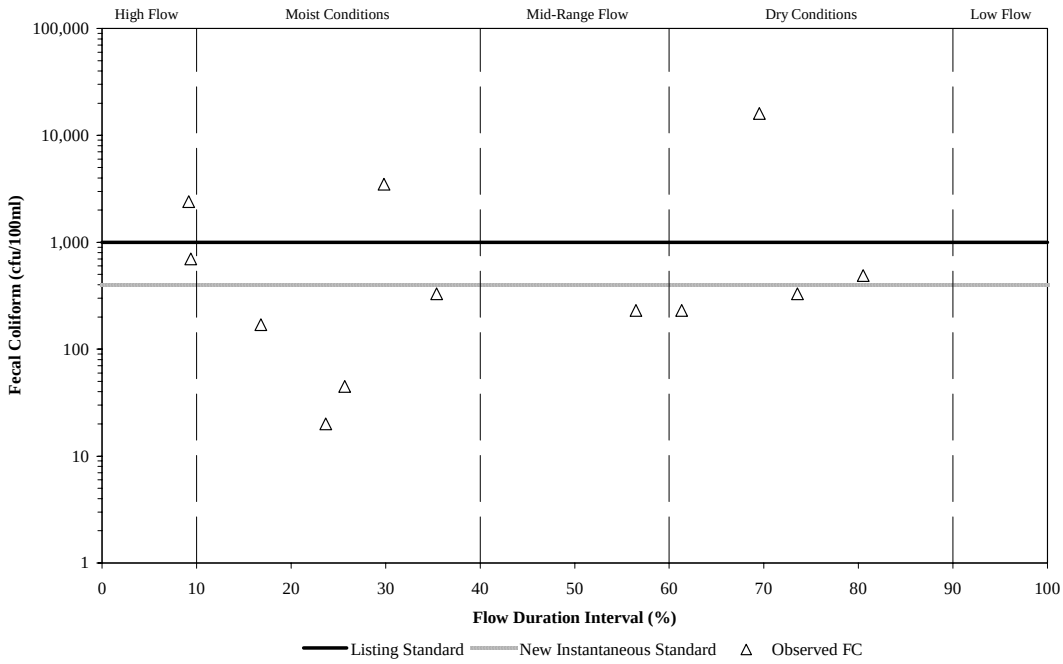

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 5ANTW155.06) and discharge (USGS Gaging Station #02044500) in the Nottoway River impairment.

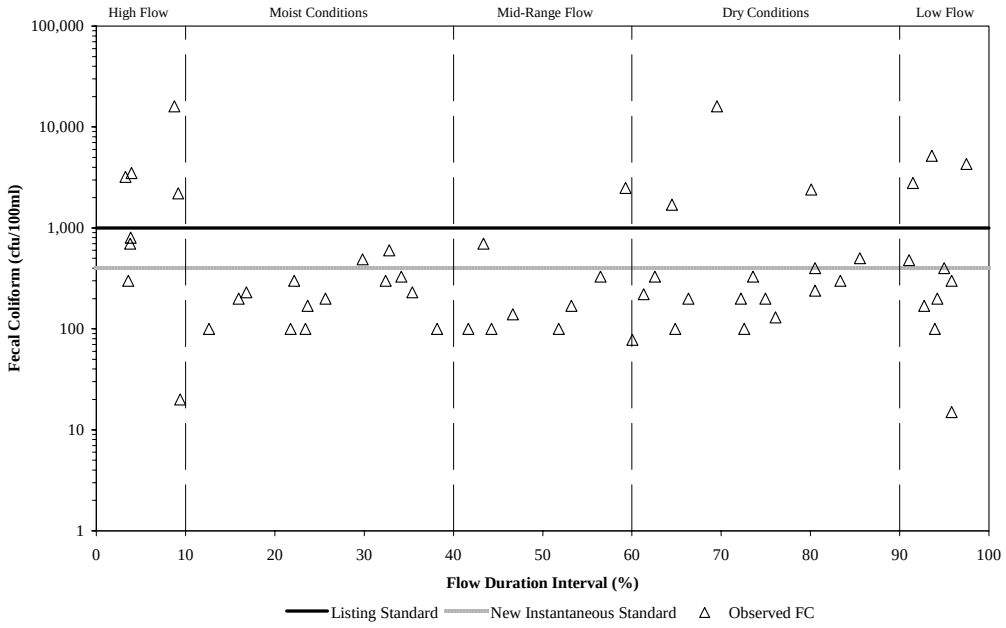

Figure 2.2 Relationship between fecal coliform concentrations (VADEQ Station 5ALNT004.68) and discharge (USGS Gaging Station #02044500) in the Little Nottoway River impairment.

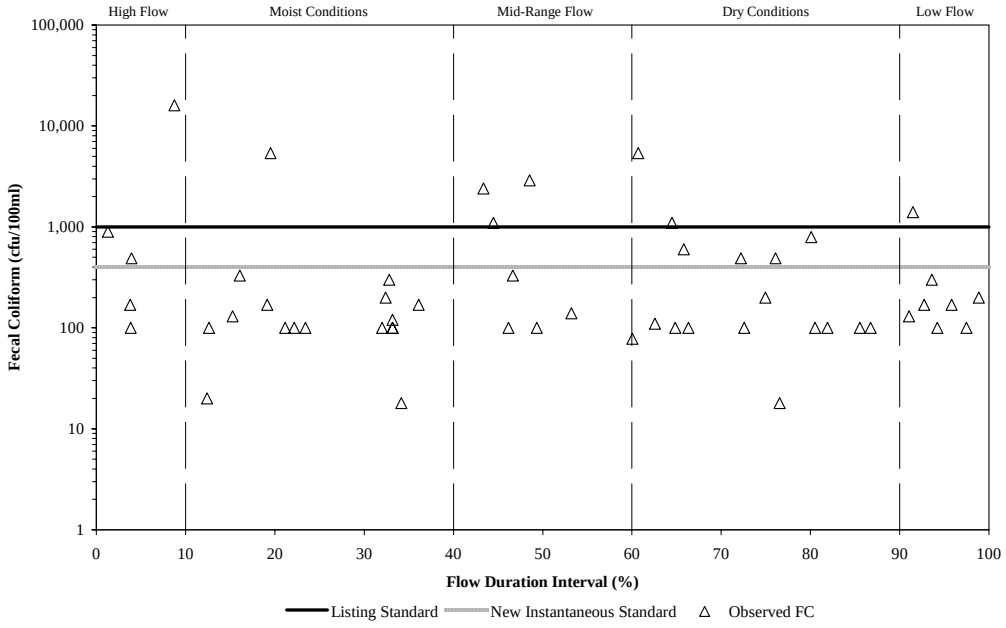

Figure 2.3 Relationship between fecal coliform concentrations (VADEQ Station 5ABHC003.73) and discharge (USGS Gaging Station #02044500) in the Big Hounds Creek impairment.

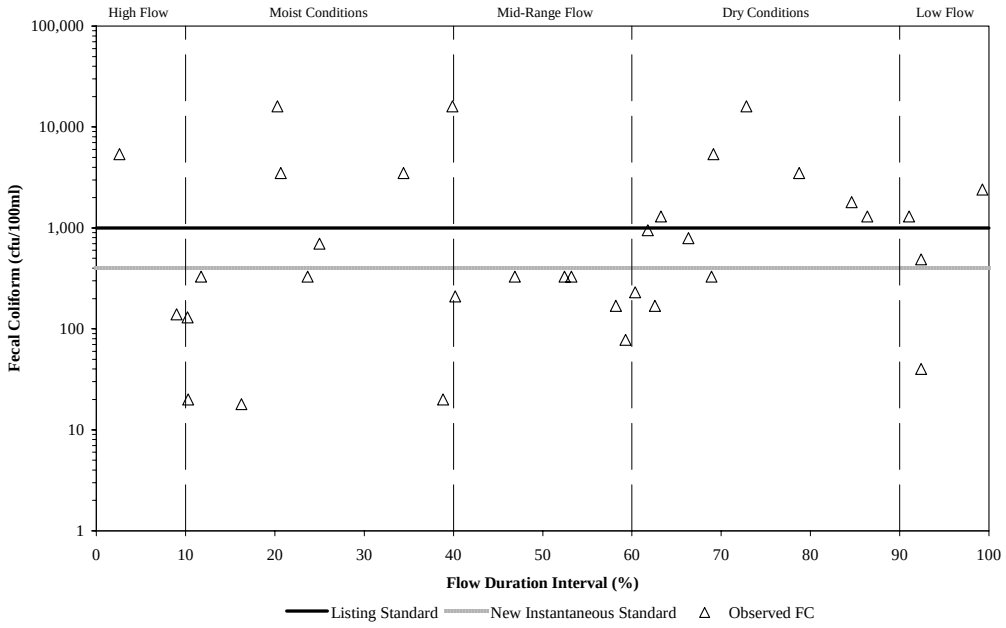

Figure 2.4 Relationship between fecal coliform concentrations (VADEQ Station 5ABPC000.12) and discharge (USGS Gaging Station #02044500) in the Beaverpond Creek impairment.

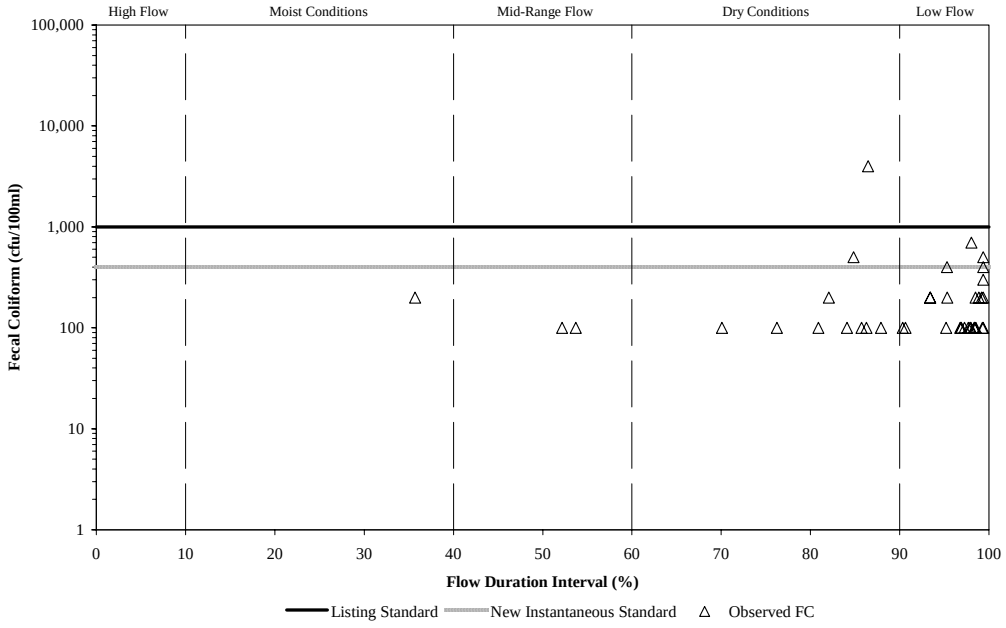

Figure 2.5 Relationship between fecal coliform concentrations (VADEQ Station 5ARCN003.36) and discharge (USGS Gaging Station #02045500) in the Raccoon Creek impairment.

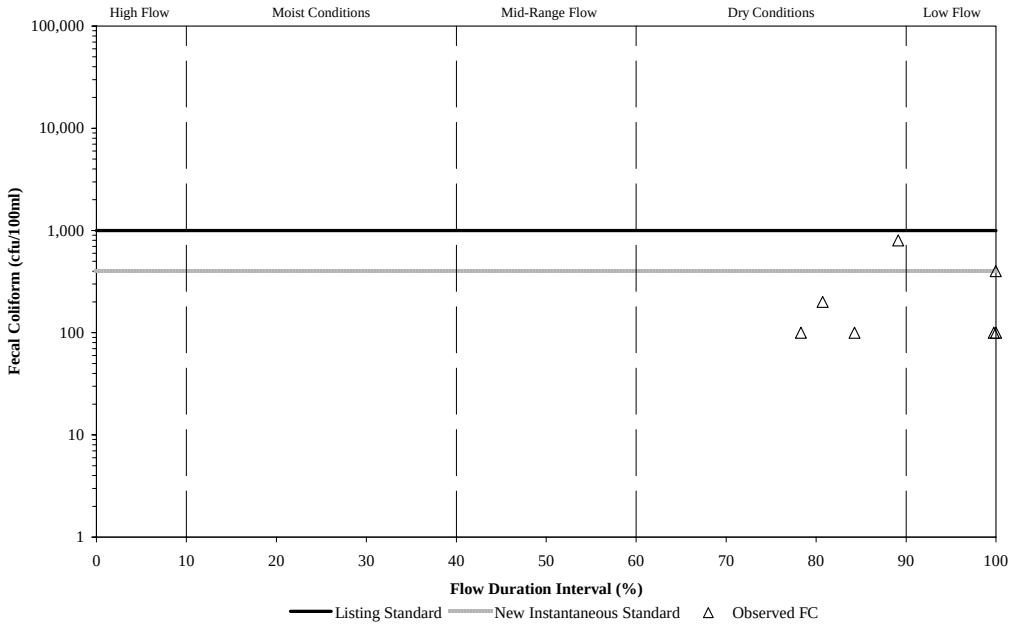

Figure 2.6 Relationship between fecal coliform concentrations (VADEQ Station 5ACPP006.04) and discharge (USGS Gaging Station #02047500) in the Cypress Swamp impairment.

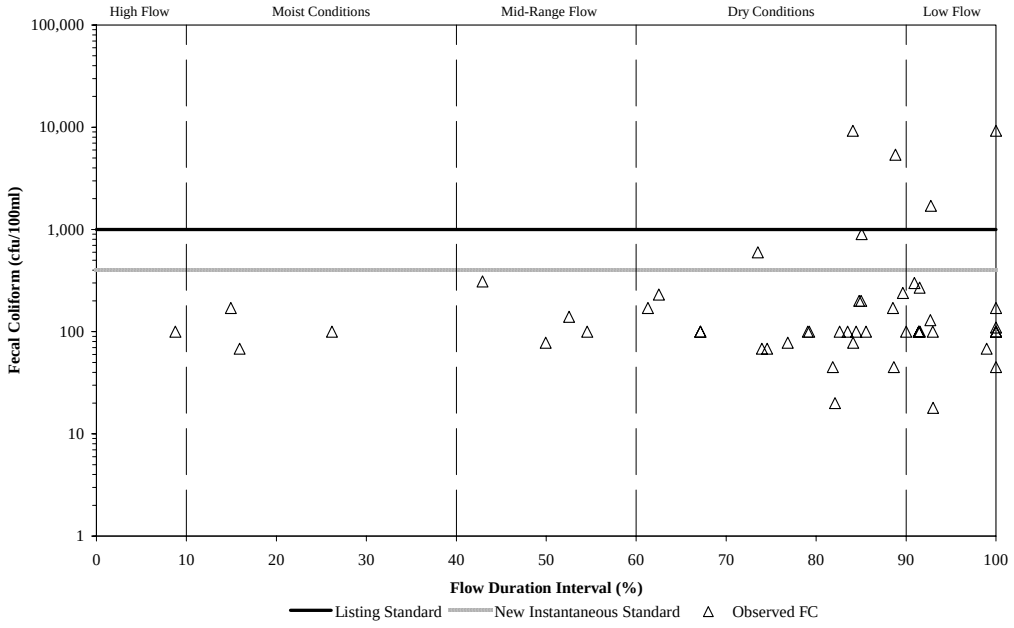

Figure 2.7 Relationship between fecal coliform concentrations (VADEQ Station 5ACPP003.20) and discharge (USGS Gaging Station #02047500) in the Cypress Swamp impairment.

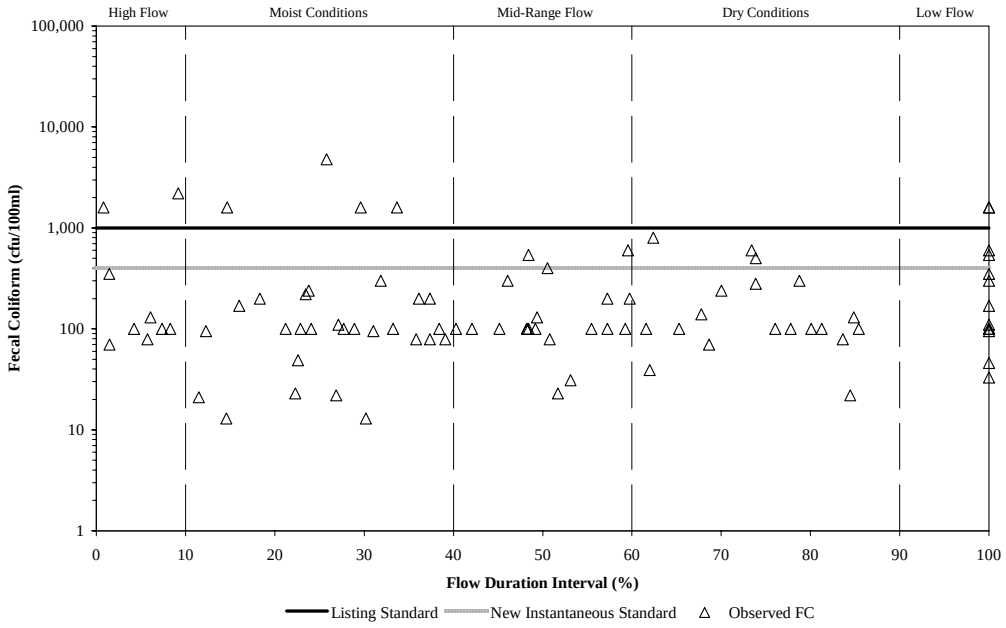

Figure 2.8 Relationship between fecal coliform concentrations (VADEQ Station 5ARKN006.40) and discharge (USGS Gaging Station #02047500) in the Rattlesnake (Creek) Swamp impairment.

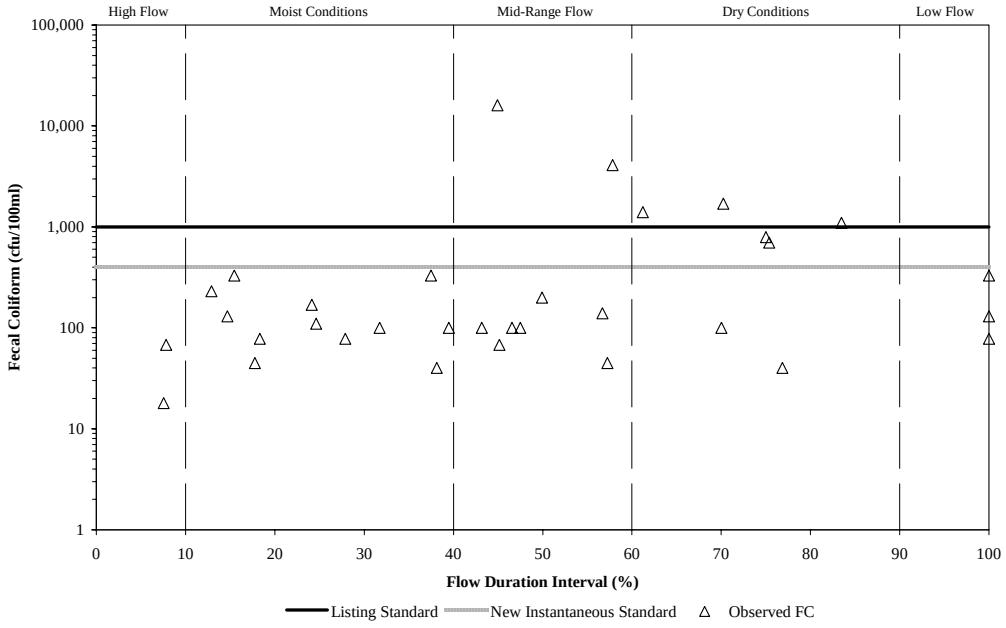

Figure 2.9 Relationship between fecal coliform concentrations (VADEQ Station 5AMSW006.77) and discharge (USGS Gaging Station #02047500) in the Mill Swamp impairment.

2.4 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Chowan Study Area watersheds. An examination of data from water quality stations used in the 303(d) assessment was performed and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.4.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from 20 VADEQ in-stream monitoring stations used for TMDL assessment; and
- Bacteria enumerations and bacterial source tracking from 12 VADEQ in-stream monitoring stations analyzed during TMDL development.

2.4.1.1 Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples, collected by VADEQ, were analyzed from February 1968 through March 2004 (Figures 2.10 and 2.11) and are included in the analysis. Samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 400 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.2 summarizes the fecal coliform samples collected at the in-stream monitoring stations used for TMDL assessment.

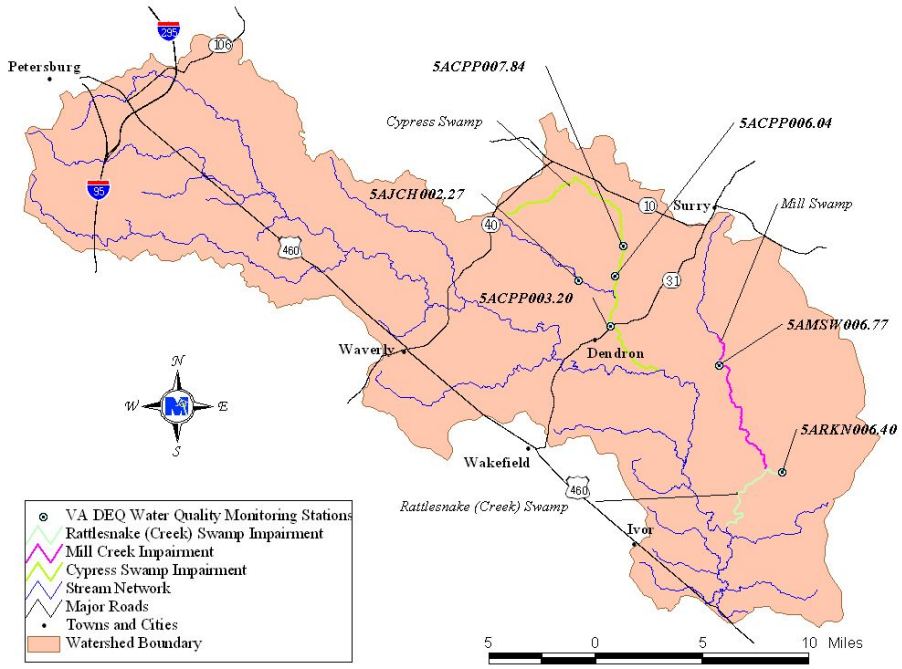

Figure 2.10 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Upper Blackwater River watershed.

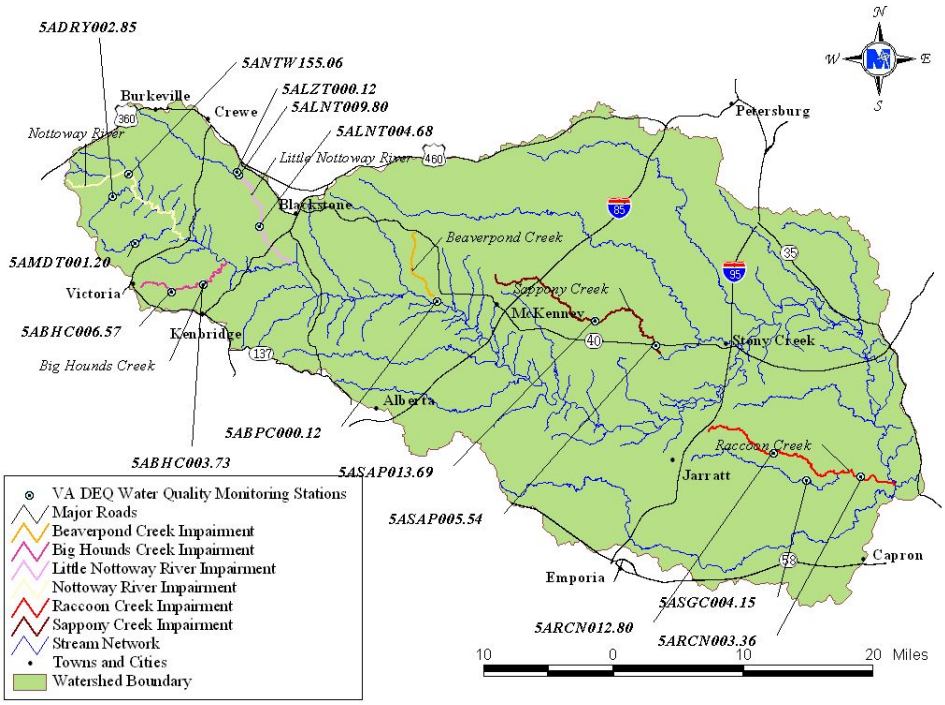

Figure 2.11 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Upper Nottoway River watershed.

Table 2.2 Summary of fecal coliform and *E. coli* (cfu/100 ml) sampling conducted by VADEQ for period February 1968 through May 2004.

Stream Name	Station Id	Sampled Dates	Count	Parameter Name	Minimum	Maximum	Mean	Median
Upper Blackwater River Basin								
Cypress Swamp	5ACPP003.20	9/90-3/04	55	Fecal coliform	18	9,200	592	100
		12/03-3/04	4	*E. coli*	12	44	28	28
Cypress Swamp	5ACPP006.04	5/01-6/03	12	Fecal coliform	100	800	242	100
Cypress Swamp	5ACPP007.84	7/03-3/04	9	Fecal coliform	25	2,000	383	75
		7/03-3/04	9	*E. coli*	20	800	163	60
Johnchecohunk Swamp	5AJCH002.27	7/03-3/04	9	Fecal coliform	25	1,300	366	250
Mill Swamp	5AMSW006.77	7/03-3/04	9	*E. coli*	20	300	132	100
		11/03-3/04	5	*E. coli*	14	134	55	38
Rattlesnake (Creek) Swamp	5ARKN006.40	8/94-3/04	102	Fecal coliform	13	4,800	312	100
		10/03-3/04	7	*E. coli*	28	142	67	60
Upper Nottoway River Basin								
Beaverpond Creek	5ABPC000.12	9/94-4/01	34	Fecal coliform	18	16,000	2,457	410
		2/02-3/04	17	*E. coli*	25	2,000	441	200

Table 2.2 Summary of fecal coliform and *E. coli* (cfu/100 ml) sampling conducted by VADEQ for period February 1968 through May 2004 (cont.).

Stream Name	Station Id	Sampled Dates	Count	Parameter Name	Minimum	Maximum	Mean	Median
Upper Nottoway River Basin (cont.)								
Big Hounds Creek	5ABHC003.73	9/90-6/03	58	Fecal coliform	18	16,000	794	130
		7/03-12/03	6	*E. coli*	25	280	160	165
Big Hounds Creek	5ABHC006.57	10/74-6/79	36	Fecal coliform	100	8,000	878	100
Dry Creek	5ADRY002.85	7/03-3/04	9	*E. coli*	25	100	50	25
Lazaretto Creek	5ALZT000.12	4/80-6/03	8	Fecal coliform	18	1,600	277	100
		4/03-10/03	5	*E. coli*	25	600	140	25
Little Nottoway River	5ALNT004.68	10/90-6/03	61	Fecal coliform	15	16,000	1,192	300
		7/03-12/03	6	*E. coli*	25	330	168	153
Little Nottoway River	5ALNT009.80	2/68-9/74	60	Fecal coliform	100	240,000	6,180	230
		7/03-3/04	9	*E. coli*	25	320	114	75
Modest Creek	5AMDT001.20	7/03-3/04	9	*E. coli*	25	230	77	50
Nottoway River	5ANTW155.06	7/94-4/97 & 4/03-3/04	18	Fecal coliform	20	16,000	1,388	200
		7/03-3/04	10	*E. coli*	10	280	85	38

Table 2.2 Summary of fecal coliform and *E. coli* (cfu/100 ml) sampling conducted by VADEQ for period February 1968 through May 2004 (cont.).

Stream Name	Station Id	Sampled Dates	Count	Parameter Name	Minimum	Maximum	Mean	Median
Upper Nottoway River Basin (cont.)								
Raccoon Creek	5ARCN003.36	7/90-3/04	72	Fecal coliform	4	16,000	742	100
		11/03-3/04	5	*E. coli*	1	88	29	14
Raccoon Creek	5ARCN012.80	7/03-3/04	9	Fecal coliform	25	580	114	25
		7/03-3/04	9	*E. coli*	10	140	31	20
Sappony Creek	5ASAP005.54	11/03-3/04	5	Fecal coliform	10	150	74	80
		11/03-3/04	5	*E. coli*	20	112	50	34
Sappony Creek	5ASAP013.69	9/94-3/04	44	Fecal coliform	20	16,000	635	100
		7/03-3/04	13	*E. coli*	10	60	32	25
Spring Creek	5ASGC004.15	7/03-3/04	9	Fecal coliform	25	250	73	50
		7/03-3/04	9	*E. coli*	10	120	40	20

2.4.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from August 2003 through July 2004. Specifically, water quality samples were taken at 12 sites throughout the Chowan Study Area Samples were analyzed for fecal coliform, *E. coli* and *enterococci* concentrations, based upon the nature of the impairment. Nine of these sites were also analyzed for bacteria source (*i.e.*, human, livestock, pet, wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech, Inc. (Figures 2.12 and 2.13). Tables 2.3 and 2.4 summarize the fecal coliform and *E. coli* concentration data, respectively, at the ambient stations. BST results are presented and discussed in greater detail in Section 2.4.2.1.

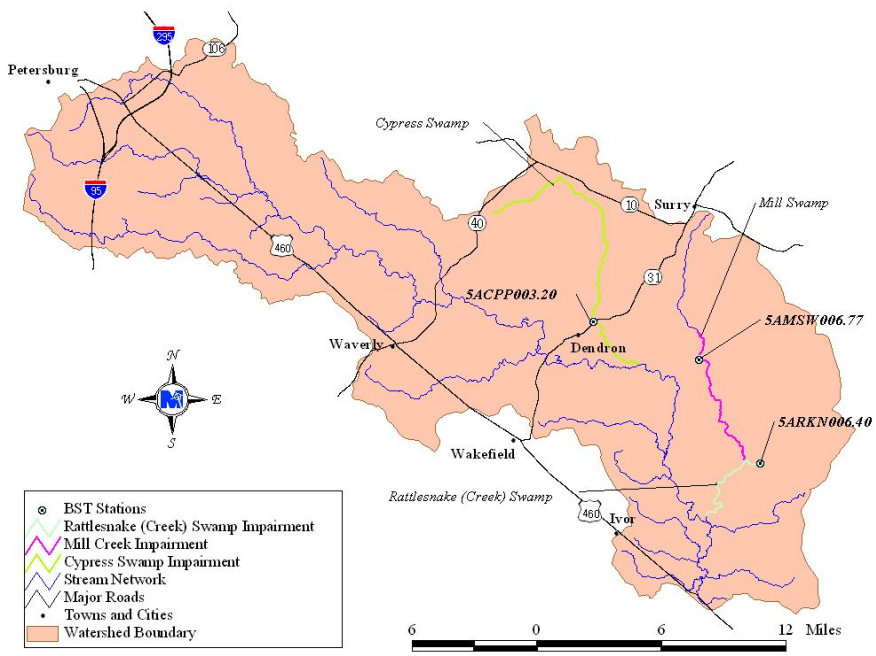

Figure 2.12 Location of BST water quality monitoring stations in the Upper Blackwater River watershed.

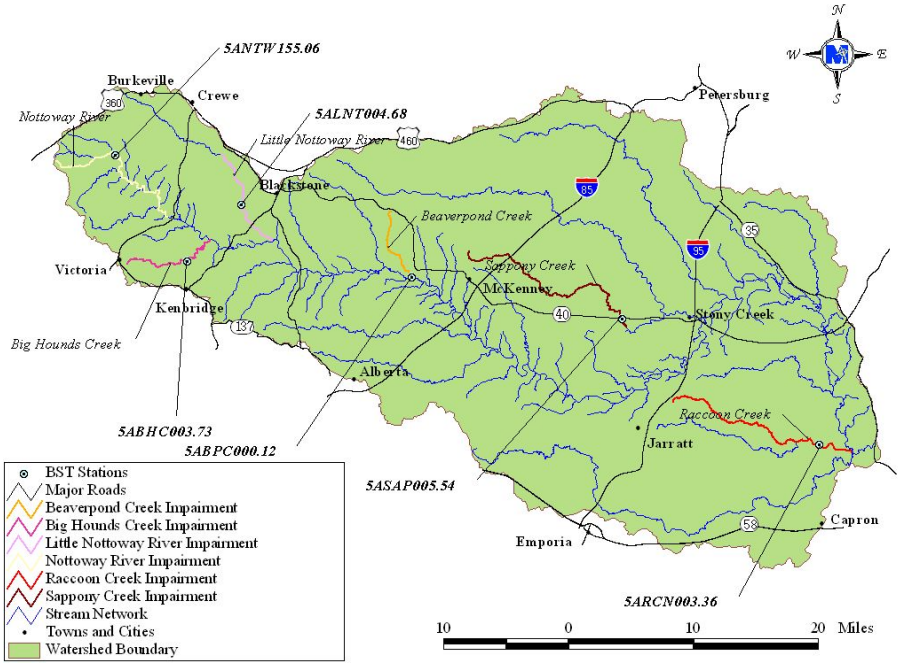

Figure 2.13 Location of BST water quality monitoring stations in the Upper Nottoway River watershed.

Table 2.3 Summary of fecal coliform (cfu/100 ml) sampling conducted by VADEQ during TMDL development.

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
Upper Blackwater River Basin							
Cypress Swamp	5ACPP003.20	12	1	6,000	638	70	17
	5ACPP007.84	12	25	2,000	448	75	25
Mill Swamp	5AMSW006.77	11	20	2,800	375	80	18
Rattlesnake Creek Swamp	5ARNK006.40	12	20	5,900	643	115	17
Upper Nottoway River Basin							
Beaverpond Creek	5ABPC000.12	12	10	5,600	1,075	170	33
Big Hounds Creek	5ABHC003.73	12	20	3,200	483	195	25
Little Nottoway	5ALNT004.68	12	30	3,800	632	150	25
Nottoway River	5ANTW155.06	12	10	2,700	365	120	17
Raccoon Creek	5ARCN003.36	12	4	800	183	95	17
	5ARCN012.80	12	25	580	117	25	8
Sappony Creek	5ASAP005.54	12	10	4,800	512	95	8
	5ASAP013.69	12	25	950	180	63	8

[1]Violations based on new fecal coliform instantaneous standard (*i.e.*, 400 cfu/100ml)

Table 2.4 Summary of *E. coli* (cfu/100 ml) sampling conducted by VADEQ during TMDL development.

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
Upper Blackwater River Basin							
Cypress Swamp	5ACPP003.20	12	12	290	114	48	33
	5ACPP007.84	12	20	800	204	85	17
Mill Swamp	5AMSW006.77	11	14	400	103	66	9
Rattlesnake Creek Swamp	5ARNK006.40	12	28	260	120	120	8
Upper Nottoway River Basin							
Beaverpond Creek	5ABPC000.12	12	36	3,000	709	206	50
Big Hounds Creek	5ABHC003.73	12	4	500	161	125	25
Little Nottoway	5ALNT004.68	12	20	620	224	195	42
	5ALNT009.80	12	25	400	123	63	25
Nottoway River	5ANTW136.52	12	25	300	98	88	8
	5ANTW142.08	12	25	300	56	25	8
	5ANTW155.06	12	6	300	103	60	17
Raccoon Creek	5ARCN003.36	12	1	610	126	70	17
	5ARCN012.80	12	10	420	74	25	8
Sappony Creek	5ASAP005.54	12	1	600	134	61	25
	5ASAP013.69	20	10	2,000	176	40	10

[1]Violations based on *E. coli* instantaneous standard (*i.e.*, 235 cfu/100ml)

2.4.2 Analysis of BST Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.4.2.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform an analysis of fecal coliform and *E. coli* concentrations as well as BST. BST is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The results were reported as the percentage of isolates acquired from the sample that were identified as originating from either humans, pets, livestock, or wildlife.

The BST results of water samples collected at 9 ambient stations in the Chowan Study Area drainage are reported in Tables 2.5 through 2.13. The *E. coli* enumerations are given to indicate the bacteria concentrations at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The statistical significance was determined through 2 tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations. Table 2.14 summarizes the results for each station with load-weighted average proportions of bacteria originating from the four

source categories. The load-weighted average considers the level of flow in the stream at the time of sampling, the concentration of *E. coli* measured, and the number of bacterial isolates analyzed in the BST analysis.

Table 2.5 Summary of bacterial source tracking results from water samples collected in the Nottoway River impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5ANTW155.06	7/31/2003	2,700	300	0%	0%	**79%**	**21%**
	8/20/2003	630	160	**46%**	0%	**29%**	**25%**
	9/11/2003	150	240	6%	0%	**19%**	**75%**
	10/14/2003	70	20	0%	0%	0%	100%
	11/13/2003	190	124	0%	0%	**33%**	**67%**
	12/8/2003	50	60	**83%**	0%	0%	**17%**
	2/4/2004	120	60	**42%**	**12%**	**42%**	4%
	2/25/2004	10	6	80%	0%	20%	0%
	3/24/2004	10	6	25%	0%	0%	75%
	4/19/2004	10	30	63%	0%	12%	25%
	5/10/2004	120	40	25%	0%	0%	75%
	6/23/2004	320	190	**90%**	5%	5%	0%

BOLD type indicates a statistically significant value.

Table 2.6 Summary of bacterial source tracking results from water samples collected in the Little Nottoway River impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5ALNT004.68	7/31/2003	3,800	360	**38%**	**17%**	12%	**33%**
	8/20/2003	2,200	160	**25%**	8%	**46%**	**21%**
	9/11/2003	420	620	**33%**	0%	**21%**	**46%**
	10/14/2003	160	110	**25%**	0%	17%	**58%**
	11/13/2003	310	240	**12%**	0%	12%	**76%**
	12/8/2003	100	330	**46%**	**21%**	8%	**25%**
	2/4/2004	60	140	**33%**	**12%**	**33%**	**22%**
	2/25/2004	30	48	**33%**	0%	**59%**	8%
	3/24/2004	40	20	**50%**	20%	0%	**30%**
	4/19/2004	140	220	**63%**	**17%**	8%	**12%**
	5/10/2004	190	270	**29%**	**38%**	**33%**	0%
	6/23/2004	130	170	**31%**	**57%**	12%	0%

BOLD type indicates a statistically significant value.

Table 2.7 Summary of bacterial source tracking results from water samples collected in the Big Hounds Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5ABHC003.73	7/31/2003	680	290	**17%**	8%	**71%**	4%
	8/20/2003	3,200	280	**33%**	**33%**	8%	**26%**
	9/11/2003	370	500	**54%**	0%	8%	**38%**
	10/14/2003	140	90	0%	0%	88%	12%
	11/13/2003	320	218	4%	0%	**25%**	**71%**
	12/8/2003	70	64	**25%**	**12%**	8%	**55%**
	2/4/2004	150	34	**29%**	0%	**50%**	**21%**
	2/25/2004	30	4	0%	0%	0%	100%
	3/24/2004	40	34	**38%**	5%	0%	**57%**
	4/19/2004	20	60	50%	0%	33%	17%
	5/10/2004	240	160	20%	**40%**	0%	**40%**
	6/23/2004	540	200	**74%**	13%	13%	0%

BOLD type indicates a statistically significant value.

Table 2.8 Summary of bacterial source tracking results from water samples collected in the Beaverpond Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
5ABPC000.12	7/31/2003	200	86	0%	0%	**100%**	0%
	8/20/2003	5,600	2,000	**17%**	**71%**	4%	8%
	9/11/2003	480	510	4%	0%	**58%**	**38%**
	10/14/2003	4,000	3,000	**50%**	**21%**	4%	**25%**
	11/13/2003	170	270	**29%**	**12%**	0%	**59%**
	12/8/2003	170	142	0%	**17%**	8%	**75%**
	2/4/2004	100	58	**71%**	0%	**21%**	8%
	2/25/2004	10	36	**71%**	4%	**17%**	8%
	3/24/2004	40	94	**59%**	**21%**	8%	**12%**
	4/19/2004	100	106	**46%**	**21%**	12%	**21%**
	5/10/2004	30	410	**38%**	**33%**	4%	**25%**
	6/23/2004	2,000	1,800	**38%**	8%	**33%**	**21%**

BOLD type indicates a statistically significant value.

Table 2.9 Summary of bacterial source tracking results from water samples collected in the Sappony Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:			
				Wildlife	Human	Livestock	Pet
5ASAP005.54	7/22/2003	100	10	17%	0%	83%	0%
	8/13/2003	4,800	82	0%	0%	62%	38%
	9/17/2003	200	70	12%	0%	50%	38%
	10/20/2003	270	300	0%	0%	**79%**	**21%**
	11/17/2003	150	52	**46%**	4%	**25%**	**25%**
	12/9/2003	90	112	**50%**	8%	0%	**42%**
	1/14/2004	40	30	**56%**	**19%**	6%	**19%**
	2/10/2004	80	34	**67%**	11%	0%	**22%**
	3/2/2004	10	20	**19%**	12%	12%	**57%**
	4/13/2004	270	600	0%	**33%**	4%	**63%**
	5/4/2004	40	300	**45%**	0%	**17%**	**38%**
	6/29/2004	90	1	100%	0%	0%	0%

BOLD type indicates a statistically significant value.

Table 2.10 Summary of bacterial source tracking results from water samples collected in the Raccoon Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:			
				Wildlife	Human	Livestock	Pet
5ARCN003.36	7/22/2003	800	610	**25%**	4%	12%	**59%**
	8/13/2003	430	160	0%	0%	88%	12%
	9/17/2003	330	10	**56%**	0%	6%	**38%**
	10/20/2003	130	130	**50%**	0%	**31%**	**19%**
	11/17/2003	140	88	8%	0%	**63%**	**29%**
	12/9/2003	4	8	83%	0%	17%	0%
	1/14/2004	30	14	**44%**	0%	0%	**56%**
	2/10/2004	10	0	0%	0%	0%	0%
	3/2/2004	30	32	**31%**	**23%**	0%	**46%**
	4/13/2004	40	320	**17%**	**17%**	**17%**	**49%**
	5/4/2004	60	80	**30%**	0%	5%	**65%**
	6/29/2004	190	60	17%	33%	0%	50%

BOLD type indicates a statistically significant value.

Table 2.11 Summary of bacterial source tracking results from water samples collected in the Cypress Swamp impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:			
				Wildlife	Human	Livestock	Pet
5ACPP003.20	7/23/2003	600	250	**29%**	4%	**50%**	**17%**
	8/13/2003	6,000	290	**38%**	0%	**62%**	0%
	9/15/2003	350	240	0%	0%	**100%**	0%
	10/14/2003	120	40	0%	0%	50%	50%
	11/12/2003	340	48	**54%**	0%	4%	**42%**
	12/3/2003	100	40	**50%**	4%	**25%**	**21%**
	1/14/2004	20	16	**30%**	0%	10%	**60%**
	2/17/2004	30	12	50%	0%	12%	38%
	3/3/2004	30	44	**84%**	0%	8%	8%
	4/15/2004	40	48	**84%**	0%	4%	**12%**
	5/12/2004	20	70	88%	0%	12%	0%
	6/9/2004	1	270	**66%**	**17%**	0%	**17%**

BOLD type indicates a statistically significant value.

Table 2.12 Summary of bacterial source tracking results from water samples collected in the Mill Swamp impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:			
				Wildlife	Human	Livestock	Pet
5AMSW006.77	7/14/2003	670	400	0%	4%	**96%**	0%
	8/11/2003	2,800	140	0%	0%	88%	12%
	10/20/2003	80	20	100%	0%	0%	0%
	11/17/2003	150	134	**71%**	0%	4%	**25%**
	12/8/2003	60	66	**88%**	4%	8%	0%
	1/12/2004	20	14	72%	14%	14%	0%
	2/9/2004	120	24	**27%**	0%	0%	**73%**
	3/15/2004	50	38	**17%**	0%	0%	**83%**
	4/12/2004	20	64	**50%**	8%	4%	**38%**
	5/10/2004	50	120	**25%**	0%	**25%**	**50%**
	6/14/2004	100	110	**50%**	0%	**25%**	**25%**

BOLD type indicates a statistically significant value.

Table 2.13 Summary of bacterial source tracking results from water samples collected in the Rattlesnake (Creek) Swamp impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:			
				Wildlife	Human	Livestock	Pet
5ARNK006.40	7/14/2003	270	130	0%	4%	**96%**	0%
	8/11/2003	5,900	170	12%	0%	**88%**	0%
	9/8/2003	770	260	**71%**	0%	**21%**	8%
	10/20/2003	120	40	25%	0%	75%	0%
	11/17/2003	160	144	**50%**	0%	**33%**	**17%**
	12/8/2003	110	142	**84%**	8%	8%	0%
	1/12/2004	30	28	**25%**	6%	**19%**	**50%**
	2/9/2004	70	104	**25%**	4%	**33%**	**38%**
	3/15/2004	50	28	5%	**16%**	5%	**74%**
	4/12/2004	20	92	**71%**	0%	**17%**	**12%**
	5/10/2004	70	110	75%	0%	0%	25%
	6/14/2004	150	190	**59%**	9%	0%	**32%**

BOLD type indicates a statistically significant value.

Table 2.14 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Weighted Averages:			
	Wildlife	Human	Livestock	Pet
5ABPC000.12	33%	33%	12%	22%
5ANTW155.06	28%	2%	42%	28%
5ALNT004.68	36%	14%	20%	30%
5ABHC003.73	30%	11%	28%	31%
5ASAP005.54	19%	18%	14%	49%
5ARCN003.36	21%	9%	20%	50%
5ACPP003.20	38%	3%	48%	11%
5AMSW006.77	23%	2%	57%	18%
5ARKN006.40	37%	3%	43%	17%

2.4.3 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, discharge, and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, discharge, and fecal coliform concentration data were conducted using the Mood Median Test. This test was used to compare median values of precipitation, discharge, and fecal coliform concentrations in each month. Significant differences between months within years were reported.

2.4.3.1 Precipitation

Total monthly precipitation measured at stations Camp Pickett #441322 in Nottoway County, Holland 1 E #444044 in Suffolk County, Hopewell #444101 in Prince George County, and Wakefield 1 NW #448800 in Sussex County was analyzed and no overall, long-term trends were found (Table 2.15).

Table 2.15 Summary of trend analysis on precipitation (in).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
441322	3.82	3.47	14.18	0.16	2.18	288	No Trend
444044	3.99	3.60	23.47	0.03	2.41	288	No Trend
444101	3.80	3.61	16.85	0.00	2.13	408	No Trend
448800	2.48	2.00	11.90	0.00	2.40	404	No Trend

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

A significant seasonality effect was found at station #444101. Differences in mean monthly precipitation are indicated in Table 2.16. Precipitation values in months with the same median group letter are not significantly different from each other at a 95% significance level. For example, May and July are in median group "B" and are not significantly different from each other. In months with multiple groups, precipitation values are the result of the 95% confidence interval for that month, overlapping more than one median group. For example, precipitation during the months of January, February, March, April, June, August, September, November, and December is classified in both median group "A" and "B" and is not significantly different than either group. The remaining stations had no seasonality effect.

Table 2.16 Summary of the Mood Median Test on mean monthly precipitation at station 444101 (p=0.013).

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups	
January	3.93	0.54	8.06	A	B
February	3.15	0.54	5.63	A	B
March	4.36	1.34	8.27	A	B
April	3.40	0.64	7.64	A	B
May	3.95	1.02	7.93		B
June	3.15	0.35	5.78	A	B
July	4.48	0.04	8.17		B
August	4.35	0.44	12.49	A	B
September	4.77	0.58	16.85	A	B
October	3.52	0.00	9.53	A	
November	3.29	0.42	7.00	A	B
December	3.22	0.56	7.03	A	B

2.4.3.2 Discharge

Total monthly flow measured at USGS Gaging Station #02047500 on the Blackwater River near Dendron VA, Virginia from January 1970 to September 2002 was analyzed and an overall, long-term decrease in flow was found. The slope of this decrease was estimated at –1.76 cfs/year (Table 2.17). In the remaining stations, there was either no significant trend or insufficient data to perform a trend analysis.

Table 2.17 Summary of trend analysis on flow (cfs).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
USGS #02043190	6.53	7.39	22.22	-16.08	11.21	11	--
USGS #02043200	25.98	24.62	74.36	-6.35	19.88	17	--
USGS #02044000	46.97	28.00	364.41	0.28	53.73	201	No Trend
USGS #02047000	1,346.67	909.73	9,190.93	27.42	1,300.28	720	No Trend
USGS #02047500	321.30	201.03	2,354.54	0	351.08	376	-1.76

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Differences in mean monthly flow at Station #02047500 are indicated in Table 2.18. Flows in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, July, and October are in median group "A" and are not significantly different from each other. In months with multiple groups, flow values are the result of the 95% confidence interval for that month,

overlapping more than one median group. For example, flow values during the months of May, June, August, and September are classified in both median group "A" and "B" and are not significantly different than either group. In general, flow in the fall-winter months tends to be higher than flow in the spring-summer months.

Table 2.18 Summary of the Mood Median Test on mean monthly flow at USGS Station 02047500 (p<0.001).

Month	Mean (cfs)	Minimum (cfs)	Maximum (cfs)	Median Groups	
January	42.32	2.31	90.58		B
February	54.57	3.87	114.21		B
March	54.21	6.62	148.13		B
April	36.01	4.65	84.00		B
May	17.95	0.02	112.90	A	B
June	11.00	0.00	52.22	A	B
July	6.15	0.00	30.72	A	
August	14.17	0.00	103.82	A	B
September	9.25	0.00	53.41	A	B
October	7.03	0.00	34.39	A	
November	16.74	0.00	69.49		B
December	20.66	0.00	64.22		B

Total monthly flow measured at Station #02044000 in Nottoway County, Virginia from January 1970 to September 1986 was analyzed, and a significant seasonality effect was found. Differences in mean monthly flow at Station #02044000 are indicated in Table 2.19. Flows in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, flow values in August and September are in median group "A" and are not significantly different from each other. In months with multiple groups, flow values are the result of the 95% confidence interval for that month, overlapping more than one median group. For example, flow values during the months of October and November are classified across median groups "A", "B", and "C", and are not significantly different than any of the three groups. In general, flow in the fall-winter months tends to be higher than flow in the spring-summer months.

Table 2.19 Summary of the Mood Median Test on mean monthly flow at USGS Station 02044000 (p<0.001).

Month	Mean (cfs)	Minimum (cfs)	Maximum (cfs)	Median Groups		
January	67.90	6.45	200.61		B	C
February	72.43	19.89	200.32			C
March	77.42	12.89	233.42		B	C
April	65.35	12.15	167.83		B	C
May	40.67	10.79	115.48		B	
June	27.95	2.68	198.04	A	B	
July	16.64	1.22	54.93	A	B	
August	10.52	0.67	32.46	A		
September	35.72	0.28	238.39	A		
October	55.69	1.34	364.41	A	B	C
November	47.68	4.75	223.47	A	B	C
December	46.15	6.24	94.00		B	C

Total monthly flow measured at Station #02047000 in Southampton County, Virginia from October 1941 to September 2002 was analyzed, and a significant seasonality effect was found. Differences in mean monthly flow at Station #02047000 are indicated in Table 2.20. Flows in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, flow values in May, and December are in median group “B” and are not significantly different from each other. Flow values in months with multiple groups are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, flow values during the months of March and April are classified across median groups “C” and “D”, and are not significantly different than either group. In general, flow in the winter-spring months tends to be higher than flow in the summer-fall months.

Table 2.20 Summary of the Mood Median Test on mean monthly flow at USGS Station 02047000 (p<0.001).

Month	Mean (cfs)	Minimum (cfs)	Maximum (cfs)	Median Groups			
January	2,010.53	196.48	6,115.48			C	
February	2,444.34	466.14	6,255.36				D
March	2,755.61	389.45	6,530.65			C	D
April	2,103.15	427.03	5,127.00			C	D
May	1,288.93	300.32	5,180.00		B		
June	762.16	54.80	2,245.80	A	B		
July	701.73	37.84	5,782.03	A			
August	596.21	35.71	2,831.48	A			
September	677.23	27.77	9,190.93	A			
October	668.21	27.42	4,491.06	A			
November	843.76	59.47	4,854.00	A			
December	1,308.08	98.77	4,310.32		B		

2.4.3.3 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment. All stations had no overall trends (Table 2.21).

Table 2.21 Summary of trend analysis on fecal coliform (cfu).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
5ABHC003.73	805.86	130	16,000	18	2,315.08	57	No Trend
5ABPC000.12	2,456.94	410	16,000	18	4,522.69	34	No Trend
5ACPP003.20	391.67	100	5,400	100	1,083.44	24	--
5ACPP006.04	241.67	100	800	100	235.33	12	--
5ALNT004.68	1,191.85	300	16,000	15	2,960.40	61	--
5AMSW006.77	880.24	110	16,000	18	2,823.03	33	No Trend
5ANTW155.06	1,465.59	230	16,000	25	3,861.88	17	--
5ARCN003.36	274.29	100	4,000	100	661.26	35	--
5ARKN006.40	319.38	100	4,800	13	619.84	96	No Trend
5ASAP013.69	154.74	100	950	25	209.20	19	--

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Mood Median tests were performed on each station to identify any seasonality effect within the fecal coliform data. No significant seasonality effects were found at any of the stations.

2.4.4 Summary of In-stream Water Quality Monitoring Data

Wide ranges of fecal coliform concentrations have been recorded in the watershed. Concentrations reported during TMDL development were within the range of historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Chowan Study Area. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for each impaired segment are given in Table 3.1 and shown in Figures 3.1 and 3.2.

Table 3.1 Contributing land use area for impaired segments in the Chowan Study Area.

Impaired Segment	Landuse								
	Water (acres)	Residential (acres)	Commercial & Services (acres)	Barren (acres)	Woodland (acres)	Pasture (acres)	Cropland (acres)	Wetlands (acres)	Livestock Access (acres)
Upper Blackwater River Basin									
Cypress Swamp	497	29	11	2,286	25,086	1,693	4,506	3,572	14
Mill Swamp	266	35	20	161	10,746	2,234	5,090	5,283	25
Rattlesnake Swamp	338	50	29	255	14,322	2,008	7,045	7,725	37
Upper Nottoway River Basin									
Beaverpond Creek	118	14	5	29	3,745	1,607	758	30	37
Big Hounds Creek	186	329	58	173	8,144	1,922	216	151	23
Little Nottoway River	862	756	340	631	32,381	10,678	733	1,951	185
Nottoway River*	698	140	59	2,076	33,100	3,664	393	2,042	63
Raccoon Creek	601	48	259	1,266	28,324	2,627	5,489	4,866	23
Sappony Creek	548	31	184	1,823	24,491	2,126	4,972	1,292	21

* Impairment begins at the headwaters and extends downstream to river mile 146.08.

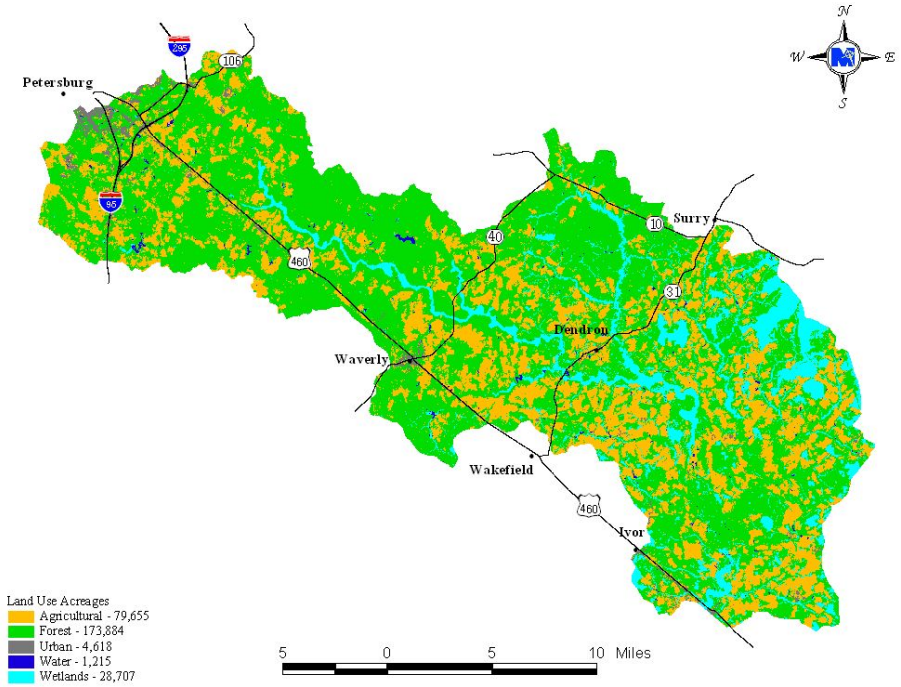

Figure 3.1 Landuses in the Upper Blackwater River watershed.

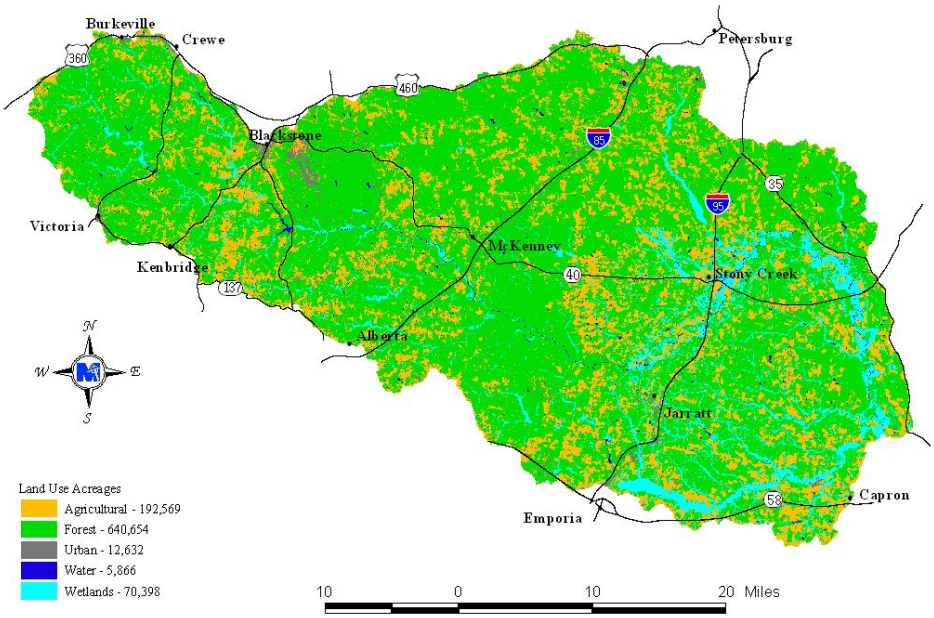

Figure 3.2 Landuses in the Upper Nottoway River watershed.

The estimated human population within the impaired drainage areas in 2004 is 14,637 with 2,930 dogs and 3,243 cats associated with this population. Table 1.2 lists agricultural production rankings for counties in the Chowan River Basin compared to all counties in Virginia (Virginia Agricultural Statistics, 2002). Counties in the Upper Blackwater and Upper Nottoway River basins are home to numerous species of wildlife, including mammals (*e.g.,* beaver, raccoon, white-tailed deer) and birds (*e.g.,* wood duck, wild turkey, Canada goose) (VDGIF, 2004) (Table 3.3).

Table 3.2 Agricultural production rankings for counties in the Chowan Study Area compared to all counties in Virginia*.

County / City	County Rankings Compared to Other Counties in Virginia						
	Cattle & Calves	Dairy	Beef	Horses	Layers	Broilers	Swine
Dinwiddie	61	35	63	55	43	21	N/A
Isle of Wight	67	N/A	66	76	18	13	2
Lunenburg	43	N/A	45	N/A	7	N/A	N/A
Nottoway	43	35	39	60	5	8	N/A
Prince Edward	44	28	30	72	9	15	N/A
Southampton	63	N/A	59	73	11	12	4
Surry	83	N/A	71	N/A	90	N/A	N/A
Sussex	73	N/A	76	67	N/A	N/A	N/A
Chesapeake	74	N/A	72	N/A	38	N/A	N/A

*VASS, 2002.

Table 3.3 Number of wildlife species, mammal types, and bird types inhabiting counties and cities within Chowan Study Area*.

County / City	Number of Wildlife Species	Number of Mammal Types	Number of Bird Types
Dinwiddie	386	46	172
Isle of Wight	418	48	203
Lunenburg	345	42	159
Nottoway	332	43	160
Prince Edward	401	43	158
Surry	444	48	198
Sussex	391	46	173
Chesapeake	493	51	220

*VDGIF, 2004.

For the period from 1972 to 2004, the portion of the Chowan Study Area near Camp Pickett, Virginia received an average annual precipitation of approximately 46.44 inches, with 53% of the precipitation occurring during the May through October growing season (SERCC,

2004). Average annual snowfall is 7.9 inches, with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 56.4 ºF. The highest average daily temperature of 86.8 ºF occurs in August, while the lowest average daily temperature of 24.0 ºF occurs in January (SERCC, 2004).

For the period from 1948 to 2004, the portion of the Chowan Study Area near Stony Creek, Virginia received an average annual precipitation of approximately 44.98 inches, with 55% of the precipitation occurring during the May through October growing season (SERCC, 2004). Average annual snowfall is 8.6 inches, with the highest snowfall occurring during February (SERCC, 2004). Average annual daily temperature is 57.9 ºF. The highest average daily temperature of 90.2 ºF occurs in July, while the lowest average daily temperature of 26.4 ºF occurs in January (SERCC, 2004).

3.2 Assessment of Point Sources

Five (5) point sources are permitted in the Chowan Study Area through the Virginia Pollutant Discharge Elimination System (VPDES). Three of the five point sources are permitted in the Upper Nottoway River Basin, and two are in the Upper Blackwater River Basin (Table 3.4). Figure 3.4 and Figure 3.5 show the permitted locations. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted discharges are expected not to exceed the 126 cfu/100ml *E. coli* standard. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations (including fecal coliform concentrations) are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard.

Table 3.5 summarizes data from VPDES Confined Animal Feeding Operations (CAFO) and from Virginia Pollution Abatement (VPA) facilities along with the streams that receive potential runoff from these facilities. Figure 3.6 shows the VPA and CAFO locations. These

11 permitted sources do not have direct discharges to waterways but runoff from the area could contain fecal coliform and *E. coli* bacteria.

Table 3.4 Summary of VPDES permitted point sources in the Chowan Study Area.

Receiving Water	Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Availability
Upper Blackwater River Basin					
Cypress Swamp (Hazel Swamp)	Surry County High School	VA0029025	0.020	Yes	1/90 – 3/01
Cypress Swamp (Hazel Swamp)	Surry County WWTF	VA0088463	0.13	Yes	3/01 – 8/04
Upper Nottoway River Basin					
Big Hounds Creek/U.T.	Victoria East Sewage Treatment Plant	VA0020184	0.4	Yes	2/99 - 4/04
Mallory Creek	DOC - Nottoway Correctional Center	VA0066869	0.35	Yes	5/99 - 4/04
Little Nottoway River/U.T.	Nottoway County Schools Nottoway High	VA0061158	0.0256	Yes	5/99 - 4/04

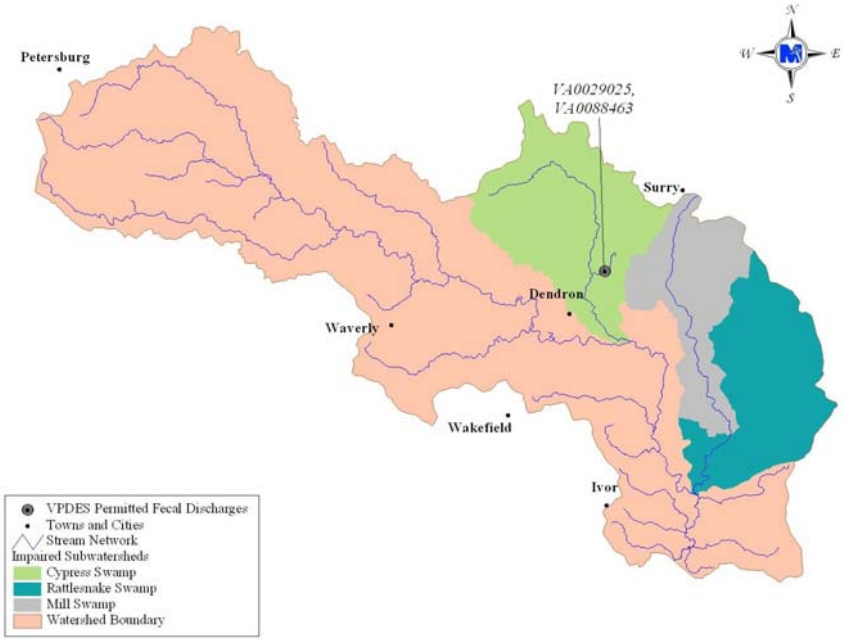

Figure 3.3 Location of VPDES permitted point sources in the Upper Blackwater River watershed.

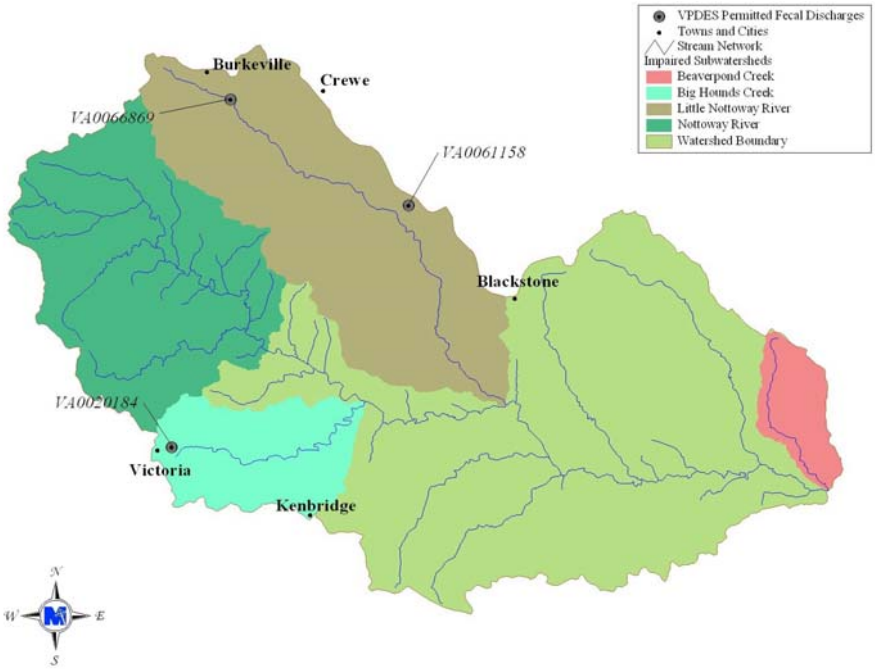

Figure 3.4 Location of VPDES permitted point sources in the Upper Nottoway River watershed.

Table 3.5 Summary of VPA and CAFO permits in the Chowan Study Area.

Watershed	Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Availability
Upper Nottoway River Basin					
Little Nottoway River	Hood Wallace	VPG270010	Poultry	No	ND
Little Nottoway River	Ingram Charles	VPG270058	Poultry	No	ND
Little Nottoway River	Ingram William T	VPG270074	Poultry	No	ND
Little Nottoway River	Oakmotte Farm	VPG270081*	Poultry	No	ND
Little Nottoway River	Randy Reynolds	VPG270087	Poultry	No	ND
Little Nottoway River	Rolling Acres Farm	VPG270049*	Poultry	No	ND
Little Nottoway River	Triple R Farm	VPG270018*	Poultry	No	ND
Upper Nottoway River	Jeffrey W. Dunn	VPG270062*	Poultry	No	ND
Upper Nottoway River	Big Oak Farm	VPG170043	CAFO	No	ND
Upper Nottoway River	Super Chic Ltd.	VPG270024	Poultry	No	ND
Upper Nottoway River	Walter Berryman Glascock	VPG270068	Poultry	No	ND

* Indicates poultry facility with some animals outside watershed boundary.
ND – no data, facility not required to submit monitoring data.

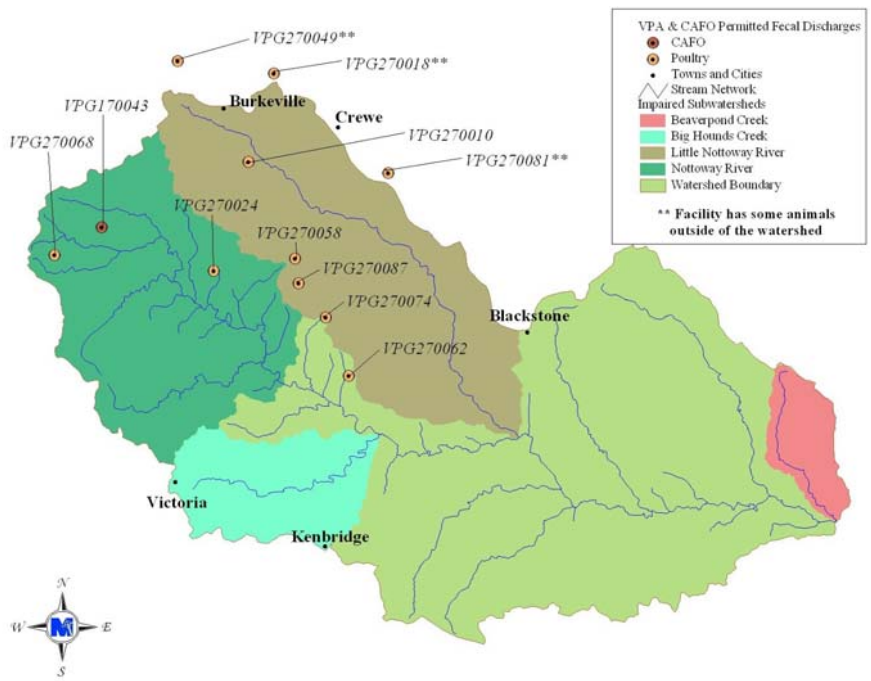

Figure 3.5 Location of VPA and CAFO permitted point sources in the Upper Nottoway River watershed.

3.3 Assessment of Nonpoint Sources

In the Chowan Study Area, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, land application of waste (livestock and biosolids), livestock, wildlife, and pets. Sources were identified and enumerated. MapTech collected samples of fecal coliform sources (*i.e.*, wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.4.2.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category "Other Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of

sewage via a pit-privy or through the use of a straight pipe (direct stream outfall). Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.6).

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter-spring

months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (MapTech, 2001). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.6 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2004 in areas contributing to impaired segments in the Chowan Study Area.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Upper Blackwater River Basin					
Cypress Swamp	1,118	436	0	396	41
Mill Swamp	843	338	0	305	33
Rattlesnake Swamp	1,147	446	0	413	33
Upper Nottoway River Basin					
Beaverpond Creek	254	122	4	113	4
Big Hounds Creek	2,058	983	484	461	39
Little Nottoway River	4,858	1,634	419	1,145	70
Nottoway River**	2,588	623	186	419	17
Raccoon Creek	773	394	49	311	34
Sappony Creek	998	448	67	352	29

* Houses with sewage disposal systems other than sanitary sewer and septic systems.
** Impairment begins at the headwaters and extends downstream to river mile 146.08.

3.3.2 Biosolids

Biosolids from seven wastewater sources (Table 3.7 and Table 3.8) have been applied to agricultural lands in the Chowan Study Area. Between 2001 and 2003 an average of 5,799.12 dry tons and 17,648.27 wet tons were applied per year to the watershed (MapTech, 2004). Table 3.9 list the acres permitted for biosolids application, number of acres biosolids applied to, dry tons of biosolids applied, wet tons of biosolids applied, and amount of fecal coliform applied to the area contributing to impairments in the Chowan Study Area. The application of biosolids to agricultural lands is strictly regulated in Virginia (VDH, 1997). Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. Class B biosolids may not have a fecal

coliform density greater than 1,995,262 cfu/g (total solids). Application rates must be limited to a maximum of 15 dry tons/acre per three-year period.

Table 3.7 Source and application of dry biosolids within the Chowan Study Area.

Source of Biosolids	Dry Tons Applied In		
	2001	2002	2003
Blue Plains	480.18	6,442.96	3,699.48
City of Richmond	643.57	2,479.53	2,255.40
Bowie, MD		44.65	12.76
Arlington Wastewater Auth.			155.22
Chesterfield Co			201.92
City of Petersburg			602.53
Henrico Co			379.15
Total	1,123.75	8,967.14	7,306.47

Table 3.8 Source and application of wet biosolids within the Chowan Study Area.

Source of Biosolids	Average cfu/gram	Wet Tons Applied In		
		2001	2002	2003
Blue Plains	5.6320E+10	1,590.32	22,440.11	10,025.35
City of Richmond	2.0982E+10	2,336.11	6,975.92	3,375.50
Bowie, MD	1.8373E+09		1,087.68	23.34
Arlington Wastewater Auth.	8.6491E+08			523.00
Chesterfield Co	1.9071E+09			1,153.18
City of Petersburg	2.8553E+09			1,726.56
Henrico Co	2.7911E+09			1,687.75
Total		3,926.43	30,503.71	18,514.68

Table 3.9 Acres permitted for biosolids application, number of acres biosolids applied to, dry tons of biosolids applied, wet tons applied in the Chowan Study Area.

Impairment	Acres Permitted	Acres Applied (2001-2003)	Dry Tons Applied (2001-2003)	Wet Tons Applied (2001-2003)
Upper Blackwater River Basin				
Cypress Swamp	0.00	0.00	0.00	0.00
Mill Swamp	0.00	0.00	0.00	0.00
Rattlesnake Swamp	0.00	0.00	0.00	0.00
Upper Nottoway River Basin				
Beaverpond Creek	1,439.35	1,331.60	7,387.58	18,248.74
Big Hounds Creek	0.00	0.00	0.00	0.00
Little Nottoway River	3,702.50	3,000.10	8,614.56	28,553.13
Nottoway River*	0.00	0.00	0.00	0.00
Raccoon Creek	137.60	137.60	613.54	3,551.95
Sappony Creek	365.20	355.30	781.68	2,591.00

* Impairment begins at the headwaters and extends downstream to river mile 146.08.

3.3.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Chowan Study Area and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. In addition to dogs in households, there were reports of large kennels for the purpose of housing hunting dogs in the vicinity of the impaired segments in the Upper Nottoway River drainage and in the area around Raccoon Creek and Sappony Creek. Attempts to contact officials who could provide estimates of the number of these types of operations, and there locations were unsuccessful. Given the existing estimates of dog populations in these watersheds, ranging between 0.5% to 6.0 % of total fecal production, significantly larger numbers of dogs could be a significant source of fecal coliform. Therefore, this should be a consideration during development of implementation plans. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia

by MapTech. A summary of the data collected is given in Table 3.10. Table 3.11 lists the domestic animal populations for impairments in the Chowan Study Area.

Table 3.10 Domestic animal population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.11 Estimated domestic animal populations in areas contributing to impaired segments in the Chowan Study Area.

Impaired Segment	Dogs	Cats
Upper Blackwater River Basin		
Cypress Swamp	268	261
Mill Swamp	180	202
Rattlesnake Swamp	238	267
Upper Nottoway River Basin		
Beaverpond Creek	65	73
Big Hounds Creek	525	588
Little Nottoway River	873	977
Nottoway River*	332	372
Raccoon Creek	210	235
Sappony Creek	239	268

*Impairment begins at the headwaters and extends downstream to river mile 146.08.

3.3.4 Livestock

The predominant types of livestock in the impaired streams of this Chowan Study Area are poultry, beef cattle and swine although all types of livestock identified were considered in modeling the watershed. Additionally, as the Chowan River drainage encompasses a vast area, the individual impaired streams in this study have a large diversity in the proportion of contributing livestock species. Operations range from small to large in size, including several operations permitted under either VPA or CAFO regulations. Table 3.5 gives a summary of these permitted operations in the drainage area of impaired streams in the Chowan Study Area. Table 3.12 gives a summary of livestock populations in the Chowan Study Area during the period for source assessment, organized by impairment. Animal populations were based on communication with Virginia Cooperative Extension Service

(VCE), Virginia Department of Conservation and Recreation (DCR), Natural Resources Conservation Service (NRCS), Southside Soil and Water Conservation District (SSWCD), Peanut Soil and Water Conservation District (PSWCD), J.R. Horsley Soil and Water Conservation District (JRHSWCD), Appomattox River Soil and Water Conservation District (ARSWCD), Piedmont SWCD (PSWCD), Farm Services Agency, local extension agents, watershed visits, and verbal communication with farmers. Note that Beef and Dairy cattle population numbers are based on adult beef and milking cattle only, while the "total cattle" category includes adult cattle as well as calves and replacements. Values of fecal coliform density of livestock sources were based on sampling performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.13.

Table 3.12 Livestock populations in areas contributing to impaired segments in the Chowan Study Area.

Impaired Segment	All cattle	Beef	Dairy	Hog	Horse	Sheep	Poultry*	Goats
Upper Blackwater River Basin								
Cypress Swamp	20	10	0	80	25	0	0	0
Mill Swamp	303	153	0	275	33	0	0	20
Rattlesnake Swamp	105	53	0	0	2	0	0	0
Upper Nottoway River Basin								
Beaverpond Creek	269	137	0	150	33	0	0	47
Big Hounds Creek	516	282	0	0	26	4	0	0
Little Nottoway River	4,603	1781	73	0	150	218	381,680	0
Nottoway River**	1,149	574	0	5,551	58	7	114,800	4
Raccoon Creek	544	274	0	7,100	34	0	37,700	0
Sappony Creek	217	117	0	32	49	8	0	0

* Poultry as reported in this table includes broilers and layers as a single population, however, broilers and layers are modeled as individual sources in the water quality model as they have significantly different fecal coliform production rates.
** Impairment begins at the headwaters and extends downstream to river mile 146.08.

Table 3.13 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Dairy (1,400 lb)	120.4	271,000
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Swine (135 lb)	11.3	400,000
Swine Lagoon	N/A	95,300[1]
Sheep (60 lb)	2.4	43,000
Goat (140 lb)	5.7	15,000
Dairy Separator	N/A	32,000[1]
Dairy Storage Pit	N/A	44,600[1]
Poultry		
Broiler	0.17	586,000
Layer	0.26	586,000

[1]units are cfu/100ml

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.*, pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Table 3.14 shows the average percentage of collected dairy waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.14 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total				Land use
	Dairy	*Beef*	*Swine*	*Poultry*	
January	1.50	8.33	0.00	0.00	Cropland
February	1.75	8.33	0.00	5.00	Cropland
March	17.00	8.34	20.00	25.00	Cropland
April	17.00	8.34	20.00	20.00	Cropland
May	17.00	8.33	20.00	5.00	Cropland
June	1.75	8.33	0.00	5.00	Pasture
July	1.75	8.33	0.00	5.00	Pasture
August	1.75	8.33	0.00	5.00	Pasture
September	5.00	8.34	0.00	10.00	Cropland
October	17.00	8.34	20.00	10.00	Cropland
November	17.00	8.33	20.00	10.00	Cropland
December	1.50	8.33	0.00	0.00	Cropland

Poultry is one of the major livestock commodities in the Chowan Study Area and poultry litter is the primary source of land-applied livestock waste. The transfer of poultry litter for use as a soil amendment is becoming more common within the state of Virginia. The VADEQ maintains records of poultry litter transfers, and a review of these records indicates that significant amounts of litter have been transferred into and utilized within the Upper Nottoway River watershed, and the Little Nottoway River watershed as early as 1998. Table 3.15 contains a summary of the poultry litter transfers in this watershed.

Table 3.15 Transfer of poultry litter within the Chowan Study Area.

Water Body	1998 (tons)	1999 (tons)	2000 (tons)	2001 (tons)	2002 (tons)	2003 (tons)
Nottoway River	60	70	95	934	2209	1096
Little Nottoway River	---	---	---	---	---	400

All livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was reported by the NRCS, VADCR, and VCE (Tables 3.16 through 3.17) and local stakeholders. Horses, sheep, and goats were assumed to be in pasture 100% of the time.

Based on discussions with local stakeholders, VCE, and NRCS, it was concluded that beef cattle were expected to make a significant contribution through direct deposition to streams in areas where the water flowed freely. In areas with stream fencing BMPs in place, or areas

with large amounts of standing or slowly moving water (*i.e.*, swamps) it was concluded that direct deposition was minimal to non-existent. For areas where direct deposition by cattle is assumed, the average amount of time spent by dairy and beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Tables 3.16 through Table 3.17.

Table 3.16 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.3	0.7	0
February	23.3	0.7	0
March	22.6	1.4	0
April	21.8	2.2	0
May	21.8	2.2	0
June	21.1	2.9	0
July	21.1	2.9	0
August	21.1	2.9	0
September	21.8	2.2	0
October	22.6	1.4	0
November	22.6	1.4	0
December	23.3	0.7	0

Table 3.17 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.5 Wildlife

The predominant wildlife species in the Chowan Study Area were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland

Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, source sampling, and site visits. Population densities were calculated from data provided by VDGIF and FWS, and are listed in Table 3.18 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987). The numbers of animals estimated to be in the Chowan Study Area are reported in Table 3.19. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999b). Table 3.20 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech. The only value that was not obtained from MapTech sampling in the watershed was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999a). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.21.

Table 3.18 Wildlife population density.

County/City	Deer (an/ac of habitat)	Turkey (an/ac)	Goose (an/ac)	Duck (an/ac)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
Dinwiddie	0.019	0.005	0.003	0.006	2.75	0.0703	4.8
Isle of Wight	0.029	0.008	0.004	0.010	2.75	0.0703	4.8
Lunenburg	0.018	0.005	0.003	0.003	2.75	0.0703	4.8
Nottoway	0.027	0.005	0.003	0.003	2.75	0.0703	4.8
Prince Edward	0.028	0.007	0.003	0.003	2.75	0.0703	4.8
Southampton	0.041	0.006	0.004	0.009	2.75	0.0703	4.8
Surry	0.038	0.009	0.004	0.010	2.75	0.0703	4.8
Sussex	0.029	0.006	0.004	0.010	2.75	0.0703	4.8

Table 3.19 Wildlife populations in the Chowan Study Area.

Impairment	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Upper Blackwater River Basin							
Cypress Swamp	1,204	332	141	356	8,199	759	258
Mill Swamp	816	200	79	201	3,760	387	131
Rattlesnake Swamp	1,092	274	100	254	4,750	510	159
Upper Nottoway River Basin							
Beaverpond Creek	144	24	21	28	819	143	44
Big Hounds Creek	242	53	34	39	1,406	259	19
Little Nottoway River	1,055	223	129	124	5,262	1,031	62
Nottoway River*	933	226	90	87	3,672	800	53
Raccoon Creek	1,228	271	119	288	6,470	947	287
Sappony Creek	698	181	79	153	2,714	698	189

* Impairment begins at the headwaters and extends downstream to river mile 146.08.

Table 3.20 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining landuse areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining landuse areas
Goose[3]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Mallard	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

1 Beaver waste load was calculated as twice that of muskrat, based on field observations.
2 Waste load for domestic turkey (ASAE, 1998).
3 Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003).

Table 3.21 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs in the Chowan Study Area, the relationship was defined through computer modeling based on data collected throughout the watersheds. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are five basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality. In this section, the selection of modeling tools, source assessment, selection of a representative period, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The Chowan Study Area contains a broad range of hydrologic systems, and thus requires a very robust and versatile modeling platform. The Upper Nottoway River and its

tributaries are essentially riverine impairments, while the tributaries of the Upper Blackwater River contain significant swamp area.

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations in riverine and swamp areas. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various landuses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

To adequately represent the spatial variation in the watershed, the Chowan River drainage area was divided into one hundred fifty-five (155) subwatersheds (Figure 4.1) for the purpose of modeling hydrology. The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model. The HSPF model is constrained by the number of operations that it is capable of representing and, thus, necessitated a division of the watershed model into six distinct

linked models. The output from one model was then routed into the next downstream model, where appropriate. Figure 4.1 shows the sub-model linkages, which were used to achieve the unified model. Water quality data (*i.e.*, fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1 and Table 4.1). In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

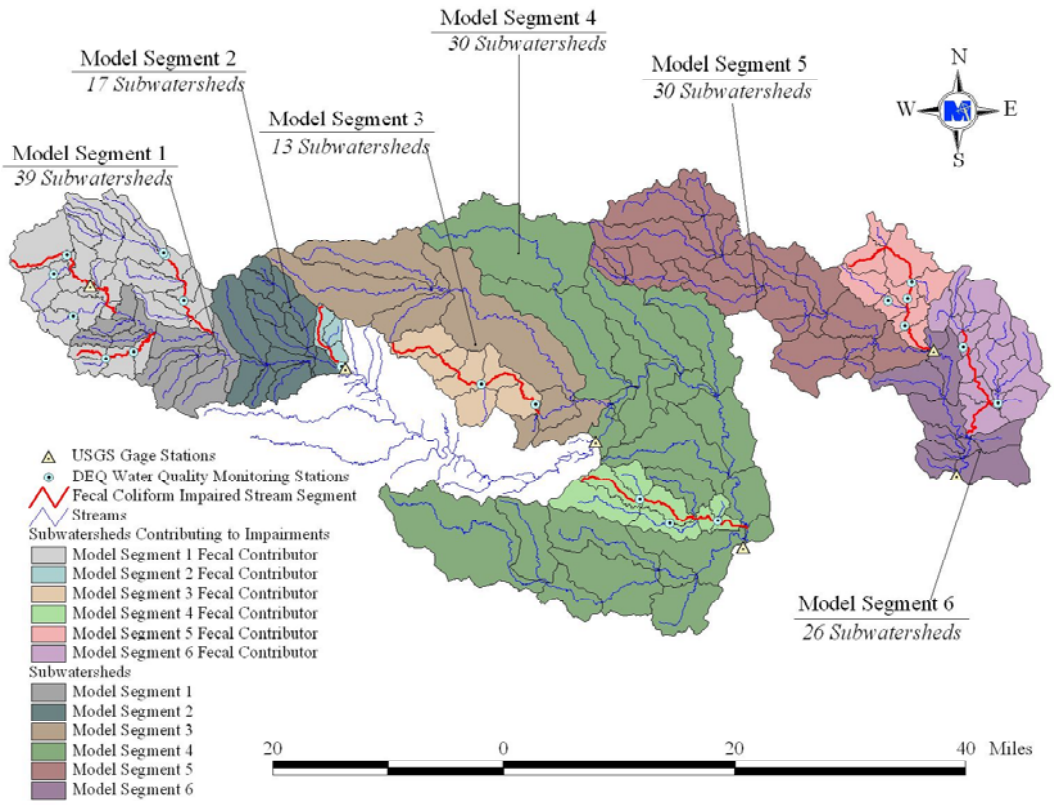

Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ Water Quality Monitoring Stations and USGS Gaging Stations in the Chowan Study Area.

Table 4.1 VADEQ Monitoring Stations and corresponding reaches in the Chowan Study Area.

Impairment	Segment ID	Station Number	Reach Number
Upper Blackwater River Basin			
Cypress Swamp	5	5ACPP007.84	13
Cypress Swamp	5	5ACPP003.20	15
Mill Swamp	6	5AMSW006.77	23
Rattlesnake (Creek) Swamp	6	5ARKN006.40	31
Upper Nottoway River Basin			
Beaverpond Creek	2	5ABPC000.12	39
Big Hounds Creek	1	5ABHC003.73	33
Little Nottoway	1	5ALNT004.68	22
Nottoway River	1	5ANTW155.06	01
Raccoon Creek	4	5ARCN012.80	18
Raccoon Creek	4	5ARCN003.36	20
Sappony Creek	3	5ASAP013.69	11
Sappony Creek	3	5ASAP004.00	13

Using aerial photographs, MRLC identified 14 landuse types in the watersheds. The 14 landuse types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 4.2). Within each subwatershed, up to the nine landuse types were represented. Each landuse had parameters associated with it that described the hydrology of the area (*e.g.,* average slope length) and the behavior of pollutants (*e.g.,* fecal coliform accumulation rate). Table 4.3 shows the consolidated landuse types and the area existing in each impairment. These landuse types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular landuse (Table 4.2). Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Table 4.2 Consolidation of MRLC landuse categories for the Chowan Study Area.

TMDL Landuse Categories	Pervious/Impervious (Percentage)	MRLC Landuse Classifications (Class No.)
Water	Impervious (100%)	Open Water (11)
Residential	Pervious (80%) Impervious (20%)	Low Intensity Residential (21) High Intensity Residential (22) Urban/Recreational Grasses (85)
Commercial and Services	Pervious (80%) Impervious (20%)	Commercial/Industrial/Transportation (23)
Barren	Pervious (100%)	Quarries/Strip Mines/Gravel Pits (32) Transitional (33)
Woodland	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Pasture	Pervious (100%)	Pasture/Hay (81)
Cropland	Pervious (100%)	Row Crops (82)
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)
Livestock Access	Pervious (100%)	Pasture/Hay (81)

Table 4.3 Spatial distribution of landuse types in the Chowan Study Area.

Impaired Segment	Landuse								
	Water (ac)	Residential (ac)	Commercial & Services (ac)	Barren (ac)	Woodland (ac)	Pasture (ac)	Cropland (ac)	Wetlands (ac)	Livestock Access (ac)
Upper Blackwater River Basin									
Cypress Swamp	497	29	11	2,286	25,086	1,693	4,506	3,572	14
Mill Swamp	266	35	20	161	10,746	2,234	5,090	5,283	25
Rattlesnake Swamp	338	50	29	255	14,322	2,008	7,045	7,725	37
Upper Nottoway River Basin									
Beaverpond Creek	118	14	5	29	3,745	1,607	758	30	37
Big Hounds Creek	251	383	59	307	11,612	2,321	266	302	26
Little Nottoway River	862	756	340	631	32,381	10,678	733	1,951	185
Nottoway River	698	140	59	2,076	33,100	3,664	393	2,042	63
Raccoon Creek	601	48	259	1,266	28,324	2,627	5,489	4,866	23
Sappony Creek	548	31	184	1,823	24,491	2,126	4,972	1,292	21

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with landuse type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 2002 were used for the water quality calibration period (1998-2003) and data representing 1995 were used for validation period

(1993-1998). Data representing 2004 were used for the allocation runs in order to represent current conditions.

4.3.1 Point Sources

There are five permitted point discharges in the Chowan Study Area. All of these facilities are permitted for fecal control, with design discharges ranging from 0.020-0.4 MGD (see Table 3.4). The design flow capacity was used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 ml to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels. For calibration and current condition runs, a lower value of fecal coliform concentration was used, based upon a regression analysis relating Total Residual Chlorine (TRC) levels and fecal coliform concentrations. Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

The number of septic systems in the 70 subwatersheds modeled for water quality in the Chowan Study Area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watersheds to enumerate the septic systems. Each residential landuse area was assigned a number of septic systems based on census data. A total of 3,363 septic systems were estimated in the Chowan Study Area in 1995. During allocation runs, the number of households was projected to 2004, based on current growth rates (USCB, 2000) resulting in 3,837 septic systems (Table 4.4). The number of septic systems was projected to increase to 4,101 by 2009.

Table 4.4 Estimated failing septic systems.

Impaired Segment	Septic Systems	Failing Septic Systems	Uncontrolled Discharges
Upper Blackwater River Basin			
Cypress Swamp	365	92	41
Mill Swamp	271	77	33
Rattlesnake (Creek) Swamp	400	87	33
Upper Nottoway River Basin			
Beaverpond Creek	113	29	4
Big Hounds Creek	461	145	39
Little Nottoway River	1,145	296	70
Nottoway River	419	99	17
Raccoon Creek	311	78	34
Sappony Creek	352	93	29

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of the TMDLs for the Chowan Study Area. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the wasteload for the average size household

in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.3.2.3 Sewer System Overflows

During the model calibration/validation period, (October 1993 to July 2003) there were 12 total reported sewer overflows (nine were during the modeling time period and were used in the bacteria models). While it may be assumed that additional occurrences of sewer overflows were likely undetected, a statistical analysis of meteorological events and sewer overflows was not able to be determined, so no projection of undetected sewer overflows was performed. The majority of sewer overflow event reports contained an estimate of the volume of sewage discharged, so the model included these discharges. The concentration of fecal bacteria discharged was considered equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2004 were used for the allocation runs, while these numbers were projected back to 2002 for the calibration and 1995 for validation runs. The numbers are based on data provided by VCE, DCR, NRCS, SSWCD, JRSWCD, ARSWCD, PSWCD, VASS and FSA as well as taking into account growth rates in Dinwiddie, Lunenburg, Nottoway, Prince Edward, Southampton, and Sussex counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995; VASS, 2002). For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.13). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal

coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.3.3.1 Land Application of Collected Manure

Significant collection of livestock manure occurs on various dairy, beef, horse, and swine farms. For each farm in the drainage area, the average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.3.4. For dairy farms, the amount of waste collected was first based on proportion of milking cows, as the milking herd represented the only cows subject to confinement and, therefore, waste collection. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. If beef cattle were reported as being confined for some percentage of time, the waste produced while in confinement was added to this total. Finally, values for the percentage of loafing lot waste collected, based on data provided by SWCD representatives and local stakeholders, were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.14). Swine were assumed to be in confinement 100% of the time with all waste stored in a lagoon. Stored waste was spread on pastured land. It was assumed that 100% of land-applied waste is available for transport in surface runoff unless the waste is incorporated in the soil by plowing during seedbed preparation. Percentage of cropland plowed and amount of waste incorporated was adjusted using calibration for the months of planting.

4.3.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and goat) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture landuse type was area-weighted.

4.3.3.3 Direct Deposition to Streams

Beef cattle are the primary sources of direct deposition by livestock in the Chowan Study Area. The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" landuse, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the Chowan Study Area. With urban populations growing, the disposal of biosolids will take on increasing importance. Class B biosolids are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. Detailed records of biosolids application location, timing and quantity were available, enabling the water quality modeling to be carried out in an "as applied" fashion, wherein the water quality model received land based inputs of biosolids loads on the day in which they actually occurred. During both model calibration and allocation runs biosolids were modeled as having a fecal concentration of 375,000 cfu/g, the mean value of measured biosolids concentrations observed in samples from 30 sources applied during 1991 (VADEQ, 2003). Applications were modeled as being spread onto the land surface over a six hour period on the date of reported application, in the case of a multiple day application, loads were split evenly over the period reported. An assumption of proper application was made, wherein no biosolids were modeled as being spread in stream corridors. During this analysis, the water quality model predicted that in the majority of watersheds in this study, biosolids application resulted in a negligible increase in

instantaneous violations. However, the total loading sensitivity analysis (see section 4.6.2, Figures 4.22 through 4.24) predicted a linear relationship between increased fecal coliform concentrations in land applications and concentrations in the stream, implying that a significant increase in the area of land eligible for biosolids application could potentially have a negative impact on water quality.

4.3.5 Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.3.5). An example of one of these layers is shown in Figure 4.2. This layer was overlaid with the landuse layer and the resulting area was calculated for each landuse in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

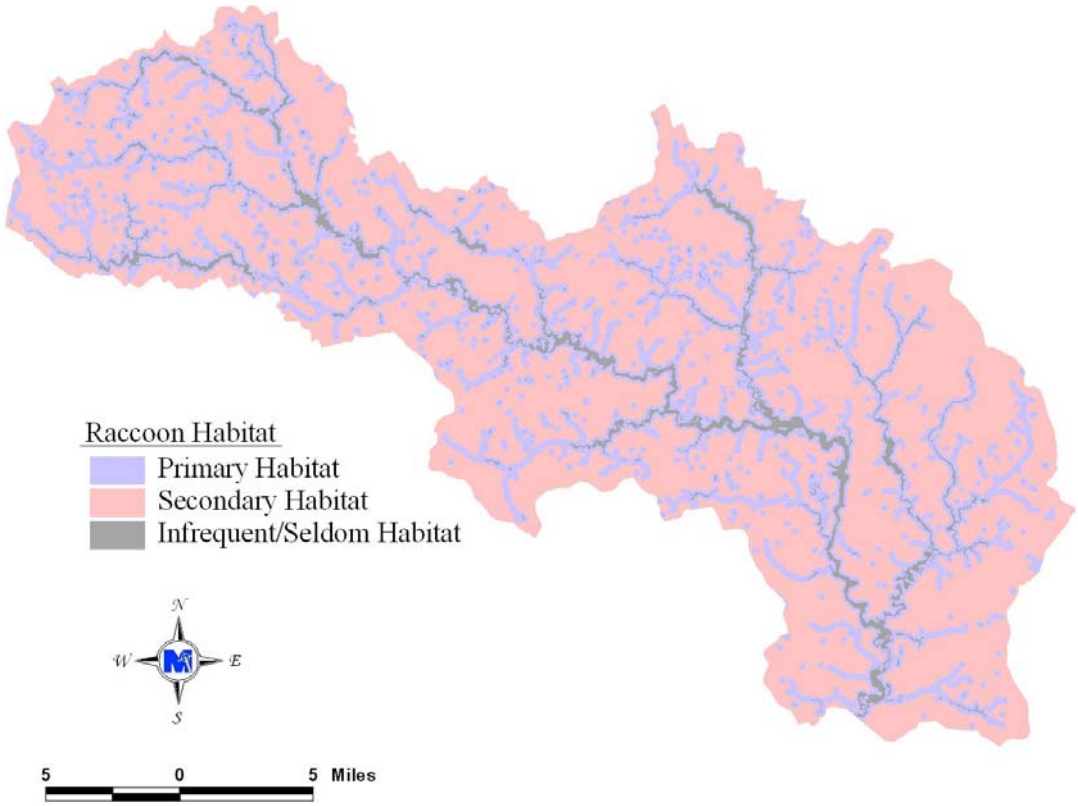

Figure 4.2 Example of raccoon habitat layer in the Chowan Study Area (Blackwater River), as developed by MapTech.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck wasteloads were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. No seasonal variation was assumed for the remaining species. For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.21). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term

(1995–2004) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.3.3. Waste from pets was distributed on residential landuses. The locations of households were taken from the 1990 and 2000 Census (USCB, 1990 and USCB, 2000). The landuse and household layers were overlaid, which resulted in number of households per landuse. The number of animals per landuse was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each landuse segment was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1995 and 2004.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at some subwatershed outlets. One outlet was considered the beginning of the next reach, when appropriate. In the case of a confluence, sections were surveyed above the confluence for each tributary and below the confluence on the main stream.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

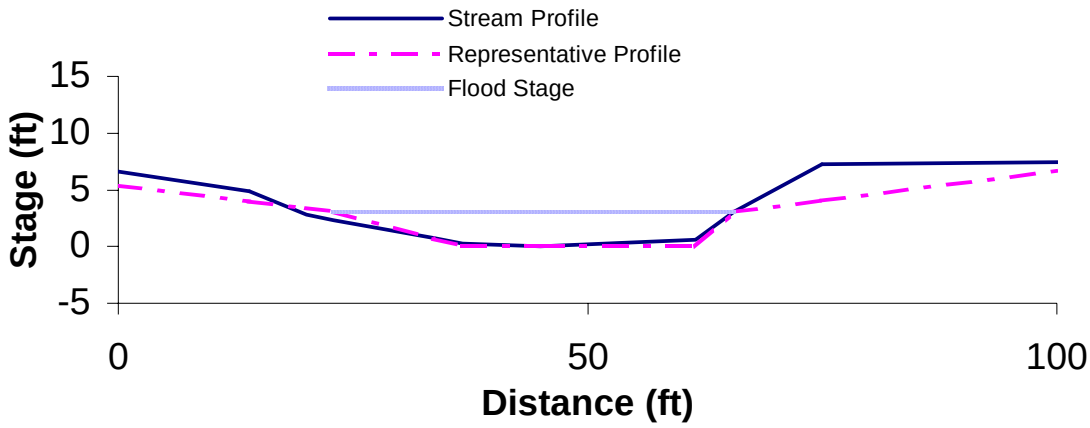

Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel; these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness

coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.5). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

Table 4.5 Example of an "F-table" calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
0.1	0.6	1.69	0.05
0.17	10.76	4.46	24.26
0.77	10.76	10.44	241.7
7.67	11.84	82.36	11150.2
9.59	13.64	104.21	16167.77
11.99	35.37	186.7	21029.3
14.39	36.12	270.99	38599.01
246.99	108.79	16985.15	17519166
479.6	181.45	50601.57	76135368

4.5 Selection of Representative Modeling Period

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Mean daily discharge at USGS Gaging Station 02044500 in the Upper Nottoway River, was available from 1946 through 2002. USGS Gaging Stations, 02045500 and 02047000 on the Nottoway River in the vicinity of Raccoon and Sappony Creeks was available from 1941 through 2002. For modeling in the Cypress Swamp, Mill Swamp and Rattlesnake (Creek) Swamp, USGS Gaging Station 02047500 on the Blackwater River near Dendron, Virginia was available from 1942 to 2002. The modeling period was selected to include the VADEQ assessment period from July 1990 through June 2001 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002 and 2004 Section 303(d) lists. The fecal concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were

recorded in all flow regimes, thus it was concluded that the critical hydrological condition included a wide range of wet and dry seasons.

In order to select a modeling period representative of the critical hydrological condition from the available data, the mean daily flow and precipitation for each season were calculated for the period 1971 through 2002. The results of this analysis are shown in Figures 4.4 through 4.9. This resulted in 31 observations of flow and precipitation for each season. The mean and variance of these observations were calculated. Next, a candidate period was chosen based on the availability of mean discharge data closest to the fecal coliform assessment period (7/90-6/03). The representative period was chosen from this candidate period such that the mean and variance of each season in the modeled period was not significantly different from the historical data (see Tables 4.6 through 4.8). Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting periods for hydrologic calibration were as follows: Upper Nottoway segment – October 1990 to September 1995, Raccoon/Sappony Creek segment – October 1990 to September 1995, and Blackwater River segment – October 1991 to September 1996. Not only did these periods satisfy criteria for a representative hydrologic period and hydrologic data availability, it also coincided with the beginning of a period of intensive water quality monitoring in the Chowan Study Area. For hydrologic validation, the periods selected were October 1997 to September 2002 for all segments.

For water quality calibration, data availability was the governing factor in the choice of calibration, validation, and allocation periods. The period containing the greatest amount of monitored data dispersed over the most stations, and for which the assessment of potential sources was most accurate (10/1/1998 to 9/30/2003), was chosen as the calibration period. This period contained 198 water quality data points spread over 12 stations. The period from 10/1/1993 to 9/30/1998 was chosen as the validation period, with 208 data points over 10 water quality sampling stations. This validation period also coincided with the representative hydrological period and therefore was chosen as the allocation period to ensure that the critical conditions in the watershed were being simulated during water quality allocations.

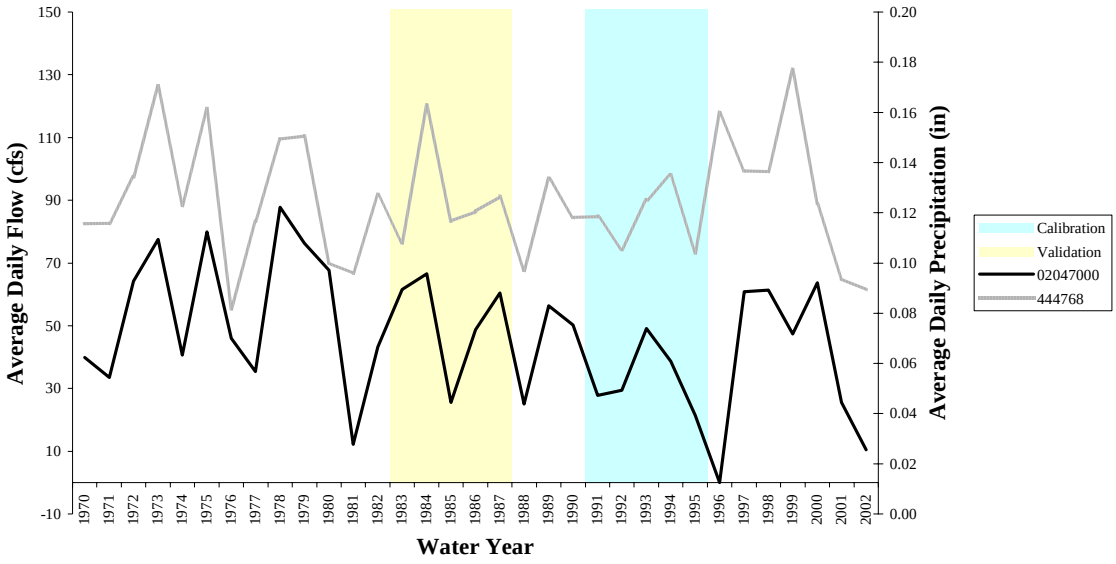

Figure 4.4 Annual Historical Flow (USGS Station 02047000) and Precipitation (Station 444768) Data

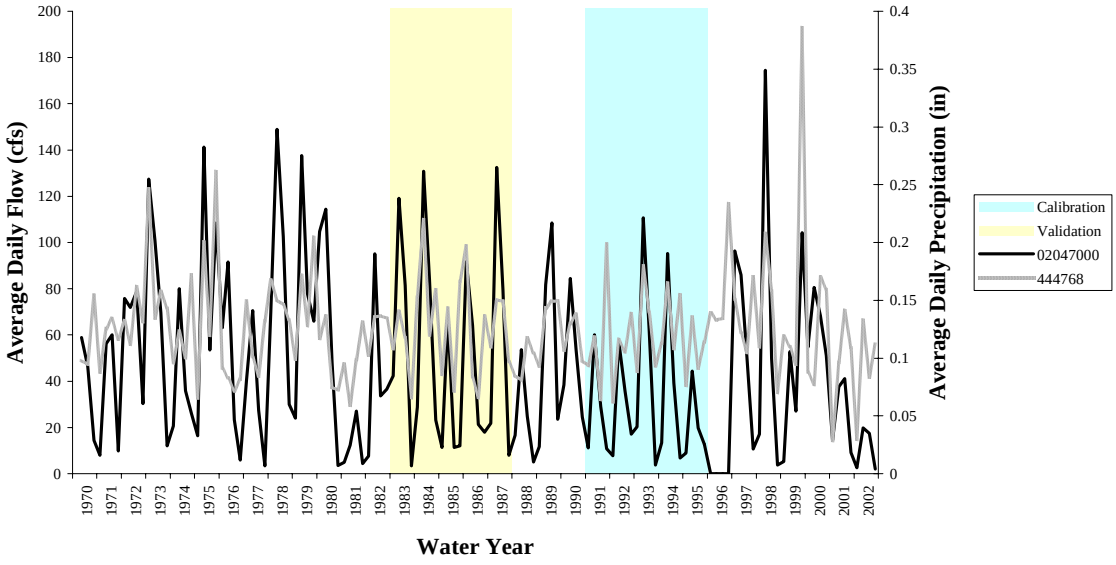

Figure 4.5 Seasonal Historical Flow (USGS Station 02047000) and Precipitation (Station 444768) Data

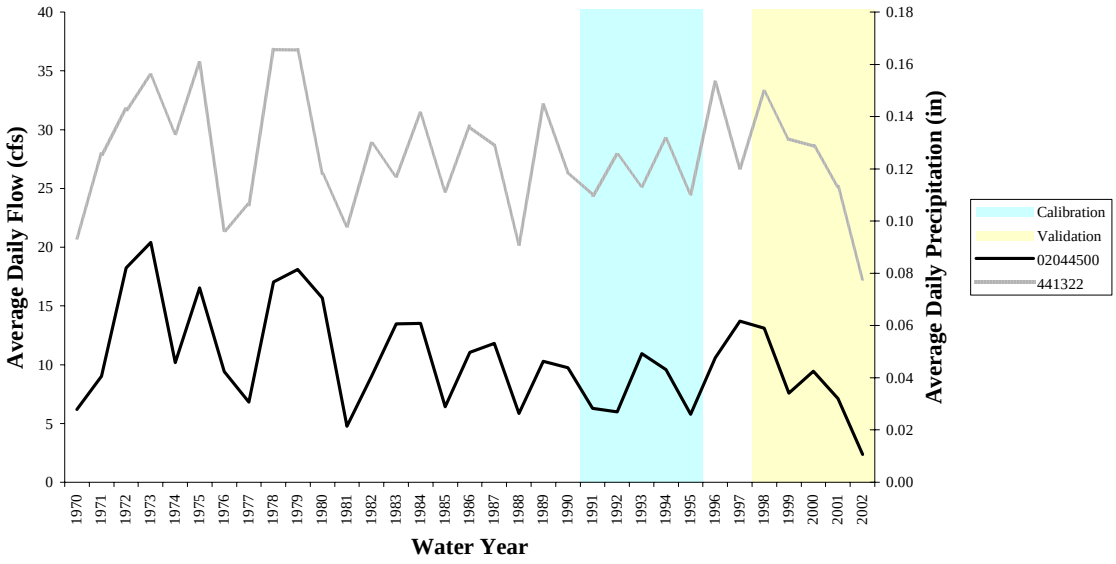

Figure 4.6 Annual Historical Flow (USGS Station 02044500) and Precipitation (Station 441322) Data

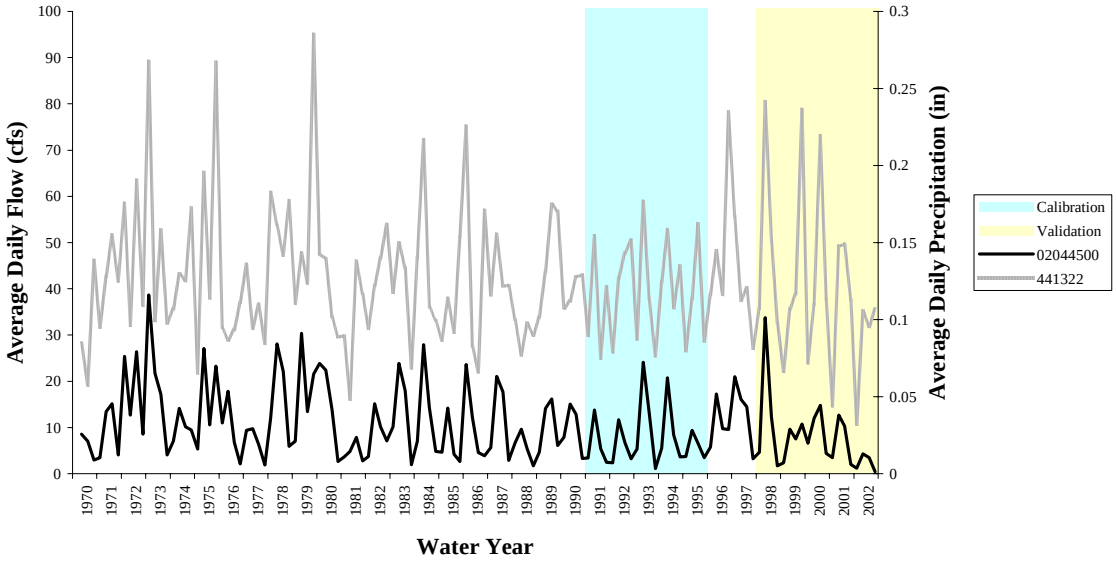

Figure 4.7 Seasonal Historical Flow (USGS Station 02044500) and Precipitation (Station 441322) Data

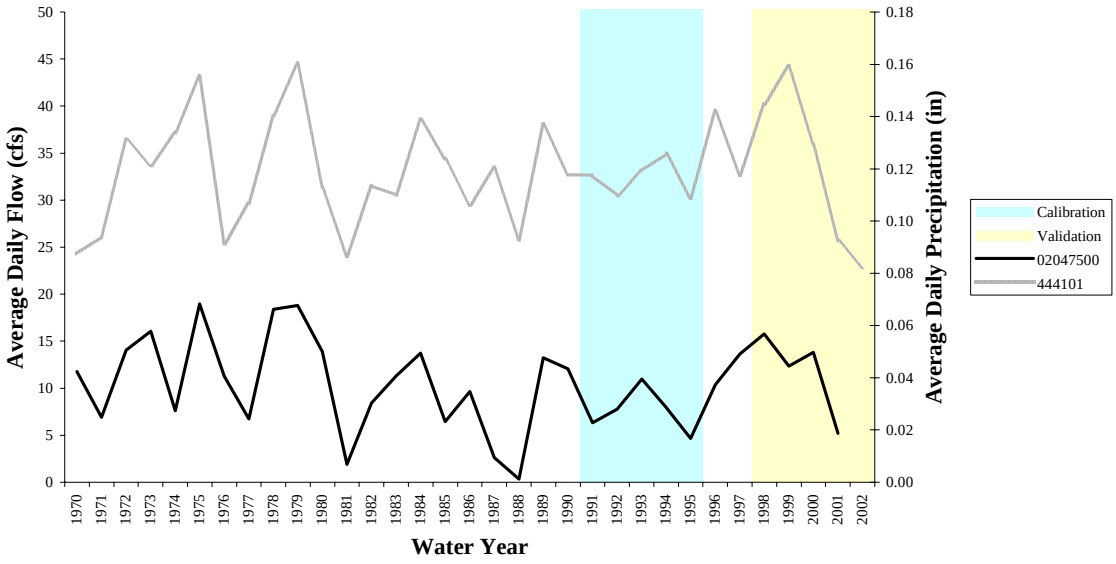

Figure 4.8 Annual Historical Flow (USGS Station 02047500) and Precipitation (Station 444101) Data

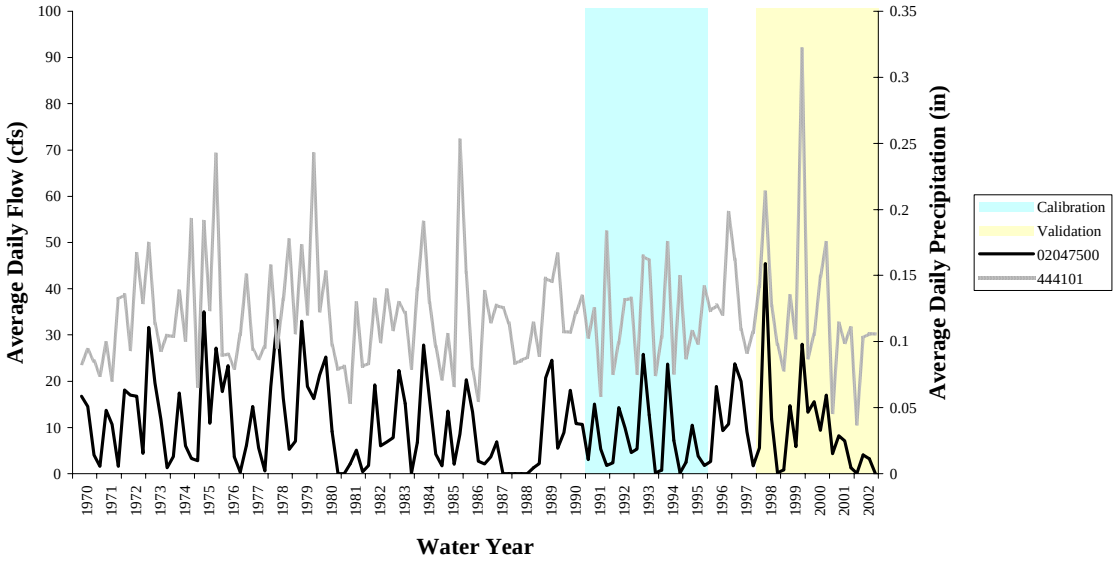

Figure 4.9 Seasonal Historical Flow (USGS Station 02047500) and Precipitation (Station 444101) Data

Table 4.6 Comparison of modeled period to historical records Upper Nottoway.

	Mean Flow (cfs)				Precipitation (in/day)			
	USGS Station 02044500				Primary Station 441322 Secondary Station 440187*			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1971-2002)							
Mean	8.93	16.67	11.30	5.13	0.1131	0.1292	0.1254	0.1361
Variance	71.15	54.58	28.88	26.34	0.0024	0.0016	0.0012	0.0030
	Calibration & Validation Period (10/90 – 09/95, 10/97 – 09/02)							
Mean	3.85	15.23	8.88	3.31	0.0781	0.1441	0.1333	0.1237
Variance	2.75	74.30	13.28	8.28	0.0010	0.0017	0.0017	0.0030
	p-Values							
Mean	0.00	0.32	0.06	0.08	0.0007	0.0018	0.0017	0.0020
Variance	0.00	0.25	0.11	0.04	0.0348	0.3955	0.2164	0.2878

*Secondary Station utilized only when Primary Station was off-line.

Table 4.7 Comparison of modeled period to historical records Blackwater.

	Mean Flow (cfs)				Precipitation (in/day)			
	USGS Station 02047500				Primary Station 444101 Secondary Station 449213*			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1971-2002)							
Mean	7.70	18.46	9.13	5.19	0.1042	0.1229	0.1083	0.1422
Variance	68.97	92.43	32.08	53.12	0.0012	0.0013	0.0008	0.0034
	Calibration & Validation Period (10/90 – 09/95, 10/97 – 09/02)							
Mean	3.80	17.74	7.64	5.50	0.0838	0.1340	0.1111	0.1490
Variance	14.71	136.77	10.52	89.01	0.0009	0.0015	0.0010	0.0048
	p-Values							
Mean	0.02	0.43	0.15	0.46	0.0362	0.2104	0.3995	0.3894
Variance	0.01	0.20	0.04	0.14	0.3426	0.3911	0.2896	0.2193

*Secondary Station utilized only when Primary Station was off-line.

Table 4.8 Comparison of modeled period to historical records Raccoon.

	Mean Flow (cfs)				Precipitation (in/day)			
	USGS Station 02047000				Primary Station 444768 Secondary Station 442790*			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1971-2002)							
Mean	33.66	82.79	48.12	21.24	0.1088	0.1307	0.1161	0.1449
Variance	1153.81	1631.16	707.69	693.52	0.0019	0.0014	0.0009	0.0039
	Calibration & Validation Period (10/90 – 09/95, 10/82 – 09/87)							
Mean	25.73	88.14	46.31	11.59	0.1085	0.1451	0.1032	0.1322
Variance	650.48	1109.79	775.89	41.22	0.0016	0.0014	0.0009	0.0016
	p-Values							
Mean	0.218	0.338	0.428	0.031	0.494	0.147	0.122	0.226
Variance	0.184	0.279	0.393	0.000	0.406	0.453	0.510	0.083

*Secondary Station utilized only when Primary Station was off-line.

4.6 Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

4.6.1 Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in Table 4.9, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value, and the model was run for water years 1993-1998. Where an increase of 50% exceeded the maximum value for the parameters, the maximum

value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and LZSN (Lower Zone Storage), and to a lesser extent by UZSN (Upper Zone Storage), which governs surface transport, and LZETP (Lower Zone Evapotranspiration), which affects soil moisture. Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the *Low Flows* and *Summer Flow Volume* statistics) were AGWRC (Groundwater Recession Rate), BASETP (Base Flow Evapotranspiration), LZETP and, to a lesser extent, infiltration. The responses of these and other hydrologic outputs are reported in Tables 4.10 through 4.12.

Table 4.9 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	1.670-11.414
INFILT	Soil Infiltration Capacity	in/hr	0.037-0.240
AGWRC	Groundwater Recession Rate	---	0.925-0.986
BASETP	Base Flow Evapotranspiration	---	0.060-0.130
INTFW	Interflow Inflow	---	2.0-10.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.04-0.37
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.01-0.3
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.370-1.878
MON-MANNING	Monthly Manning's *n* for Overland Flow	---	0.001-0.6
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.01-0.92

Table 4.10 HSPF Sensitivity analysis results for hydrologic model parameters, model segment 1, Nottoway River.

Model Parameter	Parameter Change (%)	Percent Change In Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	7.08	24.48	-77.55	29.67	-18.13	-41.37	17.50	9.22
AGWRC[1]	0.92	5.61	16.26	-68.45	26.90	-14.36	-44.69	3.97	7.72
AGWRC[1]	0.96	3.60	9.76	-54.83	19.44	-6.08	-42.03	-11.43	5.66
AGWRC[1]	0.999	-28.68	-16.65	-35.10	-26.14	-42.39	-32.30	16.38	-27.26
BASETP	-50	6.01	-1.49	35.20	-1.56	7.18	49.70	6.39	-6.57
BASETP	-10	1.12	-0.32	6.85	-0.32	1.42	9.12	1.14	-0.92
BASETP	10	-1.06	0.32	-6.57	0.31	-1.41	-8.52	-1.05	0.20
BASETP	50	-4.87	1.65	-30.90	1.50	-6.82	-38.29	-4.41	-2.97
DEEPFR	-50	23.23	8.99	54.29	14.82	24.82	59.39	34.52	15.16
DEEPFR	-10	4.62	1.79	10.77	2.96	4.96	11.58	6.87	3.31
DEEPFR	10	-4.60	-1.79	-10.62	-2.97	-4.96	-11.32	-6.84	-3.55
DEEPFR	50	-22.68	-8.93	-51.42	-14.85	-24.61	-53.72	-33.74	-21.13
INFILT	-50	8.06	29.85	-35.76	21.69	-0.59	-30.42	-4.25	10.22
INFILT	-10	1.14	4.49	-5.58	3.30	-0.03	-5.19	-1.46	1.91
INFILT	10	-1.00	-3.98	5.06	-2.97	0.02	4.80	1.54	-1.69
INFILT	50	-3.96	-16.50	21.34	-12.33	0.06	21.22	7.53	-7.01
INTFW	10	0.05	0.03	-0.09	0.05	0.07	-0.05	0.04	0.06
INTFW	50	0.18	0.17	-0.37	0.20	0.27	-0.22	0.14	0.24
INTFW	100	0.29	0.35	-0.59	0.33	0.40	-0.37	0.21	0.37
INTFW	200	0.41	0.57	-0.84	0.49	0.53	-0.55	0.26	0.53
LZSN	-50	17.18	28.11	-0.36	27.51	5.26	-14.92	33.29	18.02
LZSN	-10	2.69	4.36	-0.50	4.33	1.19	-2.61	3.79	2.96
LZSN	10	-2.45	-3.93	0.58	-3.93	-1.22	2.33	-2.92	-2.67
LZSN	50	-10.47	-16.55	2.41	-16.60	-6.13	8.93	-8.88	-11.40
MON-INTERCEP	-50	2.38	-1.73	15.45	-0.19	1.84	14.57	9.08	0.36
MON-INTERCEP	-10	0.43	-0.21	2.54	-0.02	0.42	2.34	1.41	0.07
MON-INTERCEP	10	-0.39	0.17	-2.29	0.01	-0.38	-2.10	-1.35	-0.10
MON-INTERCEP	50	-1.79	0.75	-10.49	-0.03	-1.50	-9.98	-6.08	-0.76
MON-LZETP	-50	11.23	6.78	33.99	9.47	3.80	22.29	42.74	5.81
MON-LZETP	-10	1.08	0.63	3.28	0.98	0.35	1.93	3.92	0.60
MON-LZETP	10	-1.05	-0.62	-3.03	-0.98	-0.34	-1.84	-3.68	-0.65
MON-LZETP	50	-7.77	-5.11	-20.71	-7.24	-3.15	-15.97	-22.53	-6.53
MON-MANNING	-50	0.24	0.84	-0.55	0.52	0.05	-0.51	0.02	0.32
MON-MANNING	-10	0.04	0.12	-0.08	0.08	0.00	-0.08	0.00	0.05
MON-MANNING	10	-0.03	-0.11	0.07	-0.07	0.00	0.07	0.00	-0.04
MON-MANNING	50	-0.14	-0.47	0.32	-0.32	0.00	0.29	0.02	-0.18
MON-UZSN	-50	8.59	15.64	-5.40	15.29	1.36	-7.10	11.89	9.60
MON-UZSN	-10	1.40	2.38	-0.94	2.66	0.24	-1.30	0.95	1.64
MON-UZSN	10	-1.32	-2.18	0.93	-2.53	-0.27	1.24	-0.60	-1.55
MON-UZSN	50	-6.04	-9.98	4.42	-11.63	-1.59	5.58	-0.69	-6.86

[1]Actual parameter value used

Table 4.11 HSPF Sensitivity analysis results for hydrologic model parameters, model segment 3, Sappony Creek.

Model Parameter	Parameter Change (%)	Percent Change In Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	3.43	13.51	-28.53	8.74	-10.38	8.84	9.79	3.51
AGWRC[1]	0.92	1.92	6.38	-20.08	5.97	-6.66	3.66	2.47	1.99
AGWRC[1]	0.97	-0.99	-2.11	11.42	-3.48	2.33	0.76	2.35	-1.18
AGWRC[1]	0.999	-29.46	-24.09	9.45	-32.90	-41.08	-21.14	32.27	-29.59
BASETP	-50	4.11	-1.47	38.05	-1.13	8.76	18.72	3.79	3.37
BASETP	-10	0.71	-0.27	6.20	-0.20	1.62	3.00	0.63	0.66
BASETP	10	-0.66	0.25	-5.67	0.19	-1.55	-2.67	-0.61	-0.63
BASETP	50	-2.95	1.17	-24.06	0.82	-7.31	-10.68	-2.88	-2.87
DEEPFR	-50	12.14	6.09	25.83	9.30	14.27	16.66	18.83	12.02
DEEPFR	-10	2.40	1.23	4.83	1.86	2.82	3.20	3.75	2.38
DEEPFR	10	-2.42	-1.23	-5.10	-1.86	-2.81	-3.35	-3.75	-2.40
DEEPFR	50	-11.94	-6.21	-25.04	-9.33	-13.92	-15.70	-18.59	-11.88
INFILT	-50	6.14	23.10	-28.44	11.88	-4.71	10.93	-2.06	6.24
INFILT	-10	0.78	3.53	-5.24	1.89	-0.89	0.80	-1.11	0.81
INFILT	10	-0.68	-3.18	4.66	-1.74	0.90	-0.71	1.19	-0.72
INFILT	50	-2.57	-13.15	20.41	-7.47	4.38	-1.95	6.55	-2.73
INTFW	10	0.07	0.04	-0.24	0.04	0.04	0.31	0.10	0.07
INTFW	50	0.30	0.28	-0.51	0.17	0.12	1.38	0.38	0.30
INTFW	100	0.47	0.54	-0.72	0.30	0.17	2.08	0.55	0.47
INTFW	200	0.65	0.85	-0.94	0.45	0.24	2.71	0.72	0.65
LZSN	-50	20.96	24.69	17.05	27.51	3.41	11.86	55.27	21.05
LZSN	-10	2.86	3.47	0.95	4.30	1.00	-0.46	4.31	2.88
LZSN	10	-2.38	-2.98	-0.44	-3.72	-1.03	0.87	-2.41	-2.41
LZSN	50	-8.34	-11.35	2.52	-13.93	-4.98	6.63	-1.22	-8.47
MON-INTERCEP	-50	1.28	-0.24	7.78	-0.02	2.44	2.82	4.31	1.25
MON-INTERCEP	-10	0.23	-0.03	1.40	0.00	0.45	0.46	0.80	0.23
MON-INTERCEP	10	-0.24	0.05	-1.65	0.00	-0.43	-0.66	-0.74	-0.24
MON-INTERCEP	50	-1.13	0.16	-7.23	-0.03	-2.07	-2.76	-3.33	-1.10
MON-LZETP	-50	27.54	19.54	90.36	17.49	5.40	78.63	118.24	26.34
MON-LZETP	-10	2.83	2.19	8.02	2.10	0.55	8.21	9.64	2.79
MON-LZETP	10	-2.96	-2.45	-8.01	-2.18	-0.58	-9.30	-8.92	-2.93
MON-LZETP	50	-16.06	-12.80	-40.70	-12.12	-5.01	-48.23	-42.48	-16.02
MON-MANNING	-50	0.26	0.97	-0.53	0.53	0.00	-0.23	-0.04	0.26
MON-MANNING	-10	0.03	0.16	-0.21	0.09	0.00	-0.16	-0.01	0.03
MON-MANNING	10	-0.05	-0.15	-0.08	-0.09	0.00	-0.04	0.01	-0.05
MON-MANNING	50	-0.17	-0.61	0.16	-0.34	-0.01	0.10	0.09	-0.17
MON-UZSN	-50	9.63	19.28	-2.00	11.10	4.48	15.81	9.55	9.61
MON-UZSN	-10	1.46	2.95	-0.59	1.88	0.35	2.64	0.81	1.46
MON-UZSN	10	-1.34	-2.69	0.42	-1.75	-0.23	-2.67	-0.54	-1.34
MON-UZSN	50	-5.59	-11.18	2.25	-7.81	-0.46	-10.76	-1.15	-5.62

[1]Actual parameter value used

Table 4.12 HSPF Sensitivity analysis results for hydrologic model parameters, model segment 5, Cypress Swamp.

Model Parameter	Parameter Change (%)	Percent Change In Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC[1]	0.85	1.31	8.05	-24.28	2.49	-2.26	2.80	3.53	1.31
AGWRC[1]	0.92	0.14	0.72	-2.42	0.37	-0.39	0.29	0.28	0.14
AGWRC[1]	0.96	-1.67	-6.54	25.17	-5.13	4.91	-2.97	-0.70	-1.67
AGWRC[1]	0.999	-43.03	-39.96	-32.30	-47.21	-50.29	-37.98	-3.20	-43.03
BASETP	-50	2.41	-2.64	38.94	-3.10	11.03	8.05	-2.85	2.41
BASETP	-10	0.43	-0.44	6.41	-0.50	1.99	1.26	-0.67	0.43
BASETP	10	-0.41	0.40	-5.85	0.45	-1.90	-1.12	0.65	-0.41
BASETP	50	-1.80	1.71	-24.01	1.87	-8.24	-4.91	2.93	-1.80
DEEPFR	-50	1.89	1.23	4.21	1.62	2.06	1.95	2.80	1.89
DEEPFR	-10	0.38	0.25	0.83	0.32	0.41	0.39	0.56	0.38
DEEPFR	10	-0.38	-0.25	-0.84	-0.32	-0.41	-0.39	-0.56	-0.38
DEEPFR	50	-1.88	-1.23	-4.14	-1.62	-2.06	-1.93	-2.79	-1.88
INFILT	-50	1.60	7.84	-19.77	3.98	-1.32	2.38	-4.18	1.60
INFILT	-10	0.18	1.25	-4.01	0.68	-0.37	0.20	-0.92	0.18
INFILT	10	-0.15	-1.16	3.83	-0.63	0.39	-0.10	0.88	-0.15
INFILT	50	-0.50	-5.10	17.10	-2.79	2.03	-0.12	4.08	-0.50
INTFW	10	0.01	0.03	-0.03	0.01	0.01	0.01	-0.01	0.01
INTFW	50	0.03	0.09	-0.13	0.03	0.05	0.05	-0.04	0.03
INTFW	100	0.04	0.14	-0.22	0.04	0.07	0.07	-0.06	0.04
INTFW	200	0.06	0.18	-0.31	0.05	0.10	0.09	-0.09	0.06
LZSN	-50	19.77	14.97	24.62	27.48	12.84	-1.10	32.49	19.77
LZSN	-10	2.06	1.95	0.19	2.94	2.27	0.46	-1.14	2.06
LZSN	10	-1.75	-1.71	-0.03	-2.44	-2.20	-0.66	1.89	-1.75
LZSN	50	-7.90	-7.69	-4.07	-10.43	-10.78	-4.47	10.62	-7.90
MON-INTERCEP	-50	1.70	-1.02	17.60	-0.83	6.32	2.52	0.05	1.70
MON-INTERCEP	-10	0.29	-0.15	2.85	-0.16	1.08	0.50	-0.07	0.29
MON-INTERCEP	10	-0.27	0.14	-2.61	0.15	-1.00	-0.53	0.10	-0.27
MON-INTERCEP	50	-1.19	0.66	-11.61	0.69	-4.36	-2.58	0.50	-1.19
MON-LZETP	-50	23.46	10.47	87.10	19.79	6.74	21.81	102.60	23.46
MON-LZETP	-10	3.81	1.78	12.26	3.99	1.34	2.69	12.77	3.81
MON-LZETP	10	-4.78	-2.44	-13.63	-5.20	-1.88	-3.62	-13.74	-4.78
MON-LZETP	50	-24.74	-14.82	-56.75	-23.46	-12.45	-34.49	-55.98	-24.74
MON-MANNING	-50	0.01	0.00	0.00	0.02	0.01	0.01	-0.03	0.01
MON-MANNING	-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-MANNING	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-MANNING	50	-0.01	0.00	0.01	-0.01	0.00	-0.01	0.01	-0.01
MON-UZSN	-50	4.53	7.05	-3.16	3.96	5.96	7.52	-1.82	4.53
MON-UZSN	-10	0.71	1.15	-0.75	0.74	0.71	1.28	-0.45	0.71
MON-UZSN	10	-0.66	-1.09	0.75	-0.73	-0.60	-1.16	0.44	-0.66
MON-UZSN	50	-2.87	-4.94	3.77	-3.50	-2.20	-4.99	2.31	-2.87

[1]Actual parameter value used

4.6.2 Water Quality Parameter Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 1993 through 1998, and model parameters established for 2003 conditions (see section 4.5 for a complete explanation of selected model time periods). The four HSPF parameters impacting the model's water quality response (Table 4.13) were increased and decreased by amounts that were consistent with the range of values for the parameter. Monthly interflow concentration (MON-IFLW CONC) and FSTDEC (First Order Decay) were the parameters with the greatest influence on monthly geometric mean concentration, although MON-SQOLIM and WSQOP also showed significant potential to influence this value (Tables 4.14 through 4.16). Graphical depictions of the results of this sensitivity analysis can be seen in Figures 4.10 through 4.21.

Table 4.13 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-IFLW CONC	Interflow Concentration	---	0-3.6E+07
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0-4.5E+12
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0-2.8
FSTDEC	In-stream First Order Decay Rate	1/day	0.88-1.75

Table 4.14 Percent change in average monthly *E. coli* geometric mean for the years 1998-2003 for Model Segment 1.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2003											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	17.92	11.78	12.47	10.64	12.44	11.70	25.50	33.15	23.94	32.66	20.56	19.57
FSTDEC	-10	3.09	2.12	2.25	1.95	2.24	2.10	3.96	4.92	3.72	5.10	3.45	3.25
FSTDEC	10	-2.89	-2.02	-2.14	-1.87	-2.14	-2.00	-3.59	-4.39	-3.37	-4.60	-3.20	-3.01
FSTDEC	50	-12.85	-9.25	-9.84	-8.67	-9.78	-9.18	-15.24	-18.16	-14.35	-19.25	-14.02	-13.16
SQOLIM	-50	-15.04	-9.09	-9.20	-6.82	-8.66	-9.98	-6.48	-6.14	-7.25	-13.22	-9.56	-13.26
SQOLIM	-25	-7.55	-4.37	-4.26	-3.02	-3.94	-4.24	-2.80	-2.78	-3.40	-6.66	-4.64	-6.34
SQOLIM	50	11.42	6.32	5.68	3.40	4.68	4.51	3.16	3.40	4.56	9.45	6.24	8.55
SQOLIM	100	20.72	11.72	10.32	5.62	7.89	7.44	5.33	5.91	8.19	17.24	11.01	15.07
WSQOP	-50	13.25	13.87	11.09	9.21	8.57	7.28	5.43	6.46	10.94	16.75	8.42	8.02
WSQOP	-10	1.42	1.43	1.16	0.95	0.88	0.87	0.56	0.63	1.11	1.58	0.88	0.94
WSQOP	10	-2.29	-2.42	-2.04	-1.65	-1.54	-1.57	-0.89	-1.03	-1.89	-2.66	-1.51	-1.62
WSQOP	50	-7.66	-8.16	-7.10	-5.56	-5.06	-5.60	-3.16	-3.48	-6.27	-8.63	-5.05	-5.52
MON-IFLW CONC	-100	-39.78	-59.90	-61.40	-65.36	-51.81	-59.83	-24.81	-17.73	-43.53	-13.66	-29.34	-41.53
MON-IFLW CONC	-50	-15.79	-23.89	-22.76	-26.09	-19.00	-22.78	-9.94	-6.29	-15.72	-5.29	-11.69	-15.07
MON-IFLW CONC	50	13.48	20.81	19.03	22.91	15.86	19.48	8.46	5.23	13.23	4.50	9.83	12.33
MON-IFLW CONC	100	25.68	39.94	36.06	44.05	30.05	37.22	16.09	9.90	25.14	8.58	18.63	23.18

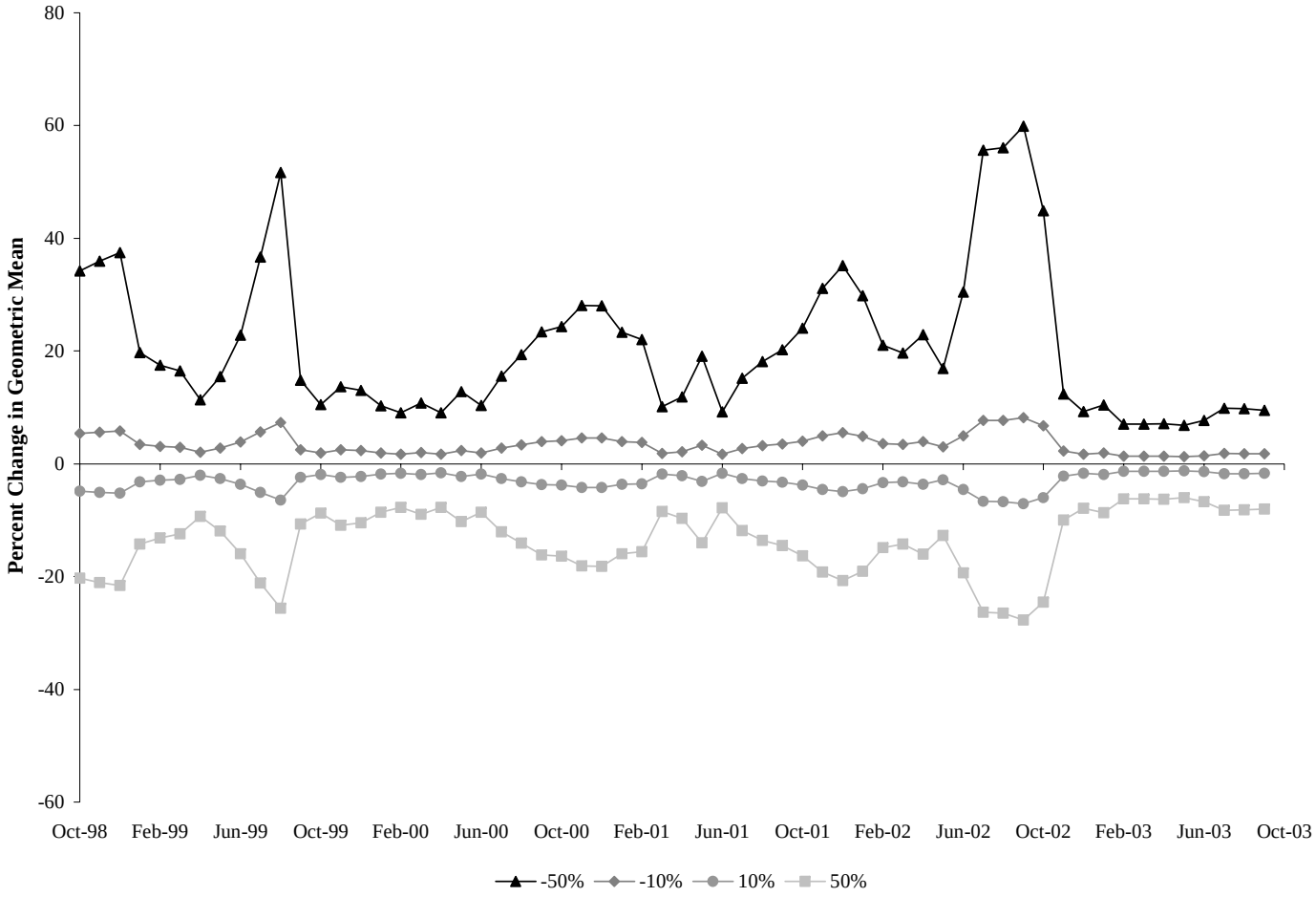

Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 1, as affected by changes in the in-stream first-order decay rate (FSTDEC).

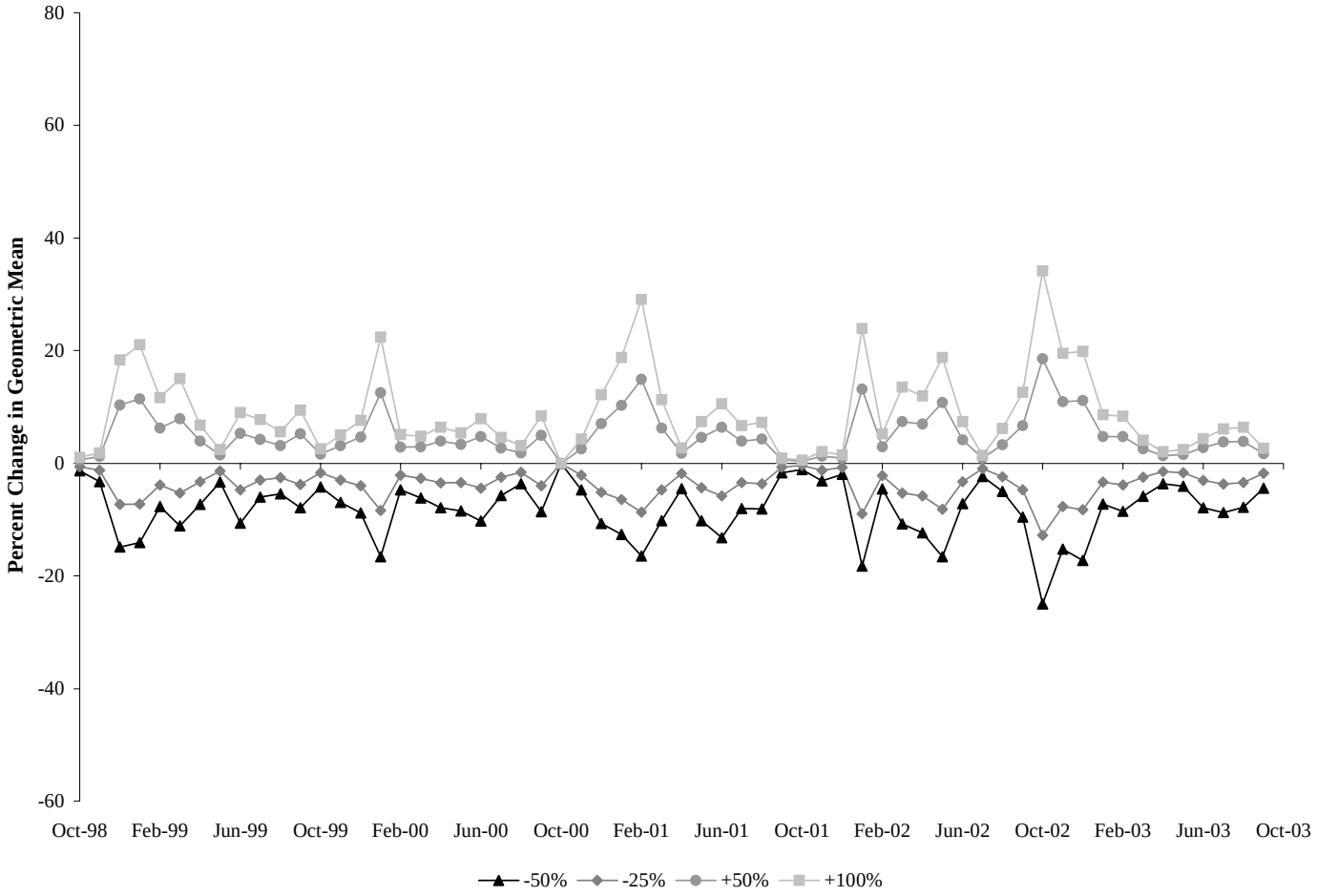

Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 1, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

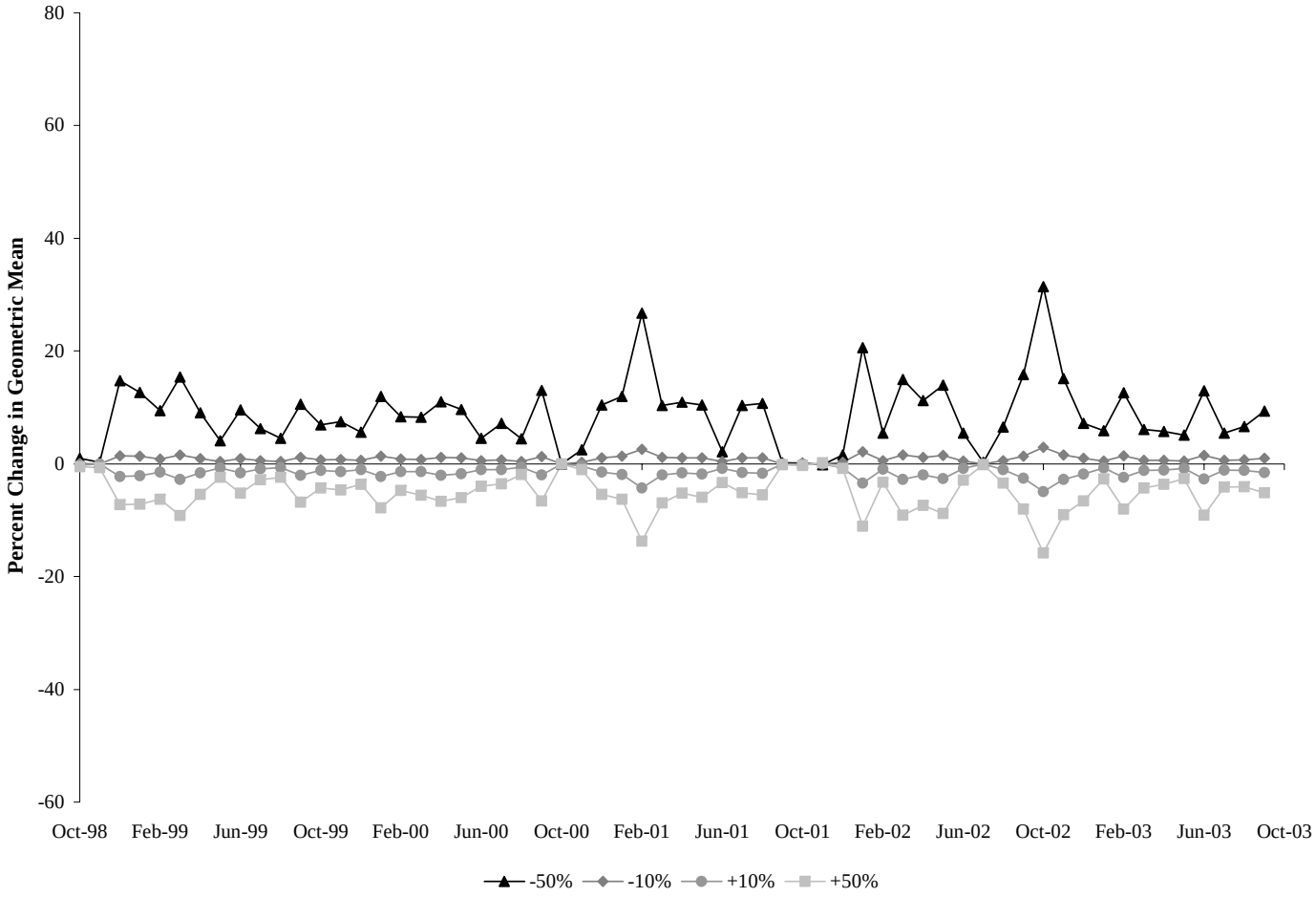

Figure 4.12 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 1, as affected by changes in the wash-off rate from land surfaces (WSQOP).

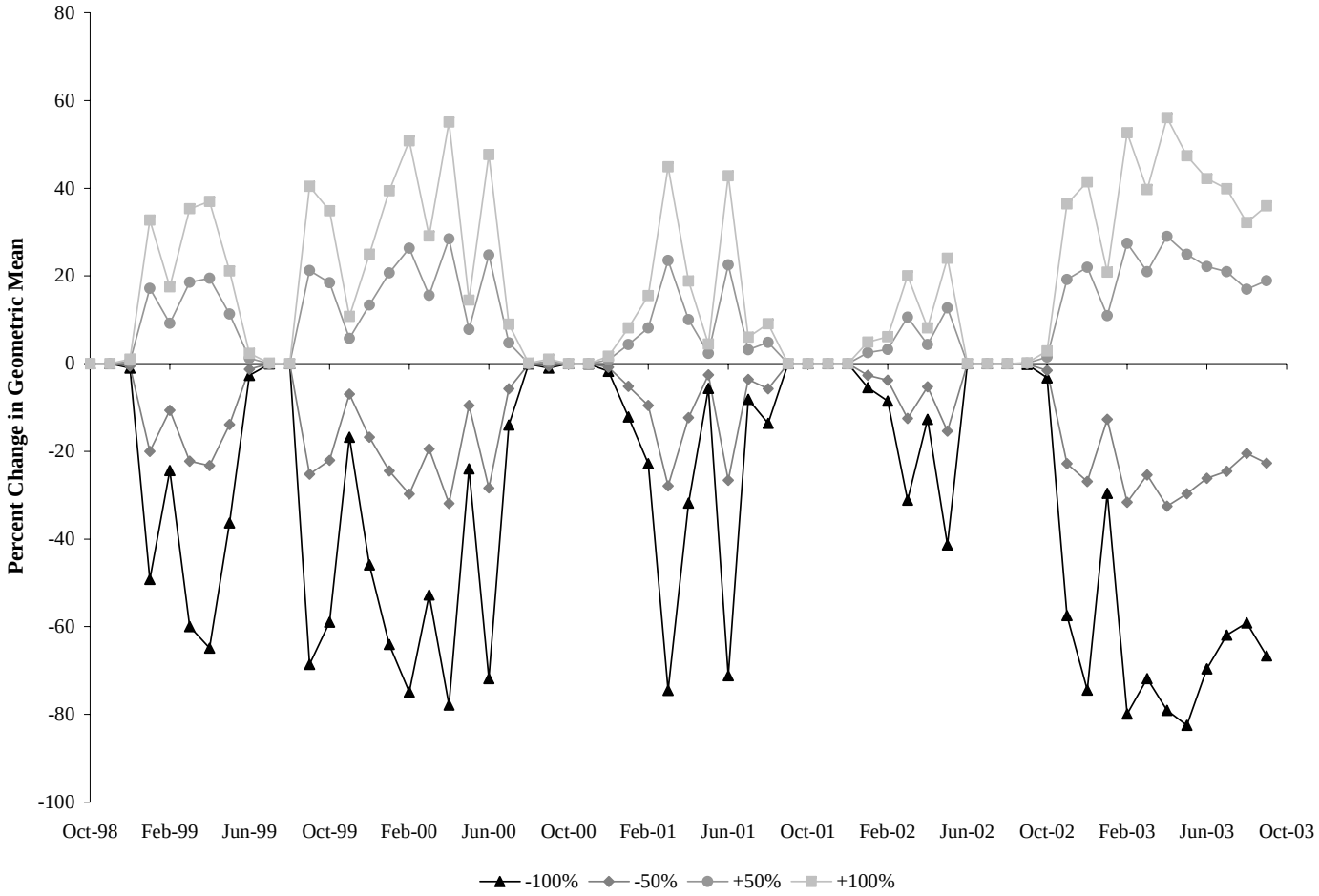

Figure 4.13 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 1, as affected by changes in the concentration of fecal bacteria in interflow (MON-IFLW-CONC).

Table 4.15 Percent change in average monthly *E. coli* geometric mean for the years 1998-2003 for Model Segment 3.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2003											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	32.46	16.62	17.63	14.09	19.58	21.70	53.36	51.13	27.11	37.43	34.18	28.15
FSTDEC	-10	5.12	2.93	3.10	2.55	3.38	3.47	7.13	7.03	4.13	5.30	4.79	4.03
FSTDEC	10	-4.64	-2.77	-2.91	-2.43	-3.17	-3.19	-6.16	-6.11	-3.73	-4.69	-4.23	-3.60
FSTDEC	50	-19.59	-12.50	-13.09	-11.17	-14.06	-13.84	-24.35	-24.36	-15.79	-19.30	-17.38	-15.13
SQOLIM	-50	-2.68	-1.63	-1.67	-1.80	-2.89	-1.53	-3.75	-4.54	-1.30	-1.49	-2.96	-1.29
SQOLIM	-25	-1.24	-0.74	-0.75	-0.73	-1.19	-0.64	-1.51	-1.91	-0.58	-0.61	-1.26	-0.55
SQOLIM	50	1.84	1.04	1.11	0.94	1.42	0.78	1.87	2.46	0.82	0.76	1.57	0.73
SQOLIM	100	3.46	1.88	2.07	1.64	2.38	1.37	3.34	4.36	1.53	1.34	2.80	1.30
WSQOP	-50	3.15	2.14	2.19	2.65	2.72	1.68	6.50	5.43	1.46	1.27	1.66	0.82
WSQOP	-10	0.40	0.27	0.28	0.37	0.33	0.20	0.82	0.72	0.19	0.17	0.23	0.12
WSQOP	10	-0.34	-0.23	-0.24	-0.32	-0.29	-0.17	-0.69	-0.57	-0.16	-0.14	-0.20	-0.10
WSQOP	50	-1.43	-1.00	-1.16	-1.34	-1.07	-0.71	-2.56	-2.21	-0.60	-0.52	-0.86	-0.41
MON-IFLW CONC	-100	-77.62	-87.12	-90.70	-92.29	-75.11	-82.49	-52.62	-59.24	-83.64	-53.83	-68.42	-74.58
MON-IFLW CONC	-50	-31.33	-39.40	-38.76	-40.68	-30.35	-37.07	-20.84	-24.96	-36.91	-21.36	-29.70	-31.44
MON-IFLW CONC	50	26.79	35.76	34.48	36.57	26.36	33.60	17.34	21.59	33.10	18.22	26.80	27.56
MON-IFLW CONC	100	52.64	71.54	68.60	72.99	52.11	67.19	33.80	42.60	66.00	35.81	53.54	54.56

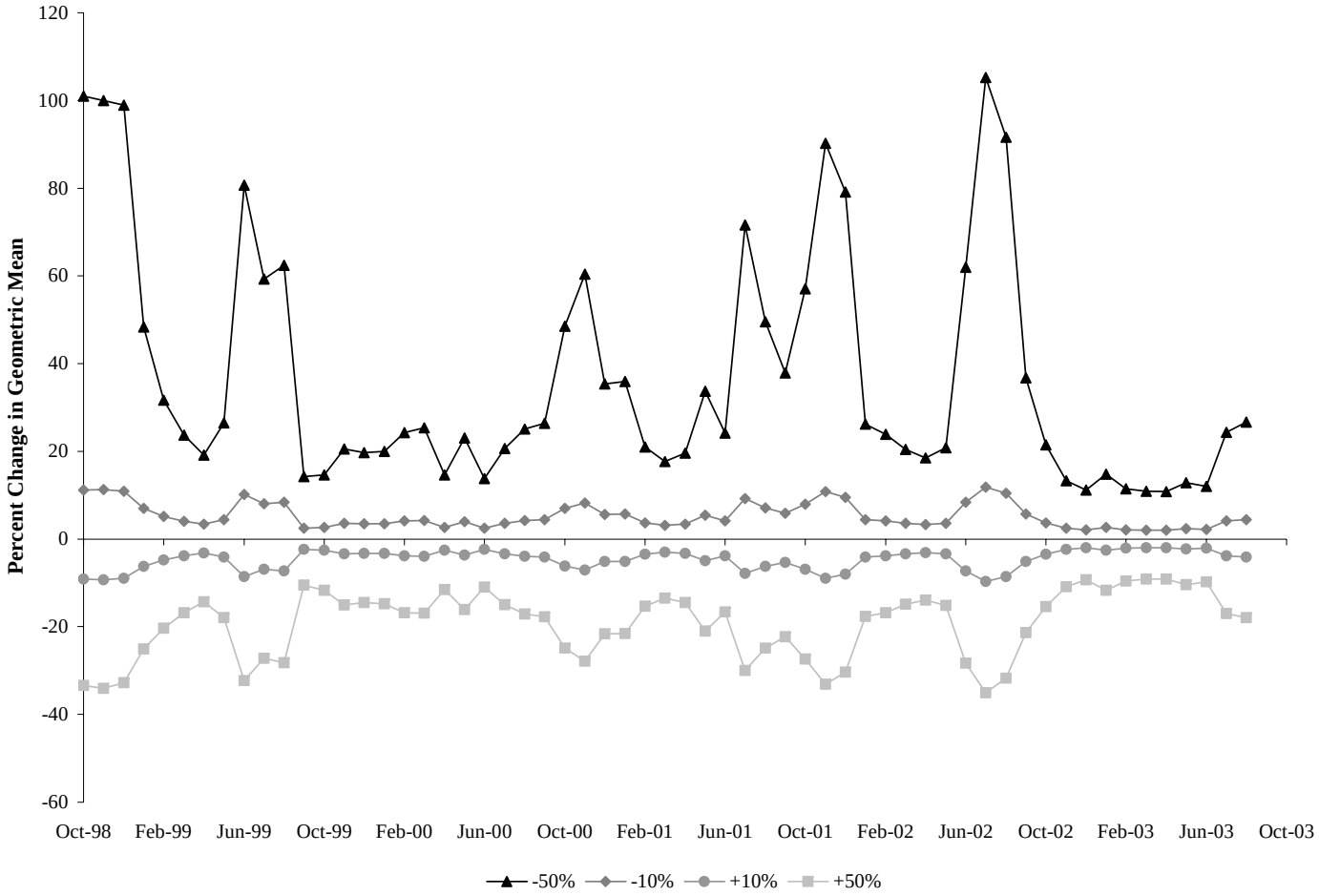

Figure 4.14 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 3, as affected by changes in the in-stream first-order decay rate (FSTDEC).

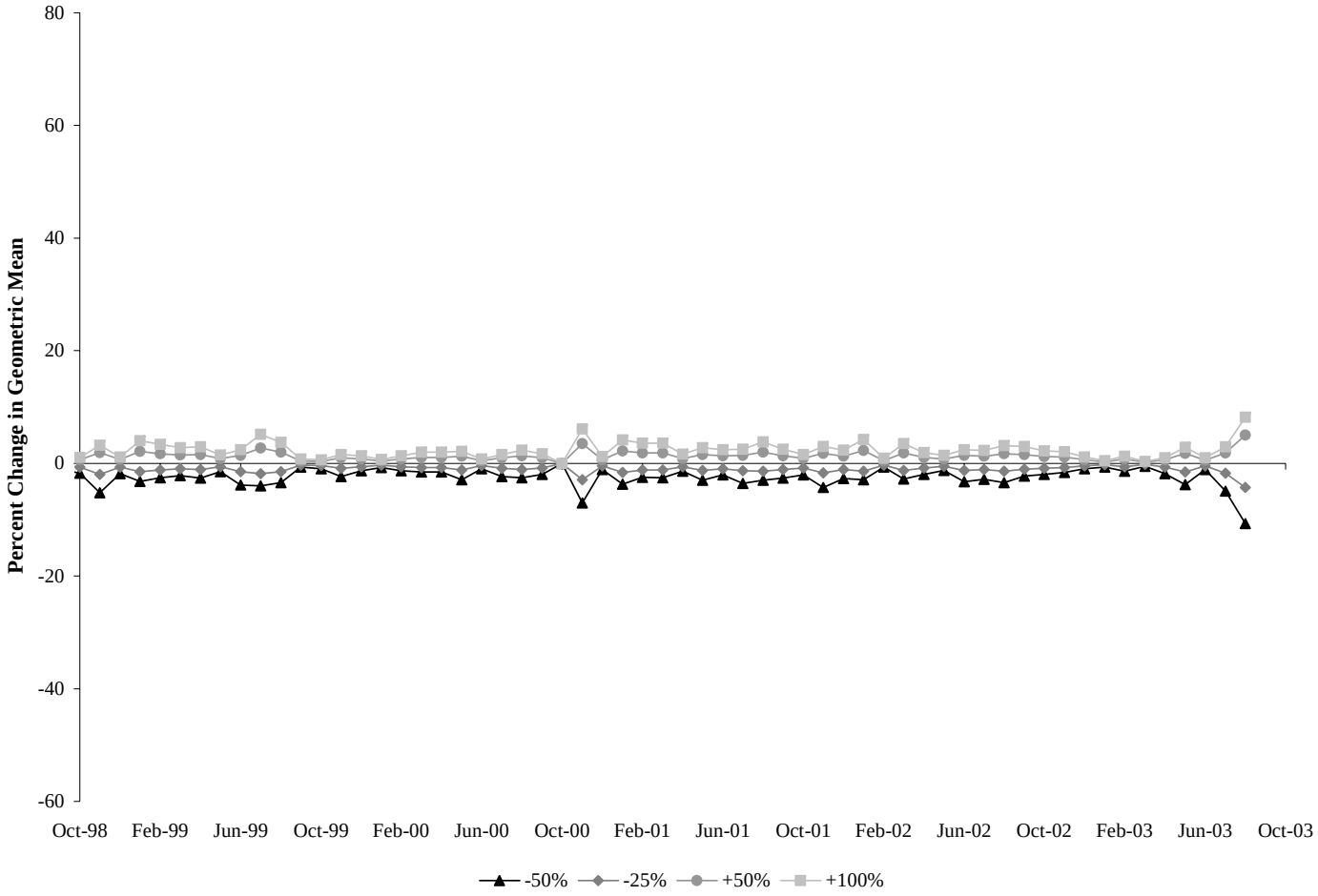

Figure 4.15 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 3, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

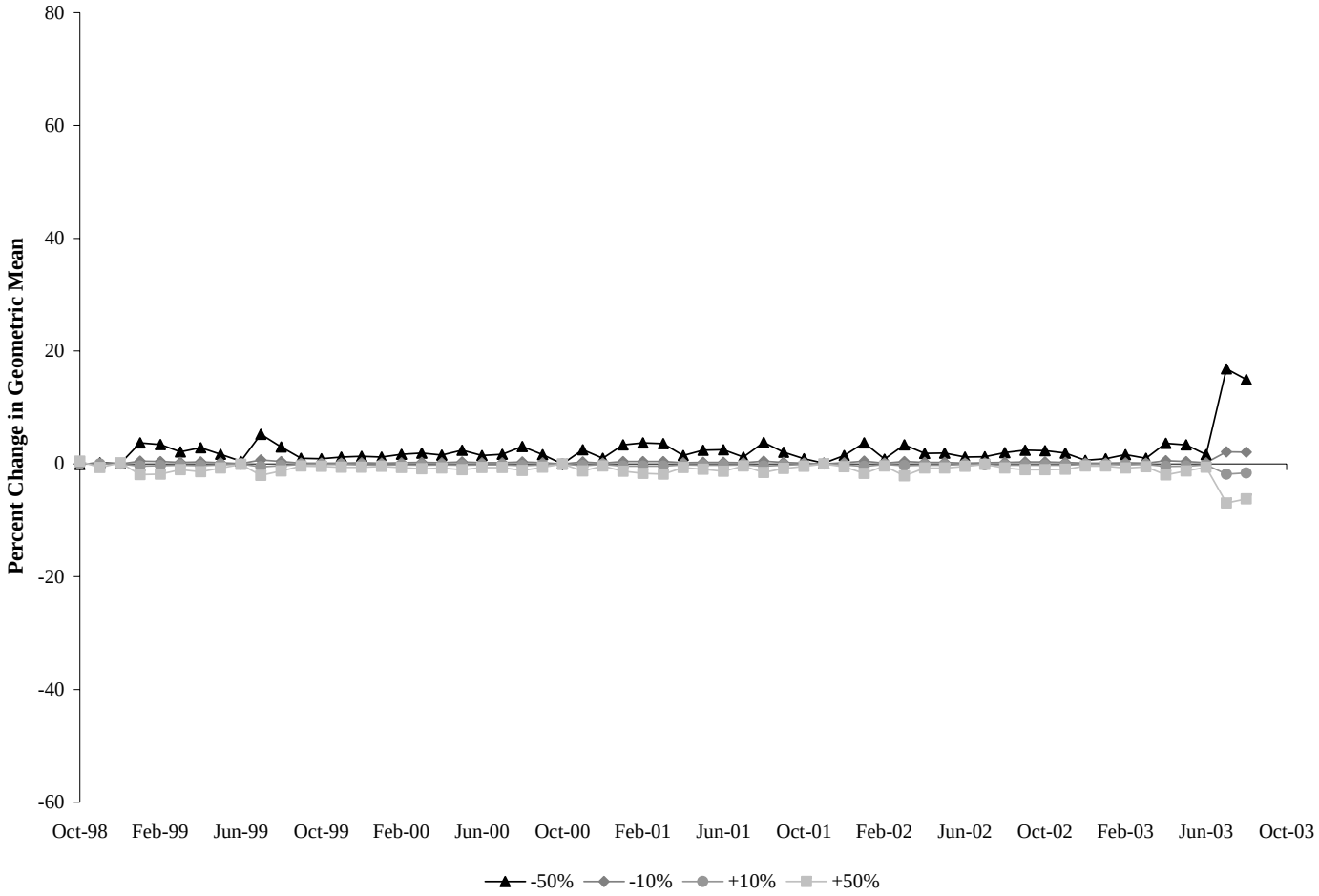

Figure 4.16 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 3, as affected by changes in the wash-off rate from land surfaces (WSQOP).

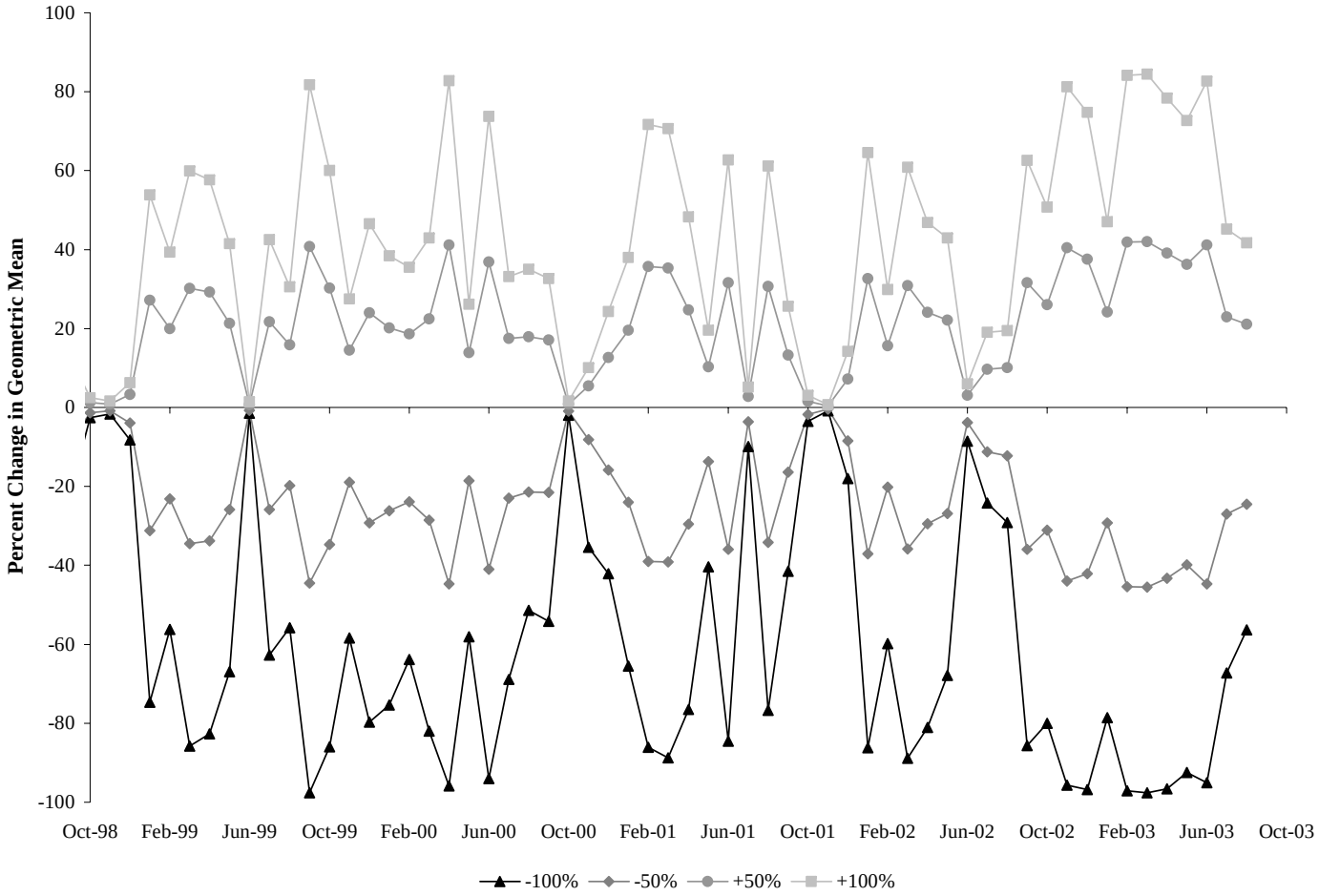

Figure 4.17 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 3, as affected by changes in the concentration of fecal bacteria in interflow (MON-IFLW-CONC).

Table 4.16 Percent change in average monthly *E. coli* geometric mean for the years 1998-2003 for Model Segment 5.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2003											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	20.74	19.87	21.69	22.45	49.15	60.20	66.56	49.78	42.75	62.18	64.68	39.96
FSTDEC	-10	3.57	3.43	3.68	3.78	6.81	7.39	8.40	6.75	6.01	7.92	7.91	5.71
FSTDEC	10	-3.56	-3.42	-3.66	-3.74	-6.32	-6.68	-7.58	-6.25	-5.59	-7.17	-7.11	-5.39
FSTDEC	50	-15.60	-15.05	-15.93	-16.19	-24.83	-25.54	-28.65	-24.60	-22.13	-27.31	-26.90	-21.75
SQOLIM	-50	-10.73	-7.66	-9.37	-6.75	-6.53	-5.72	-6.16	-6.48	-6.30	-3.54	-4.85	-7.09
SQOLIM	-25	-5.05	-3.63	-4.35	-3.11	-2.93	-2.55	-2.83	-3.02	-2.93	-1.62	-2.11	-3.29
SQOLIM	50	7.61	5.57	6.48	4.62	4.18	3.52	4.05	4.44	4.35	2.43	2.78	4.89
SQOLIM	100	13.68	10.21	11.75	8.36	7.44	6.22	7.29	8.01	7.89	4.41	4.85	8.78
WSQOP	-50	13.87	10.25	12.27	8.28	8.09	6.20	6.97	8.06	7.31	4.35	4.14	9.68
WSQOP	-10	1.88	1.38	1.66	1.14	1.09	0.82	0.92	1.07	0.96	0.55	0.55	1.26
WSQOP	10	-1.63	-1.20	-1.44	-1.00	-0.95	-0.71	-0.80	-0.93	-0.83	-0.47	-0.48	-1.08
WSQOP	50	-6.47	-4.77	-5.75	-4.02	-3.78	-2.77	-3.16	-3.65	-3.27	-1.83	-1.92	-4.23
MON-IFLW CONC	-100	-24.98	-26.35	-27.04	-25.23	-8.56	-8.06	-7.50	-7.17	-19.43	-7.26	-5.84	-13.70
MON-IFLW CONC	-50	-11.50	-12.25	-11.49	-14.52	-5.07	-4.84	-3.62	-4.98	-10.29	-3.28	-2.76	-6.37
MON-IFLW CONC	50	10.20	10.99	9.90	12.86	4.37	4.35	3.14	4.33	8.72	2.93	2.44	5.60
MON-IFLW CONC	100	19.63	21.26	18.90	24.77	8.35	8.44	6.06	8.34	16.62	5.69	4.67	10.73

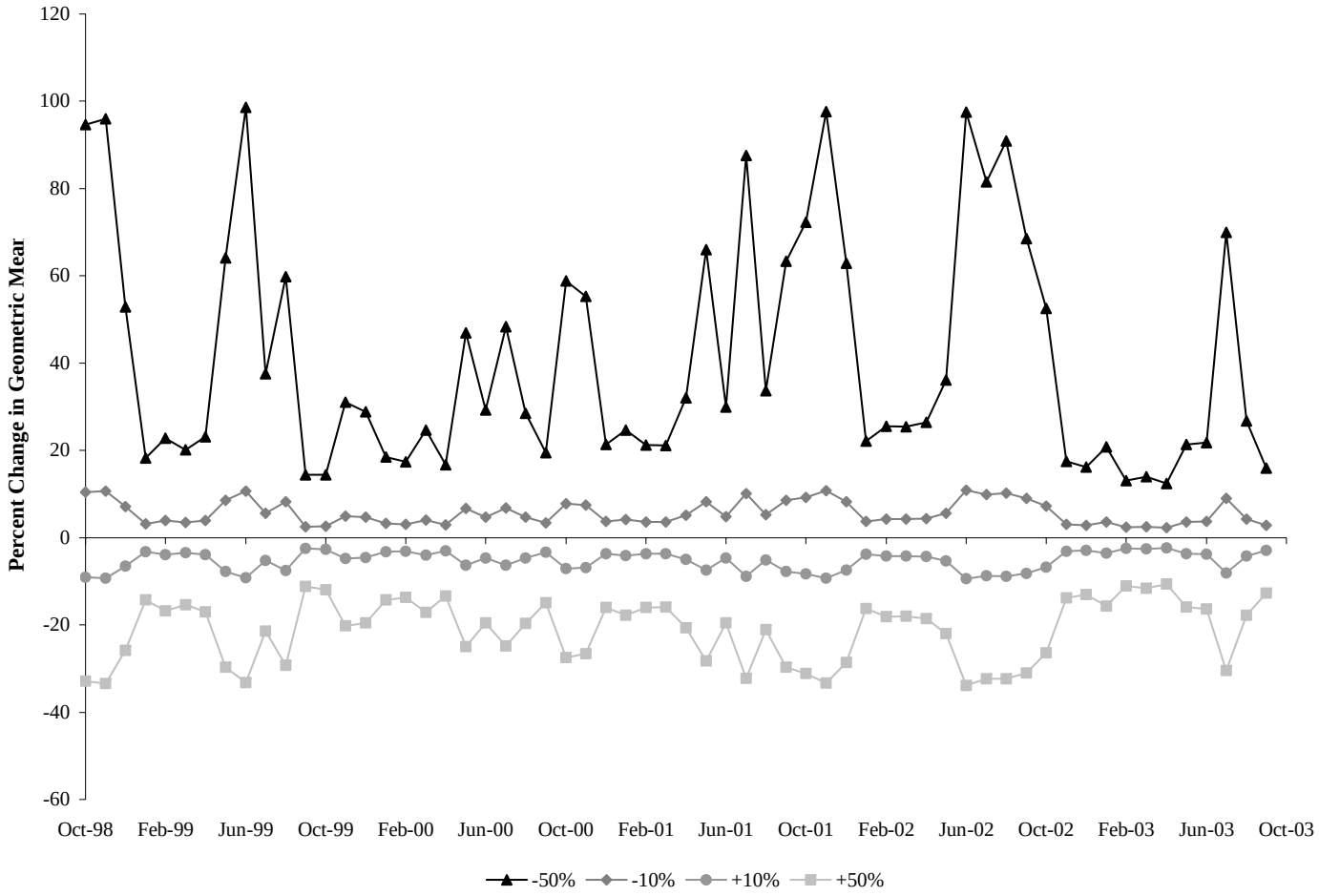

Figure 4.18 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 5, as affected by changes in the in-stream first-order decay rate (FSTDEC).

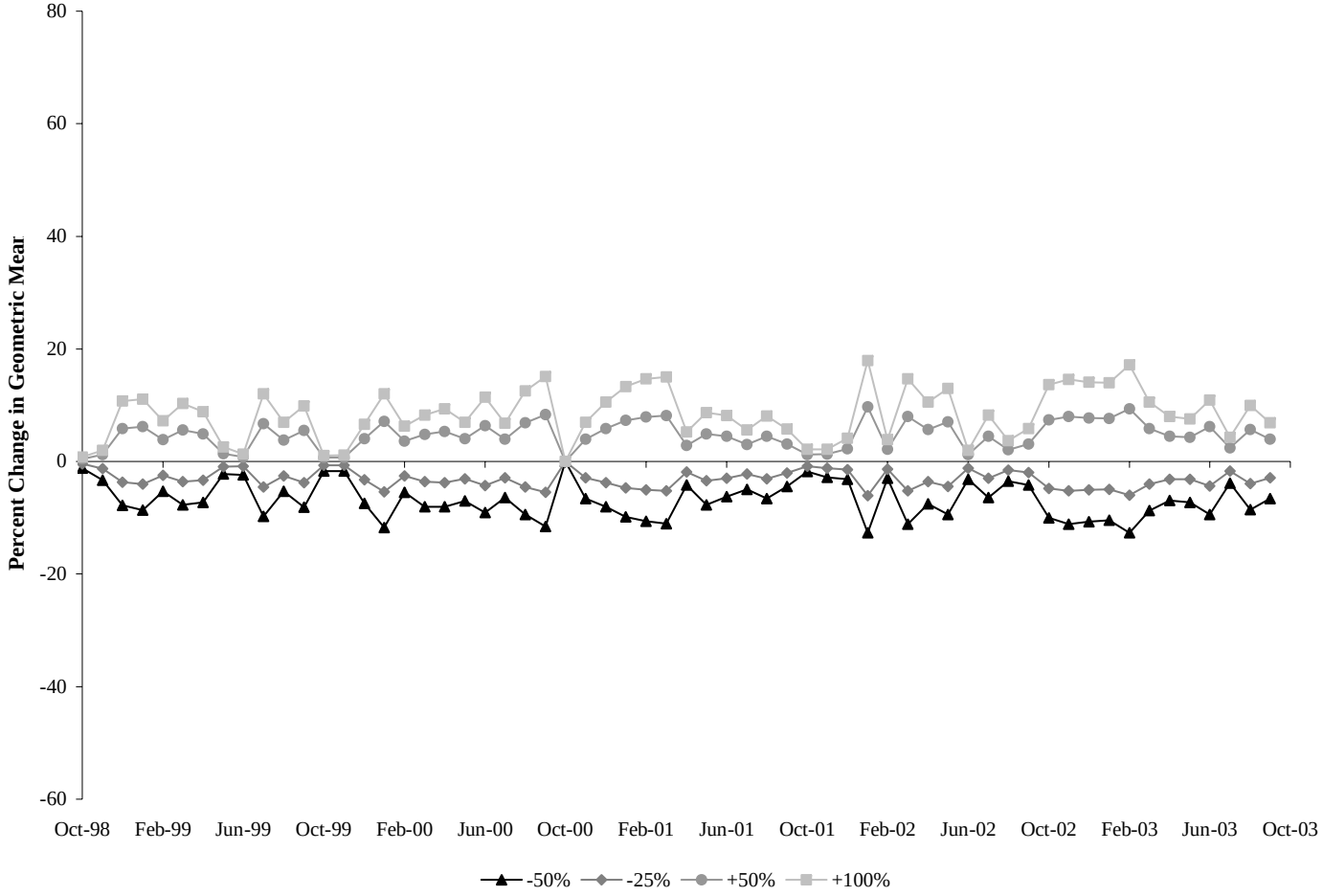

Figure 4.19 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 5, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

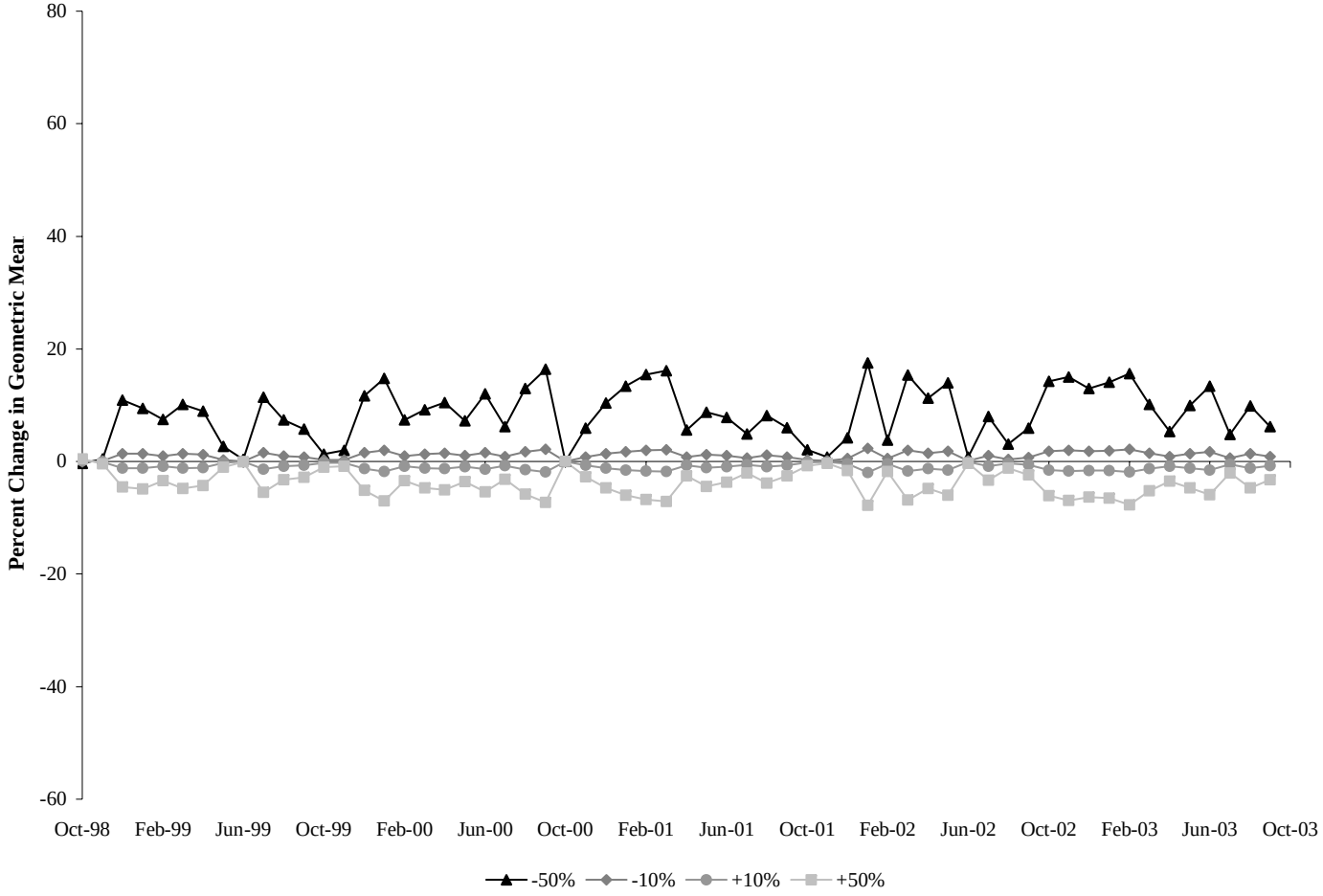

Figure 4.20 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 5, as affected by changes in the wash-off rate from land surfaces (WSQOP).

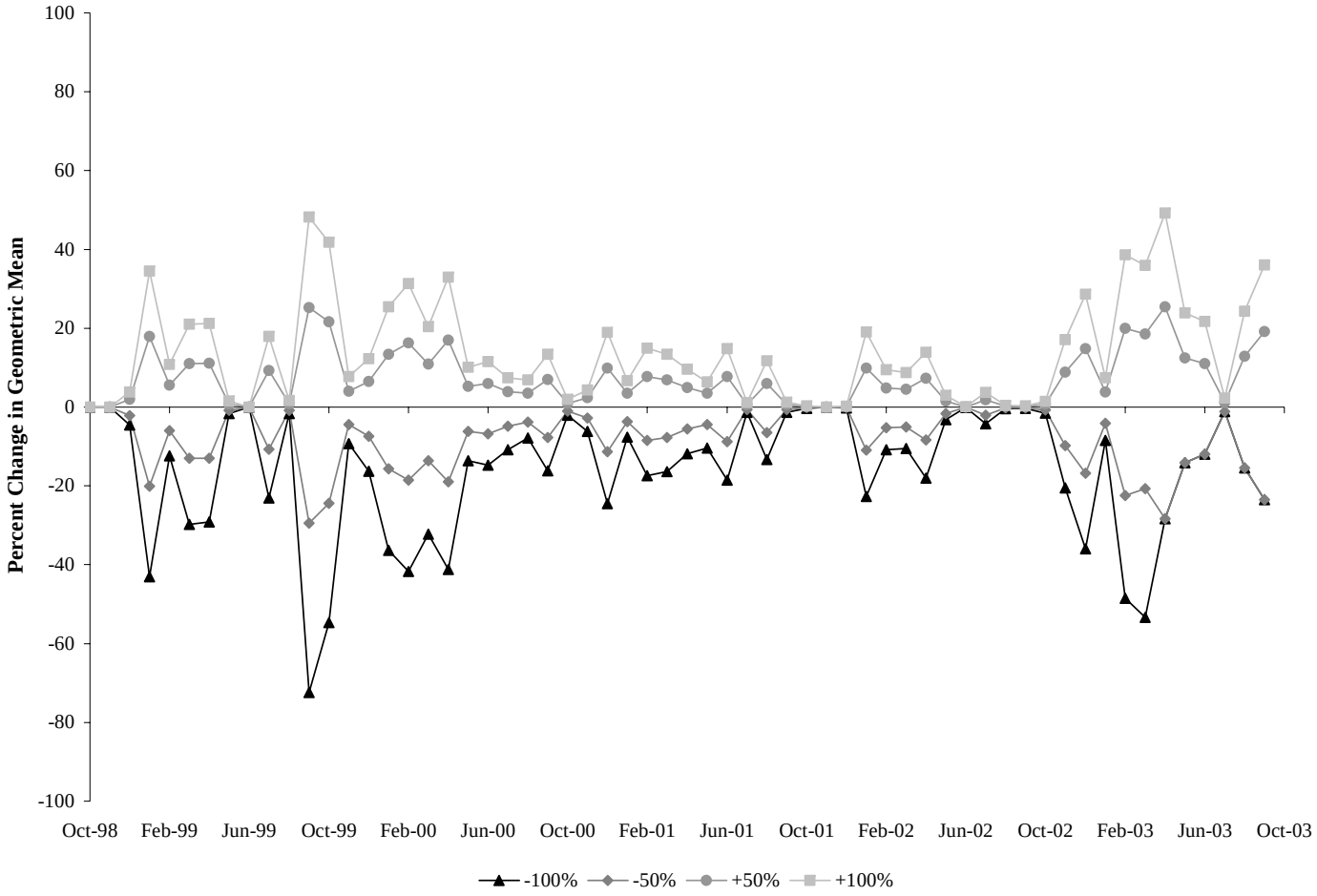

Figure 4.21 Results of sensitivity analysis on monthly geometric-mean concentrations in Model Segment 5, as affected by changes in the concentration of fecal bacteria in interflow (MON-IFLW-CONC).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. It is evident in Figures 4.22 through 4.24 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs greatly between land applied and direct loadings; a 100% increase in the land applied loads results in an increase of over 90% in stream loads, while a 100% increase in direct loads results in less than a 10% increase in stream loads. In contrast, the sensitivity analysis of geometric mean concentrations showed that direct loads had the greatest impact, with land applied loads having a lesser, but still significant impact (Figures 4.25 through 4.30).

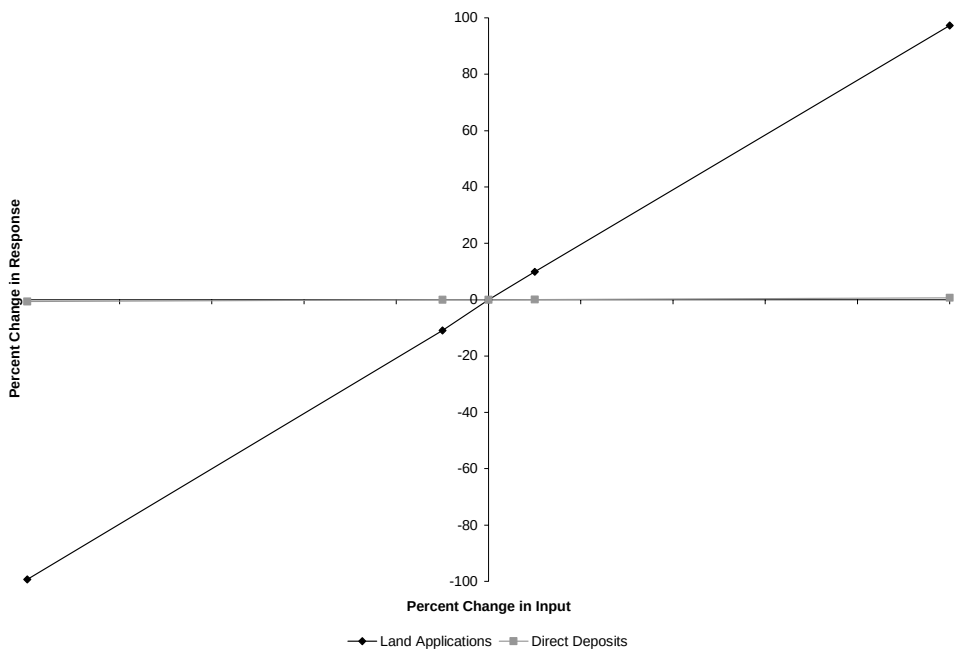

Figure 4.22 Results of total loading sensitivity analysis for segment 1, Nottoway River.

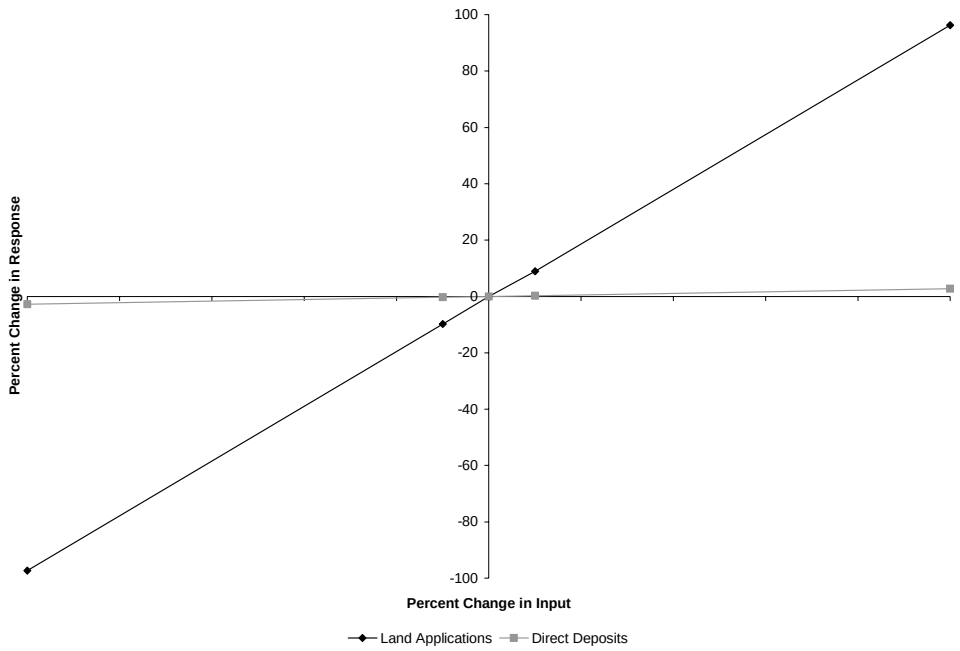

Figure 4.23 Results of total loading sensitivity analysis for segment 3, Sappony Creek.

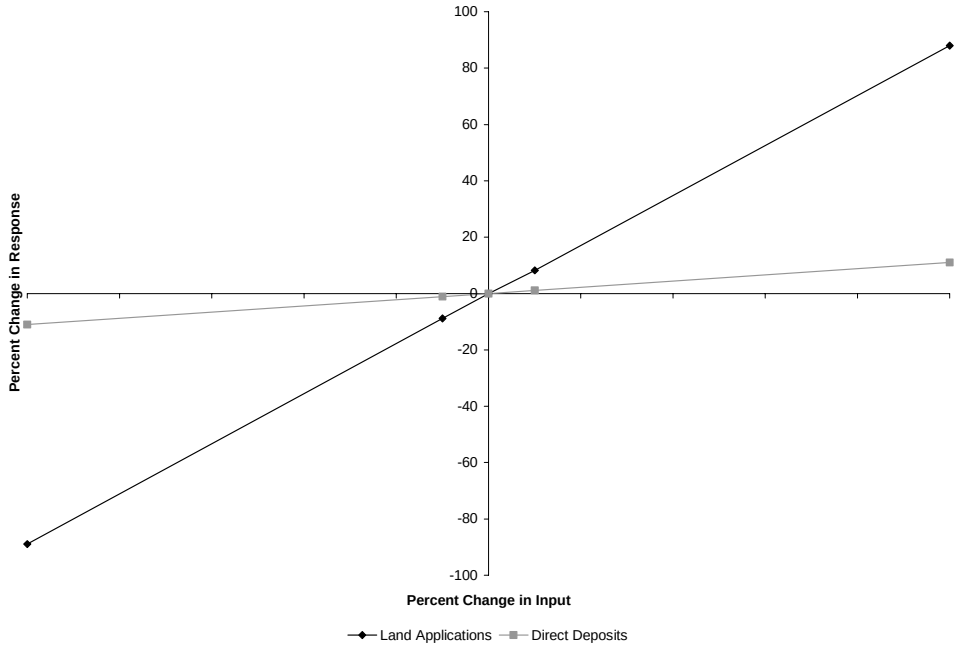

Figure 4.24 Results of total loading sensitivity analysis for segment 5, Cypress Swamp.

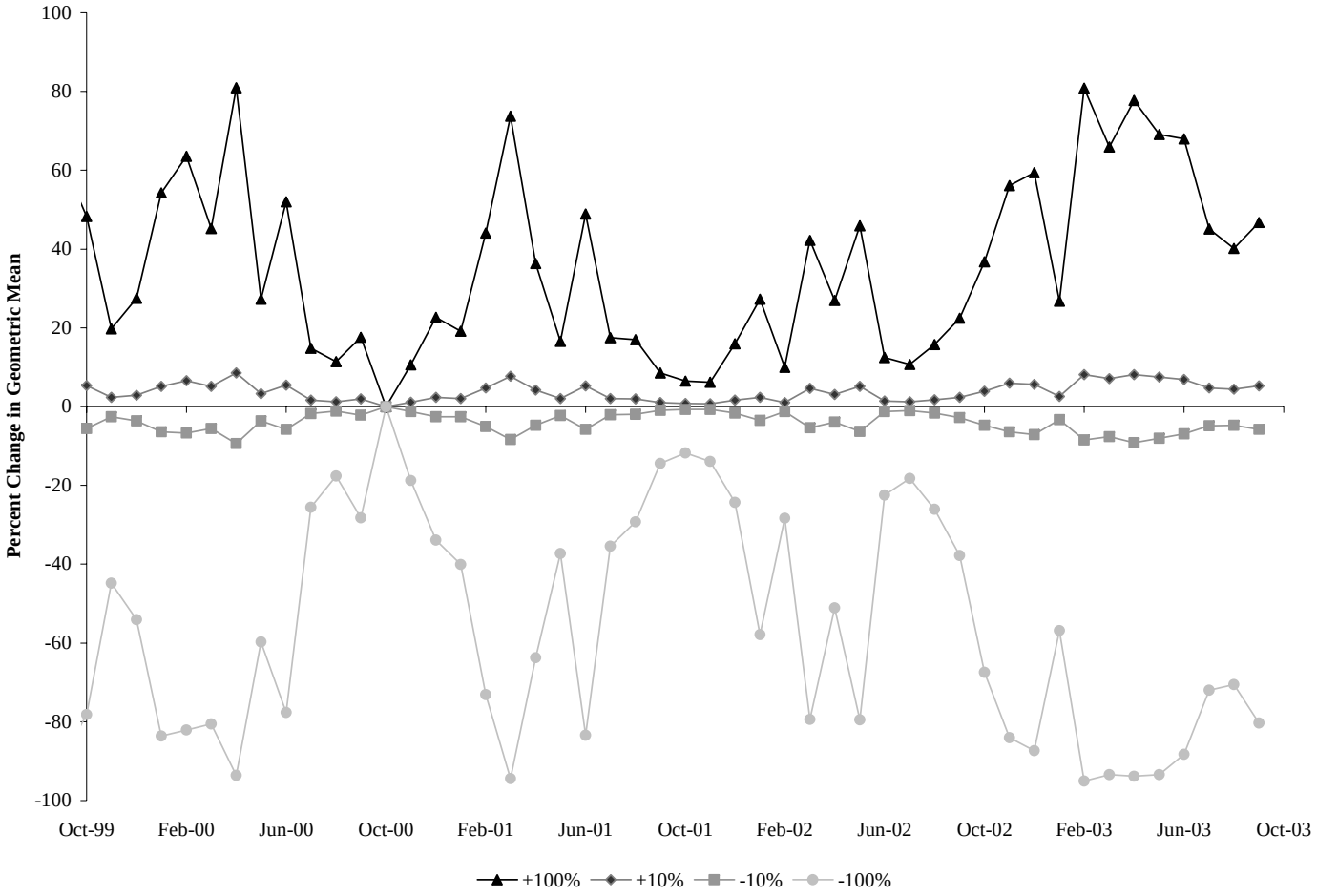

Figure 4.25 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 1, Nottoway River watershed, as affected by changes in land-based loadings.

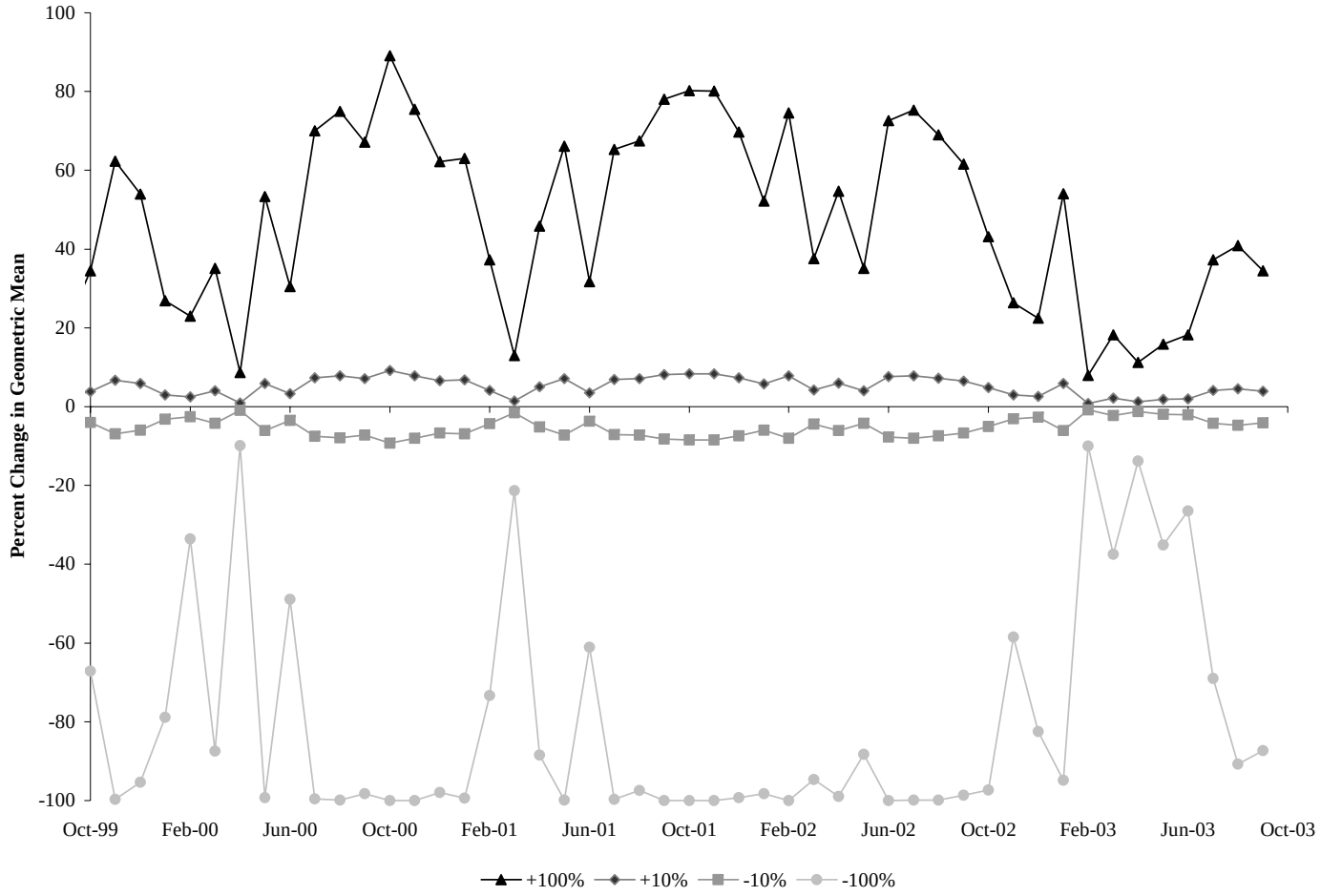

Figure 4.26 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 1, Nottoway River watershed, as affected by changes in loadings from direct nonpoint sources.

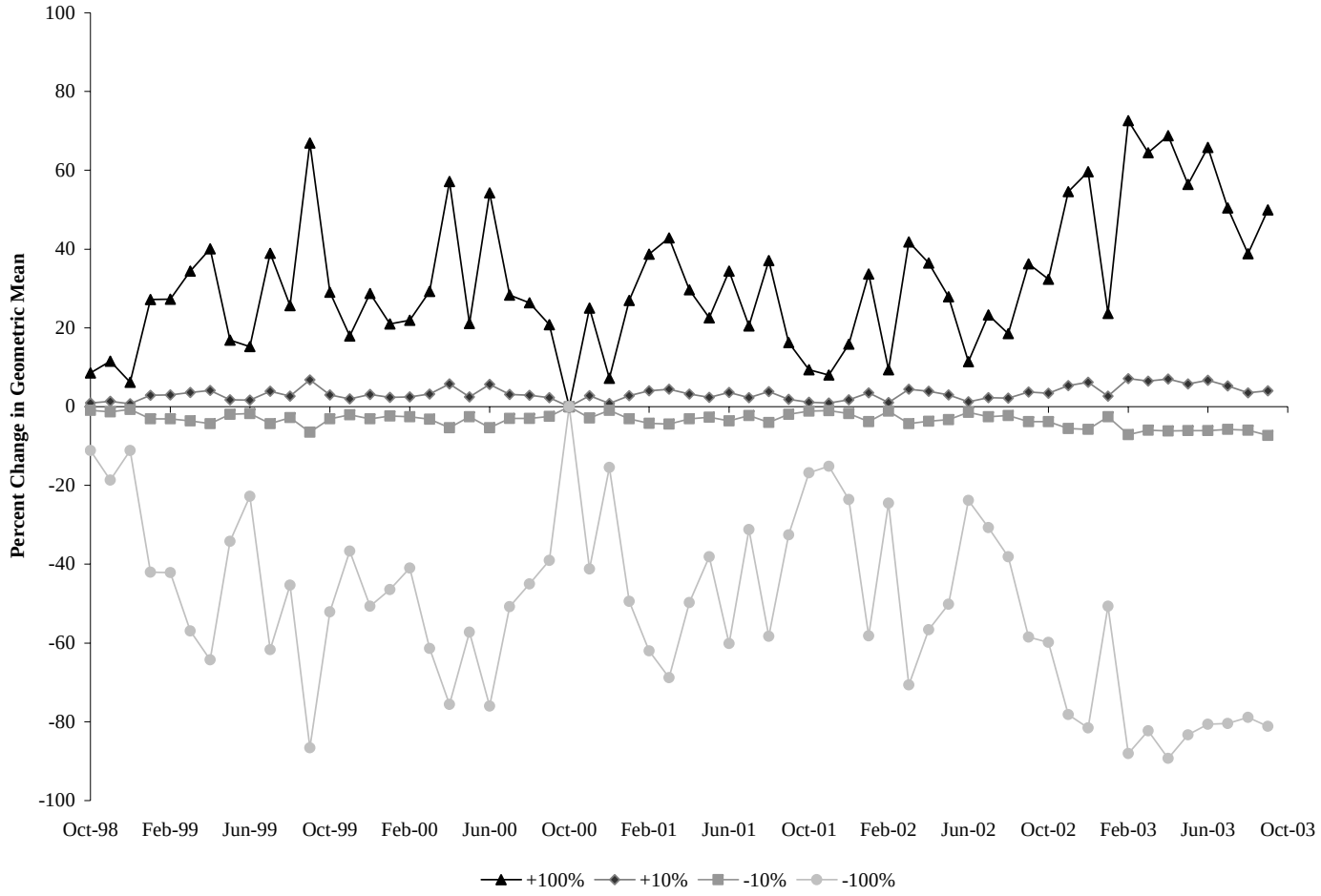

Figure 4.27 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 3, Sappony Creek watershed, as affected by changes in land-based loadings.

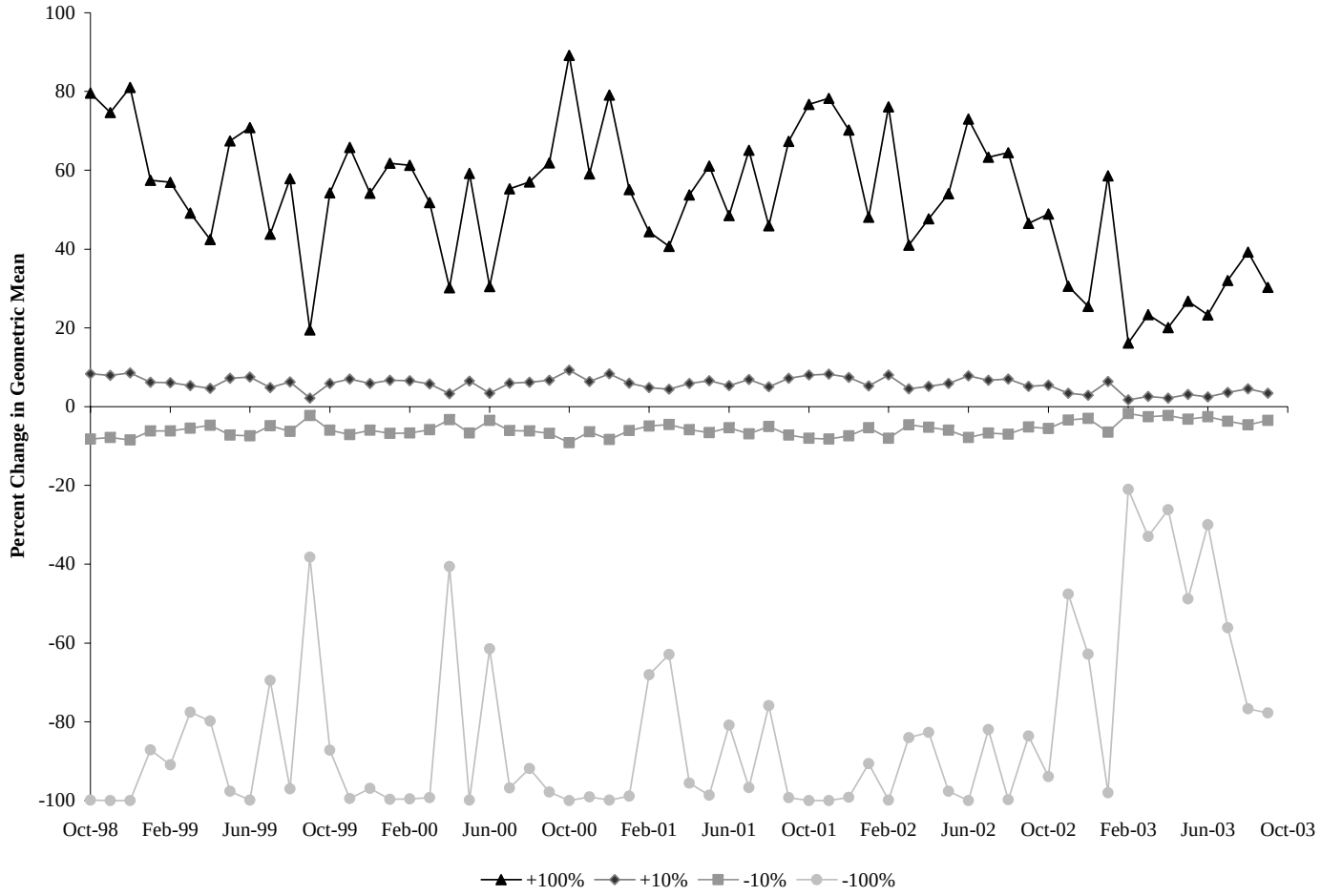

Figure 4.28 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 3, Sappony Creek watershed, as affected by changes in loadings from direct nonpoint sources.

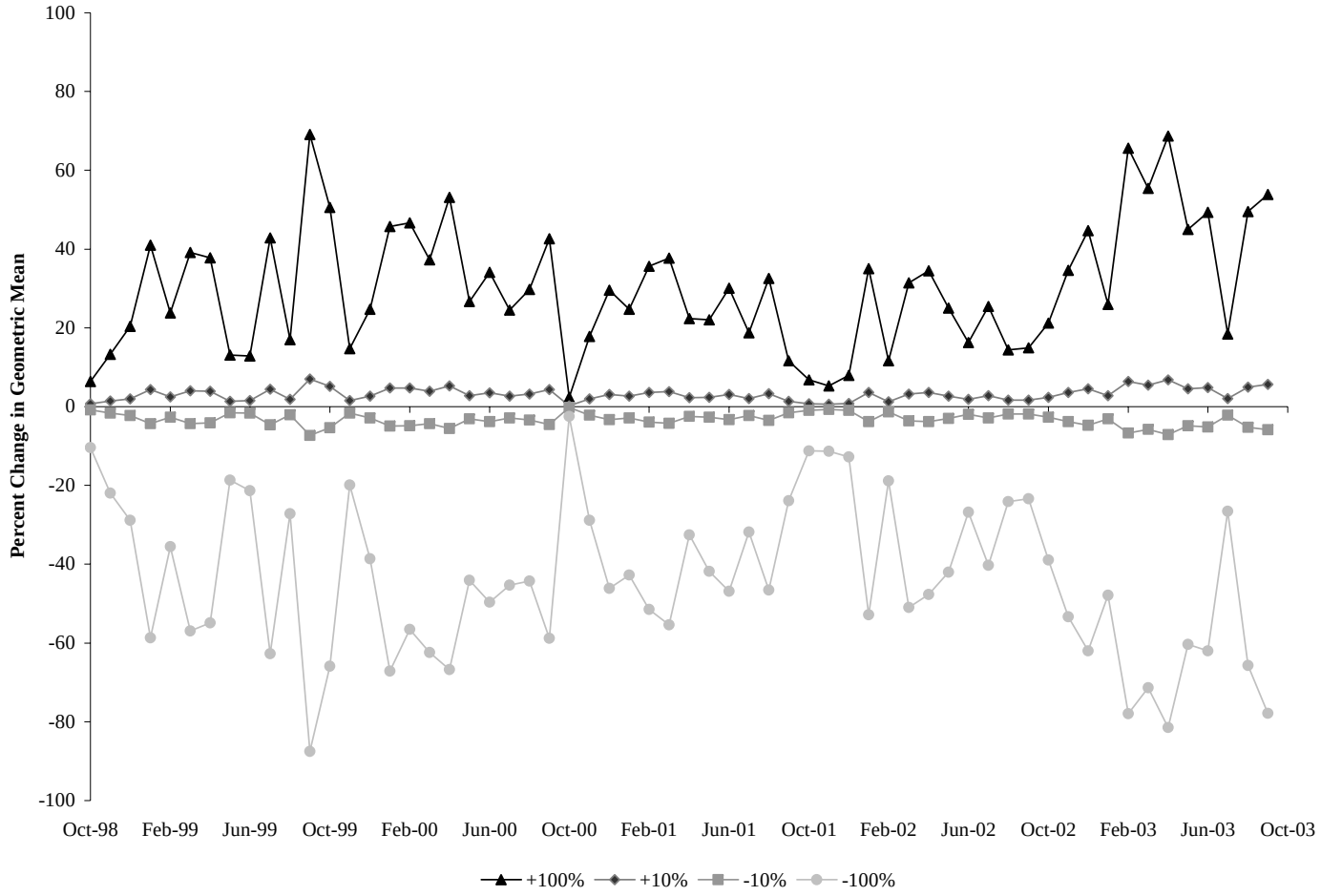

Figure 4.29 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 5, Cypress Swamp watershed, as affected by changes in land-based loadings.

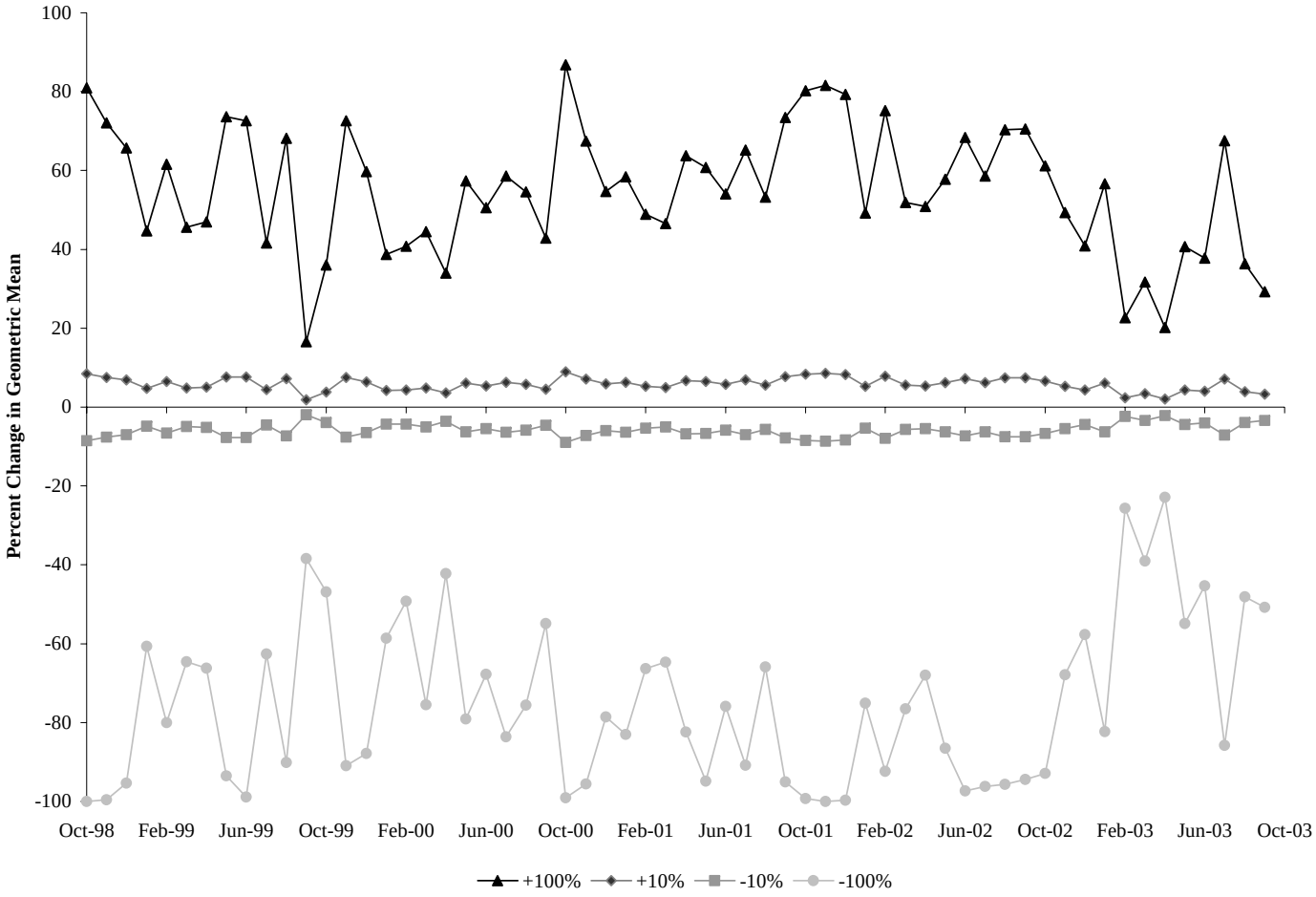

Figure 4.30 Results of sensitivity analysis on monthly geometric-mean concentrations in segment 5, Cypress Swamp watershed, as affected by changes in loadings from direct nonpoint sources.

4.7 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, landuse, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

4.7.1 Hydrologic Calibration and Validation

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (SLSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), forest coverage (FOREST), slope of overland flow plane (LSUR), groundwater recession flow (KVARY), maximum and minimum air temperature affecting PET (PETMAX, PETMIN, respectively), infiltration equation exponent (INFEXP), infiltration capacity ratio (INFILD), active groundwater storage PET (AGWETP), Manning's *n* for overland flow plane (NSUR), interception (RETSC), and the weighting factor for hydraulic routing (KS). Table 4.17 contains the typical range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

The model was calibrated for hydrologic accuracy using daily flow data from USGS Gaging Stations 02044500, 02045500 and 02047000 on the Nottoway River for the period October 1990 through September 1995 (Table 4.18), and USGS Gaging Station 02047500 on the Blackwater River for the period October 1990 through September 1995 (Table 4.19). Figures 4.25 through 4.36 display comparisons of modeled versus observed data for the entire calibration period, representative single water years, and for individual storms for each calibration station.

NCDC weather stations Camp Pickett (441322), Emporia (448129), Stony Creek (442790), Hopewell (444101), and Holland (444044) were used to supply precipitation input for the HSPF model. For the entire modeling period, only daily precipitation values were available, thus daily rainfall values were interpolated to hourly values in order to provide model input on an hourly basis. This interpolation was performed in an HSPF utility called WDMUtil, and is referred to as disaggregation. In this process, a daily rainfall total is divided up into hourly values using a representative distribution scheme. Daily values were disaggregated using two different schemes: 1) a station matching disaggregation scheme and 2) a triangular disaggregation scheme. The station matching procedure involved identifying a rain gage reporting hourly data in close proximity to the Chowan Study Area whose daily total precipitation was within 5% of the total daily precipitation value of a station within the study area. In this case, the distribution of rainfall at the station within the watershed was disaggregated based on the precipitation pattern reported at the hourly station. When this condition failed, the precipitation was disaggregated based on a triangular distribution, over an 8-hour period.

Table 4.17 Model parameters utilized for hydrologic calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	1	1
LZSN	in	2.0 – 15.0	0.0-12.64	0.0-12.93
INFILT	in/hr	0.001 – 0.50	0.05-0.37	0.03-0.42
LSUR	ft	100 – 700	0.0-1097.44	7.5-1097.43
SLSUR	---	0.001 – 0.30	0.0-0.05	0.0-0.05
KVARY	l/in	0.0 – 5.0	0.0	0.0
AGWRC	l/day	0.85 – 0.999	0.98	0.895 – 0.986
PETMAX	degF	32.0 – 48.0	40.0	40.0
PETMIN	degF	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.01	0.04 – 0.37
BASETP	---	0.0 – 0.20	0.01	0.06– 0.13
AGWETP	---	0.0 – 0.20	0.0	0.0 – 0.7
CEPSC	in	0.01 - 0.40	0.0 – 0.2	0.03 – 0.3
UZSN	in	0.05 – 2.0	0.0–1.647	0.07– 1.88
NSUR	---	0.10 – 0.50	0.001 – 0.6	0.05 – 0.60
INTFW	---	1.0 – 10.0	1	2.0 – 10.0
IRC	l/day	0.30 – 0.85	0.50	0.5 – 0.8
LZETP	---	0.1 – 0.9	0.0 – 0.8	0.01 – 0.92
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

Table 4.18 Hydrology calibration criteria and model performance for period 10/1/1990 through 9/30/1995 at USGS Gaging Station 02044500 on Nottoway River (model segment 2, subshed 13).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	48.57	47.29	-2.62%
Upper 10% Flow Values:	22.02	21.42	-2.73%
Lower 50% Flow Values:	6.85	6.37	-6.89%
Winter Flow Volume	24.90	24.45	-1.78%
Spring Flow Volume	12.68	13.91	9.65%
Summer Flow Volume	4.48	3.50	-21.86%
Fall Flow Volume	6.50	5.43	-16.51%
Total Storm Volume	45.46	46.35	1.94%
Winter Storm Volume	24.13	24.22	-0.38%
Spring Storm Volume	11.90	13.67	14.81%
Summer Storm Volume	3.71	3.28	-11.75%
Fall Storm Volume	5.72	5.19	-9.32%

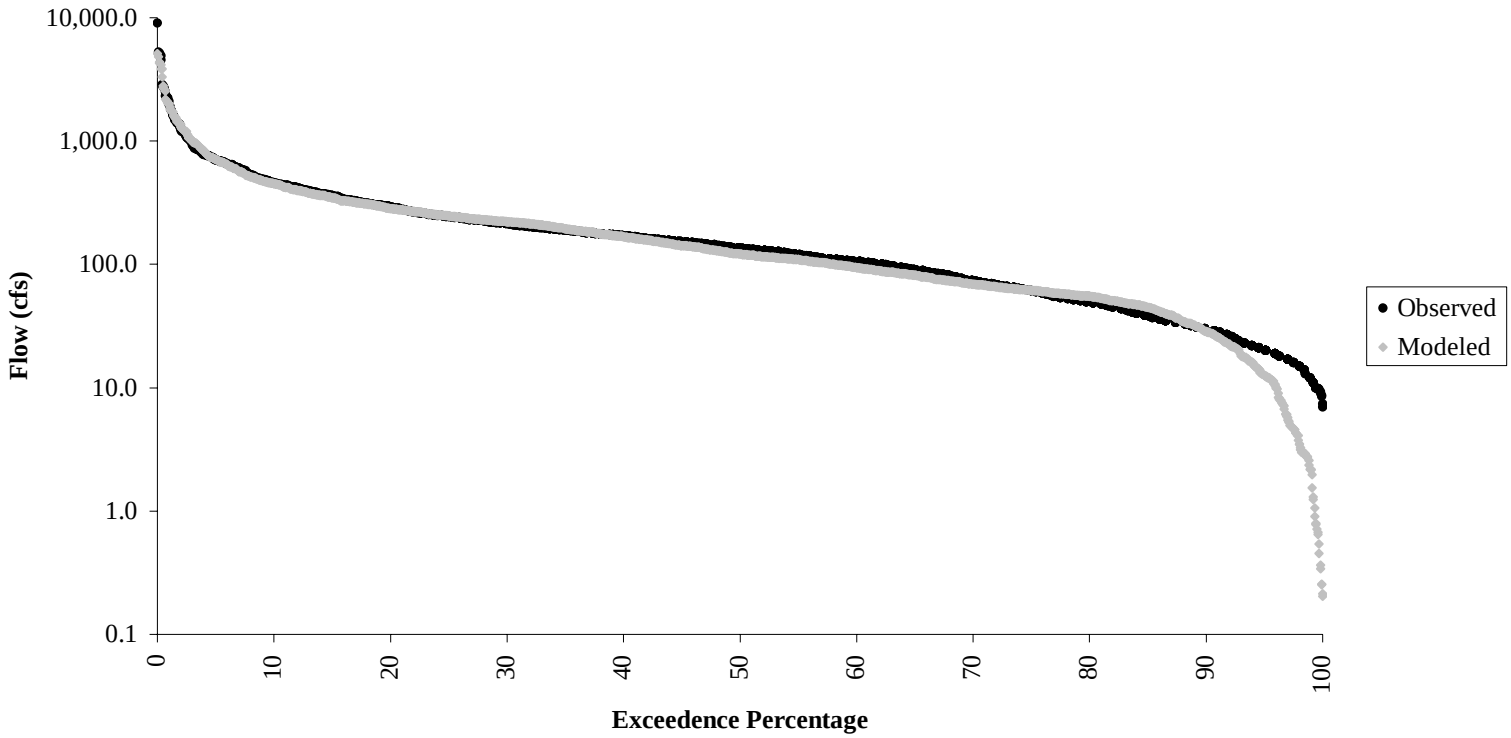

Figure 4.31 Nottoway River flow duration at USGS Gaging Station 02044500 for calibration period 10/1/1990 through 9/30/1995 (model segment 2, subshed 13).

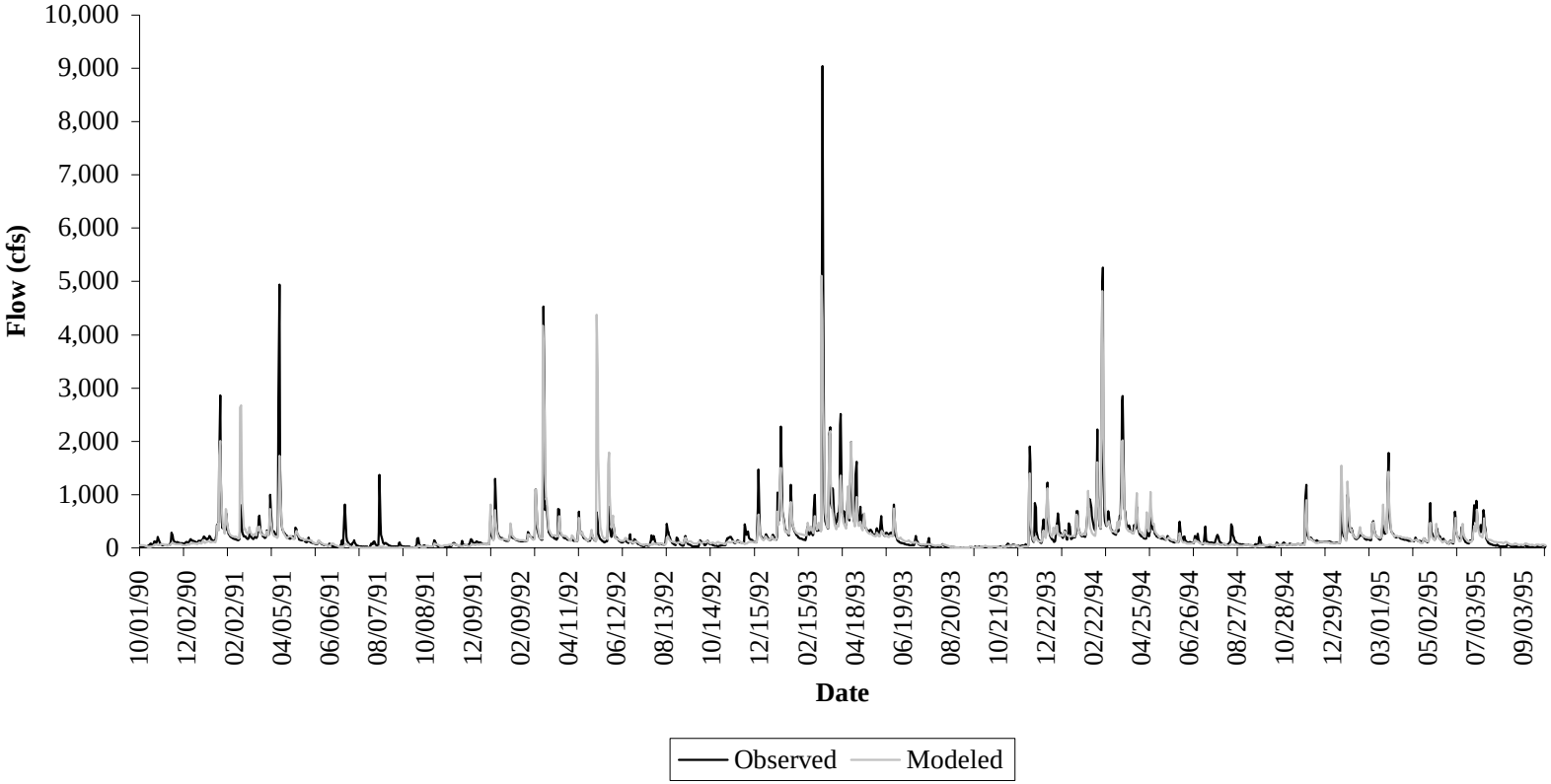

Figure 4.32 Calibration results for period 10/1/1990 through 9/30/1995 at USGS Gaging Station 02044500 on Nottoway River (model segment 2, subshed 13).

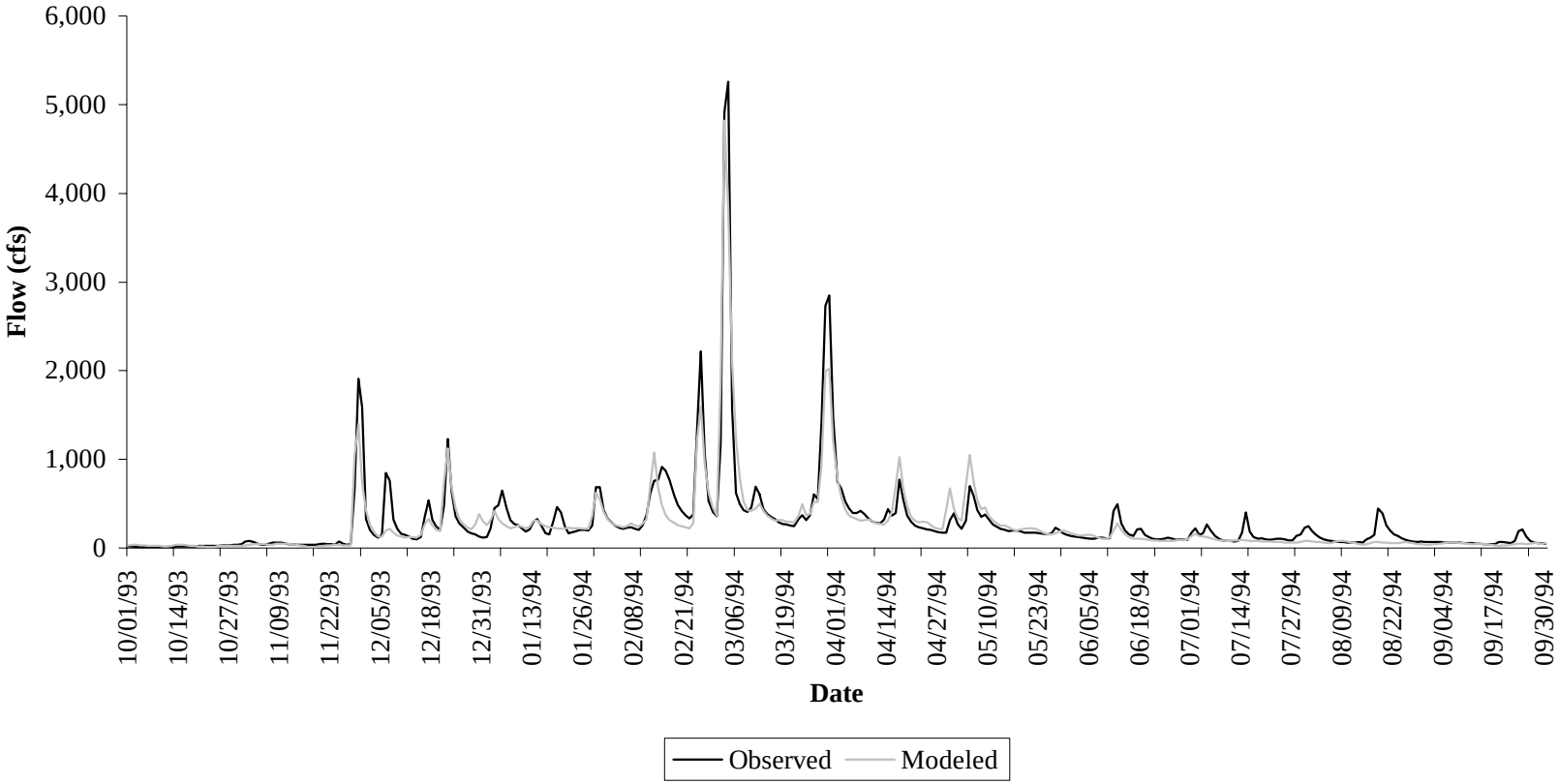

Figure 4.33 Calibration results for period 10/01/93 through 09/30/94 for USGS Gaging Station 02044500 on Nottoway River (model segment 2, subshed 13).

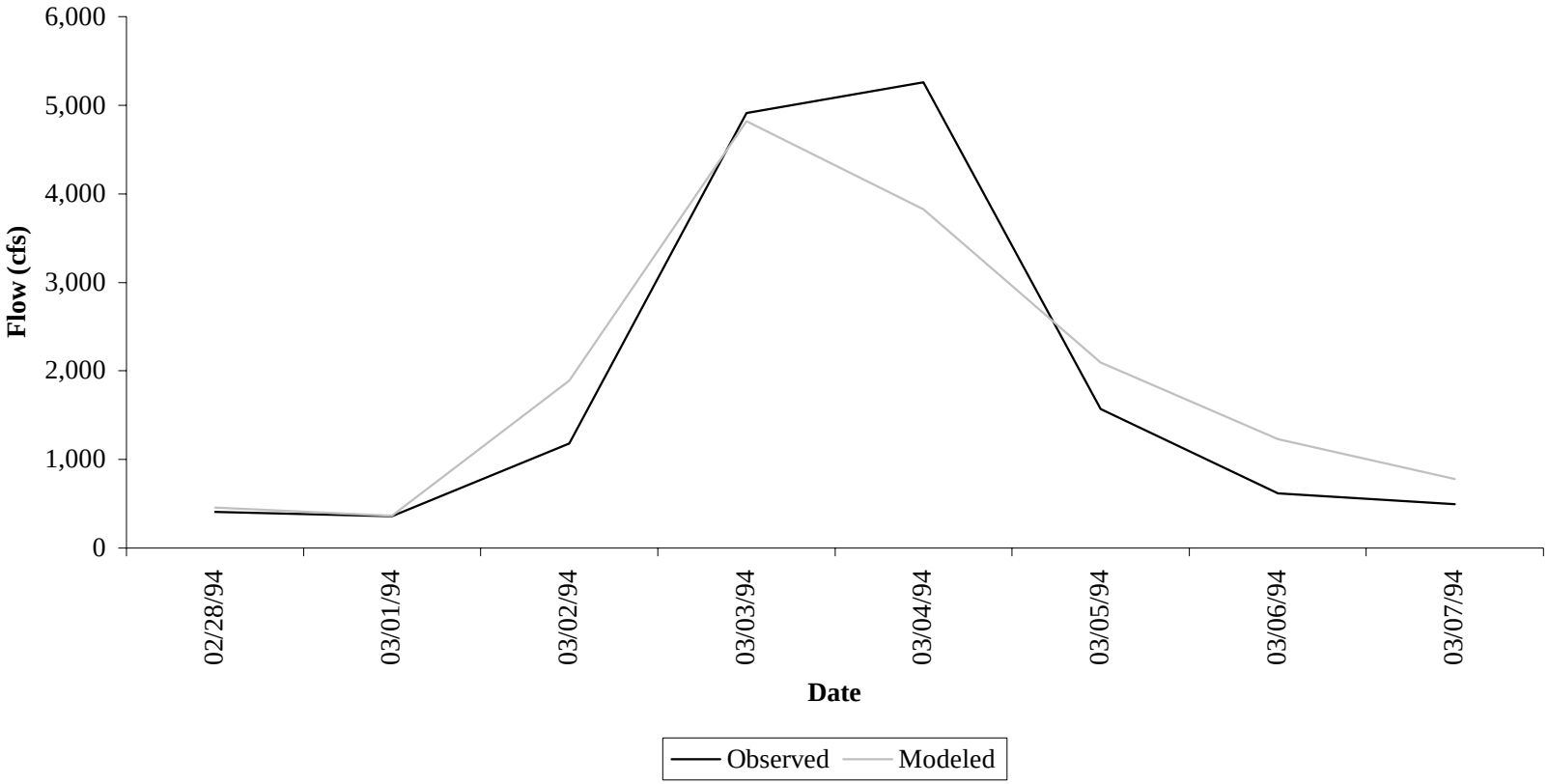

Figure 4.34 Calibration results for a single storm event at USGS Gaging Station 02044500 on Nottoway River (model segment 2, subshed 13).

Table 4.19 Hydrology calibration criteria and model performance for period 10/1/1991 through 9/30/1996 at USGS Gaging Station 02047500 on Upper Blackwater River (model segment 5, subshed 6).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	52.60	54.36	3.33%
Upper 10% Flow Values:	24.15	23.65	-2.06%
Lower 50% Flow Values:	3.97	3.87	-2.62%
Winter Flow Volume	29.14	27.55	-5.46%
Spring Flow Volume	13.51	14.20	5.09%
Summer Flow Volume	5.60	7.23	29.24%
Fall Flow Volume	4.36	5.37	23.35%
Total Storm Volume	52.60	54.36	3.33%
Winter Storm Volume	29.14	27.55	-5.46%
Spring Storm Volume	13.51	14.20	5.09%
Summer Storm Volume	5.60	7.23	29.24%
Fall Storm Volume	4.36	5.37	23.35%

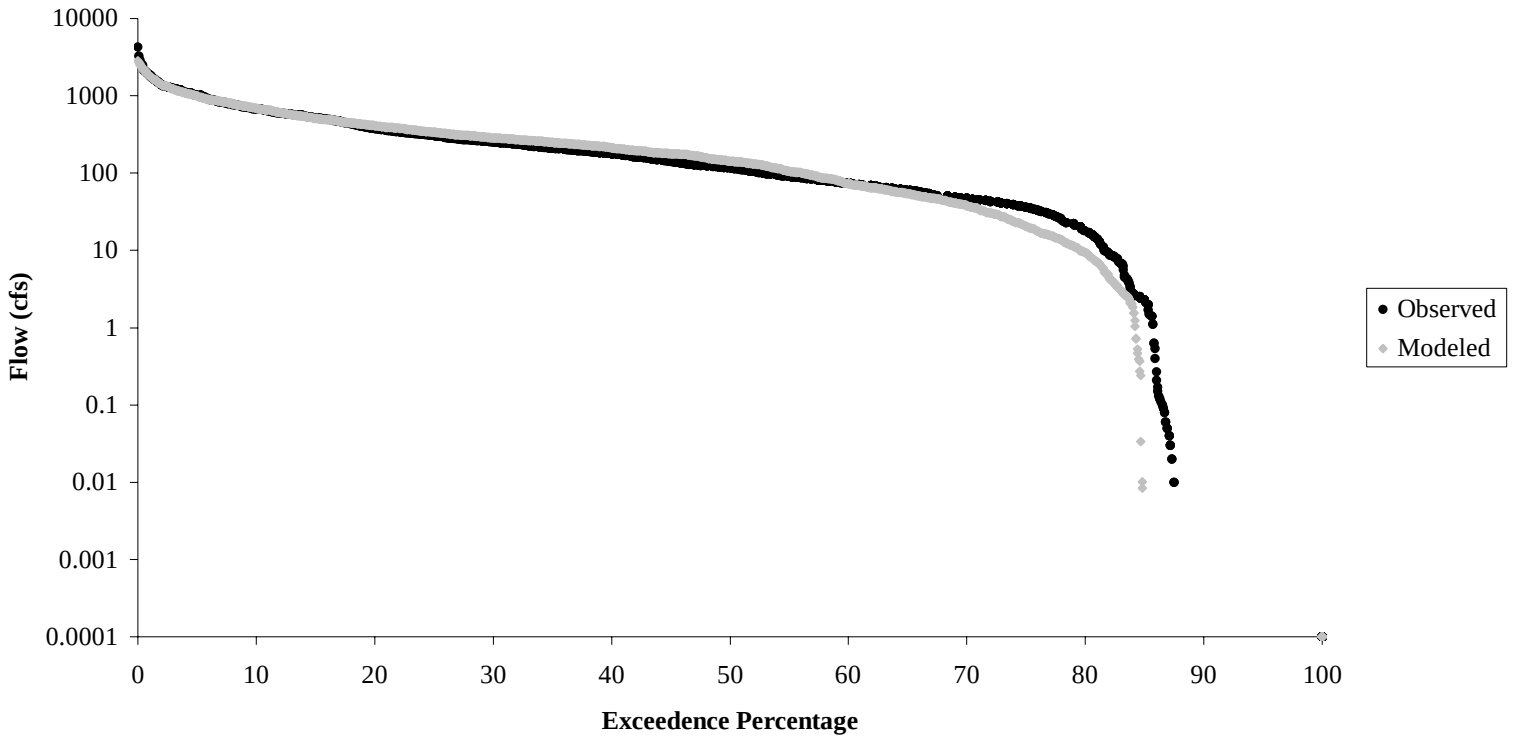

Figure 4.35 Blackwater River flow duration at USGS Gaging Station 02047500 for calibration period 10/1/1991 through 9/30/1996 (model segment 5, subshed 6).

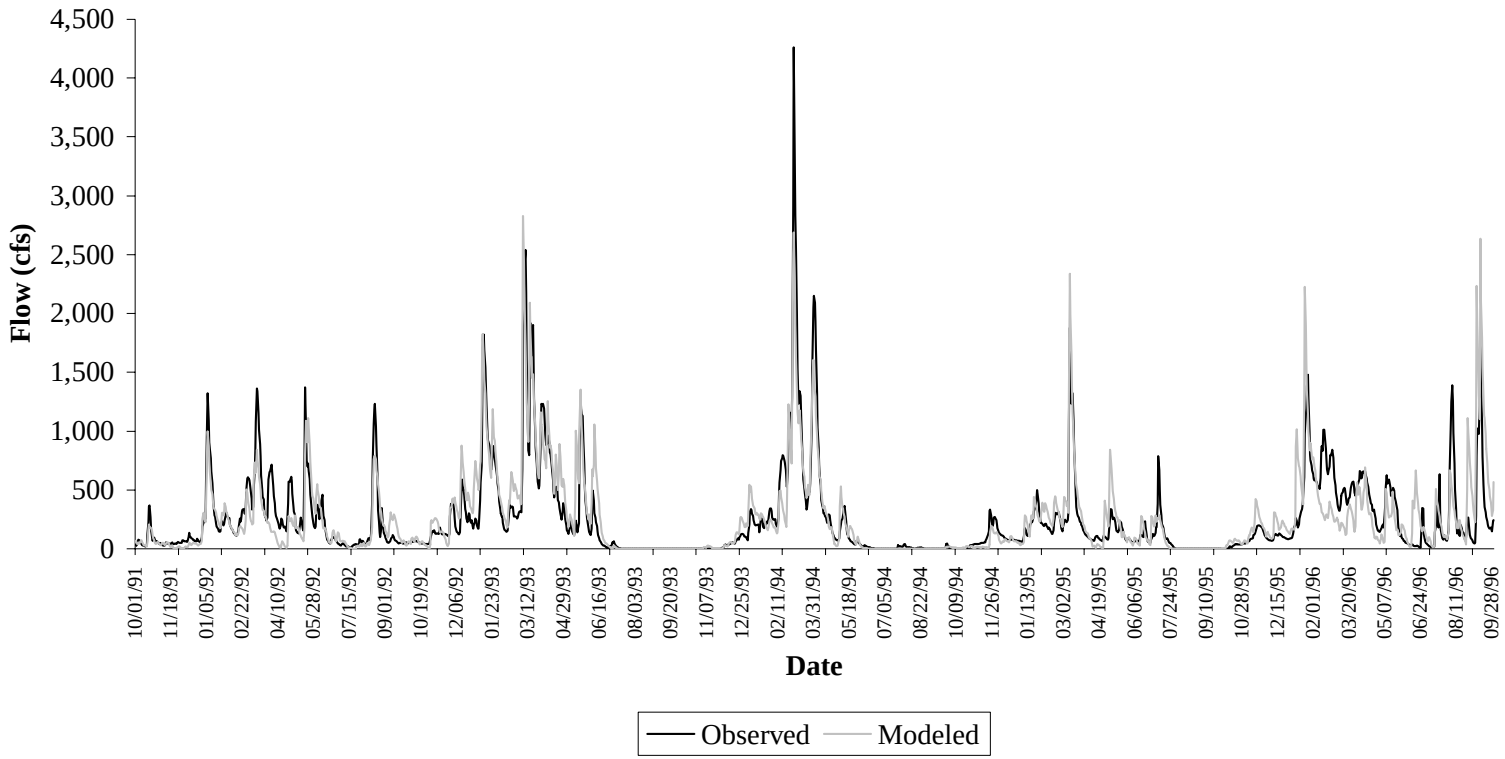

Figure 4.36 Calibration results for period 10/1/1991 through 9/30/1996 at USGS Gaging Station 02047500 on Blackwater River (model segment 5, subshed 6).

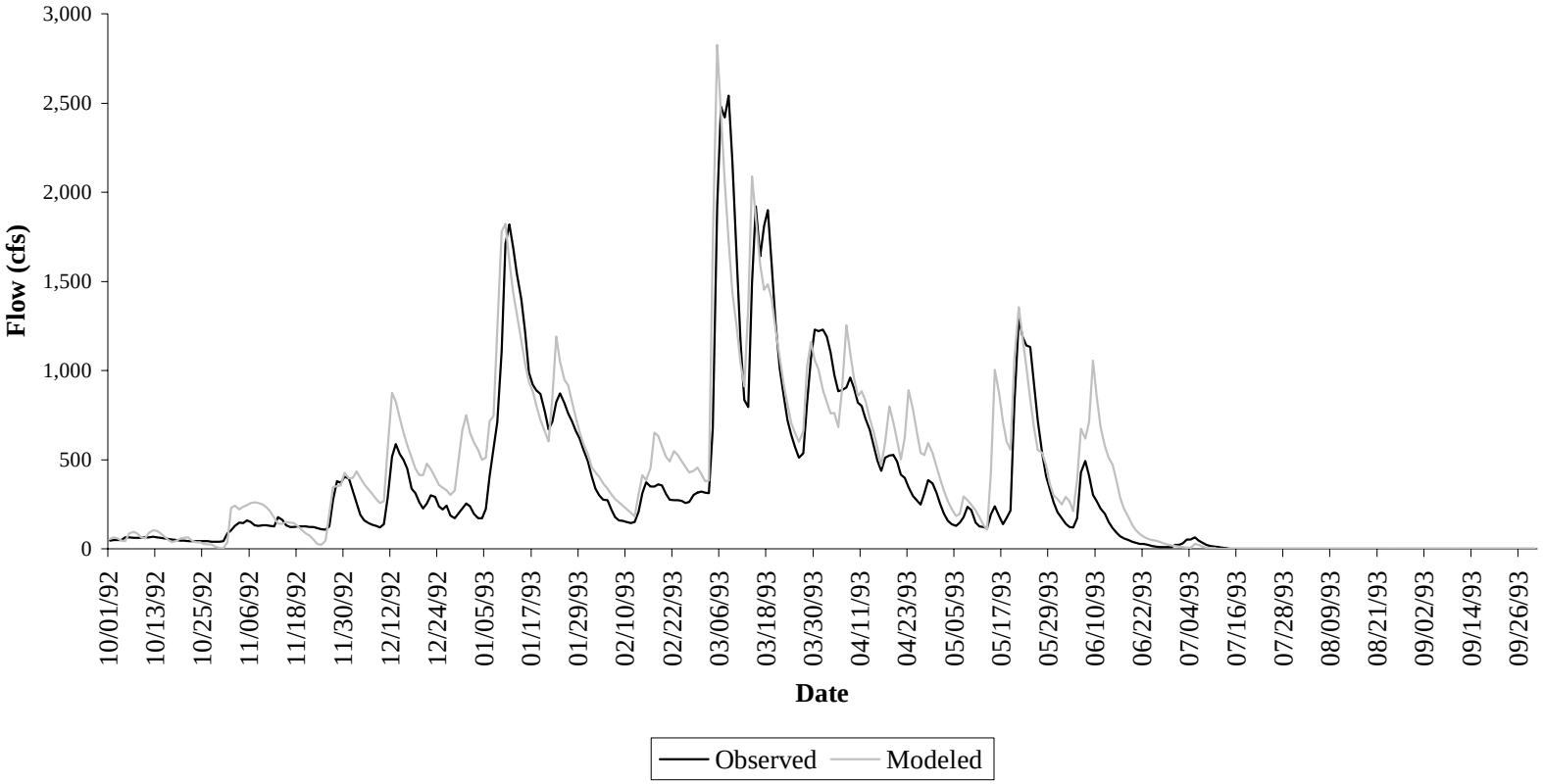

Figure 4.37 Calibration results for period 10/01/92 through 09/30/93 for USGS Gaging Station 02047500 on Blackwater River (model segment 5, subshed 6).

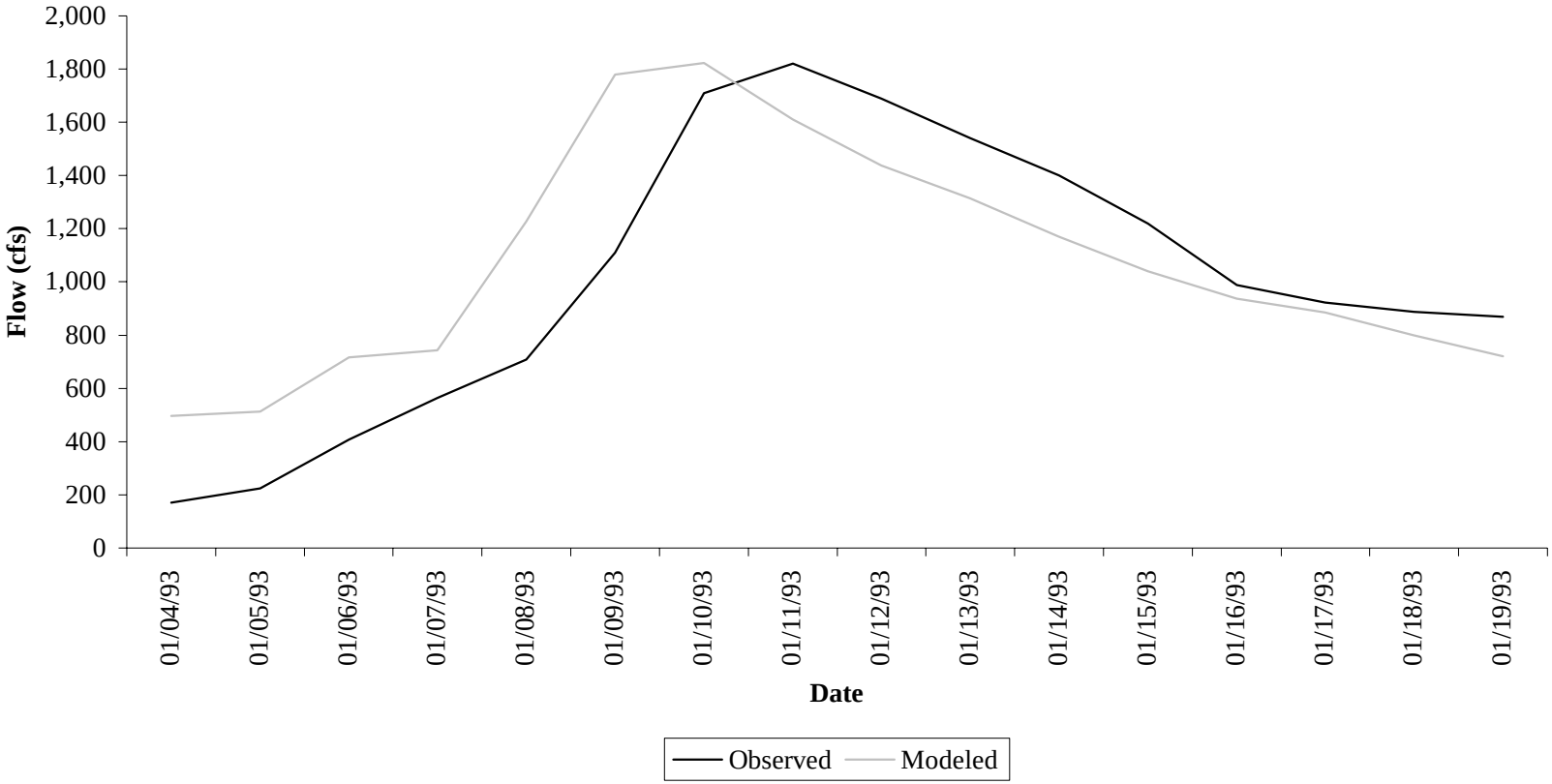

Figure 4.38 Calibration results for a single storm event at USGS Gaging Station 02047500 on Blackwater River (model segment 5, subshed 6).

Table 4.20 Hydrology calibration criteria and model performance for period 10/1/1990 through 9/30/1995 at USGS Gaging Station 02047000 on Nottoway River for Raccoon Creek (model segment 4, subshed 8).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	50.14	53.47	6.65%
Upper 10% Flow Values:	25.59	28.64	11.94%
Lower 50% Flow Values:	3.55	3.45	-2.66%
Winter Flow Volume	27.24	29.99	10.06%
Spring Flow Volume	14.39	13.85	-3.74%
Summer Flow Volume	4.14	4.66	12.48%
Fall Flow Volume	4.36	4.98	14.10%
Total Storm Volume	49.59	53.47	7.82%
Winter Storm Volume	27.11	29.98	10.61%
Spring Storm Volume	14.25	13.85	-2.82%
Summer Storm Volume	4.00	4.66	16.31%
Fall Storm Volume	4.23	4.98	17.76%

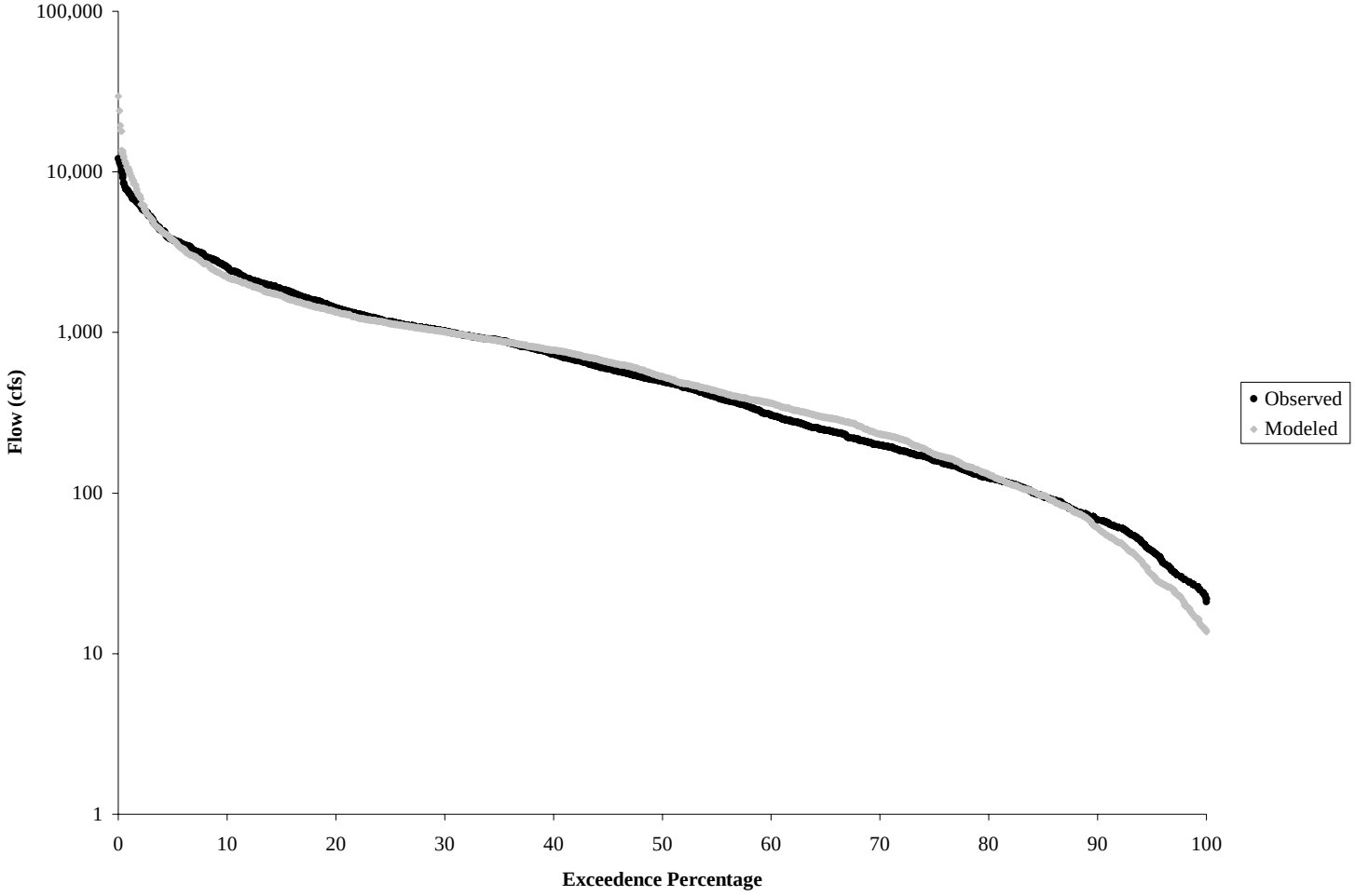

Figure 4.39 Nottoway River flow duration at USGS Gaging Station 02047000 for calibration period 10/1/1990 through 9/30/1995 for Raccoon Creek (model segment 4, subshed 8).

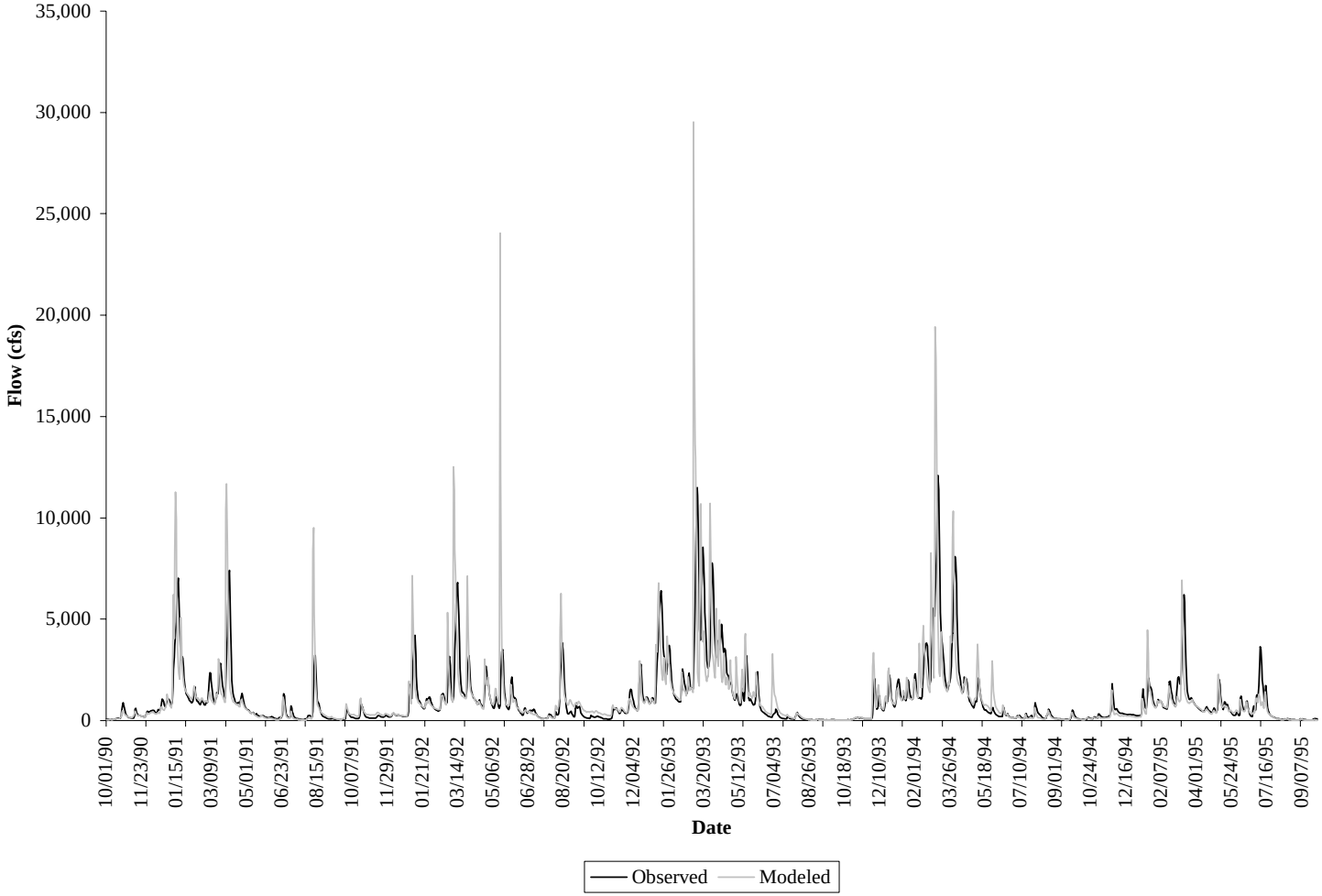

Figure 4.40 Calibration results for period 10/1/1990 through 9/30/1995 at USGS Gaging Station 02047000 on Nottoway River for Raccoon Creek (model segment 4, subshed 8).

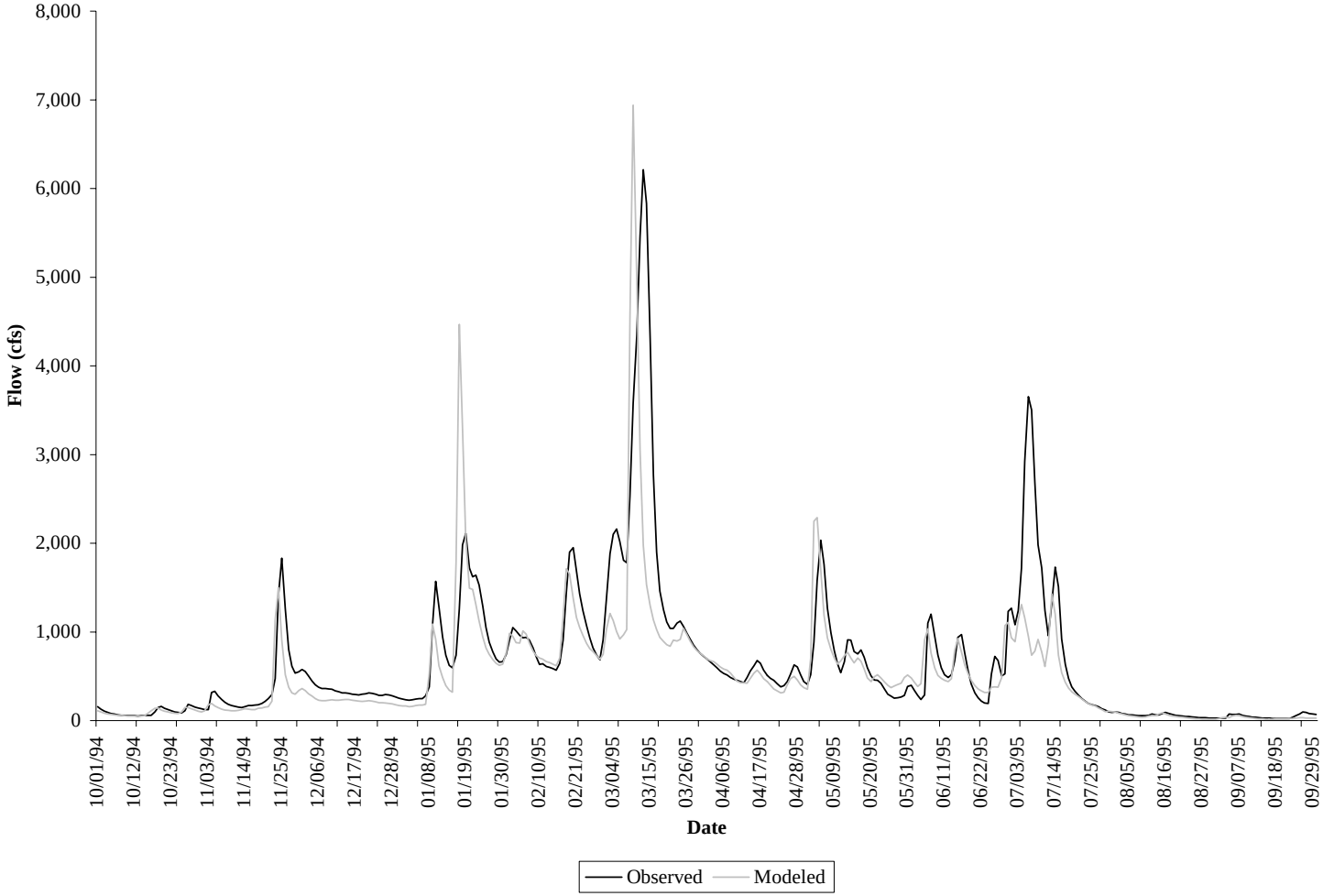

Figure 4.41 Calibration results for period 10/01/92 through 09/30/93 for USGS Gaging Station 02047000 on Nottoway River for Raccoon Creek (model segment 4, subshed 8).

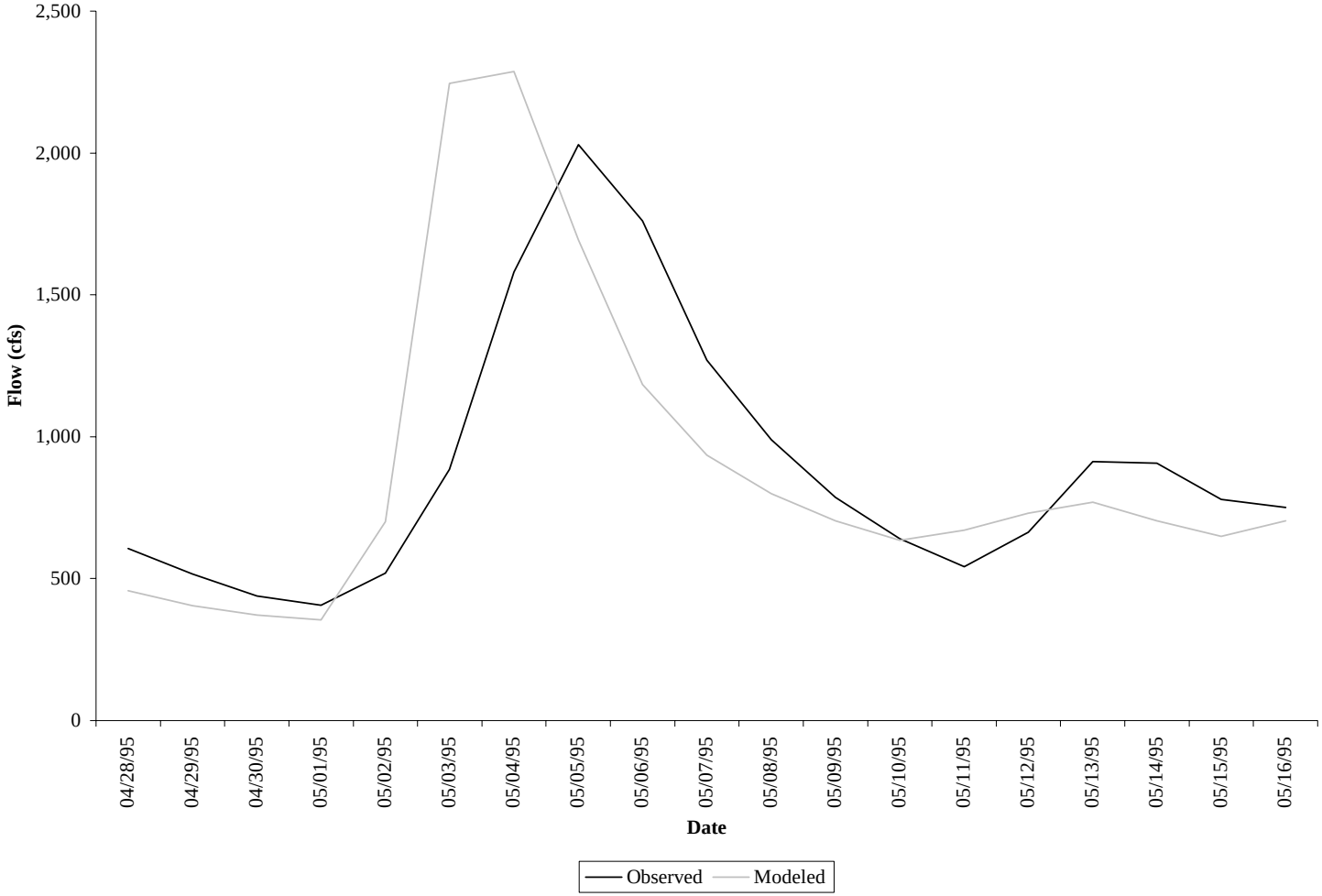

Figure 4.42 Calibration results for a single storm event at USGS Gaging Station 02047000 on Nottoway River for Raccoon Creek (model segment 4, subshed 8)

4.7.2 Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the maximum values were at times censored at 8,000 cfu/100ml and, at other times, at 16,000 cfu/100ml. Limited amount of measured data for use in calibration and the practice of censoring both high (over 24,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

The water quality calibration was conducted from 10/1/1998 through 9/30/2003. Four parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP), and concentration of fecal coliform in interflow (IOQC). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.22). Figures 4.37 through 4.48 show the results of calibration.

Table 4.21 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0E+00 – 1.0E+20	8.1E+05 to 3E+10	8.1E+05 to 3E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	8E+6 to 1E+11	8E+7 to 1E+12
WSQOP	in/hr	0.05 – 3.00	0.2 – 3.0	0.02 – 0.5
MON-IFLW-CON	FC/ft^3	0.0E+00 – 1.0E+06	1,000	0.00035 * MON-ACCUM
AOQC	FC/ft^3	0 – 10	0	0
DQAL	FC/100ml	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.00	1.15	0.25 to 2.20
THFST	---	1.0 – 2.0	1.07	1.07

The hydrologic behavior of these areas was characterized by a high degree of interflow, and consequently low degree of direct runoff in these areas, it was necessary to simulate interflow concentrations of fecal coliform in order to match the observed recession curves of pollution plots. In addition to the relatively gradual recession of the falling arm of pollution plots, evidence of bacterial concentrations in shallow sub-surface flow has been detected (Rickmond Engineering, 2002). In order to reflect the variations in loading on land, and to provide for realistic mode response during reduction scenarios, the interflow concentration IOQC, was varied monthly and was computed as a function of loading (MON-ACCUM).

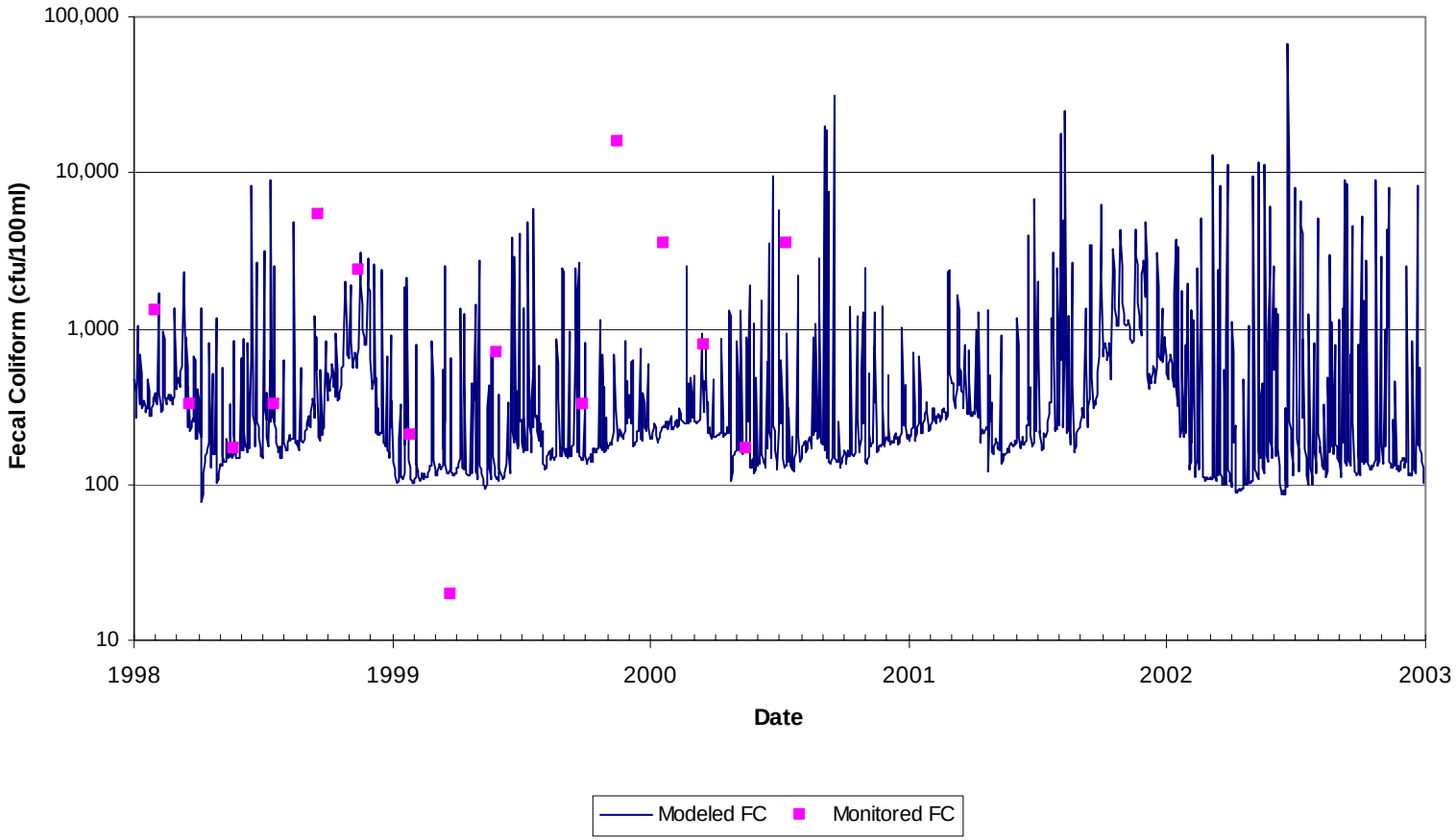

Figure 4.43 Quality calibration results for period 10/1/1998 to 9/30/2003 Beaverpond Creek, model segment 2, subshed 39.

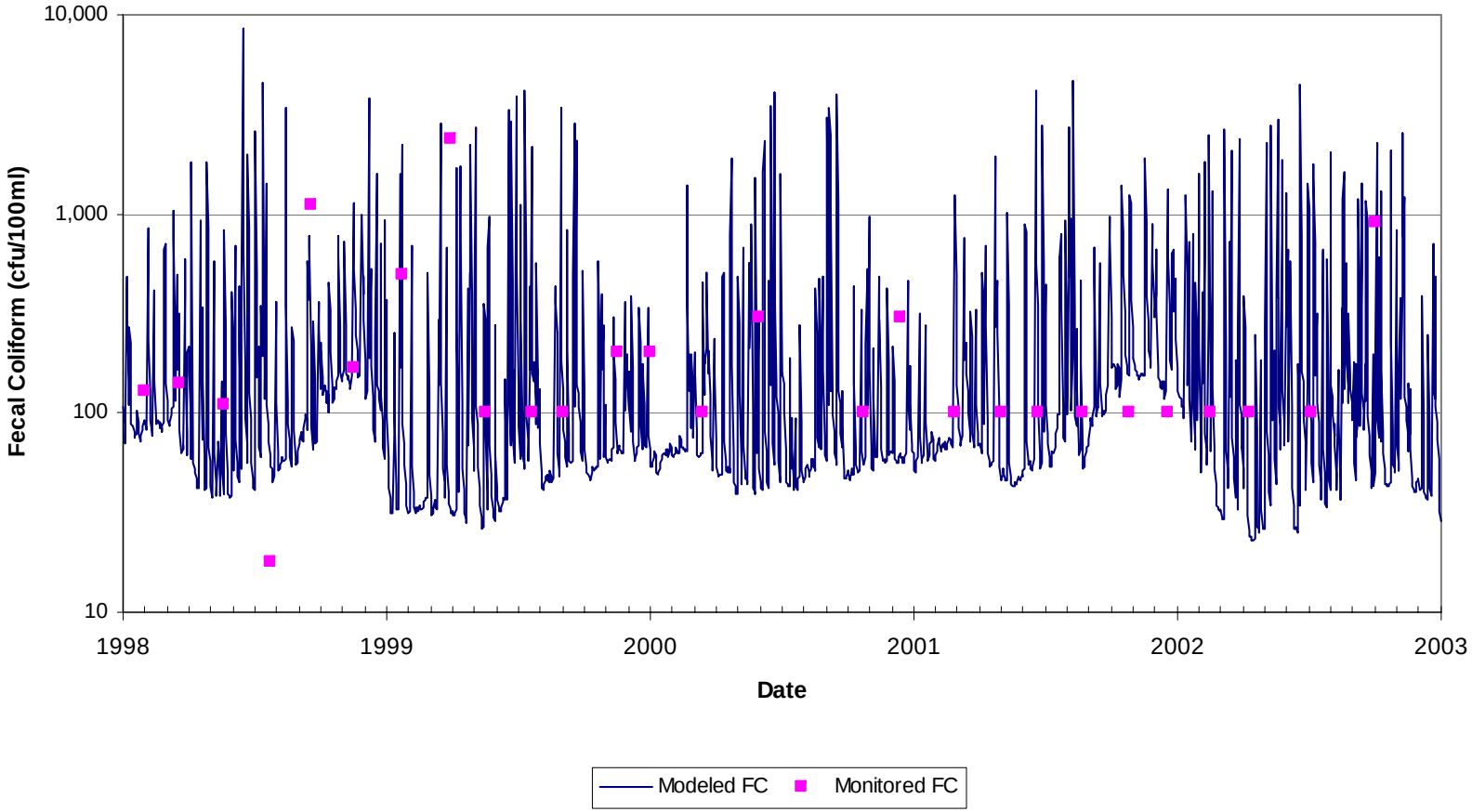

Figure 4.44 Quality calibration results for period 10/1/1998 to 9/30/2003 Big Hounds Creek, model segment 1, subshed 33.

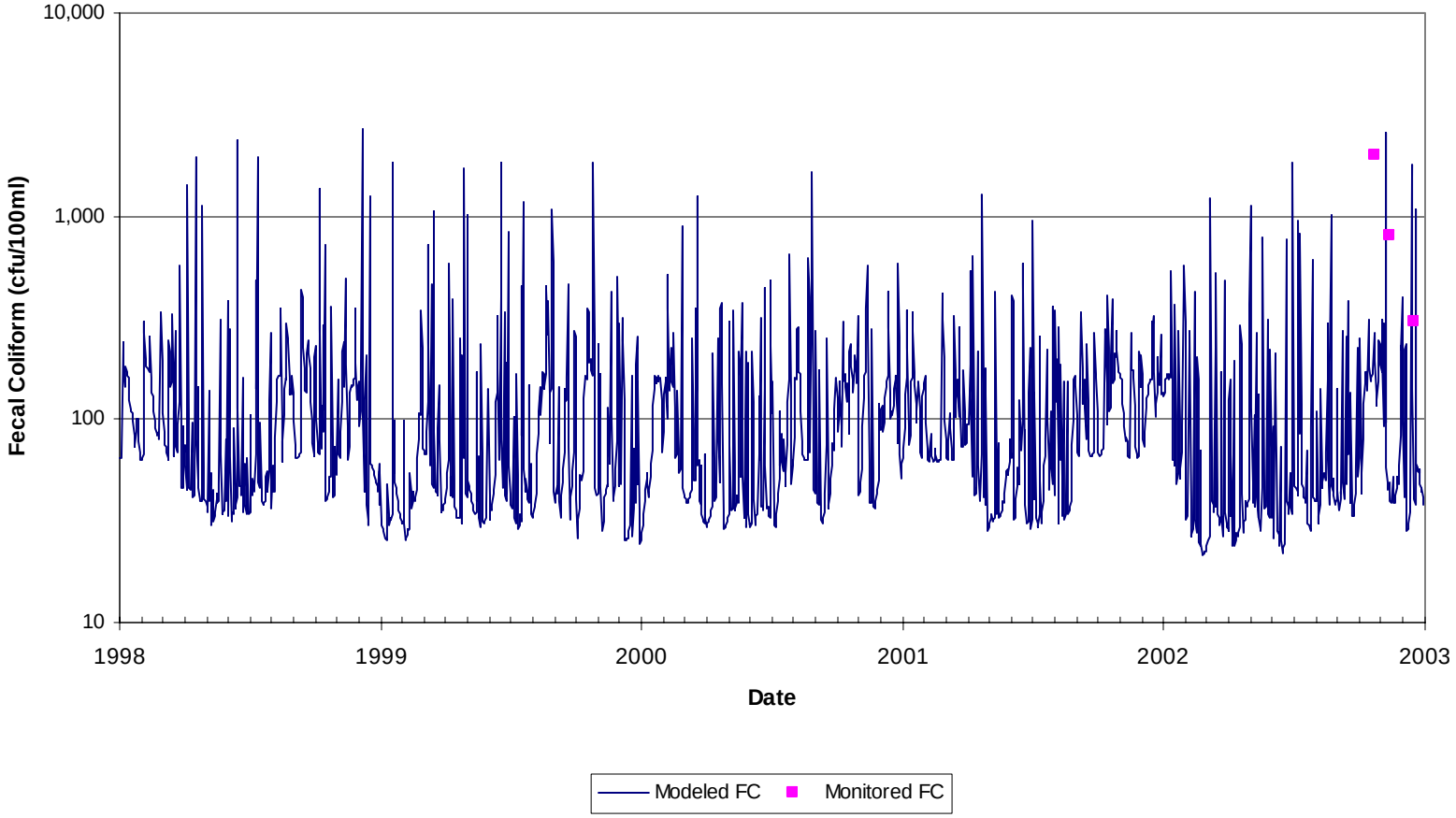

Figure 4.45 Quality calibration results for period 10/1/1998 to 9/30/2003 Cypress Swamp, model segment 5, subshed 13.

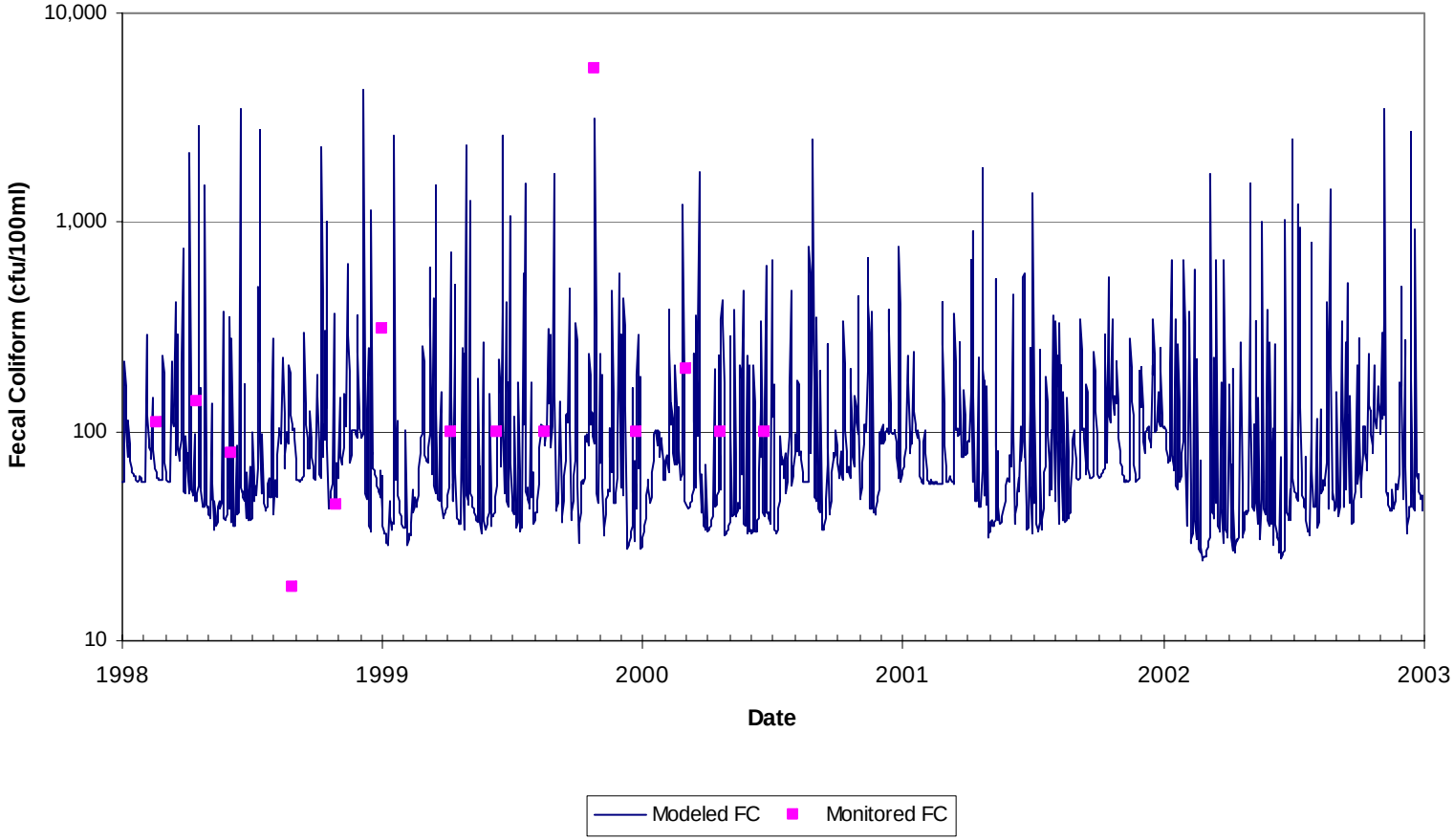

Figure 4.46 Quality calibration results for period 10/1/1998 to 9/30/2003 Cypress Swamp, model segment 5, subshed 15.

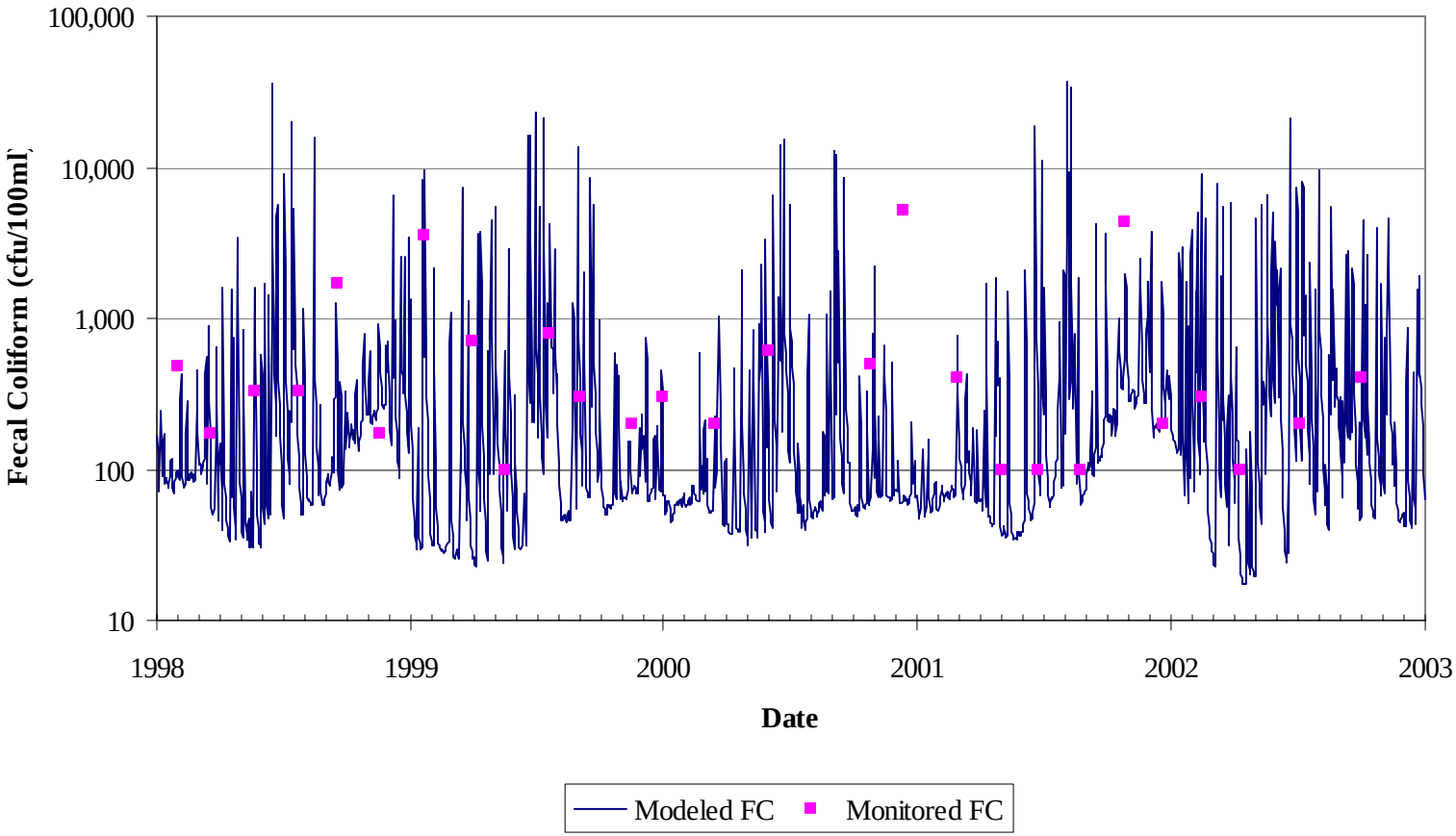

Figure 4.47 Quality calibration results for period 10/1/1998 to 9/30/2003 Little Nottoway River, model segment 1, subshed 22.

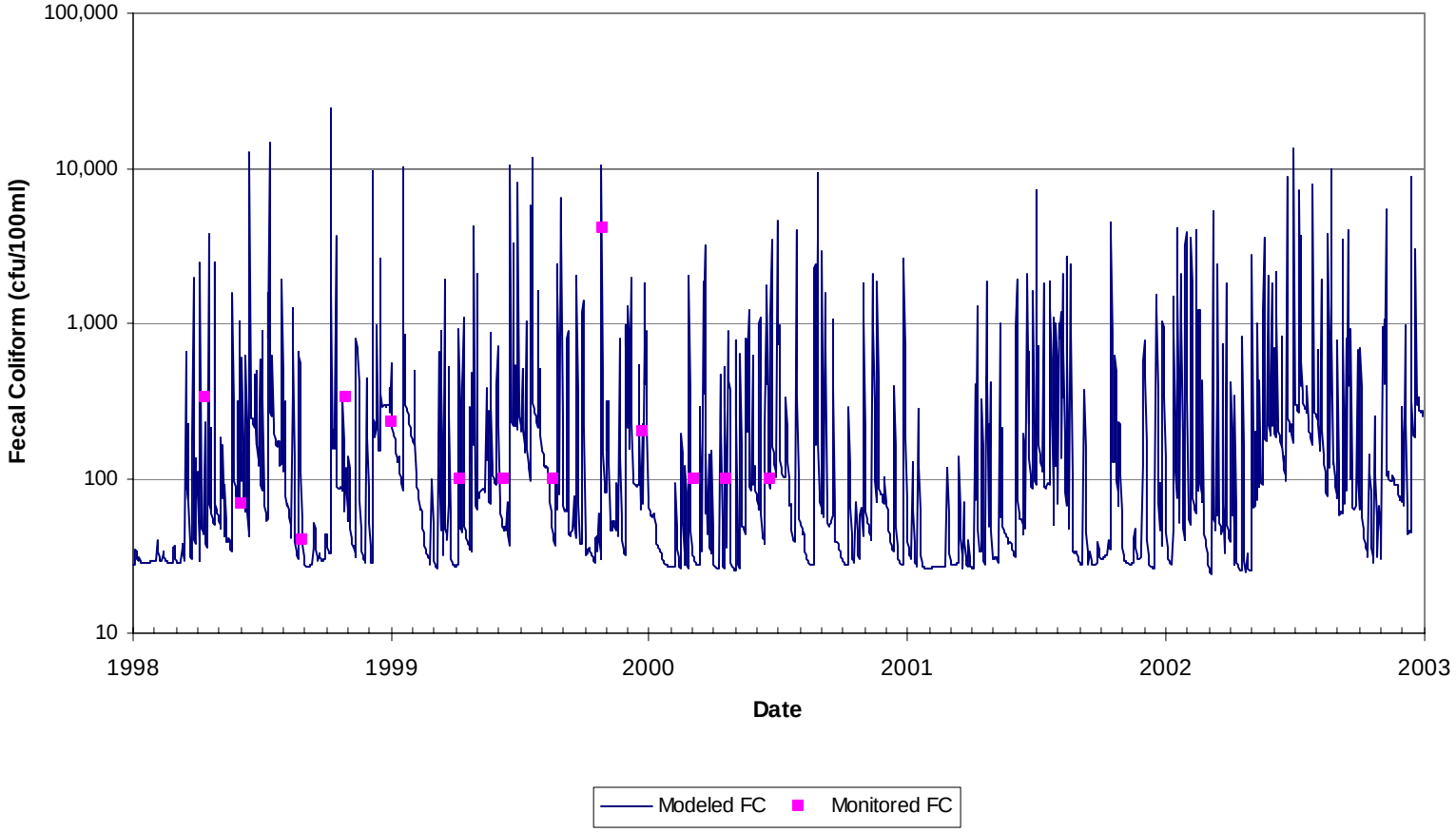

Figure 4.48 Quality calibration results for period 10/1/1998 to 9/30/2003 Mill Swamp, model segment 6, subshed 23.

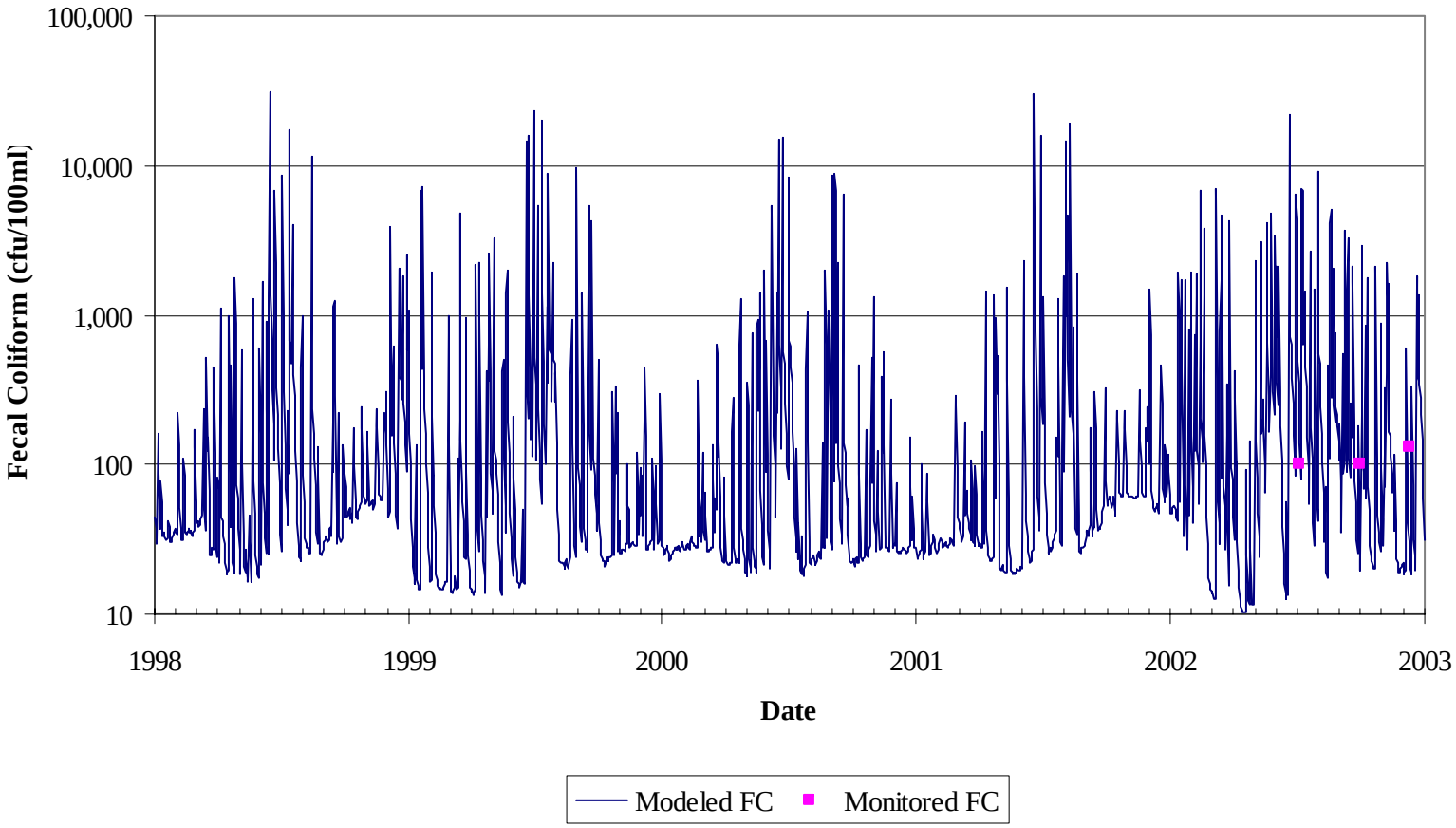

Figure 4.49 Quality calibration results for period 10/1/1998 to 9/30/2003 Nottoway River, model segment 1, subshed 1.

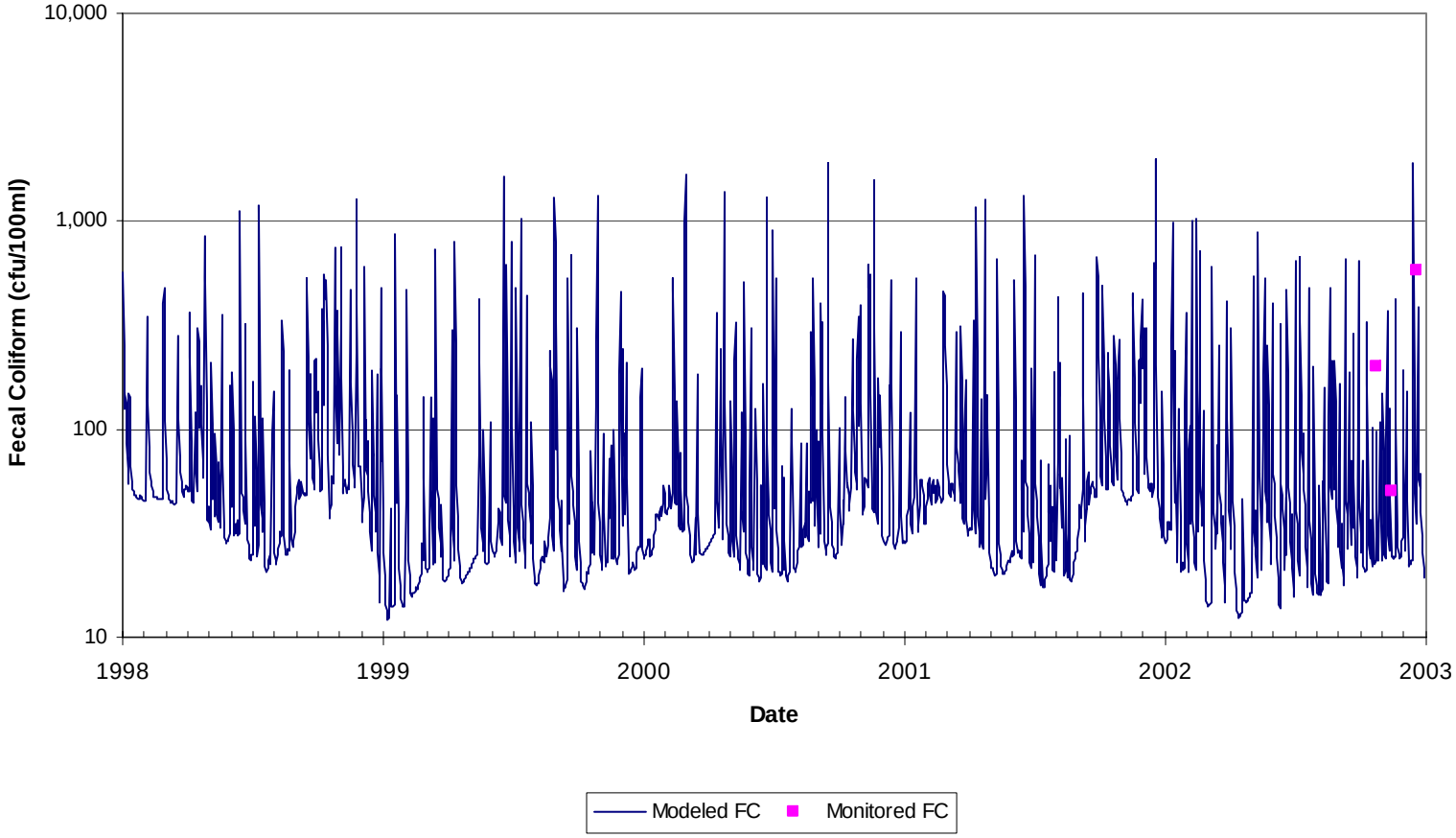

Figure 4.50 Quality calibration results for period 10/1/1998 to 9/30/2003 Raccoon Creek, model segment 4, subshed 18.

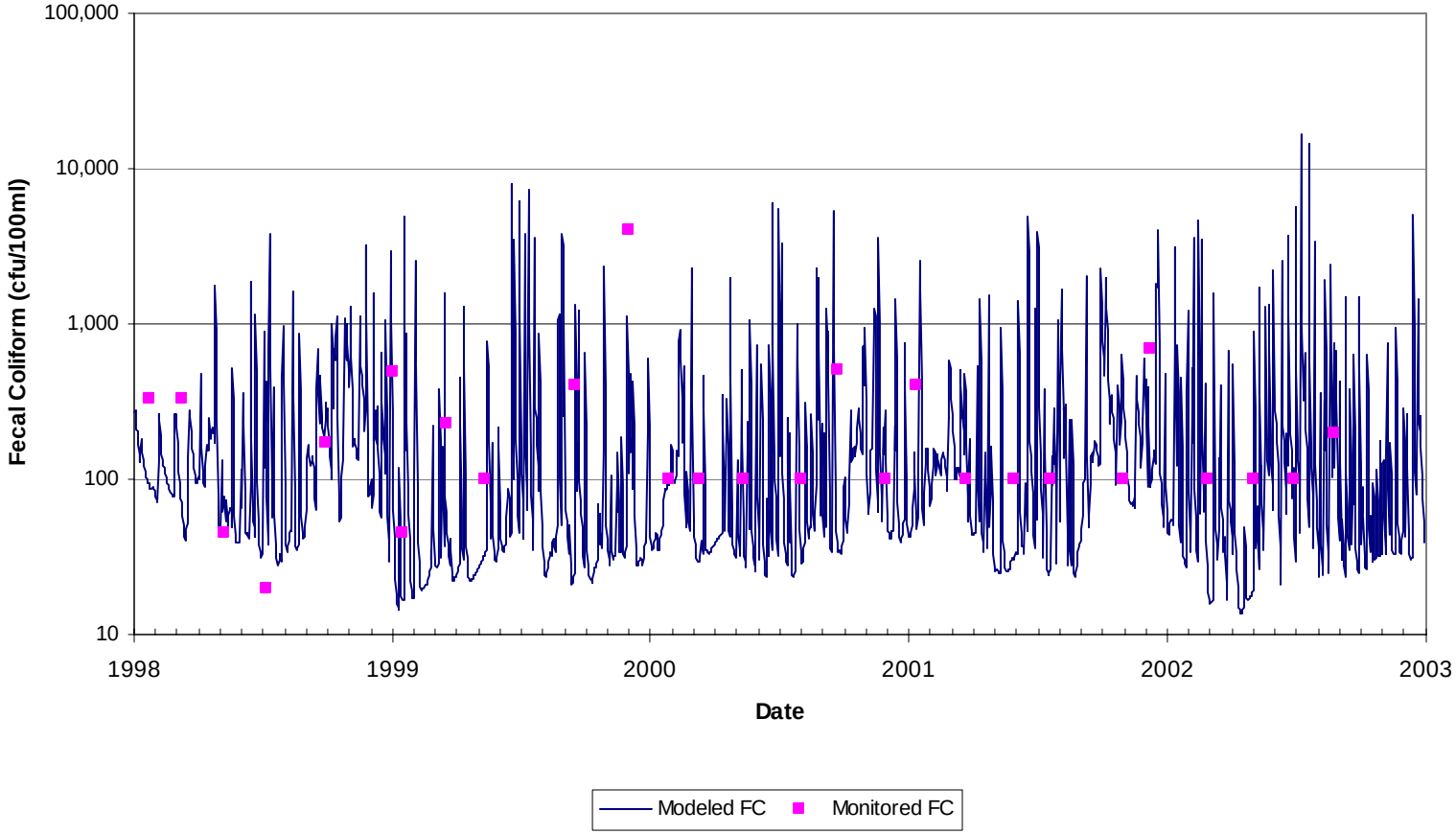

Figure 4.51 Quality calibration results for period 10/1/1998 to 9/30/2003 Raccoon Creek, model segment 4, subshed 20.

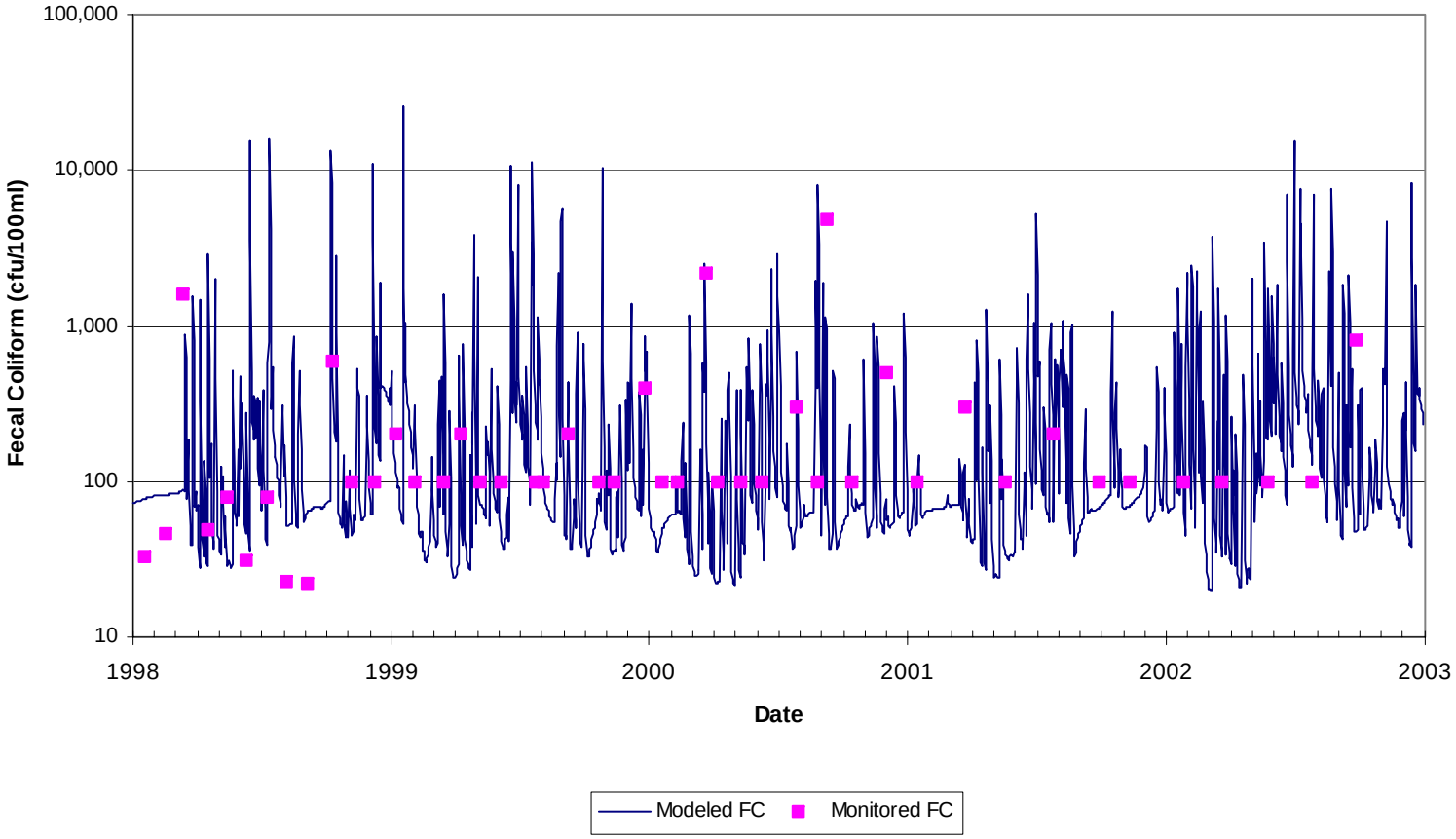

Figure 4.52 Quality calibration results for period 10/1/1998 to 9/30/2003 Rattlesnake (Creek) Swamp, model segment 6, subshed 31.

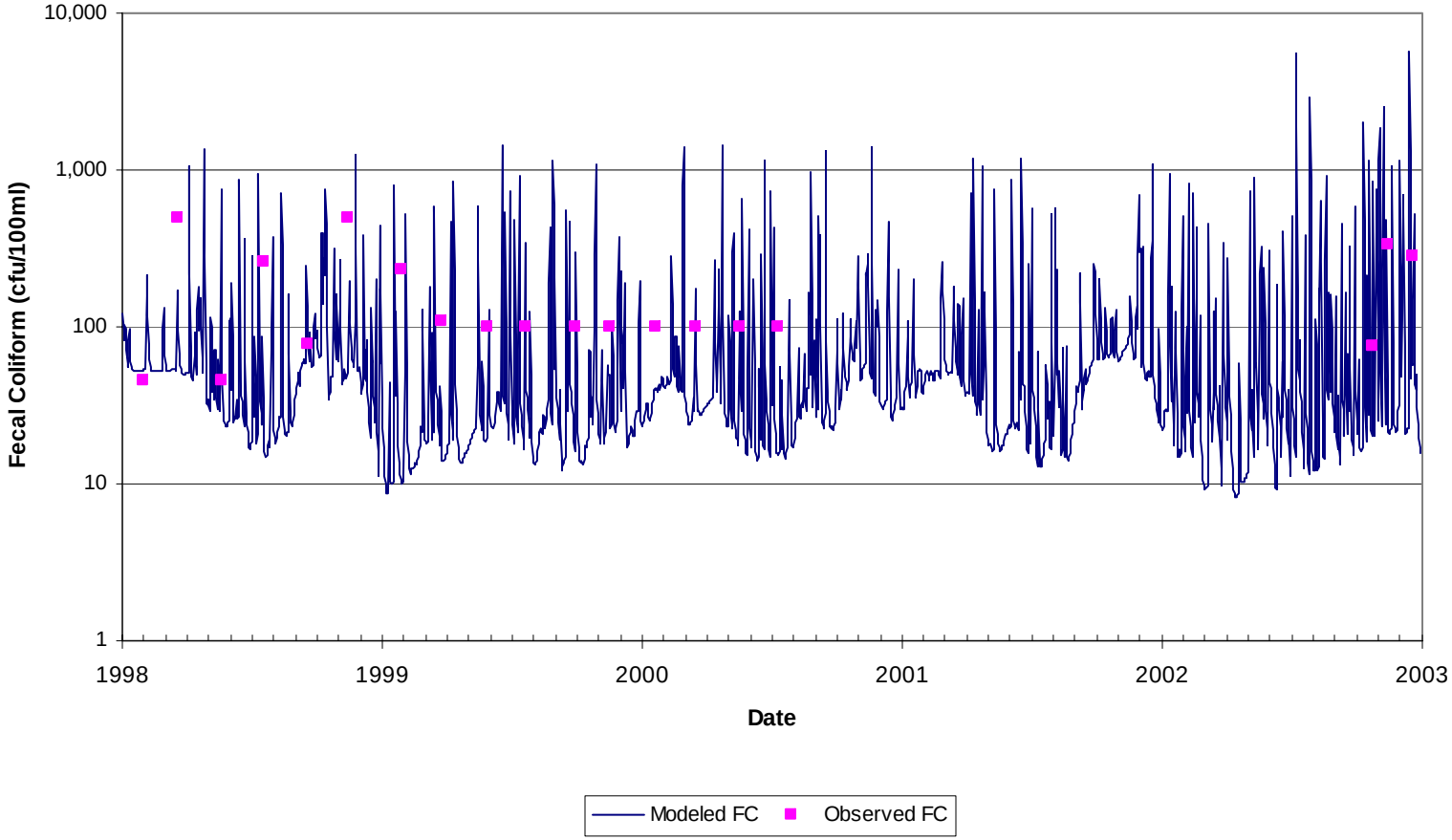

Figure 4.53 Quality calibration results for period 10/1/1998 to 9/30/2003 Sappony Creek, model segment 3, subshed 11.

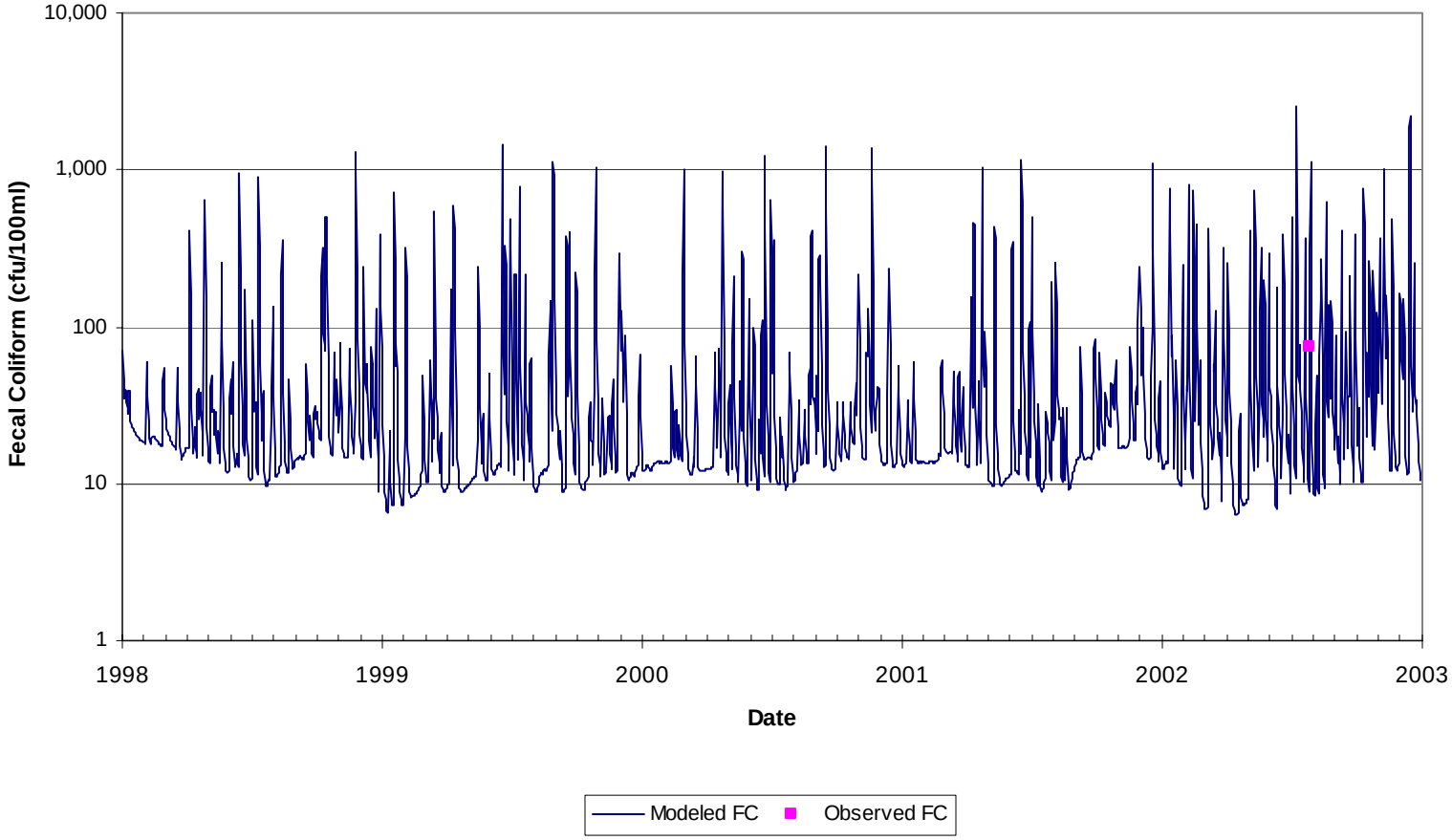

Figure 4.54 Quality calibration results for period 10/1/1998 to 9/30/2003 Sappony Creek, model segment 3, subshed 13.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data (Chapter 2) and found to be at reasonable levels (Table 4.22). The standard errors in Table 4.22 range from a low of 10 to a high of 259. Even the highest value in this range can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the taking of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 cfu is compared to a simulated high value that may be an order of magnitude or more above the censor limit. The highest standard error (259) coincides with the highest simulated maximum value (66,764). The next highest standard error is 104 and the majority of standard errors are less than 50. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.22 Results of analyses on calibration runs.

WQ Monitoring Station	Mean Standard Error (cfu/100ml)	Maximum Simulated Value (cfu/100ml)
5ANTW155.06	10	23,263
5ALNT004.68	83	37,233
5ABHC003.73	27	8,600
5ABPC000.12	259	66,764
5ASAP013.69	15	5,984
5ASAP004.00	11	2,545
5ARCN012.80	29	1,983
5ARCN003.36	32	16,864
5ACPP007.84	104	2,712
5ACPP003.20	61	4,368
5AMSW006.77	54	24,070
5ARKN006.40	38	25,608

Table 4.23 shows the predicted and observed values for instantaneous standard violation rate, and geometric mean for all impaired stream segments in the Chowan Study Area. A least squares regression of observed versus modeled geometric means for stations with greater than 10 values (yielding 2 values per year), gives an R^2 of 0.72, a fairly strong relationship. This reflects that for the majority of stations with a substantial sample population, differences between both the violation rates and geometric means are well within the range of reasonable model error. In the case of Beaverpond Creek, however, the model predicts substantially lower violation rates and geometric mean concentrations.

For Beaverpond Creek, the observed fecal coliform violation rate during model calibration is 53.30%, as compared to a modeled exceedance percentage of only 26.74%; however, this is based on an observed sample size of only 15 samples, all occurring in the first half of the calibration period. The graph in Figure 4.37 shows a generally good agreement between observed and modeled fecal coliform values, with only a single event in which the model predicts no standards violation coinciding with an observed violation. If the observed violation rate is in fact a precise measure of the water quality conditions in the watershed, potential sources of model uncertainty must be sought. Potential areas of modeled uncertainty given the observed violation rate in the range of 50% would suggest that some direct sources may be higher, such as uncontrolled residential discharges (straight pipes), livestock direct deposition or wildlife direct deposition. The number of straight pipes in a watershed is based only on census responders, and can have variability due to non-responders

and incorrectly completed forms. Livestock and wildlife direct deposition is modeled based on average time spent in the stream corridor, and is subject to some variability. In any case, the resulting reductions will not be impacted, as livestock fencing and elimination of uncontrolled residential discharges would be eliminated under an aggressive BMP implementation plan, and direct wildlife reductions are not approached in the IP process until anthropogenic sources are controlled as much as possible.

Table 4.23 Comparison of modeled and observed geometric means.

Segment Number	Reach ID	Station ID	Modeled Calibration Load Fecal Coliform 10/1/98 - 9/30/03			Monitored Fecal Coliform 10/1/98-9/30/03		
			n[1]	Geometric Mean (cfu/100ml)	Exceedances of Instantaneous Standard	*n*[1]	Geometric Mean (cfu/100ml)	Exceedances of Instantaneous Standard
1	22	5ALNT004.68	1826	244.75	27.00%	27	370.84	40.74%
1	33	5ABHC003.73	1826	157.07	13.14%	27	158.62	14.81%
2	39	5ABPC000.12	1826	295.59	26.74%	15	724.57	53.33%
3	11	5ASAP013.69	1826	118.95	5.10%	19	131.15	11.11%
4	20	5ARCN003.36	1826	162.29	14.14%	31	160.92	22.22%
5	15	5ACPP003.20	1826	122.72	4.55%	14	128.25	7.14%
6	23	5AMSW006.77	1826	158.14	14.47%	13	162.67	7.69%
6	31	5ARKN006.40	1826	154.49	15.12%	46	136.60	15.22%

The water quality validation was conducted for the time period from 10/01/1993 to 9/30/1998. The relationship between observed values and modeled values are shown in in Appendix C.

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint and sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For fecal coliform bacteria, the TMDL is expressed in terms of colony forming units (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, a MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of this TMDL are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration,
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed, and

- Modeling biosolids applications at the maximum allowable rate and fecal coliform concentration in all permitted fields.

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. The TMDLs developed for the Chowan Study Area were based on the Virginia State Standard for *E. coli* and *enterococci*. As detailed in Section 2.1, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml. The *enterococci* standard states that the calendar month geometric-mean concentration shall not exceed 35 cfu/100 ml, and that a maximum single sample concentration of *enterococci* shall not exceed 104 cfu/100 ml. According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a data set containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

where C_{ec} is the concentration of *E. coli* in cfu/100 ml, and C_{fc} is the concentration of fecal coliform in cfu/100 ml.

Pollutant concentrations were modeled over the entire duration of a representative modeling period and pollutant loads were adjusted until the standard was met (Figures 5.1 through 5.16). The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

5.2.1 Waste Load Allocations

There are five point sources currently permitted to discharge into the Chowan Study Area Figures 3.4 and 3.5 and Table 3.4. All five are permitted for fecal control. The allocation for the sources permitted for fecal control is equivalent to their current permit levels (design discharge and 200 cfu/100 ml).

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from landuses and directly applied loads in the stream (*e.g.*, livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. The BST results for 2003-2004 confirmed the presence of human, livestock, pet, and wildlife contamination. Load reductions were performed by landuse, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by landuse. Reductions on agricultural landuses (pasture and cropland) include reductions required for biosolids and imported poultry litter.

Allocation scenarios were run sequentially, beginning with headwater impairments, and then continuing with downstream impairments until all impairments were allocated to 0% exceedances of the instantaneous standard. Tables 5.1 through 5.8 represent a small portion of the scenarios developed to determine the TMDL for each impairment. Scenario 1 in each table (scenarios 1 & 2 for Rattlesnake (Creek) Swamp) describes a baseline scenario that corresponds to the existing conditions in the watershed. Model results indicate that human, livestock, and wildlife contributions are significant in all areas of the watershed. This is in agreement with the results of BST analysis presented in section 2.4.2.1.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, scenario 2 (scenario 3 for Rattlesnake (Creek) Swamp) attempts to determine the impact of non-anthropogenic sources (*i.e.*, wildlife), by exploring 100% reductions in all anthropogenic land-based and direct loads. In most cases, the model predicts that water quality standards will not be met without reductions in wildlife loads.

Since part of the TMDL development is the identification of phased implementation strategies, typical management scenarios were explored as well. Scenario 3 in each table

(scenario 4 for Rattlesnake (Creek) Swamp) contains reductions of 50% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, a 90% or 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. This scenario corresponds to what is considered to be a reasonable scenario for a stage I implementation. Further scenarios in each table explore a range of management scenarios, leading to the final allocation scenario that contains the predicted reductions needed to meet the water quality standard of 0% instantaneous violations.

5.2.2.1 Little Nottoway

The Little Nottoway River is located in the southern portion of Nottoway County and it flows in a southeasterly direction before the confluence with the Nottoway River near the Nottoway - Lunenburg county line. The impaired section begins at the Lazaretto Creek confluence and continues downstream to the mouth (9.85 stream miles). The watershed is 67% forest and 22% pasture, with the remainder in residential/commercial, cropland and wetlands.

The total fecal coliform production per year in the watershed was modeled as 79.67E+14, with a fecal coliform density of 16.43E+10 cfu/acre. Major sources of fecal coliform bacteria in the watershed are broilers (40%), beef cattle (22%) and biosolids (19%). The total estimated wildlife contribution to the fecal coliform load in this watershed is 12%. The long term VADEQ monitoring station, 5ALNT004.68, has a historical fecal coliform violation rate of 30%.

Scenario 2 in the Little Nottoway River predicts that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 3.29% of the time, with 3.33% violations of the geometric mean standard. Scenario 3 predicts that violations of the instantaneous standard will remain above 10% with moderate reductions in land-based anthropogenic sources, and a reduction of 90% of direct loads from livestock. Scenarios 4 and 5 explore increasing restrictions upon land-based and direct loads, and demonstrate the need for reductions of wildlife contributions in order to achieve 0% violations of the instantaneous standard. Scenario 6 represents what is necessary to

achieve a violation rate close to 10% of the instantaneous standard. Scenario 7 shows the final allocation scenario for the Little Nottoway River, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in anthropogenic non-point sources, and 95% reductions necessary in wildlife land-based loads along with 67% reductions in direct wildlife loads in order to obtain no violations of either standard.

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in model segment 1, Little Nottoway River.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	36.67	21.60
2	0	0	100	100	100	100	3.33	3.29
3	0	0	90	50	100	50	10.00	12.94
4	0	0	100	90	100	90	6.67	6.25
5	0	0	100	99	100	99	3.33	3.73
6	0	0	95	60	100	60	8.33	11.40
7	67	95	100	99	100	99	0.00	0.00

5.2.2.2 Big Hounds Creek

Big Hounds Creek is a tributary to the Nottoway River located in northeastern Lunenburg County and flows in a northeasterly direction. The entire main stem of Big Hounds Creek is considered impaired for fecal coliform bacteria. The watershed is 73% forest 17% pasture, and approximately 6% in urban land-uses.

The total fecal coliform production per year in the watershed was modeled as 58.54E+13, with a fecal coliform density of 52.27E+09 cfu/acre. Major sources include beef cattle (48%), muskrat (17%) and raccoon (15%). Dog and cat fecal coliform productions were higher in this watershed than most of the others with a total contribution of 6.15%. The total wildlife contribution to the fecal coliform load was 38%. The long term VADEQ monitoring station, 5ABHC003.73, has a historical fecal coliform violation rate of 26%.

Scenario 2 in the Big Hounds Creek predicts that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 3.78% of the time, with

0.00% violations of the geometric mean standard; this demonstrates that with wildlife representing a modeled 38% of the fecal coliform, the wildlife load is a significant factor in the watershed. Scenario 3 explores another scenario, with 50% reductions in all anthropogenic land-based loads, and a reduction of 90% of direct loads from livestock, and predicts that violations of the instantaneous standard will remain above 7%. Scenarios 4 and 5 explore increasing restrictions upon both land-based and direct loads, but demonstrate the need for reductions of wildlife contributions. Scenario 6 represents what is necessary to achieve an approximate 10% violation of the instantaneous standard. Scenario 7 shows the final allocation scenario for Big Hounds Creek, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in livestock non-point sources, 91% reductions in human non-point sources, with 81% reductions necessary in wildlife land-based loads in order to obtain no violations.

Table 5.2 Allocation scenarios for bacterial concentration with current loading estimates in model segment 1, Big Hounds Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	8.33	13.60
2	0	0	100	100	100	100	0.00	3.78
3	0	0	90	50	100	50	0.00	7.41
4	0	0	100	90	100	90	0.00	4.39
5	0	0	100	99	100	99	0.00	3.84
6	0	0	50	25	100	25	0.00	10.20
7	0	81	100	99	100	91	0.00	0.00

5.2.2.3 Nottoway River

The Nottoway River is located primarily in the northwestern portion of Lunenburg County, with headwaters in Prince Edward County. The impaired section begins at the headwaters and continues downstream to the backwaters of Nottoway Falls Lake (17.76 stream miles). The watershed is 78% forest with 9% pasture.

The total fecal coliform production per year in the watershed was modeled as 33.72E+14, with a fecal coliform density of 79.82E+09 cfu/acre. Major sources of fecal coliform

bacteria are broilers (28%), hogs (26%) and beef cattle (17%). The total wildlife contribution to the fecal coliform load is 19%. The long term VADEQ monitoring station, 5ANTW155.06, has a historical fecal coliform violation rate of 28%.

Scenario 2 for the Nottoway River shows that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 3.23% of the time, with 0.00% violations of the geometric mean standard. Scenario 3 predicts that violations of the instantaneous standard will remain appreciable with moderate reductions in land-based anthropogenic sources, and a reduction of 90% of direct loads from livestock, and represents what is necessary to reach an approximate 10% management scenario. Scenarios 4 and 5 explore increasingly stringent restrictions upon land-based and direct loads, and further demonstrate the need for reductions of wildlife contributions. Scenario 6 shows the final allocation scenario for the Nottoway River, which requires 100% reductions in all anthropogenic direct sources, 99.9% reductions in non-point pasture / livestock access / cropland loads, 99% reductions in residential and urban land-based loads, an 86% reduction necessary in wildlife land-based loads, and a 21% reduction in wildlife direct loads in order to obtain no violations of the standards.

Table 5.3 Allocation scenarios for bacterial concentration with current loading estimates in model segment 1, Nottoway River.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	15.00	14.25
2	0	0	100	100	100	100	0.00	3.23
3	0	0	90	50	100	50	3.33	9.70
4	0	0	100	90	100	90	0.00	4.71
5	0	0	100	99	100	99	0.00	3.51
6	21	86	100	99.9	100	99	0.00	0.00

5.2.2.4 Beaverpond Creek

Beaverpond Creek is located in the southwestern corner of Dinwiddie County and flows in a southeasterly direction before the confluence with the Nottoway River. The impaired

section includes all of the mainstem (7.17 stream miles). The watershed is 59% forested with 25% in pasture and 12% in cropland.

Total fecal coliform production per year in the watershed was modeled as 15.56E+14, with a fecal coliform density of 24.48E+10 cfu/acre. Major sources of fecal coliform bacteria are biosolids (72%) and beef cattle (9%). The total wildlife contribution to the fecal coliform load is 8%. The long term VADEQ monitoring station, 5ABPC000.12, has a historical fecal coliform violation rate of 50%.

Scenario 2 for Beaverpond Creek shows that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 10.14% of the time, with 23.33% violations of the geometric mean standard; this is a result of the fact that while wildlife only represents 8% of the total fecal loading for the watershed, the high density of fecal coliforms (24.48E+10cfu/acre) has a dramatic impact upon the model, and suggests that stringent measures will be needed in order to meet water quality standards. Scenario 3 predicts that violations of the instantaneous standard will remain very high with moderate reductions in land-based anthropogenic sources, and a reduction of 100% of direct loads from livestock. Scenarios 4 and 5 explore increasingly stringent restrictions upon land-based and direct loads, and further demonstrate the need for reductions of wildlife contributions. Scenario 5 shows the reductions necessary to approach the 10% violation rate of a phased implementation approach, and demonstrates the relatively high concentration of wildlife contributions in the watershed. Scenario 6 shows the final allocation scenario for Beaverpond Creek, which requires 100% reductions in all anthropogenic direct sources, 99.625% reductions in non-point anthropogenic loads, and shows the anticipated reductions to wildlife loads as a 99.4% reduction in wildlife direct deposition, along with a 67% reduction necessary in wildlife land-based loads in order to obtain no violations of water quality standards.

Table 5.4 Allocation scenarios for bacterial concentration with current loading estimates in model segment 2, Beaverpond Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	83.33	28.13
2	0	0	100	100	100	100	23.33	10.14
3	0	0	100	60	100	60	20.11	17.70
4	0	0	100	90	100	90	26.67	13.82
5	0	0	100	99	100	99	23.33	10.58
6	99.4	67	100	99.625	100	99	0.00	0.00

5.2.2.5 Sappony Creek

Sappony Creek is located in the southeastern portion of Dinwiddie County and flows in a southeasterly direction before its confluence with Stony Creek. Virginia DEQ recommended Sappony Creek for delisting in the 2004 305(b) 303(d) Integrated Report based on the results of on-going water quality monitoring. The water quality model predicts an instantaneous standard violation rate of approximately 7% under existing conditions, below the 10.5% listing threshold. Thus, the results of this TMDL study and water quality model supports the de-listing of this stream.

5.2.2.6 Raccoon Creek

Raccoon Creek is located in the southeastern portion of Sussex County and it flows in a southeasterly direction before its confluence with the Nottoway River. The entire main stem of the stream is impaired (19.3 stream miles). The watershed is 65% forested with 13% in cropland and 11% wetlands.

Total fecal coliform production per year in the watershed was modeled as 36.61E+14, with a fecal coliform density of 84.14E+09 cfu/acre. Major sources of fecal coliform bacteria include hogs (34%), layers (26%) and muskrat (12%). The total wildlife contribution to the fecal coliform load is 26%. The long term VADEQ monitoring station, 5ARCN003.36, has a historical fecal coliform violation rate of 14%.

Scenario 2 for Raccoon Creek shows that with mitigation of all anthropogenic sources, violations of the instantaneous standard will still occur 5.87% of the time, with 1.67% violations of the geometric mean standard. Scenario 3 predicts that violations of the instantaneous standard will remain close to 10% with moderate reductions in land-based anthropogenic sources, and a reduction of 90% of direct loads from livestock. Scenario 3 explores the reductions necessary to near the 10% violation rate of a phased implementation approach. Scenarios 4 and 5 explore greater restrictions upon land-based and direct loads, and further demonstrate the need for reductions of wildlife contributions. Scenario 6 shows the final allocation scenario for Raccoon Creek, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in non-point pasture / livestock access / cropland loads, 99% reductions in residential and urban land-based loads, and a 95% reduction necessary in wildlife land-based loads in order to obtain no violations of either standard.

Table 5.5 Allocation scenarios for bacterial concentration with current loading estimates in model segment 4, Raccoon Creek.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	11.67	14.54
2	0	0	100	100	100	100	1.67	5.87
3	0	0	90	50	100	50	5.00	10.53
4	0	0	100	90	100	90	3.33	6.80
5	0	0	100	99	100	99	1.67	6.03
6	0	95	100	99	100	99	0.00	0.00

5.2.2.7 Cypress Swamp

Cypress Swamp is located in the southern portion of Surry County and flows southeast before its confluence with the Blackwater River. The impaired section begins at Johnchecohunk Swamp and continues downstream to the Blackwater River confluence (17.10 stream miles). The watershed is 67% forested with 12% in cropland.

Total fecal coliform production per year in the watershed was modeled as 11.21E+14, with a fecal coliform density of 29.74E+09 cfu/acre. Major sources of fecal coliform

bacteria include muskrat (51%), raccoon (23%) and deer (12%). The total wildlife contribution to the fecal coliform load is 78%. The long term VADEQ monitoring station, 5ACPP003.20, has a historical fecal coliform violation rate of 11%. Conversations with local farmers indicated that livestock direct deposition was extremely limited, and the modeling was conducted accordingly – the 100% reduction shown for all allocation scenarios reflects this adjustment, and assumes there is no livestock direct deposition, and will therefore not require further reduction.

Scenario 2 for Cypress Swamp shows that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 15.25% of the time, with 18.33% violations of the geometric mean standard; this is a result of the fact that wildlife represents 78% of the total fecal loading for the watershed, and suggests that stringent measures will be needed in order to meet water quality standards. Scenario 3 predicts that violations of the instantaneous standard will remain very high with moderate reductions in land-based anthropogenic sources, and a reduction of 100% of direct loads from livestock. Scenarios 4 and 5 explore greater restrictions upon land-based and direct loads, and further demonstrate the need for reductions of wildlife contributions. Scenario 6 represents what is necessary to achieve a violation close to an approximate 10% of the instantaneous standard. Scenario 7 shows the final allocation scenario for Cypress Swamp, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in non-point anthropogenic loads, and shows the reductions to wildlife loads to be 80% in wildlife direct deposition, along with a 90% reduction necessary in wildlife land-based loads in order to obtain no violations of water quality standards.

Table 5.6 Allocation scenarios for bacterial concentration with current loading estimates in model segment 5, Cypress Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	21.67	18.82
2	0	0	100	100	100	100	18.33	15.25
3	0	0	100	50	100	50	18.33	15.80
4	0	0	100	90	100	90	18.33	15.41
5	0	0	100	99	100	99	18.33	15.25
6	25	25	100	99	100	99	13.33	10.59
7	80	90	100	99	100	99	0.00	0.00

5.2.2.8 Mill Swamp

Mill Swamp Creek is located in Surry and Isle of Wight counties. It flows in a southeasterly direction before its confluence with Rattlesnake (Creek) Swamp. The impaired section begins at the headwaters (Moores Swamp confluence) and continues downstream to the Rattlesnake (Creek) Swamp confluence (10.12 stream miles). The watershed is 45% forested with 22% wetlands and 21% cropland.

Total fecal coliform production per year in the watershed was modeled as 17.63+14, with a fecal coliform density of 73.90E+09 cfu/acre. Major sources of fecal coliform bacteria include hogs (59%), muskrat (15%) and beef cattle (9%). The total wildlife contribution to the fecal coliform load is 28%. The long term VADEQ monitoring station, 5AMSW006.77, has a historical fecal coliform violation rate of 18%. Conversations with local farmers indicated that livestock direct deposition was extremely limited, and the allocations were conducted accordingly – the 100% reduction shown for all allocation scenarios reflects this adjustment, and assumes there is no livestock direct deposition, and will therefore not require further reduction.

Scenario 2 for Mill Swamp shows that with removal of all anthropogenic sources, violations of the instantaneous standard will occur 2.8% of the time, with 0.00% violations of the geometric mean standard. Scenario 3 predicts that violations of the instantaneous standard will remain appreciable with moderate reductions in land-based

anthropogenic sources, and a reduction of 100% of direct loads from livestock; scenario 3 also represents what is necessary to achieve a violation rate close to an approximate 10% of the instantaneous standard. Scenarios 4 and 5 explore more stringent restrictions upon land-based and direct loads and further demonstrate the need for reductions of wildlife contributions. Scenario 6 shows the final allocation scenario for Mill Swamp, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in non-point anthropogenic loads, a 28% reduction in wildlife direct loads, and an 86% reduction necessary in wildlife land-based loads in order to obtain no violations of the standards.

Table 5.7 Allocation scenarios for bacterial concentration with current loading estimates in model segment 6, Mill Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	18.33	14.70
2	0	0	100	100	100	100	0.00	2.80
3	0	0	100	50	100	50	1.67	10.20
4	0	0	100	90	100	90	0.00	3.95
5	0	0	100	99	100	99	0.00	2.80
6	28	86	100	99	100	99	0.00	0.00

5.2.2.9 Rattlesnake (Creek) Swamp

Rattlesnake (Creek) Swamp is located in the northwestern corner of Isle of Wight County and flows in a southwesterly direction before its confluence with the Blackwater River. The impaired section stretches from the confluence with Pouches Swamp to the mouth at the Blackwater River (7.5 stream miles). Rattlesnake (Creek) Swamp receives flow from Mill Swamp, another impaired segment that is included in this TMDL study. The watershed is 45% forest with 24% wetlands and 22% in cropland.

Total fecal coliform production per year in the watershed was modeled as 74.62E+13, with a fecal coliform density of 23.45E09 cfu/acre. Major sources of fecal coliform bacteria include muskrat (44%) and raccoon (24%). The total wildlife contribution to the

fecal coliform load is 88%. Conversations with local farmers indicated that livestock direct deposition was extremely limited, and the modeling was conducted accordingly – the 100% reduction shown for all allocation scenarios reflects this adjustment, and assumes there is no livestock direct deposition, and will therefore not require further reduction. The long term VADEQ monitoring station, 5ARKN006.40, has a historical fecal coliform violation rate of 16%, as compared to a modeled value of 14.91% during the same period. The existing conditions reflect a decrease of over 2,800 hogs in the Rattlesnake Creek watershed, and accordingly the watershed loading rate, and instantaneous standard violation rate is decreased.

Scenario 1 indicates the existing conditions in Rattlesnake (Creek) Swamp and has a predicted violations rate 5.10%, as compared to a monitored *E. coli* violation rate of 8% during TMDL development. Scenario 2 represents an unallocated Rattlesnake (Creek) Swamp, with bacterial loads in Mill Swamp reduced so that there are 0% violations of the instantaneous standard, and predicts a violation rate of approximately 3% in Rattlesnake (Creek) Swamp. Scenario 3 for Rattlesnake (Creek) Swamp shows that with removal of all anthropogenic sources, violations of the instantaneous standard will still occur 2.25% of the time, with 0.00% violations of the geometric mean standard; this is a result of the fact that wildlife represents 88% of the total fecal loading for the watershed, and suggests that significant reductions on wildlife will be needed in order to meet water quality standards. Scenarios 4, 5 and 6 explore increasingly strong restrictions upon land-based and direct loads, and further demonstrate the need for reductions of wildlife contributions. Scenario 7 shows the final allocation scenario for Rattlesnake (Creek) Swamp, which requires 100% reductions in all anthropogenic direct sources, 99% reductions in non-point anthropogenic loads, and shows the reductions to wildlife loads to be 65% in wildlife direct deposition, along with an 84% reduction necessary in wildlife land-based loads in order to obtain no violations of water quality standards.

Table 5.8 Allocation scenarios for bacterial concentration with current loading estimates in model segment 6, Rattlesnake (Creek) Swamp.

Scenario Number	Percent Reduction in Loading from Existing Conditions						Percent Violations	
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe / Sewer Overflow	NPS Res. / Urban	GM > 126 cfu/100 ml	Single Sample > 235 cfu / 100ml
1	0	0	100	0	0	0	0.00	5.10
2	0	0	100	0	0	0	0.00	3.07
3	0	0	100	100	100	100	0.00	2.25
4	0	0	100	50	100	50	0.00	2.52
5	0	0	100	90	100	90	0.00	2.30
6	0	0	100	99	100	99	0.00	2.25
7	65	84	100	99	100	99	0.00	0.00

Figures 5.1 through 5.8 show the monthly instantaneous values for existing and allocated conditions for all impairments in the Chowan Study Area. These graphs show allocated conditions in black, with existing conditions overlaid in gray.

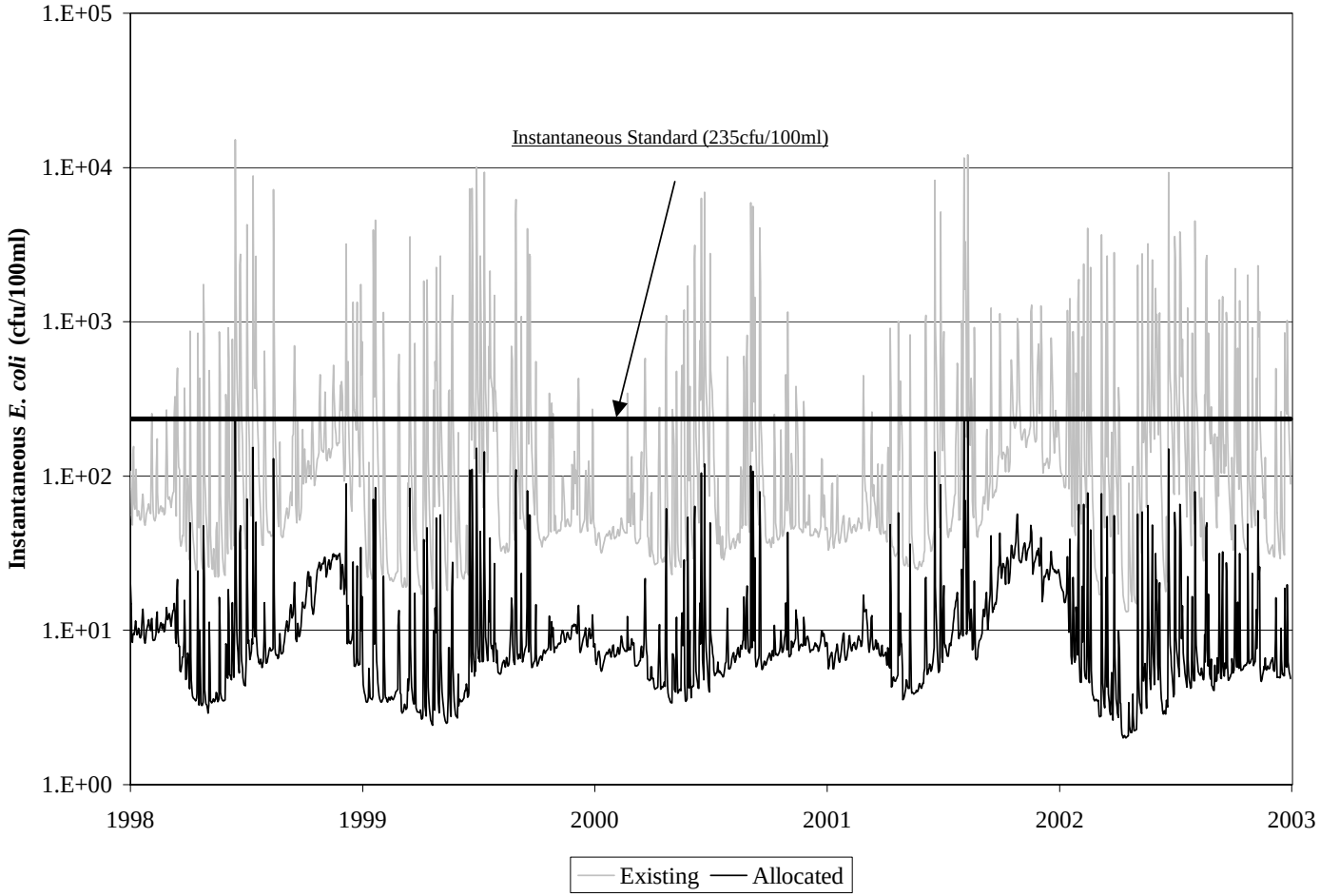

Figure 5.1 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 22, Little Nottoway River impairment.

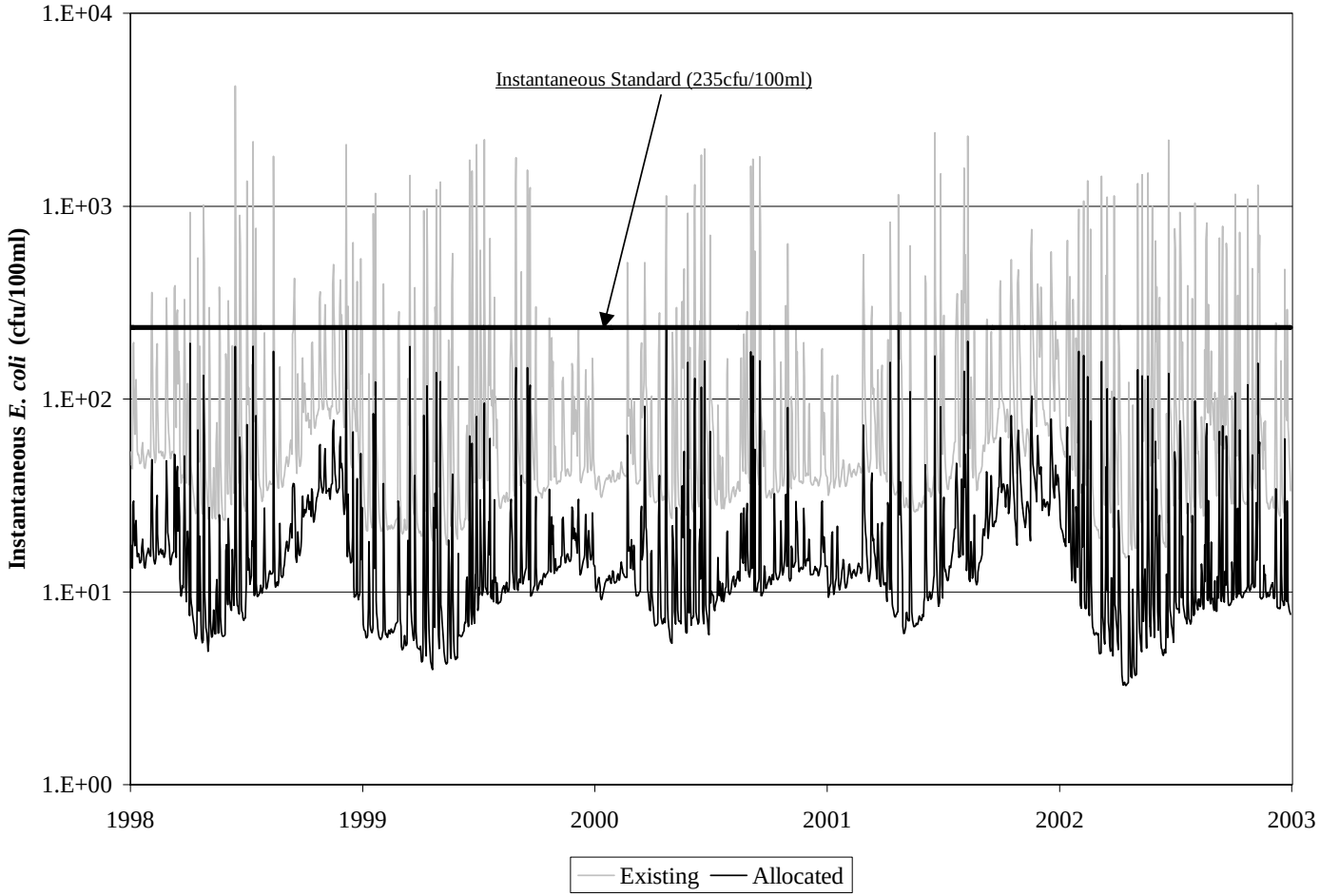

Figure 5.2 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 34, Big Hounds Creek impairment.

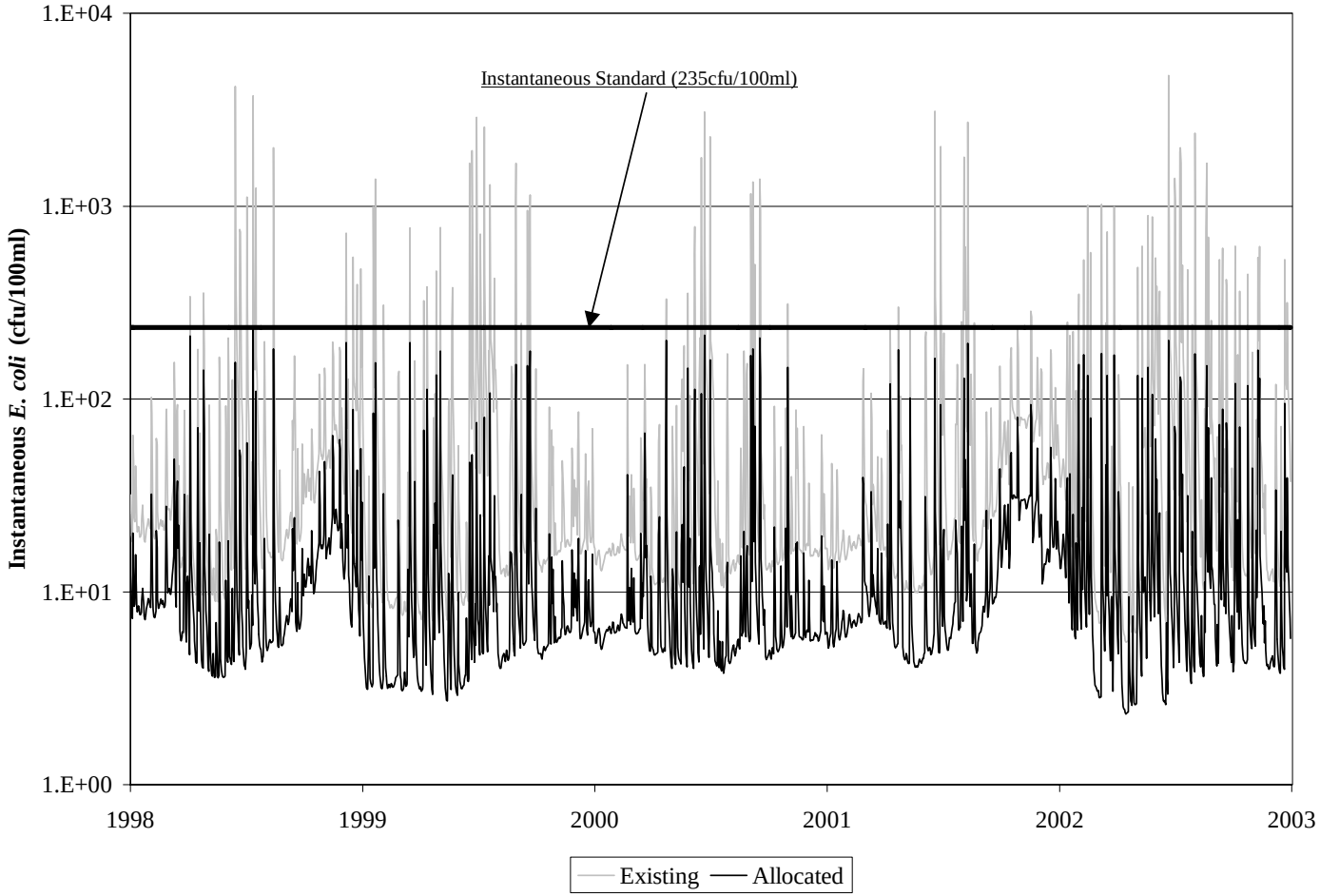

Figure 5.3 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 3, Nottoway River impairment.

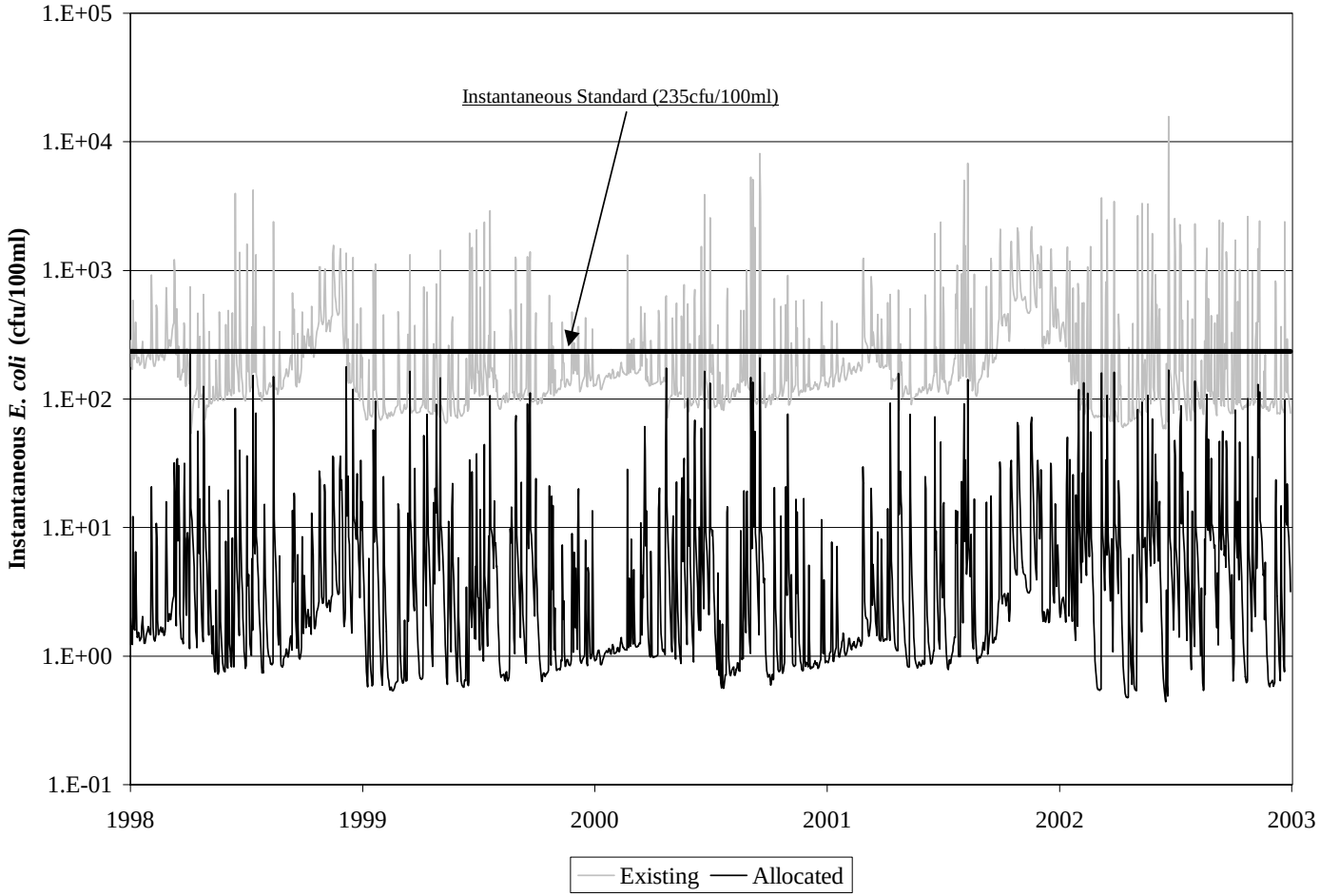

Figure 5.4 Existing and allocation scenarios of *E. coli* concentrations in model segment 2 subwatershed 39, Beaverpond Creek impairment.

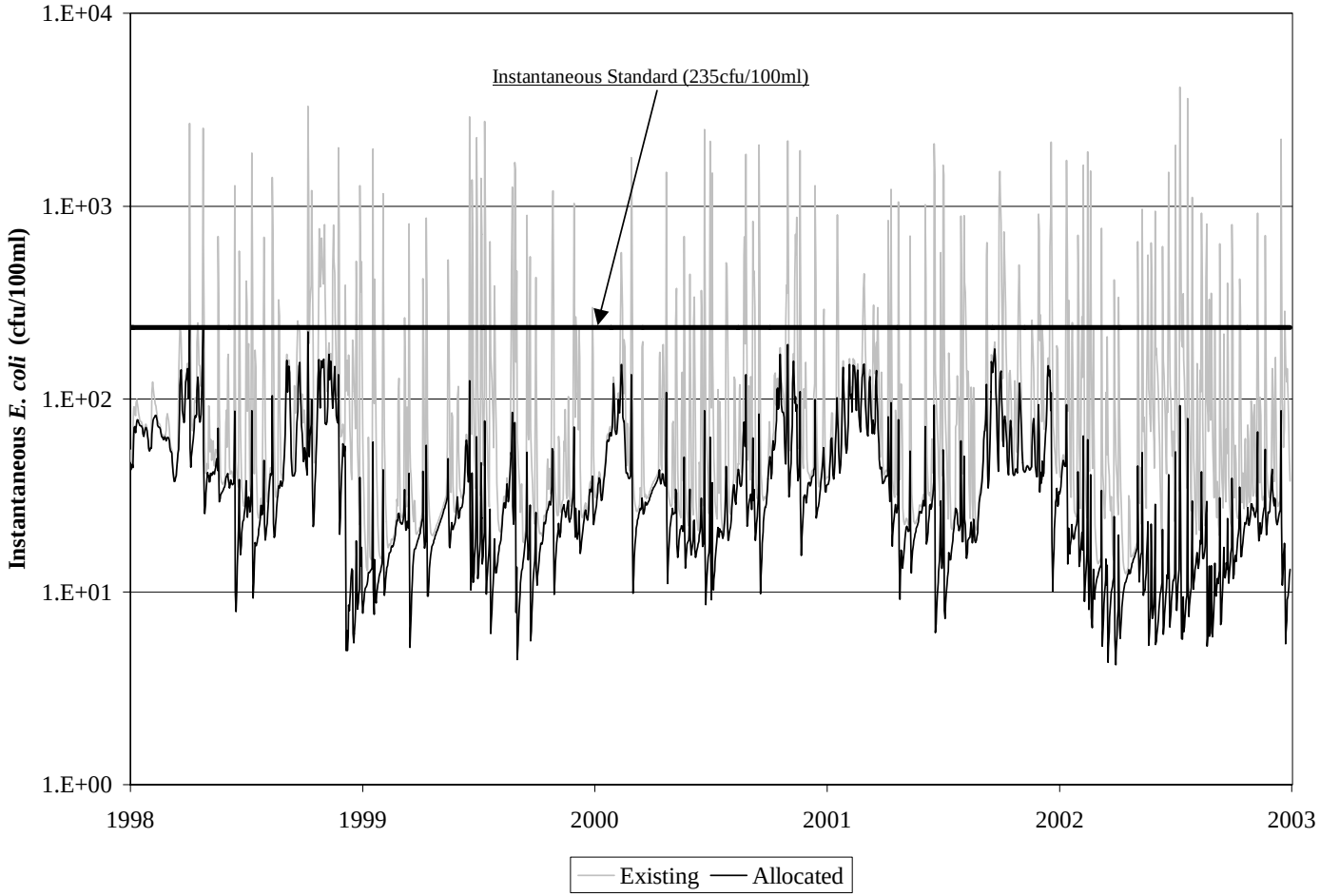

Figure 5.5 Existing and allocation scenarios of *E. coli* concentrations in model segment 4 subwatershed 21, Raccoon Creek impairment.

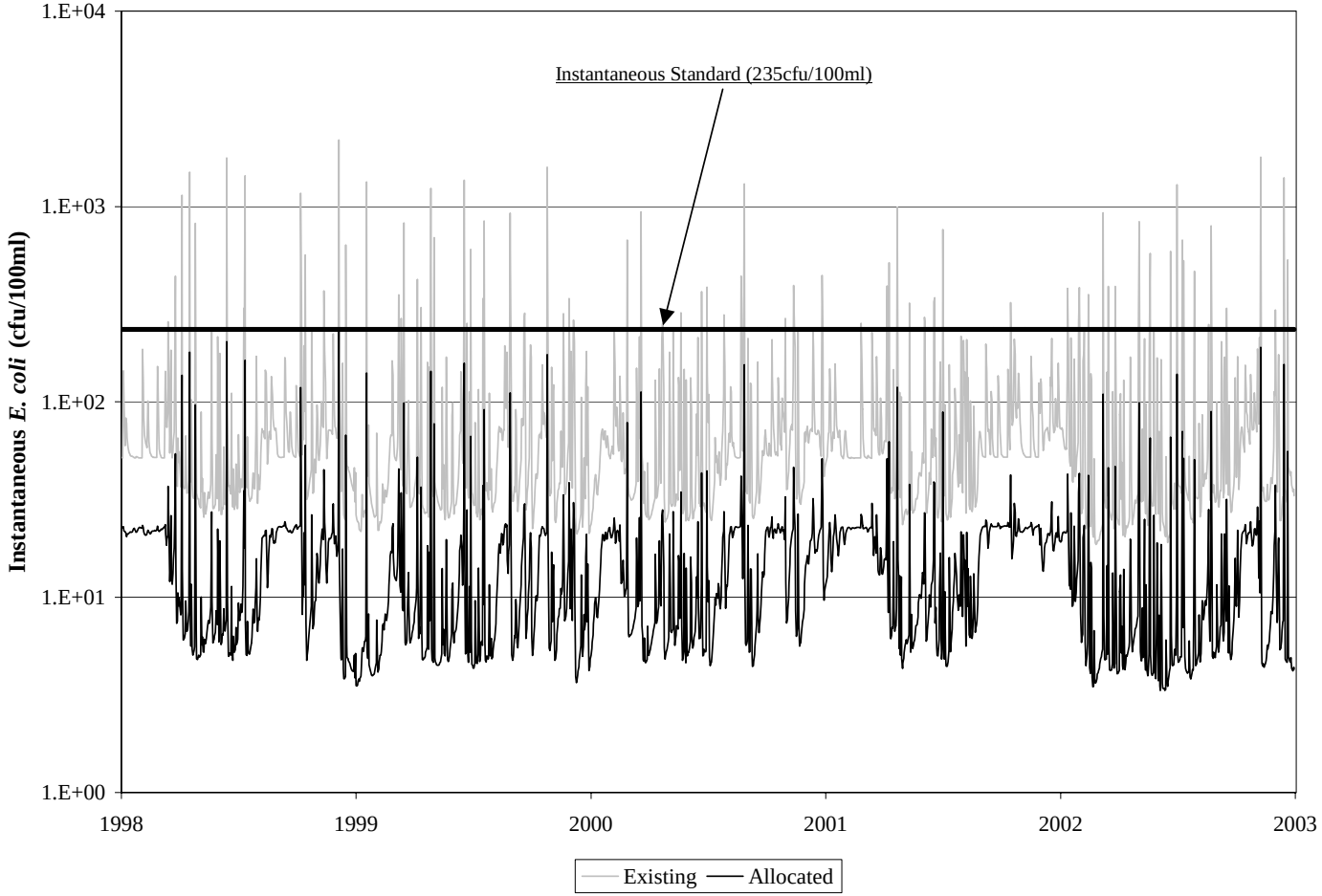

Figure 5.6 Existing and allocation scenarios of *E. coli* concentrations in model segment 5 subwatershed 15, Cypress Swamp impairment.

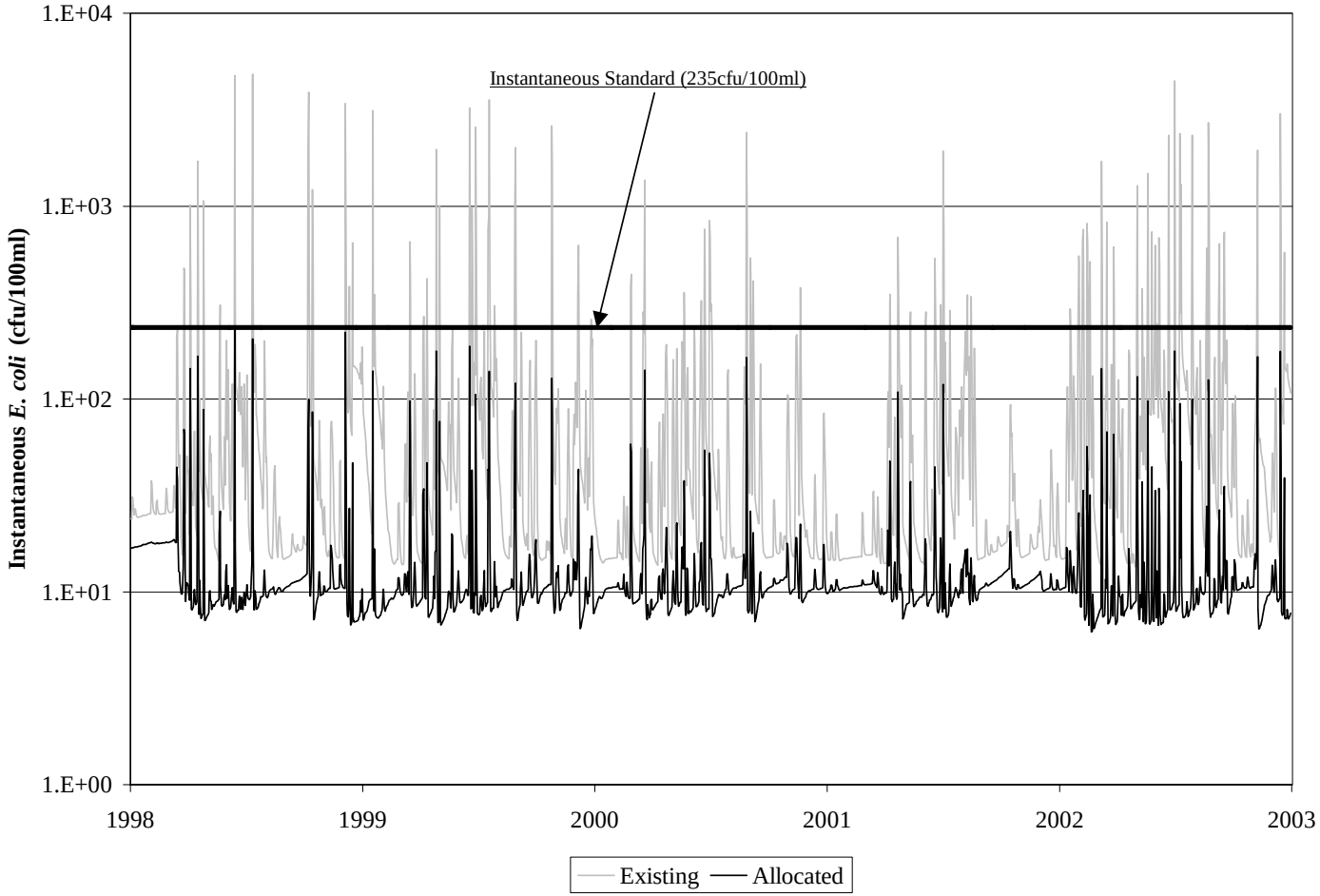

Figure 5.7 Existing and allocation scenarios of *E. coli* concentrations in model segment 6 subwatershed 25, Mill Swamp impairment.

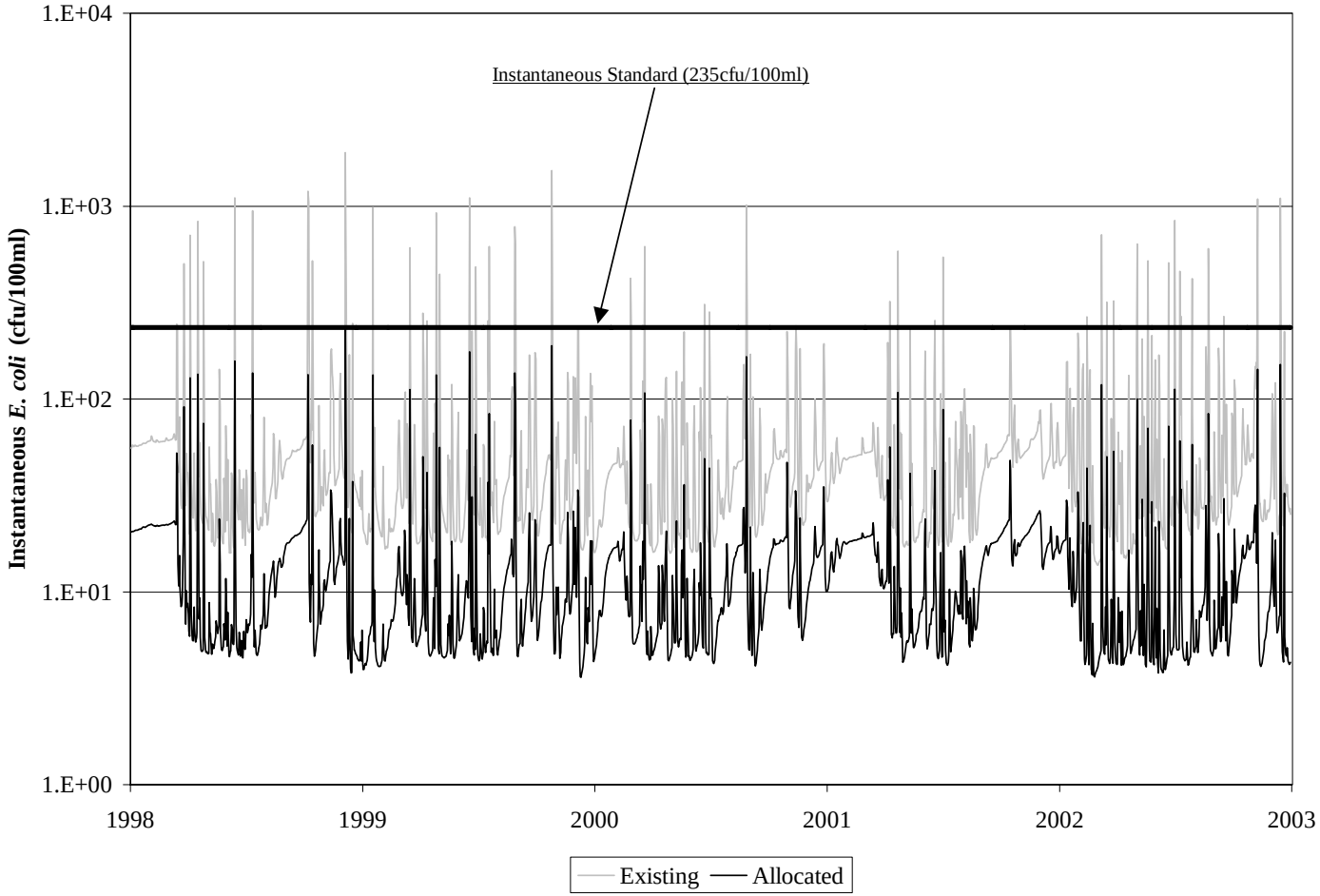

Figure 5.8 Existing and allocation scenarios of *E. coli* concentrations in model segment 6 subwatershed 32, Rattlesnake (Creek) Swamp impairment.

Figures 5.9 through 5.16 show the monthly geometric mean concentrations for existing and allocated conditions for all impairments in the Chowan Study Area. These graphs show existing conditions in gray, with allocated conditions overlaid in black. The monthly geometric mean is calculated from the daily average *E. coli* concentration, predicted by the water quality model, and is grouped by calendar month.

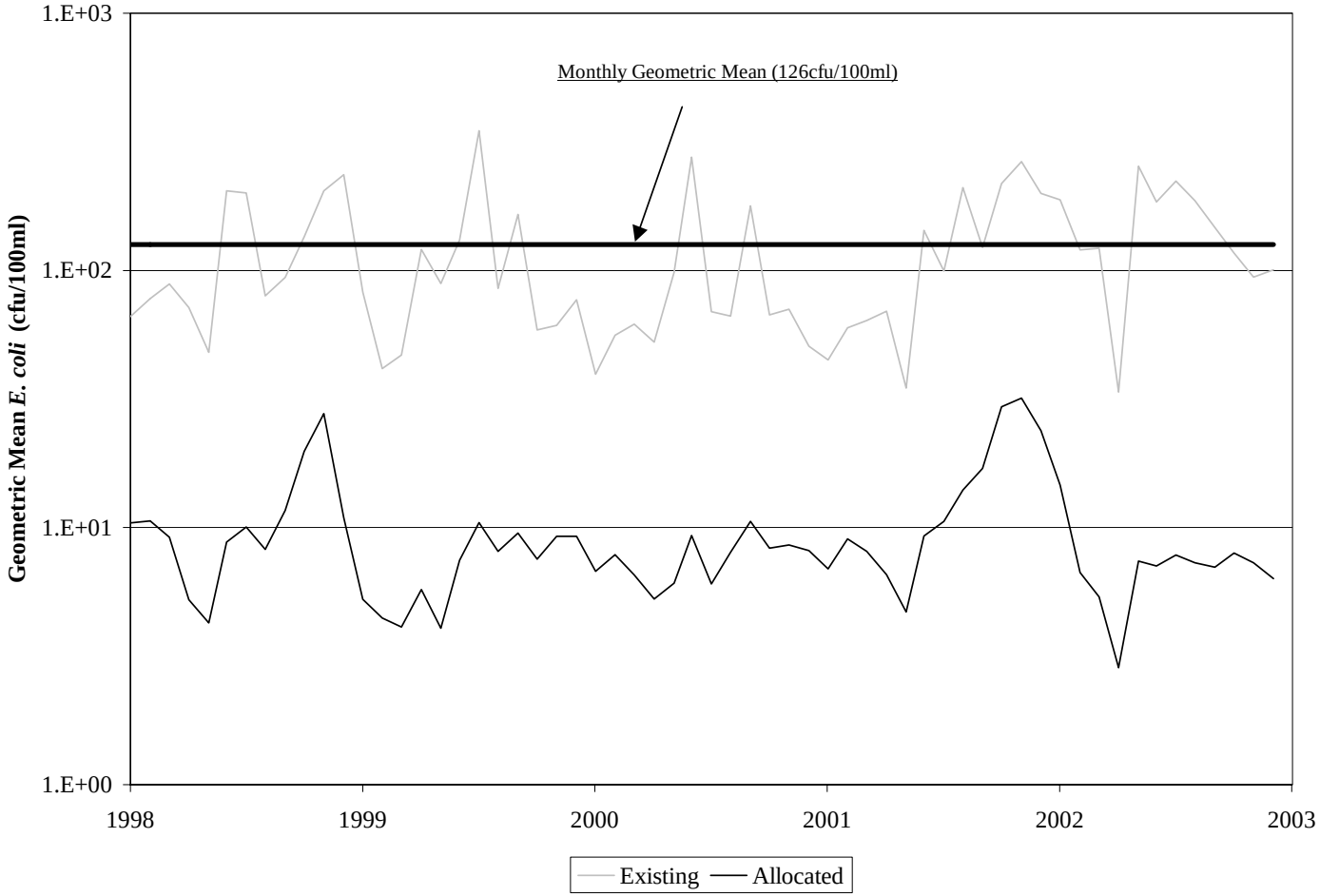

Figure 5.9 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 22, Little Nottoway River impairment.

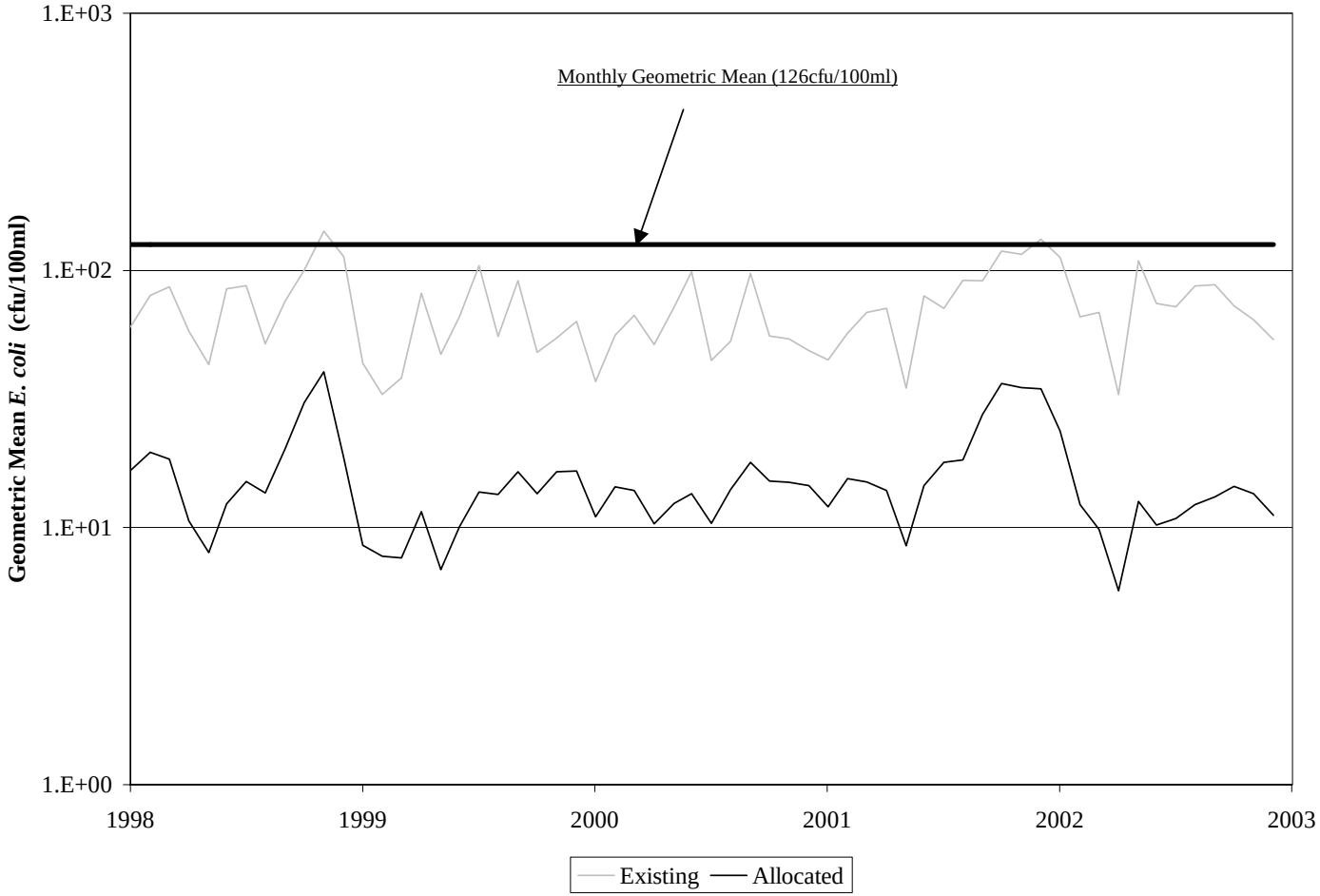

Figure 5.10 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 34, Big Hounds Creek impairment.

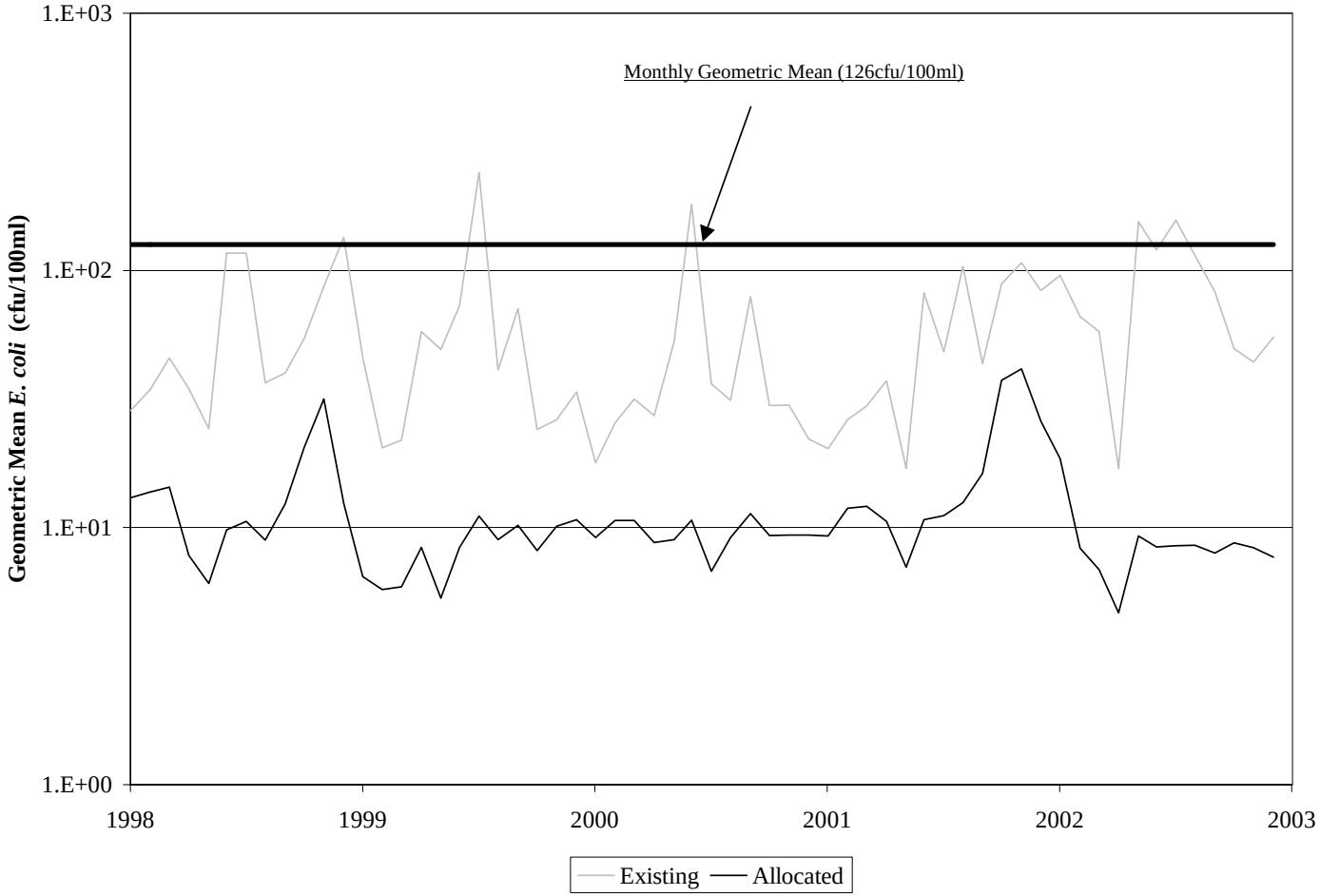

Figure 5.11 Existing and allocation scenarios of *E. coli* concentrations in model segment 1 subwatershed 3, Nottoway River impairment.

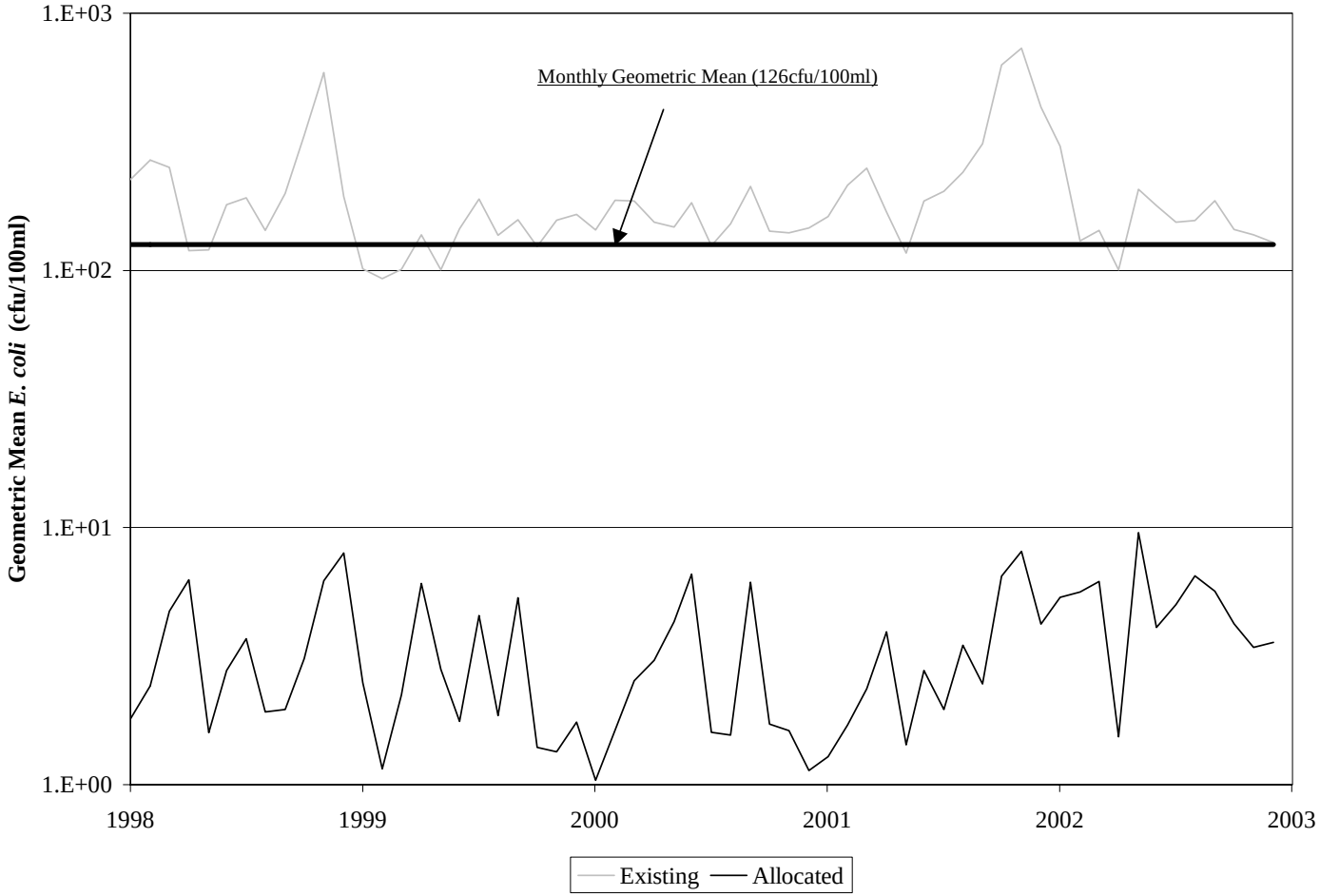

Figure 5.12 Existing and allocation scenarios of *E. coli* concentrations in model segment 2 subwatershed 39, Beaverpond Creek impairment.

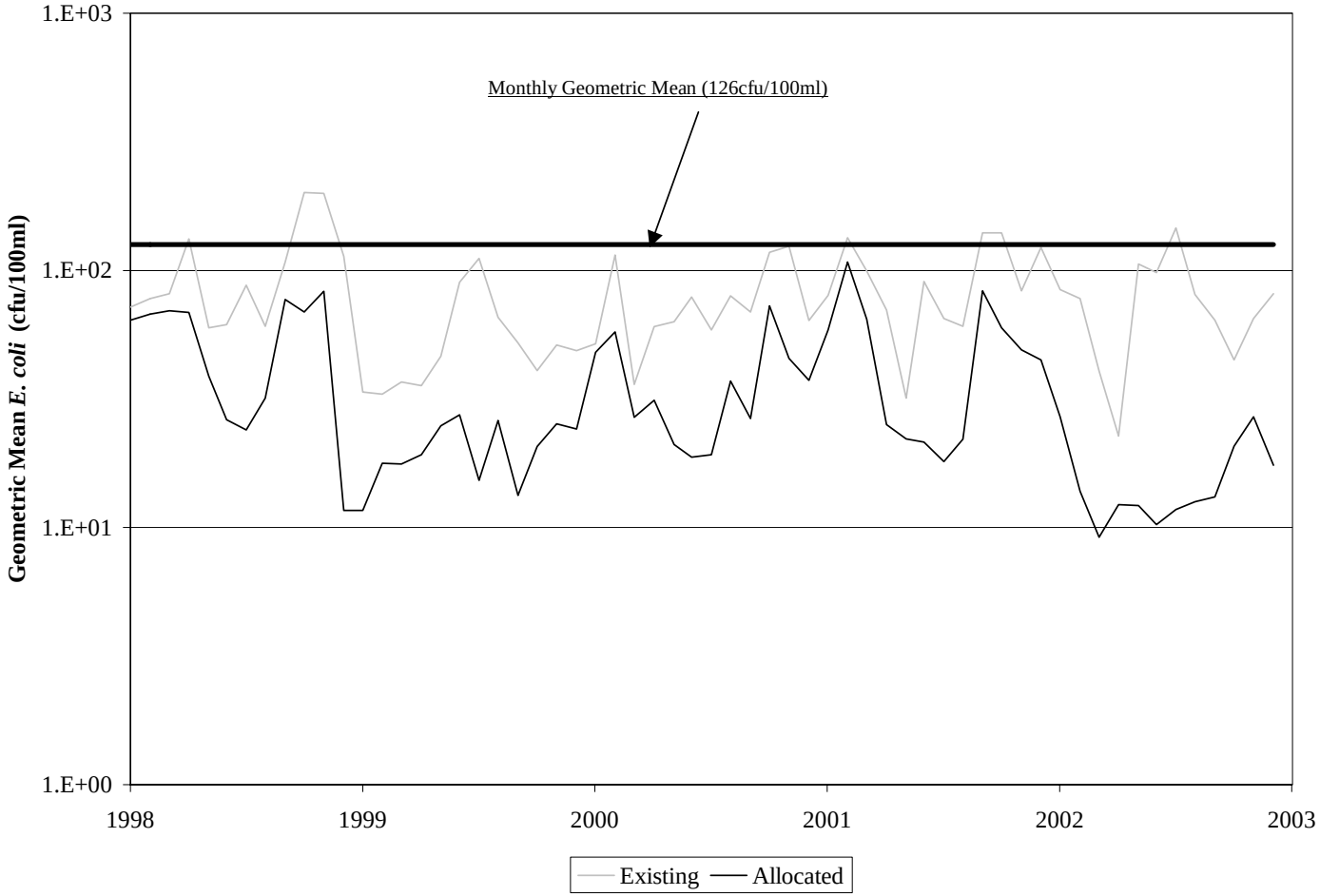

Figure 5.13 Existing and allocation scenarios of *E. coli* concentrations in segment 4 subwatershed 21, Raccoon Creek impairment.

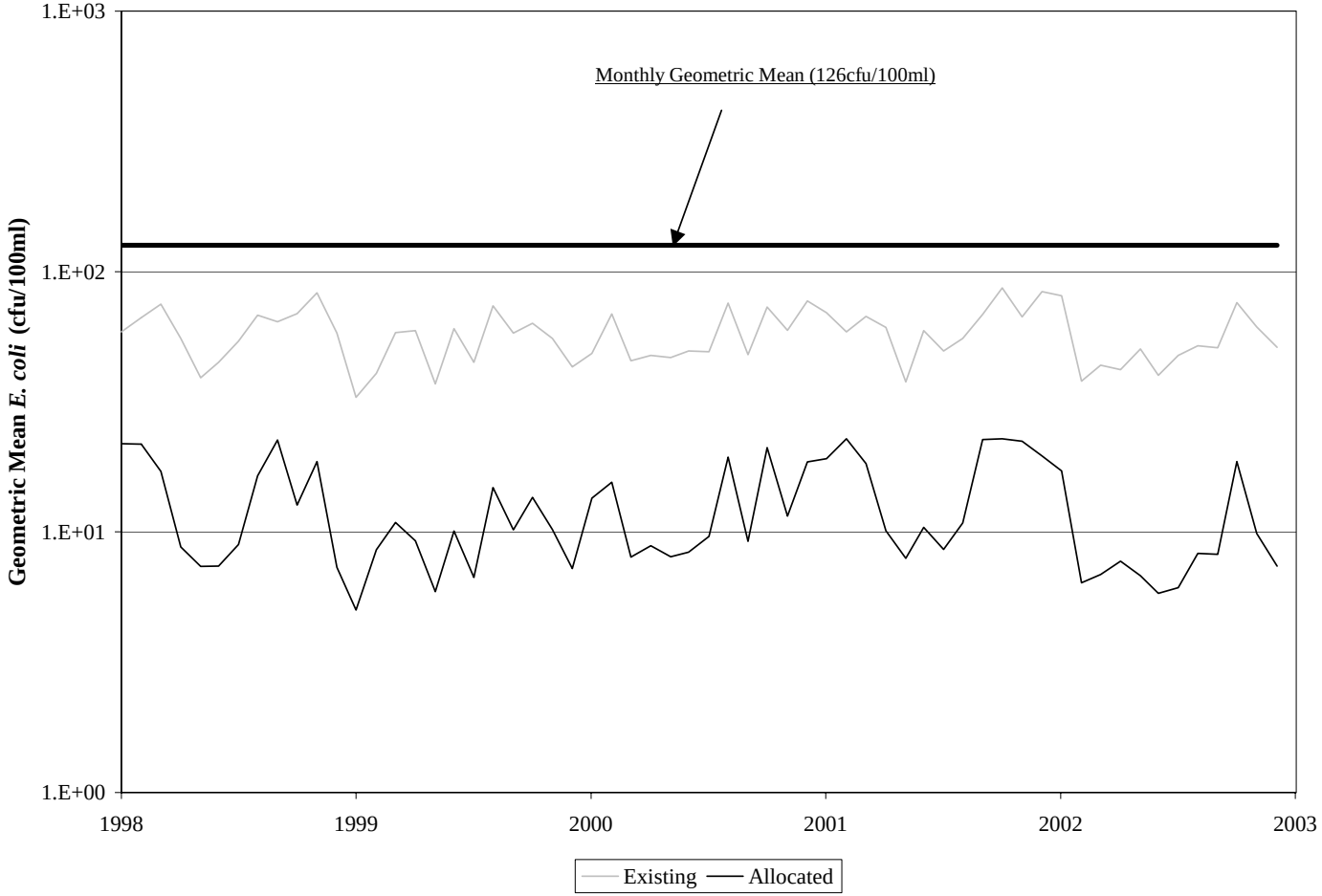

Figure 5.14 Existing and allocation scenarios of *E. coli* concentrations in model segment 5 subwatershed 15, Cypress Swamp impairment.

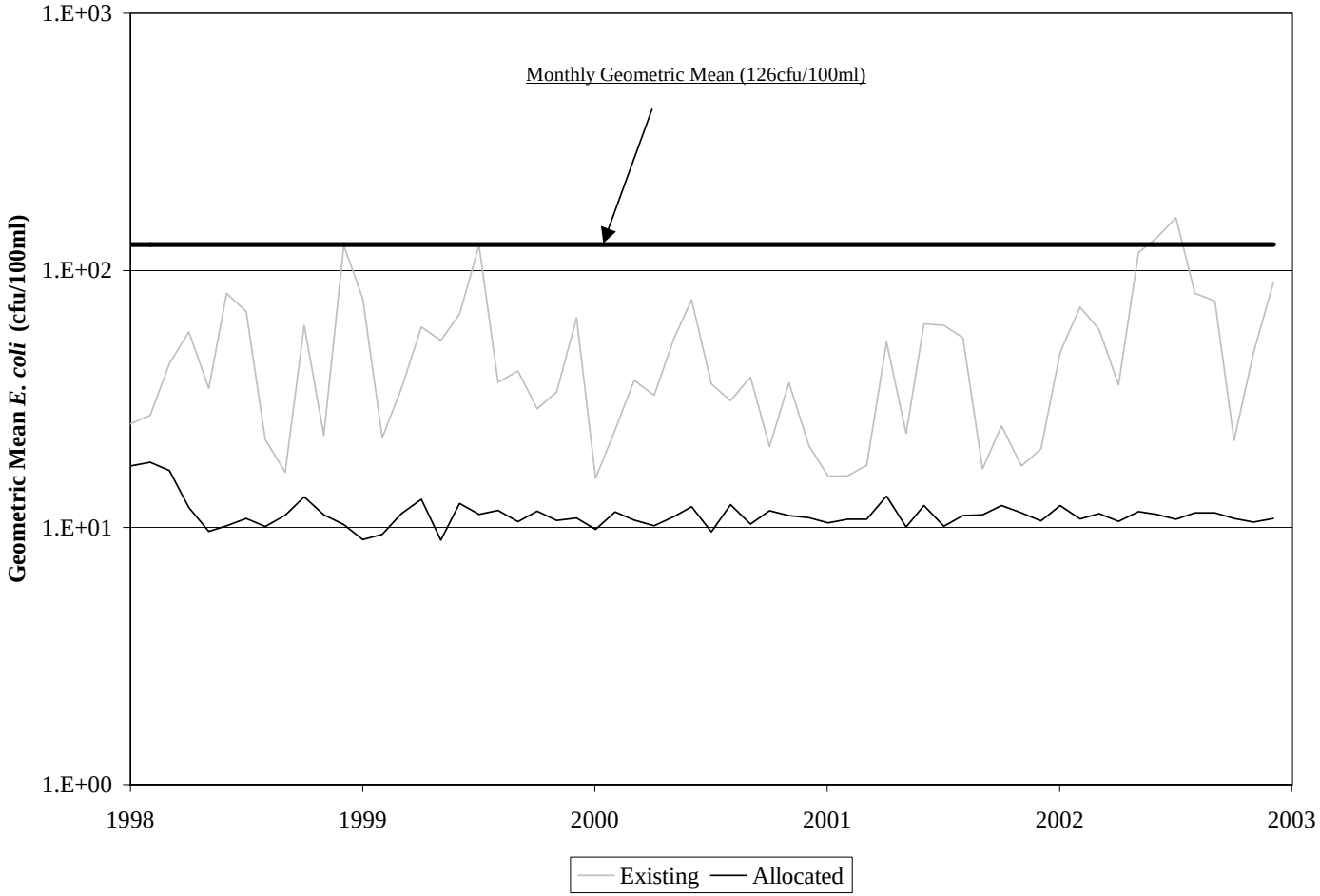

Figure 5.15 Existing and allocation scenarios of *E. coli* concentrations in model segment 6 subwatershed 25, Mill Swamp impairment.

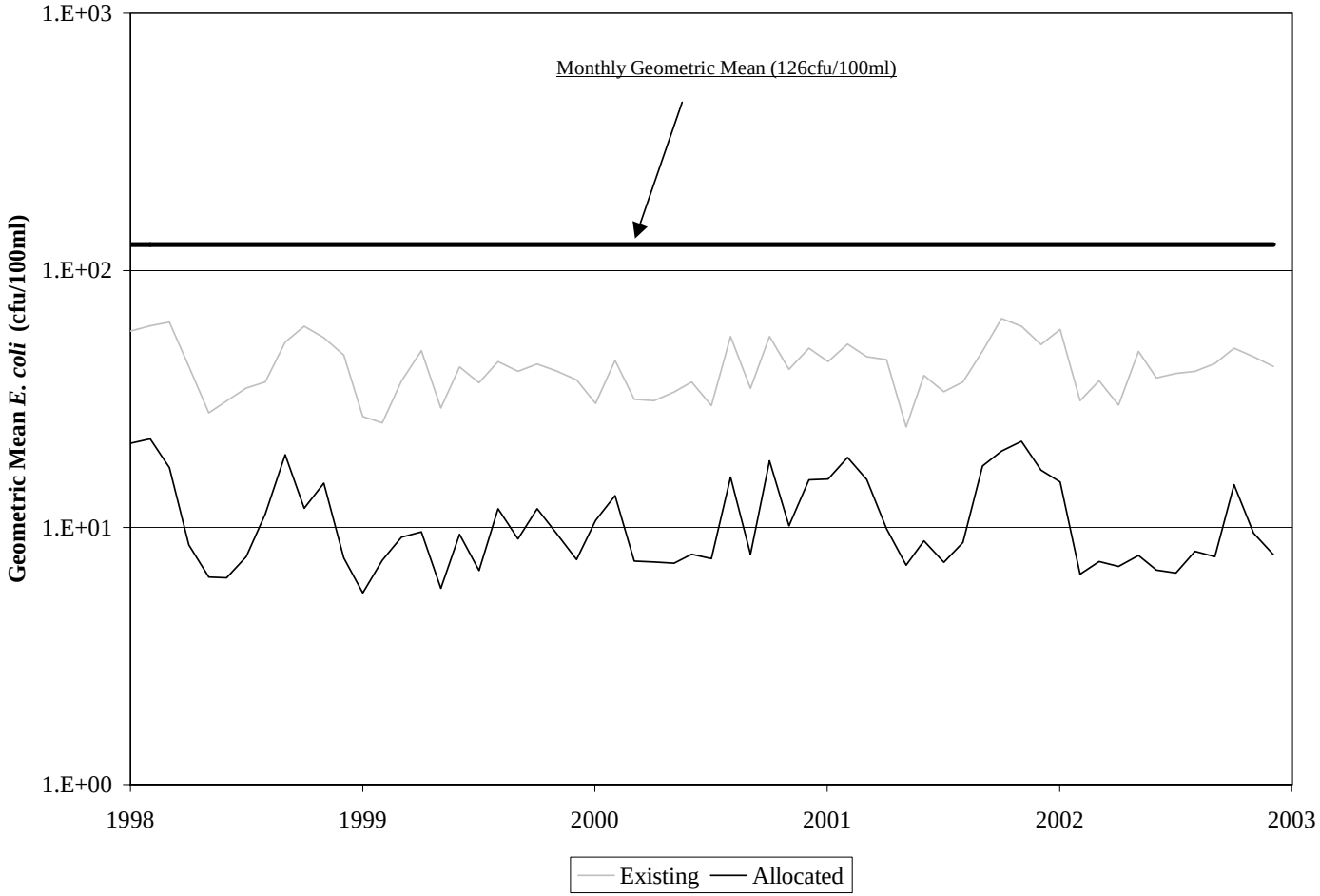

Figure 5.16 Existing and allocation scenarios of *E. coli* concentrations in model segment 6 subwatershed 32, Rattlesnake (Creek) Swamp impairment.

Tables 5.9 through 5.16 contain the existing and allocated loads for all the impairments in the Chowan Study Area, reported as total annual colony forming units (cfu) per year from both direct and land-based sources. The percent reduction needed to meet zero percent violations of water quality standards is given in the final column of these tables. Table 5.17 is known as the TMDL table, which gives the number of cfu of *E. coli* that can reach the stream in a given year, and still meet existing water quality standards. These figures are broken up into Waste Load Allocation (WLA), or the portion of fecal coliform that may come from permitted discharge sources and Load Allocation (LA), or the portion of fecal coliform that may come from the non-permitted non-point sources existing in the watershed.

Table 5.9 Land-based and Direct nonpoint source fecal coliform load reductions in the Little Nottoway River impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.05E+14	1.05E+12	99.00
Barren	7.08E+12	3.46E+11	95.00
Commercial	7.56E+12	7.56E+10	99.00
Cropland	2.97E+15	2.97E+13	99.00
Pasture	3.19E+15	3.19E+13	99.00
Residential	1.36E+14	1.36E+12	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	1.31E+14	6.63E+12	95.00
Woodland	4.77E+14	2.36E+13	95.00
Direct			
Human	6.60E+12	0.00E+00	100.00
Livestock	1.07E+13	0.00E+00	100.00
Wildlife	1.89E+13	6.25E+12	67.00

Table 5.10 Land-based and Direct nonpoint source fecal coliform load reductions in the Big Hounds Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.40E+13	1.40E+11	99.00
Barren	2.34E+12	4.42E+11	81.00
Commercial	3.06E+12	2.75E+11	91.00
Cropland	2.39E+12	2.39E+10	99.00
Pasture	3.06E+14	3.06E+12	99.00
Residential	5.37E+13	4.85E+12	91.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	9.80E+12	1.87E+12	81.00
Woodland	1.58E+14	2.85E+13	81.00
Direct			
Human	3.30E+12	0.00E+00	100.00
Livestock	1.30E+12	0.00E+00	100.00
Wildlife	5.02E+12	5.02E+12	0.00

Table 5.11 Land-based and Direct nonpoint source fecal coliform load reductions in the Nottoway River impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	2.66E+13	2.66E+11	99.00
Barren	1.81E+13	2.55E+12	86.00
Commercial	1.83E+12	1.83E+10	99.00
Cropland	1.70E+15	1.70E+13	99.00
Pasture	1.15E+15	1.15E+12	99.90
Residential	5.76E+13	5.76E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	1.15E+14	1.60E+13	86.00
Woodland	4.09E+14	5.76E+13	86.00
Direct			
Human	2.70E+12	0.00E+00	100.00
Livestock	2.80E+12	0.00E+00	100.00
Wildlife	1.33E+13	1.05E+13	21.00

Table 5.12 Land-based and Direct nonpoint source fecal coliform load reductions in the Beaverpond Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	9.74E+12	9.74E+10	99.00
Barren	5.88E+11	1.87E+11	67.00
Commercial	1.94E+11	1.94E+09	99.00
Cropland	9.41E+13	9.41E+11	99.00
Pasture	7.42E+14	2.78E+12	99.625
Residential	3.40E+13	3.40E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	2.99E+12	9.99E+11	67.00
Woodland	7.27E+13	2.38E+13	67.00
Direct			
Human	3.90E+11	0.00E+00	100.00
Livestock	8.00E+11	0.00E+00	100.00
Wildlife	2.78E+12	1.67E+10	99.40

Table 5.13 Land-based and Direct nonpoint source fecal coliform load reductions in the Raccoon Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	4.58E+12	4.58E+10	99.00
Barren	1.26E+13	6.32E+11	95.00
Commercial	1.52E+12	1.52E+10	99.00
Cropland	2.12E+15	2.12E+13	99.00
Pasture	5.09E+14	5.09E+12	99.00
Residential	2.64E+13	2.64E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	3.15E+14	1.59E+13	95.00
Woodland	4.27E+14	2.11E+13	95.00
Direct			
Human	1.10E+12	0.00E+00	100.00
Livestock	1.30E+12	0.00E+00	100.00
Wildlife	2.18E+13	2.18E+13	0.00

Table 5.14 Land-based and Direct nonpoint source fecal coliform load reductions in the Cypress Swamp impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.02E+12	1.02E+10	99.00
Barren	2.56E+13	2.56E+12	90.00
Commercial	2.47E+11	2.47E+09	99.00
Cropland	1.02E+14	1.02E+12	99.00
Pasture	5.30E+13	5.30E+11	99.00
Residential	1.38E+13	1.38E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	3.60E+14	3.60E+13	90.00
Woodland	4.53E+14	4.53E+13	90.00
Direct			
Human	1.75E+12	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	2.67E+13	5.35E+12	80.00

Table 5.15 Land-based and Direct nonpoint source fecal coliform load reductions in the Mill Swamp impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	8.76E+12	8.76E+10	99.00
Barren	1.07E+12	1.52E+11	86.00
Commercial	4.04E+11	4.04E+09	99.00
Cropland	1.04E+15	1.04E+13	99.00
Pasture	2.55E+14	2.55E+12	99.00
Residential	1.64E+13	1.64E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	1.91E+14	2.67E+13	86.00
Woodland	1.87E+14	2.62E+13	86.00
Direct			
Human	1.10E+12	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	1.20E+13	8.61E+12	28.00

Table 5.16 Land-based and Direct nonpoint source fecal coliform load reductions in the Rattlesnake (Creek) Swamp impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	3.67E+12	3.67E+10	99.00
Barren	3.81E+12	6.17E+11	84.00
Commercial	4.52E+11	4.52E+09	99.00
Cropland	7.74E+13	7.74E+11	99.00
Pasture	7.97E+13	7.97E+11	99.00
Residential	3.56E+13	3.56E+11	99.00
Water	0.00E+00	0.00E+00	0.00
Wetlands	2.25E+14	3.60E+13	84.00
Woodland	2.68E+14	4.31E+13	84.00
Direct			
Human	1.10E+12	0.00E+00	100.00
Livestock	0.00E+00	0.00E+00	100.00
Wildlife	1.52E+13	5.33E+12	65.00

Table 5.17 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Chowan Study Area watershed impairments.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Beaverpond Creek	*E. coli*	0.00E+00	2.62E+12		2.62E+12
Big Hounds Creek	*E. coli*	6.96E+11	4.45E+12		5.14E+12
VA0020184		*6.96E+11*			
Cypress Swamp	*E. coli*	2.26E+11	6.33E+12		6.56E+12
VA0088463		*2.26E+11*			
Little Nottoway	*E. coli*	6.54E+11	1.11E+13	*Implicit*	1.18E+13
VA0066869		*6.09E+11*			
VA0061158		*4.46E+10*			
Nottoway River	*E. coli*	0.00E+00	1.04E+13		1.04E+13
Mill Swamp	*E. coli*	0.00E+00	8.06E+12		8.06E+12
Raccoon Creek	*E. coli*	0.00E+00	1.44E+13		1.44E+13
Rattlesnake (Creek) Swamp	*E. coli*	0.00E+00	1.53E+13		1.53E+13

6. IMPLEMENTATION

The goal of this TMDL is to establish a three-step path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments in the Chowan Study Area. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan (IP), and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA and the citizen State Water Control Board, measures must be taken to reduce pollution levels in the stream. These measures, 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 recent *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends that the required reductions 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 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 failing septic systems and straight pipes should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as 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 could be accomplished through a sanitary sewer inspection and management program. Other readily implementable BMPs that might be appropriate for controlling urban wash-off from parking lots and roads 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 I scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

6.2 Stage I Scenarios

The goal of the Stage I scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage I scenarios were generated with the same model

setup as was used for the TMDL allocation scenarios. While specific Stage I goals for BMP implementation will be established as part of the implementation plan development process, one potential scenario is outlined below.

As presented in Chapter 5, scenarios were devised assuming reductions of 100% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. For all impairments, the model predicted violations of the water quality standards.

The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the impaired segments in the Chowan Study Area to less than 10%. The model predictions for these Stage I allocations are shown in Table 6.1.

Table 6.1 Reduction percentages for the Stage I implementation.

Impairment Name	Direct Wildlife	NPS Wildlife	Direct Live-stock	NPS Pasture / Livestock Access/ Cropland	NPS Res./ Urban	Straight Pipe/ Sewer Overflow	% Single Samples Exceeding Standard
Upper Blackwater River Basin							
Cypress Swamp	0	0	100	50	50	100	15.80
Mill Swamp	0	0	100	50	50	100	10.20
Rattlesnake (Creek) Swamp	0	0	100	50	50	100	2.52
Upper Nottoway River Basin							
Beaverpond Creek	0	0	100	60	60	100	17.70
Big Hounds Creek	0	0	50	25	25	100	10.20
Little Nottoway	0	0	95	60	60	100	11.40
Nottoway River	0	0	90	50	50	100	9.70
Raccoon Creek	0	0	90	50	50	100	10.53

Tables 6.2 through Table 6.9 detail the load reductions required to meet the Stage I Implementation described in Table 6.1.

Table 6.2 Nonpoint source allocations in the Little Nottoway River impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.05E+14	4.20E+13	60
Barren	7.08E+12	7.08E+12	0
Commercial	7.56E+12	3.02E+12	60
Cropland	2.97E+15	1.19E+15	60
Pasture	3.19E+15	1.28E+15	60
Residential	1.36E+14	5.44E+13	60
Water	0.00E+00	0.00E+00	0
Wetlands	1.31E+14	1.31E+14	0
Woodland	4.77E+14	4.77E+14	0
Direct			
Human	6.60E+12	0.00E+00	100
Livestock	1.07E+13	5.35E+11	95
Wildlife	1.89E+13	1.89E+13	0

Table 6.3 Nonpoint source allocations in the Big Hounds Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.40E+13	1.05E+13	25
Barren	2.34E+12	2.34E+12	0
Commercial	3.06E+12	2.30E+12	25
Cropland	2.39E+12	1.79E+12	25
Pasture	3.06E+14	2.30E+14	25
Residential	5.37E+13	4.03E+13	25
Water	0.00E+00	0.00E+00	0
Wetlands	9.80E+12	9.80E+12	0
Woodland	1.58E+14	1.58E+14	0
Direct			
Human	3.30E+12	0.00E+00	100
Livestock	1.30E+12	6.50E+11	50
Wildlife	5.02E+12	5.02E+12	0

Table 6.4 Nonpoint source allocations in the Nottoway River impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	2.66E+13	1.33E+13	50
Barren	1.81E+13	1.81E+13	0
Commercial	1.83E+12	9.15E+11	50
Cropland	1.70E+15	8.50E+14	50
Pasture	9.30E+14	4.65E+14	50
Residential	5.76E+13	2.88E+13	50
Water	0.00E+00	0.00E+00	0
Wetlands	1.15E+14	1.15E+14	0
Woodland	4.09E+14	4.09E+14	0
Direct			
Human	2.70E+12	0.00E+00	100
Livestock	2.80E+12	2.80E+11	90
Wildlife	1.33E+13	1.33E+13	0

Table 6.5 Nonpoint source allocations in the Beaverpond Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	9.74E+12	4.87E+12	50
Barren	5.88E+11	5.88E+11	0
Commercial	1.94E+11	9.70E+10	50
Cropland	9.41E+13	4.71E+13	50
Pasture	7.42E+14	3.71E+14	50
Residential	3.40E+13	1.70E+13	50
Water	0.00E+00	0.00E+00	0
Wetlands	2.99E+12	2.99E+12	0
Woodland	7.27E+13	7.27E+13	0
Direct			
Human	3.90E+11	0.00E+00	100
Livestock	8.00E+11	8.00E+10	90
Wildlife	2.78E+12	2.78E+12	0

Table 6.6 Nonpoint source allocations in the Raccoon Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	4.58E+12	2.29E+12	50
Barren	1.26E+13	1.26E+13	0
Commercial	1.52E+12	7.60E+11	50
Cropland	2.12E+15	1.06E+15	50
Pasture	5.09E+14	2.55E+14	50
Residential	2.64E+13	1.32E+13	50
Water	0.00E+00	0.00E+00	0
Wetlands	3.15E+14	3.15E+14	0
Woodland	4.27E+14	4.27E+14	0
Direct			
Human	1.10E+12	0.00E+00	100
Livestock	1.30E+12	1.30E+11	90
Wildlife	2.18E+13	2.18E+13	0

Table 6.7 Nonpoint source allocations in the Cypress Swamp impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	1.02E+12	5.12E+11	50
Barren	2.56E+13	2.56E+13	0
Commercial	2.47E+11	1.22E+11	50
Cropland	1.02E+14	5.07E+13	50
Pasture	5.30E+13	2.67E+13	50
Residential	1.38E+13	6.89E+12	50
Water	0.00E+00	0.00E+00	0
Wetlands	3.60E+14	3.60E+14	0
Woodland	4.53E+14	4.53E+14	0
Direct			
Human	1.75E+12	0.00E+00	100
Livestock	0.00E+00	0.00E+00	100
Wildlife	2.67E+13	2.67E+13	0

Table 6.8 Nonpoint source allocations in the Mill Swamp impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	8.76E+12	4.38E+12	50
Barren	1.07E+12	1.07E+12	0
Commercial	4.04E+11	2.02E+11	50
Cropland	1.04E+15	5.20E+14	50
Pasture	2.55E+14	1.28E+14	50
Residential	1.64E+13	8.20E+12	50
Water	0.00E+00	0.00E+00	0
Wetlands	1.91E+14	1.91E+14	0
Woodland	1.87E+14	1.87E+14	0
Direct			
Human	1.10E+12	0.00E+00	100
Livestock	0.00E+00	0.00E+00	100
Wildlife	1.20E+13	1.20E+13	0

Table 6.9 Nonpoint source allocations in the Rattlesnake (Creek) Swamp impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Livestock Access	3.67E+12	1.84E+12	50
Barren	3.81E+12	3.81E+12	0
Commercial	4.52E+11	2.26E+11	50
Cropland	7.74E+13	3.87E+13	50
Pasture	7.97E+13	3.99E+13	50
Residential	3.56E+13	1.78E+13	50
Water	0.00E+00	0.00E+00	0
Wetlands	2.25E+14	2.25E+14	0
Woodland	2.68E+14	2.68E+14	0
Direct			
Human	1.10E+12	0.00E+00	100
Livestock	0.00E+00	0.00E+00	100
Wildlife	1.52E+13	1.52E+13	0

The development of the implementation plan is expected to be an iterative process, with monitoring data refining its final design. Subsequent refinements will be made as the progress toward meeting milestones and the expressed TMDL goals are assessed. As practices are implemented, periodic analyses of water quality conditions will be conducted to evaluate the progress toward meeting end goals.

6.3 Reasonable Assurance for Implementation

6.3.1 Follow-up Monitoring

VADEQ will continue monitoring the Chowan Study Area in accordance with its ambient monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards. VADEQ solicits assistance from citizen monitoring groups in support of follow-up water quality monitoring for bacterial TMDLs.

The monitoring stations listed in Table 6.10 are trend stations and will continue to be monitored on a bi-monthly basis. Watershed monitoring stations are designed to provide complete, census-based coverage of every watershed in Virginia. Two of the major data

users in the Commonwealth (the Department of Environmental Quality and the Department of Conservation and Recreation) have indicated that this is an important function for ambient water quality monitoring.

Watershed stations are located at the mouth and within the watershed, based on a census-siting scheme. The number of stations in the watershed is determined by the NPS priority ranking thus focusing our resources on known problem areas. Watersheds are monitored on a rotating basis such that, in the 6-year assessment cycle, all 493 watersheds are monitored. These stations will be sampled at a frequency of once every other month for a two-year period on a 6-year rotating basin basis. In addition, ambient trend water quality monitoring stations have very long data records and are not included in the rotation scheme noted above. This provides for an historic view of water quality in important watersheds. Ambient trend stations are also monitored every other month. In addition to the stations listed in Table 6.10, other stations may be added as a result of implementation plan development, which is beginning at the conclusion of the TMDL development process.

Table 6.10 Ambient Trend Stations in the Chowan Study Area.

Station ID	Stream Name
TBD	Little Nottoway @ Rte. 625
TBD	Tommeheton Creek @ Rte. 638
TBD	Little Hounds Creek @ Rte. 651
TBD	Raccoon Creek

6.3.2 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. 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.

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

Once developed, VADEQ will take TMDL implementation plans to the State Water Control Board (SWCB) for approval as the plan for implementing the pollutant allocations and reductions contained in the TMDLs. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP) in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

6.3.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of “Best management practices to control or abate the discharge of pollutants when: (2) Numeric effluent limitations are infeasible…”.

For MS4/VPDES general permits, VADEQ expects revisions to the permittee’s Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. VADEQ anticipates that BMP effectiveness would be determined through

ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 6.3.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change in the Chowan Study Area would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html.

6.3.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentive Program (EQIP), the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. 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.

6.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for the Chowan

Study Area, these streams may not be able to attain standards without some reduction in wildlife load. **Virginia and EPA are not proposing the reduction of wildlife to allow for the attainment of water quality standards.**

To address this issue, Virginia has proposed (during its recent 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 February 12, 2004 and can be found at http://www.deq.state.va.us/wqs/rule.html.

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 bacterial 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. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage I scenario such as those presented previously in this chapter. The pollutant reductions in the Stage I scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of over-populations. During the implementation of the Stage I scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 6.1

above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage I 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, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

7. PUBLIC PARTICIPATION

The development of the Chowan River TMDLs greatly benefited from public participation. This section details the involvement for the Blackwater River, Raccoon Creek, Sappony Creek, and Nottoway River watershed areas.

7.1 Upper Blackwater River Watershed

In addition to the two public meetings, there were two Technical Advisory Committee (TAC) meetings. Table 7.1 details the public participation throughout the project.

The first TAC meeting for the Upper Blackwater River watershed took place on September 7, 2004 at the Isle of Wight Virginia Cooperative Extension Office in Isle of Wight, Virginia. There were 17 people in attendance, including 13 government agents, 1 MapTech representative, and 3 local stakeholders. The meeting was publicized in the *Virginia Register* and on the website at www.deq.virginia.gov/tmdl. The second TAC meeting took place on December 14, 2004 and was attended by 9 people.

The first public meeting was held at the Surry Community Center in Surry, VA on October 25, 2004 to discuss the process for TMDL development; 17 people (6 local stakeholders, 10 government agents and 1 consultant) attended. The meeting was published in the *Virginia Register* and copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received.

The final public meeting was held on March 3, 2005 at the Airfield 4-H Center in Wakefield, VA. This meeting was the forum for presenting results from both the Upper Blackwater River TMDLs and the Raccoon and Sappony Creek TMDLs. There was a 30-day public comment period, with 2 written comments received regarding this document. The meeting was publicized in the *Virginia Register*.

Table 7.1 Public participation during TMDL development for the Upper Blackwater River watershed.

Date	Location	Attendance[1]	Type	Format
9/7/04	Isle of Wight Virginia Cooperative Extension Office Public Services Center 17100 Monument Circle Suite B Isle of Wight, VA	17	1st TAC meeting	Open to public at large
10/25/04	Surry Community Center 205 Enos Farm Drive Surry, VA	17	1st Public meeting	Open to public at large
12/14/04	Isle of Wight Virginia Cooperative Extension Office Public Services Center 17100 Monument Circle Suite B Isle of Wight, VA	9	2nd TAC meeting	Open to public at large
3/3/05	Airfield 4-H Center Spain Conference Lodge Wakefield, VA	18	Final Public meeting	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

7.2 Upper Nottoway River Watershed

In addition to the two public meetings, there were two Technical Advisory Committee (TAC) meetings. Table 7.2 details the public participation throughout the project.

The first TAC meeting for the Upper Nottoway River watershed took place on August 31, 2004 in the Blackstone Town Council Chambers in Blackstone, VA. There were 23 attendees (1 consultant, 18 government agents, and 4 local stakeholders). The meeting was publicized in the *Virginia Register* and on the website at www.deq.virginia.gov/tmdl. The second TAC meeting for the Upper Nottoway River watershed took place on October 14, 2004 and was attended by 13 people. There was a third TAC meeting held on December 15, 2004 with 13 people in attendance.

The first public meeting took place on October 28, 2004 in the Blackstone Town Council Chambers located in the Blackstone Town Office Building, Blackstone, VA; 4 people

attended. The meeting was published in the *Virginia Register* and copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received.

The final public meeting was held on January 12, 2005 at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, VA. The meeting was publicized in the *Virginia Register*. The meeting was attended by 13 people, including 3 citizens, 9 government agents and 2 consultants. The topics discussed included finalization of the TMDL process, load allocations, BST results, and the kick off meeting for the implementation plan development. There was a 30-day public comment period with 2 written comments received regarding this document.

Table 7.2 Public participation during TMDL development for the Upper Nottoway River watershed.

Date	Location	Attendance[1]	Type	Format
8/31/04/04	Blackstone Town Office Building 100 West Elm Street Blackstone, VA	23	1st TAC meeting	Open to public at large
10/14/04	Blackstone Town Office Building 100 West Elm Street Blackstone, VA	13	2nd TAC meeting	
10/28/04	Blackstone Town Office Building 100 West Elm Street Blackstone, VA	4	1st Public meeting	Open to public at large
12/15/04	Blackstone Town Office Building 100 West Elm Street Blackstone, VA	13	3rd TAC meeting	Open to public at large
1/12/05	Southern Piedmont Agricultural Research and Extension Center 2375 Darvills Rd. Blackstone, VA	13	Final Public meeting	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

7.3 Raccoon Creek and Sappony Creek Watershed

In addition to the two public meetings, there were two Technical Advisory Committee (TAC) meetings. Table 7.3 details the public participation throughout the project.

The first TAC meeting for the Raccoon Creek and Sappony Creek area took place on September 1, 2004 at the Newsome Building in Sussex, VA. There were 17 attendees (1 consultant, 15 government agents, and 1 local stakeholder). The meeting was publicized in the *Virginia Register* and on the website at www.deq.virginia.gov/tmdl. The second TAC meeting took place on December 13, 2004.

The first public meeting took place on October 18, 2004 at the Sussex Judicial Center in Sussex, VA; 4 people attended. The meeting was published in the *Virginia Register* and copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received. The final public meeting took place on March 3, 2005 at the Airfield 4-H Center in Wakefield, VA. This meeting was the forum for presenting results from both the Upper Blackwater River TMDLs and the Raccoon and Sappony Creek TMDLs. There was a 30-day public comment period, with 2 written comments received regarding this document.

Table 7.3 Public participation during TMDL development for the Raccoon Sappony section watershed.

Date	Location	Attendance[1]	Type	Format
9/8/04	Sussex Department of Social Services Newsome Building 20103 Princeton Rd. Sussex, VA	17	1st TAC Meeting	Open to public at large
10/18/04	Sussex Judicial Center General District Courtroom 15098 Courthouse Rd. Sussex, VA	4	1st Public Meeting	Open to public at large
12/13/04	Isle of Wight Extension Office Public Services Center 17100 Monument Circle Suite B Isle of Wight, VA	9	2nd TAC Meeting	Open to public at large
3/3/05	Airfield 4-H Center Spain Conference Lodge Wakefield, VA	18	Final Public meeting	Open to public at large

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of committees and open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A steering committee will have the expressed purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from the VADEQ, DCR, VDH, local agricultural community, local residents, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to ensure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

REFERENCES

American Veterinary Medical Association – Center for Information Management. 1997 U.S. Pet Ownership and Demographics Sourcebook.

ASAE Standards, 45th Edition. 1998. D384.1 DEC93. Manure Production and Characteristics. St. Joseph, Mich.: ASAE.

Bidrowski, T. 2003, Virginia Department of Game and Inland Fisheries. Personal telecommunication, 07/16/04, 08/09/04.

Bidrowski, T. 2004. Virginia Department of Game and Inland Fisheries. Personal telecommunication. July 16, 2004 and August 9, 2004.

Chow, V.T. 1959. Open Channel Hydraulics. McGraw-Hill Book Company. NY.

Collins, E.R., T.M. Younos, B.B. Ross, J.M. Swisher, R.F. Shank, and K.G. Wooden. 1996. Dairy Loafing Lot Rotational Management System Non-Point Source Pollution Assessment and Demonstration. VADCR-DSWC. Agreement No. C199-319-95-10.

Costanzo, G. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. 01/29/03.

Cowan, W.L. 1956. Estimating hydraulic roughness coefficients. *Agricultural Engineering*, 37(7), pp. 473-475.

EPA. 1991. Guidance for Water-Quality-Based Decisions: The TMDL Process. EPAA440-4-91-001.

EPA. 1998a. EPA Website. Total Maximum Daily Load (TMDL) Program. Draft TMDL Program Implementation Strategy.

EPA. 1998b. Total Maximum Daily Load (TMDL) Program. Draft TMDL Program Implementation Strategy. http://www.epa.gov/OWOW/tmdl/strategy/glossary.html 02/12/98.

EPA. 1999. Guidance for Water Quality-Based Decisions: The TMDL Process. http://www.epa.gov/OWOW/tmdl/decisions/dec1c.html.

EPA. 2003. Total Maximum Daily Load (TMDL) Program and Individual Water Quality-Based Effluent Limitations. 40 CFR 130.7 (c)(1).

EPA Memorandum on TMDLs and Stormwater Permits. November 22, 2002.

Farrar, R. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication. January 15, 2003.

Fies, M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. 08/11/04, 08/12/04, and 08/24/04.

Fire Effects Information System. 1999. http://www.huntana.com/feis/animals/mammals.

Geldreich, E. E. 1978. Bacterial Populations and Indictor Concepts in Feces, Sewage, Stormwater, and Solid Wastes. In Indicators of Viruses in Water and Food, ed. G. Berg. Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Knox, W. M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. 08/03/04, 08/05/04, and 08/25/04.

MapTech. 1999a. Unpublished source sampling data. Blackwater River TMDL Study.

MapTech. 1999b. Blackwater River Riparian NPS Pollution Control Project: Database development and modeling analysis. Submitted to: David Johnson, Ferrum College. MapTech, Inc.

MapTech 2001. TMDL Development for Lower Blackwater River.

MapTech. 2002. Modeling Cattle Stream Access. Submitted to: VADCR, in cooperation with Biological Systems Engineering Department at Virginia Tech.

MapTech, 2004. Inspection of VDH monthly field reports of biosolids applications in Dinwiddie County, Lunenburg County, Nottoway County, Prince Edward County, Southampton County, and Sussex County.

Norman, G.W. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication.

Norman, G.W. 2004. 1995-2004 Virginia Spring Gobbler Harvest Report. Department of Game and Inland Fisheries.

NRCS. 2004a. SSURGO website. http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/

NRCS. 2004b. STATSGO website. http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/

Raftovich, R. V. 2004. Atlantic Flyway Breeding Waterfowl Plot Survey: Breeding Pair and Population Size Estimates 2004. U.S. Fish and Wildlife Service. Division of Migratory Bird Management. July 28, 2004.

Reneau, R.B., Jr. 2000. Crop and Soil Environmental Sciences. Virginia Tech. Personal communication. 01/07/00.

Rickmond Engineering, Inc. 2002. Surry County, Virginia Sanitary Sewer System Improvements for the Town of Dendron Service Area. Preliminary Engineering Report. Project No. 01175-210. March 6, 2002.

Rose, R.K., Cranford, J.A. 1987. Handbook of Virginia Mammals. Final Report, Project No. 567460. VA Dept. Game & Inland Fisheries, Richmond, VA: 121.

SERCC. 2002. Southeast Regional Climate Center. http://water.dnr.state.sc.us/climate/sercc/.

SERCC. 2004. Southeast Regional Climate Center. http://water.dnr.state.sc.us/climate/sercc/.

Soil Conservation Service. 1963. National Engineering Handbook. 3rd ed. Washington, D.C.: Government Printing Office.

USCB. 1990. *1990 Census*. United States Census Bureau. Washington D.C.

USCB. 2000. *2000 Census*. United States Census Bureau. Washington D.C.

USDA NASS. 1997. http://www.nass.usda.gov/census/census97/rankings/ac97s-3r.pdf

VADCR and VADEQ. 2003. Guidance Manual for Total Maximum Daily Load Implementation Plans. http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf

VADEQ. 1996. 303(d) Total Maximum Daily Load Priority List.

VADEQ. 1998. 303(d) Total Maximum Daily Load Priority List and Report.

VADEQ. 2002. 303(d) Report on Impaired Waters.

VADEQ. 2003. Guidance Memo No. 03-XXXXa – Bacteria TMDLs: Model Calibration and Verification. 01/23/03.

VADEQ. 2004. Virginia Water Quality Assessment 305(b)/303(d) Integrated Report.

VASS. 1995. Virginia Agricultural Statistics Bulletin 1995. Virginia Agricultural Statistic Service. Richmond, VA.

VASS. 2002. Virginia Agricultural Statistics Bulletin 2002. Virginia Agricultural Statistics Service. Richmond, VA.

VDGIF. 1999. http://www.dgif.state.va.us The Virginia Fish and Wildlife Information Service.

VDH. 1997. Biosolids Use Regulations 12 VAC 5-585. Virginia Department of Health. Richmond, VA.

Virginia's State Water Control Board. 1997b. Water quality standard 9 VAC 25-260-170. Fecal Coliform Standard.

Virginia's State Water Control Board. 2003. Water Quality Standards 9 VAC 25-260-5.

Weiskel. P. A., B. L. Howes, and G. R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. Environ. Sci. Technol. 30:1872-1881.

Yagow, E. 1999a. Unpublished monitoring data. Mountain Run TMDL Study.

Yagow, G., V.O. Shanholtz, R. Seale, R. Stephens, D. Johnson, C. Lunsford. 1999b. Preliminary fecal coliform assessment in the Blackwater River watershed. ASAE Paper No. 99-2185. ASAE: St. Joseph, MI.

GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

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

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. **(2)**

Biological Integrity. A waterbody's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

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

Causal analysis. A process in which data and other information are organized and evaluated using quantitative and logical techniques to determine the likely cause of an observed condition. (2)

Causal association. A correlation or other association between measures or observations of two entities or processes which occurs because of an underlying causal relationship. (2)

Causal mechanism. The process by which a cause induces an effect. (2)

Causal relationship. The relationship between a cause and its effect. (2)

Cause. 1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Coefficient of determination. Represents the proportion of the total sample variability around y that is explained by the linear relationship between *y* and *x*. (In simple linear regression, it may also be computed as the square of the coefficient of correlation *r.)* (3)

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always result in the same output.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Empirical model. *Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment*

endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. 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 (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

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.*

Hyetograph. *Graph of rainfall rate versus time during a storm event.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause. (2)

Indirect effects. Changes in a resource that is due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor. (2)

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

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 (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the*

one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

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

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Multivariate Regression. A functional relationship between 1 dependent variable and multiple independent variables that are often empirically determined from data and are used especially to predict values of one variable when given values of the others.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nonpoint source. *Pollution that 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.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

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.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

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.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Raw sewage. *Untreated municipal sewage.*

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

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

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

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

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

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.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (*e.g*. 200 cfu/100 ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (*i.e*. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Stepwise regression. All possible one-variable models of the form $E(y) = B_0 + B_1 x_1$ are fit and the "best" x_1 is selected based on the *t*-test for B_1. Next, two-variable models of the form $E(y) = B_0 + B_1 x_1 + B_2 x_i$ are fit (where x_i is the variable selected in the first step): the "second best" x_i is selected based on the test for B_2. The process continues in this fashion until no more "important" *x*'s can be added to the model. (3)

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (*e.g.* 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) 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.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

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 processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' 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 (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based effluent limitations (WQBEL). *Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation 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.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

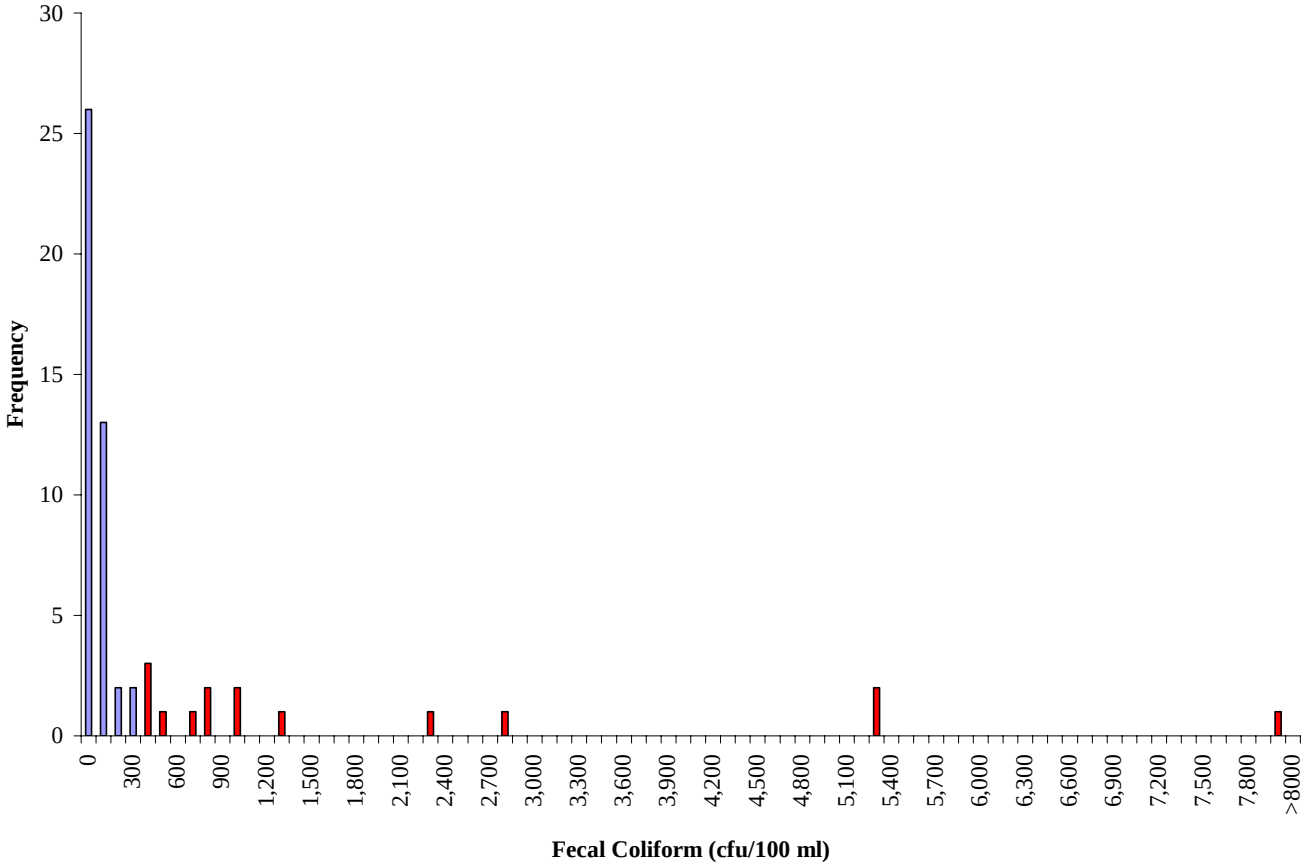

Figure A.1 Frequency analysis of fecal coliform concentrations at station 5ABHC003.73 in the Big Hounds Creek impairment for period September 1990 to June 2003.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

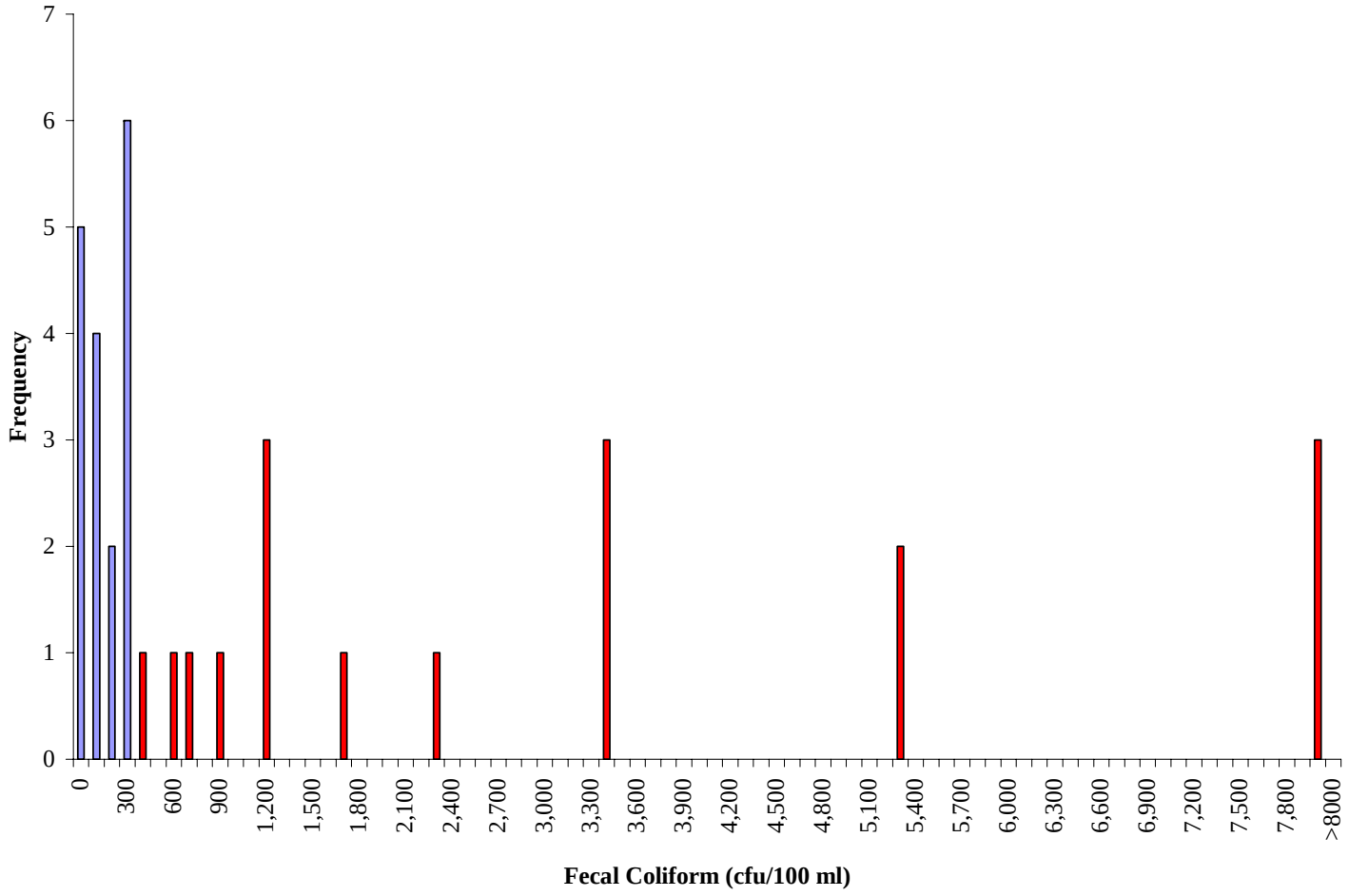

Figure A.2 Frequency analysis of fecal coliform concentrations at station 5ABPC000.12 in the Beaverpond Creek impairment for period September 1994 to April 2001.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

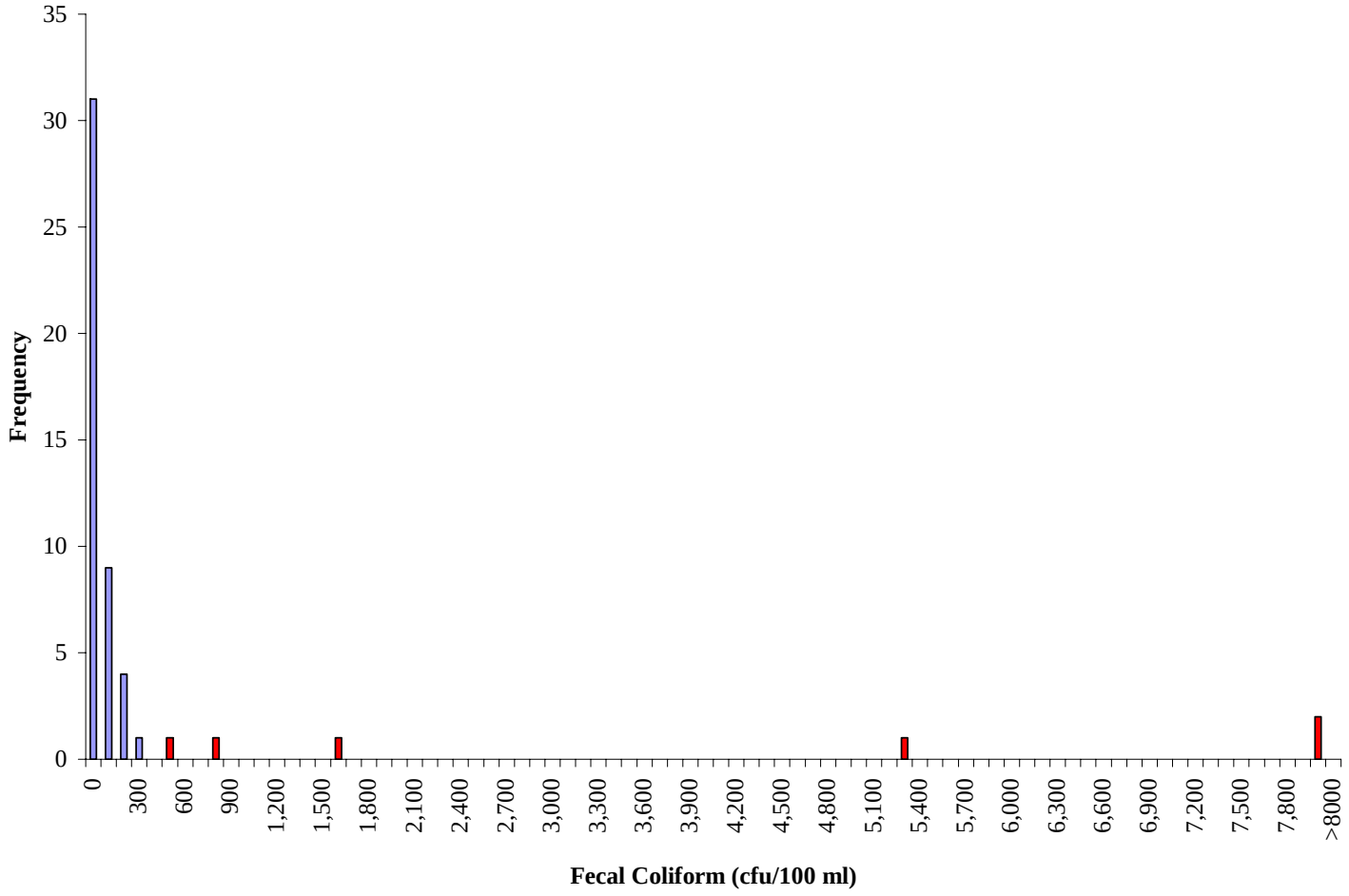

Figure A.3 Frequency analysis of fecal coliform concentrations at station 5ACPP003.20 in the Cypress Swamp impairment for period September 1990 to September 1999.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

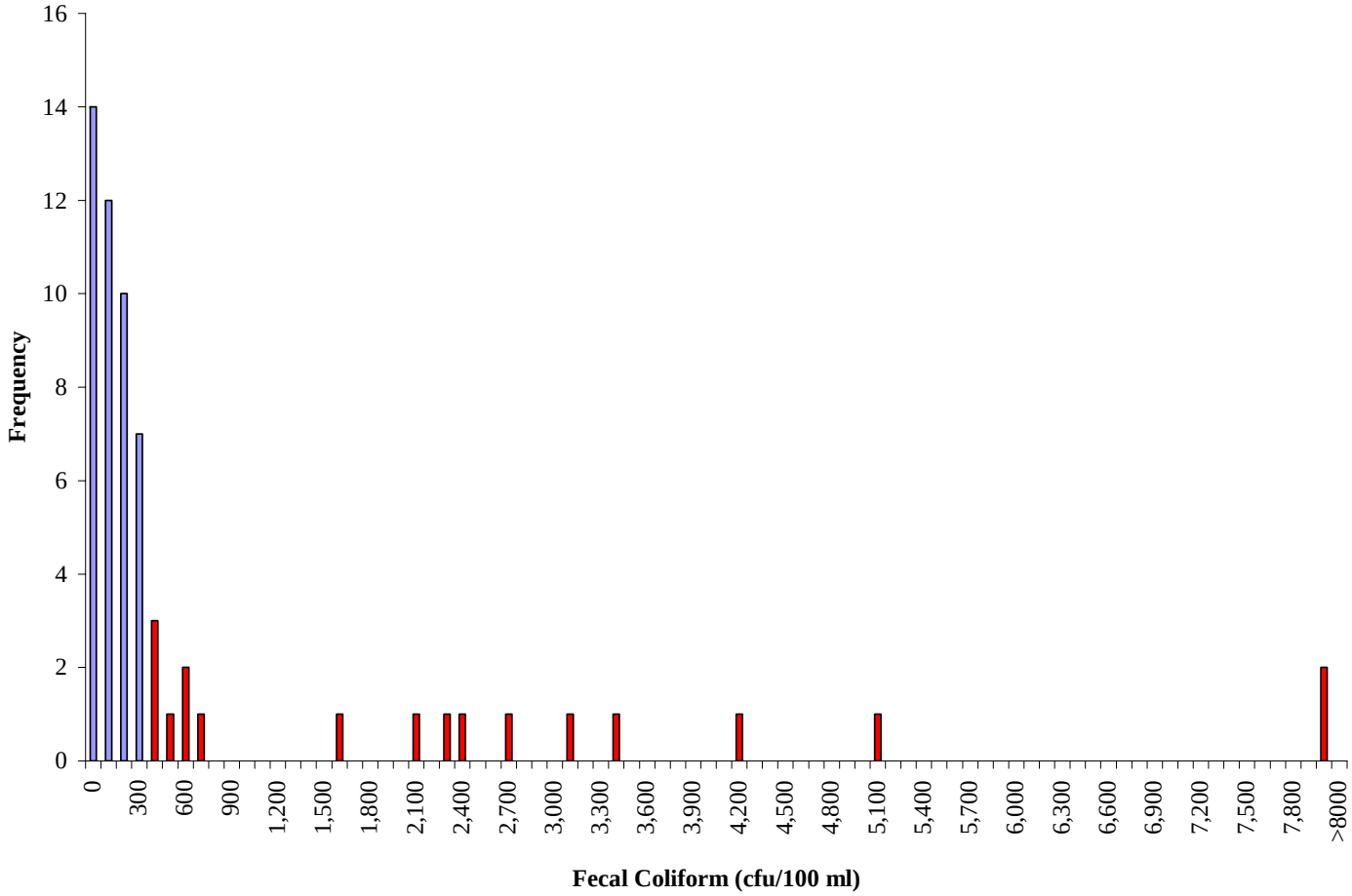

Figure A.4 Frequency analysis of fecal coliform concentrations at station 5ALNT004.68 in the Little Nottoway River impairment for period October 1990 to June 2003.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

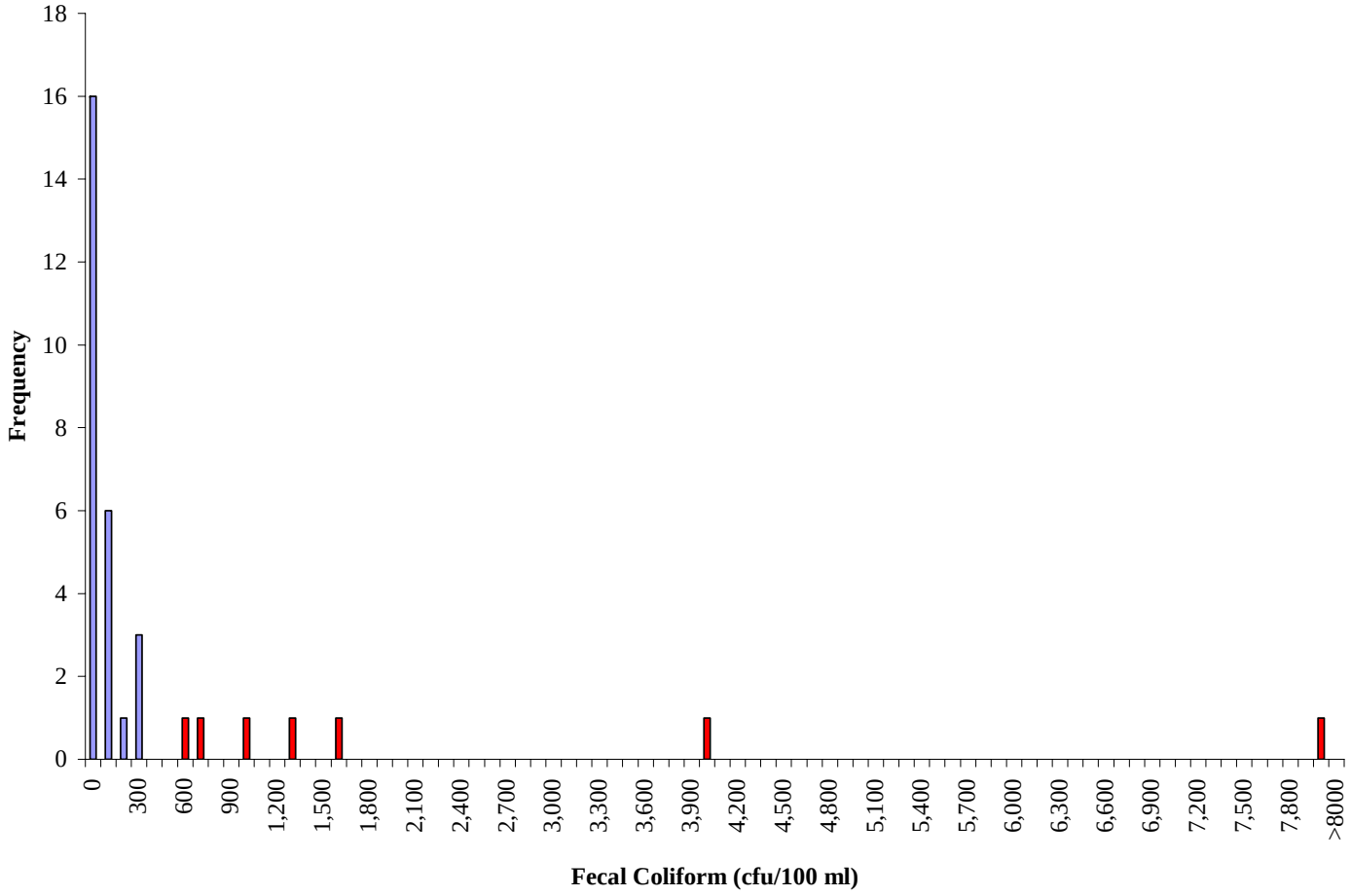

Figure A.5 Frequency analysis of fecal coliform concentrations at station 5AMSW006.77 in the Mill Swamp impairment for period August 1994 to March 2001.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

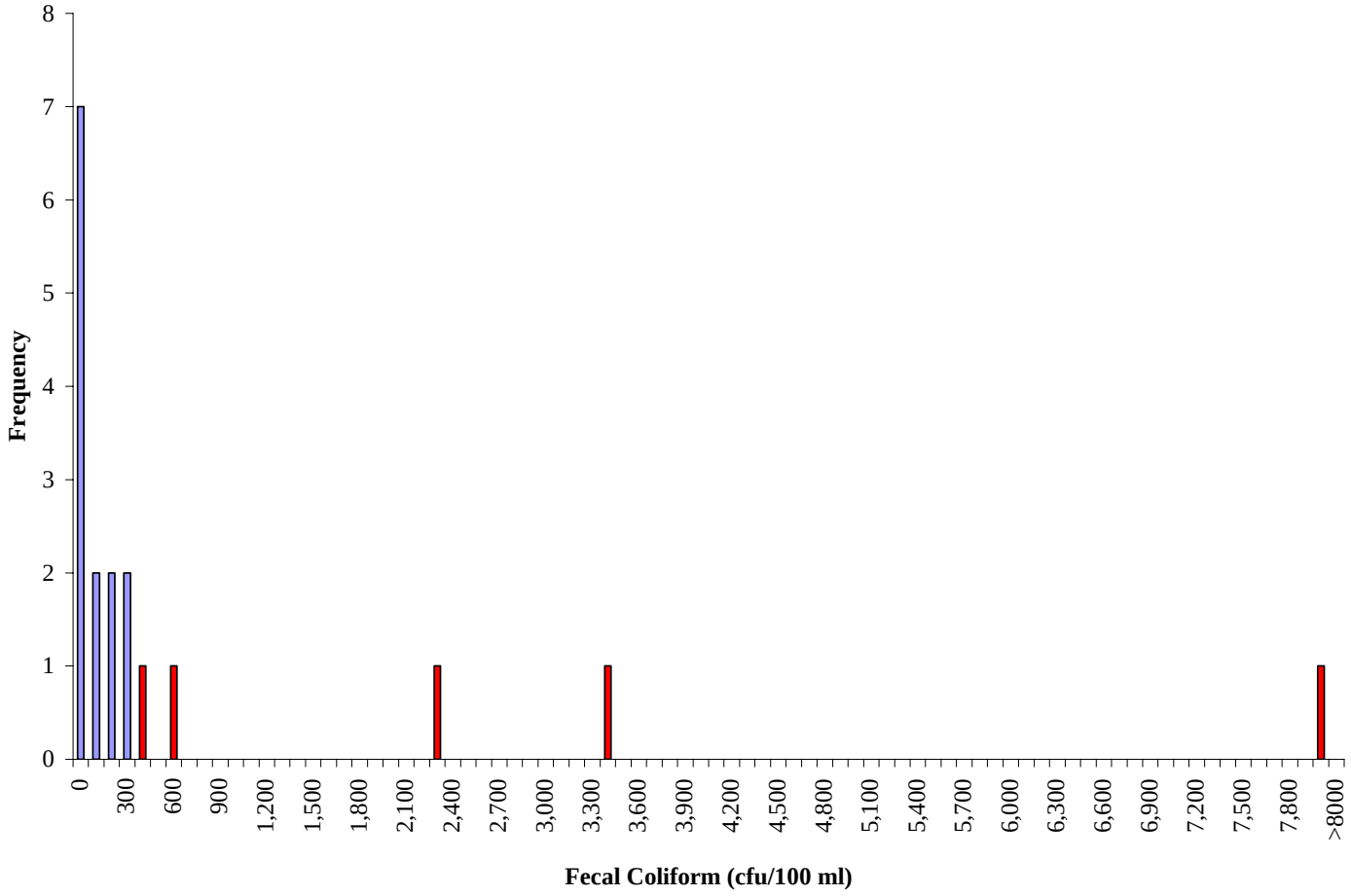

Figure A.6 Frequency analysis of fecal coliform concentrations at station 5ANTW155.06 in the Nottoway River impairment for period July 1994 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

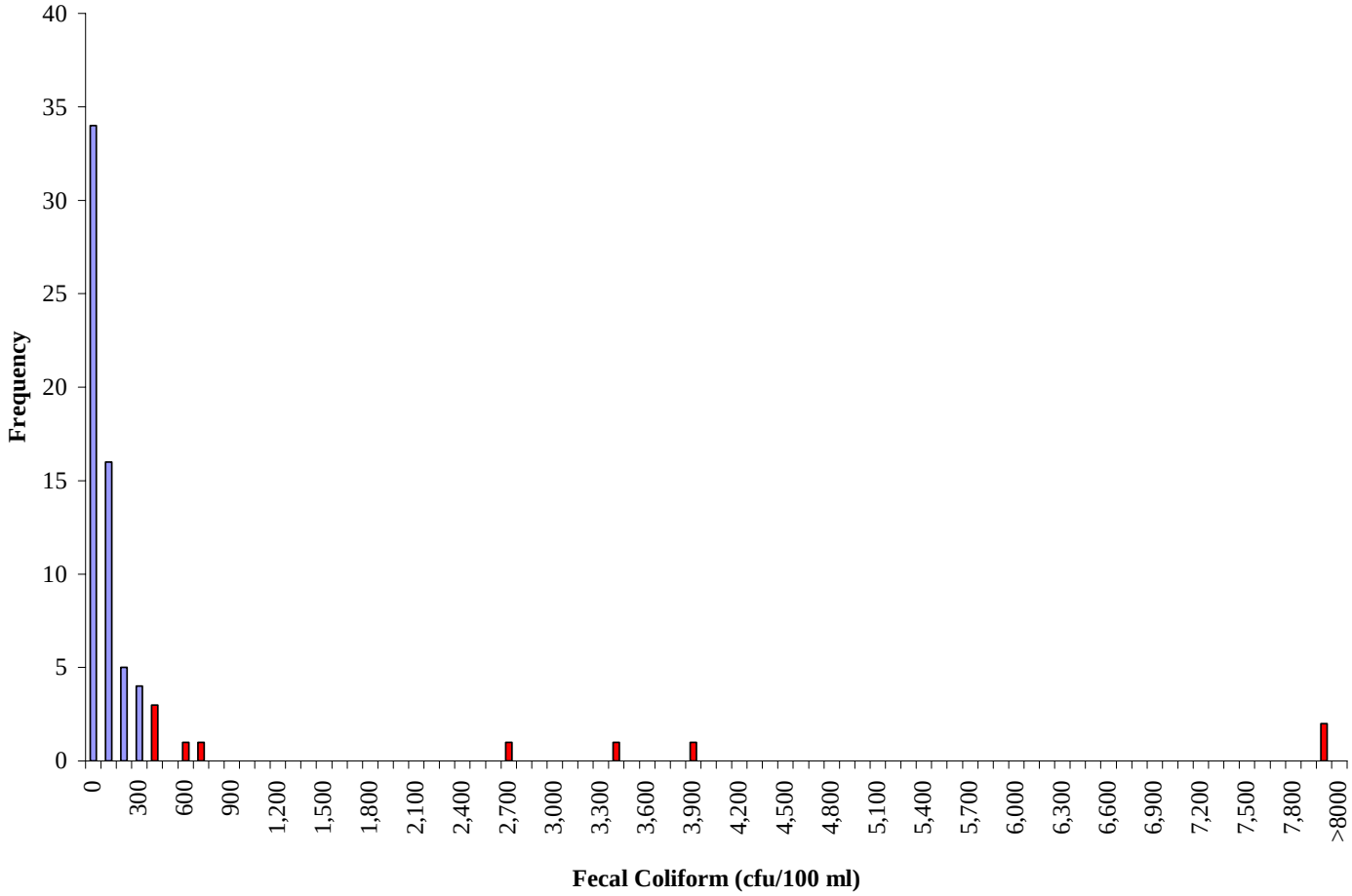

Figure A.7 Frequency analysis of fecal coliform concentrations at station 5ARCN003.36 in the Raccoon Creek impairment for period July 1990 to July 2003.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

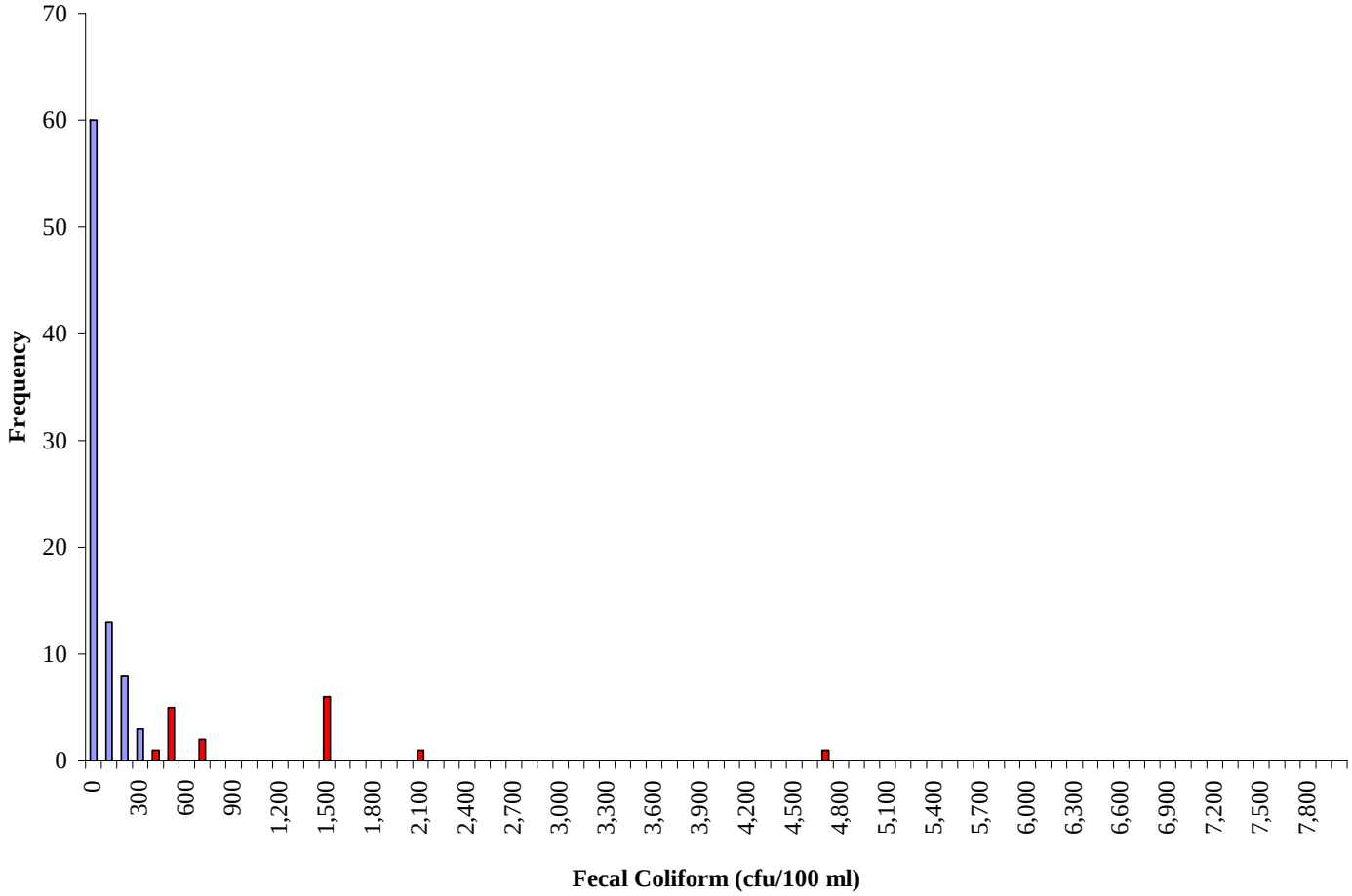

Figure A.8 Frequency analysis of fecal coliform concentrations at station 5ARKN006.40 in the Rattlesnake (Creek) Swamp impairment for period August 1994 to February 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

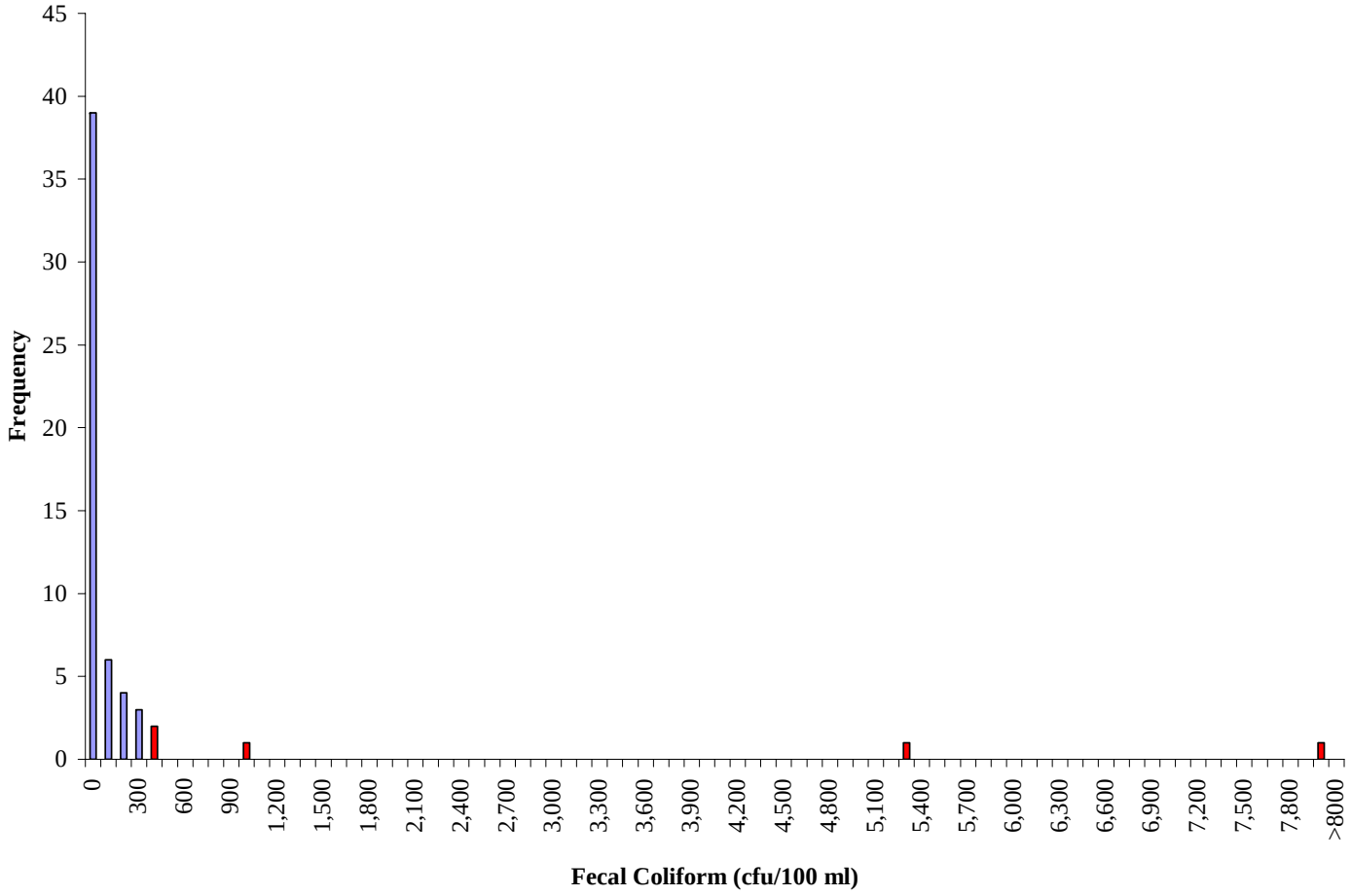

Figure A.9 Frequency analysis of fecal coliform concentrations at station 5ASAP013.69 in the Sappony Creek impairment for period September 1994 to March 2004.

*Red indicates a value which violates the listing standard of 400 cfu/100 ml.

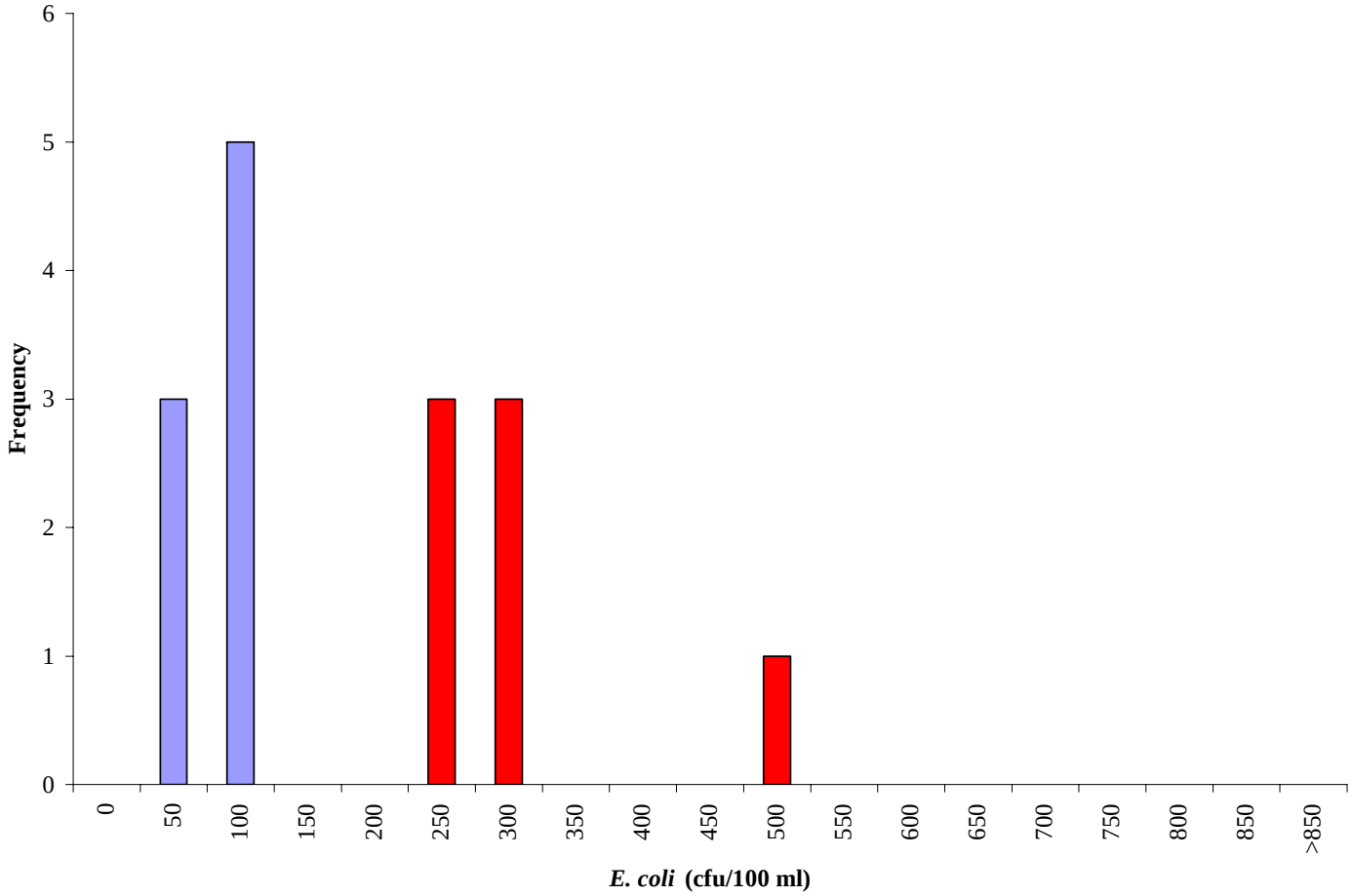

Figure A.10 Frequency analysis of *E.coli* concentrations at station 5ABHC003.73 in the Big Hounds Creek impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

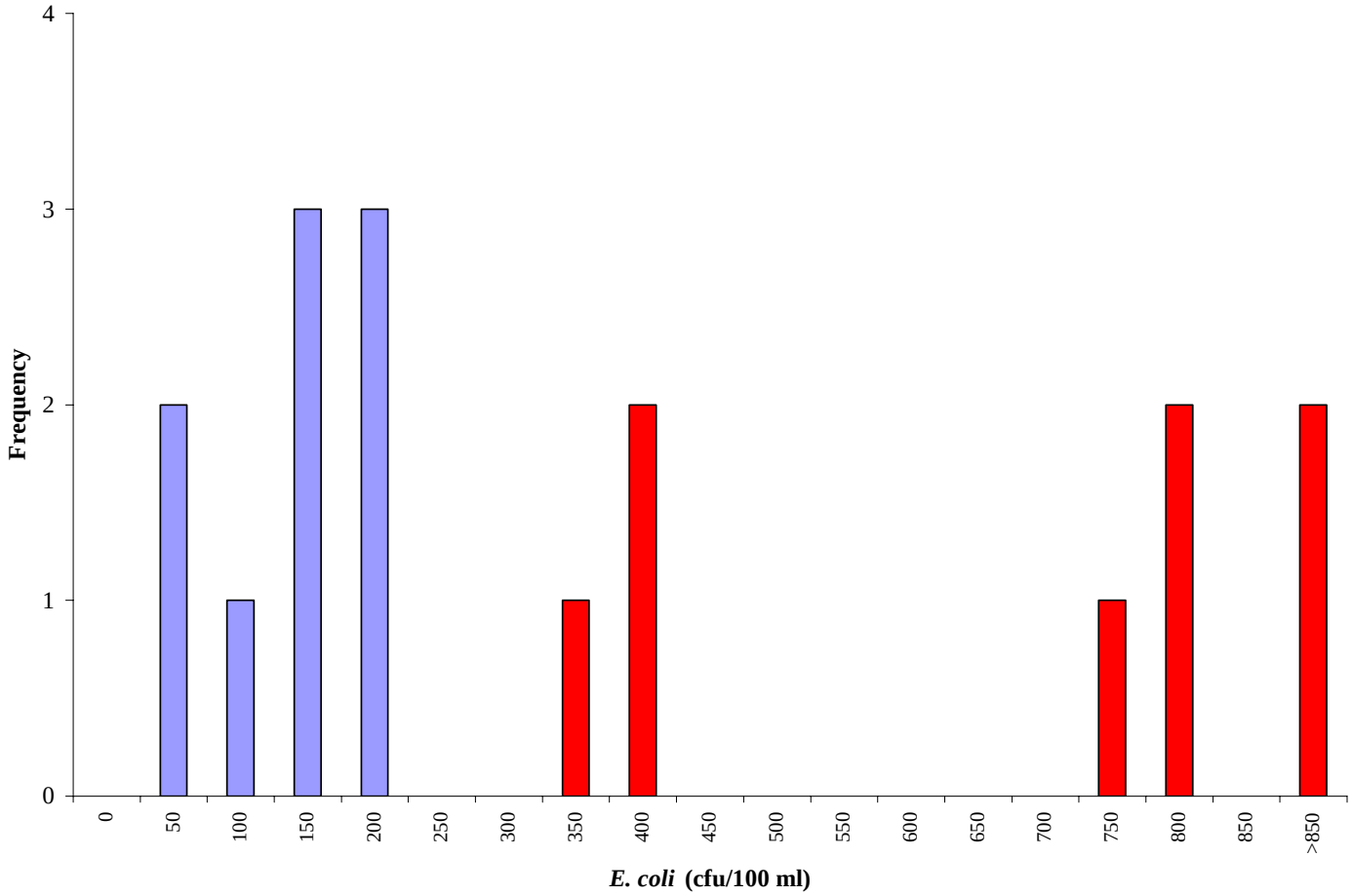

Figure A.11 Frequency analysis of *E.coli* concentrations at station 5ABPC000.12 in the Beaverpond Creek impairment for period February 2000 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

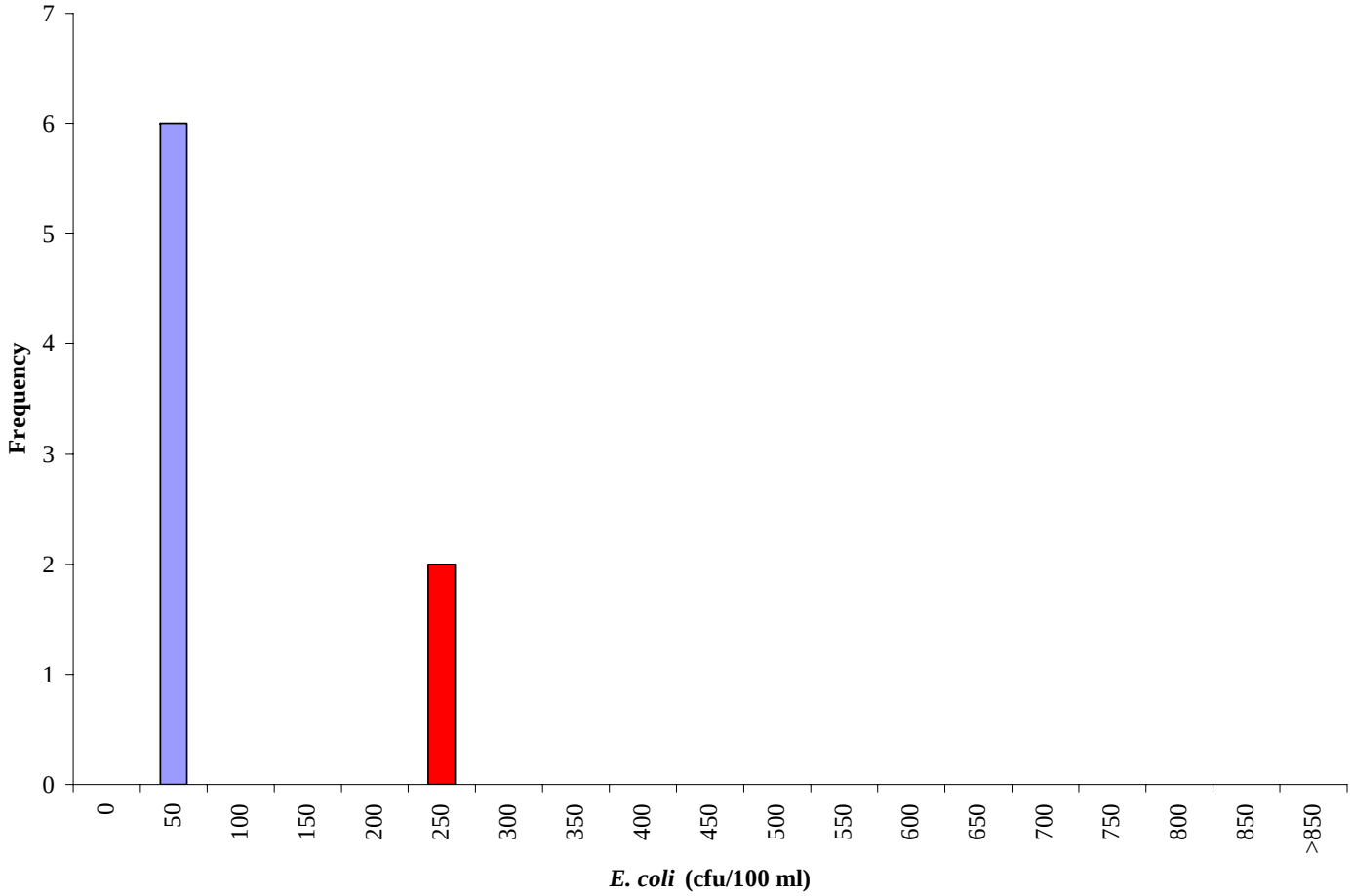

Figure A.12 Frequency analysis of *E.coli* concentrations at station 5ACPP003.20 in the Cypress Swamp impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

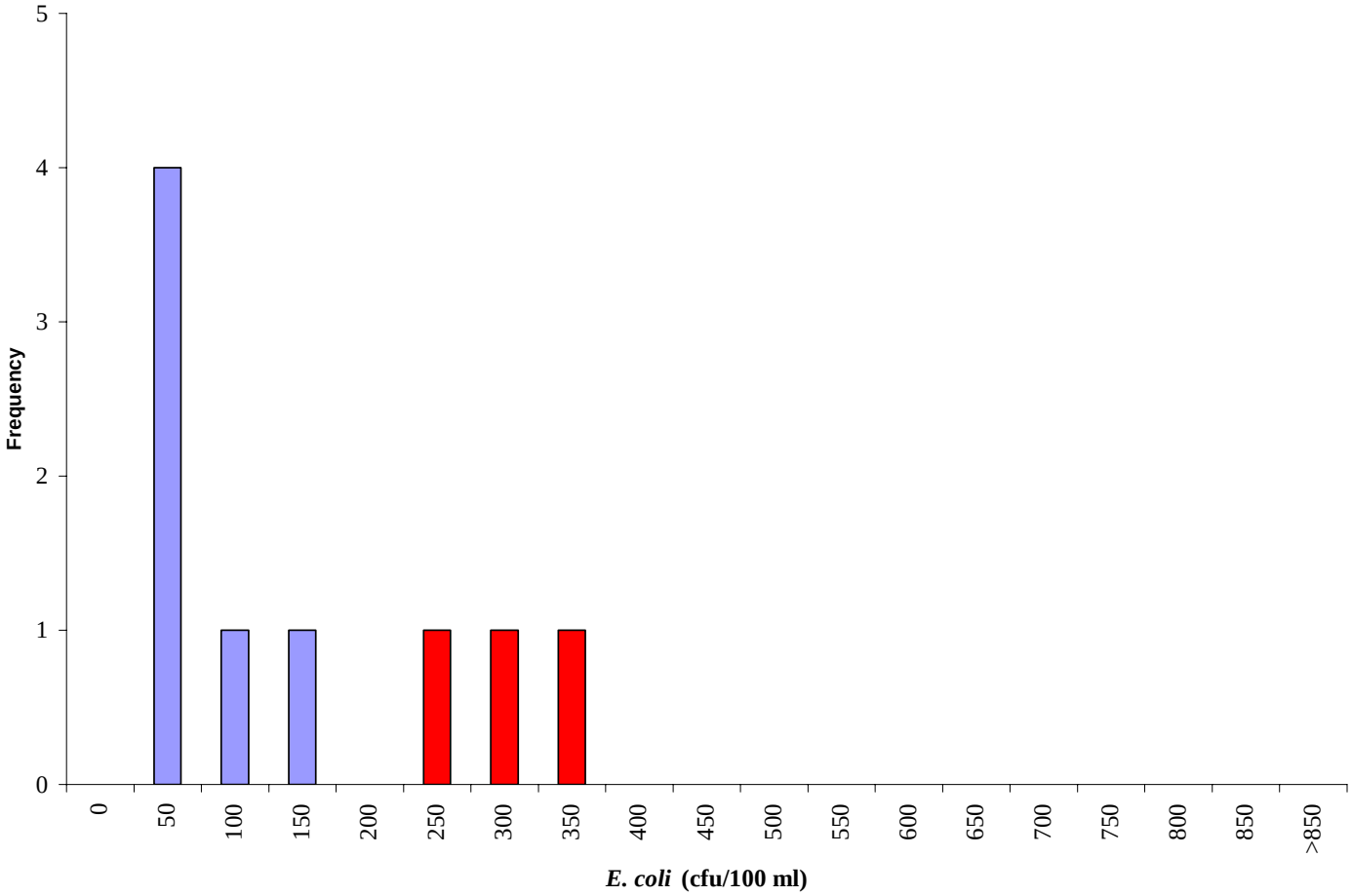

Figure A.13 Frequency analysis of *E.coli* concentrations at station 5ALNT004.68 in the Little Nottoway River impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

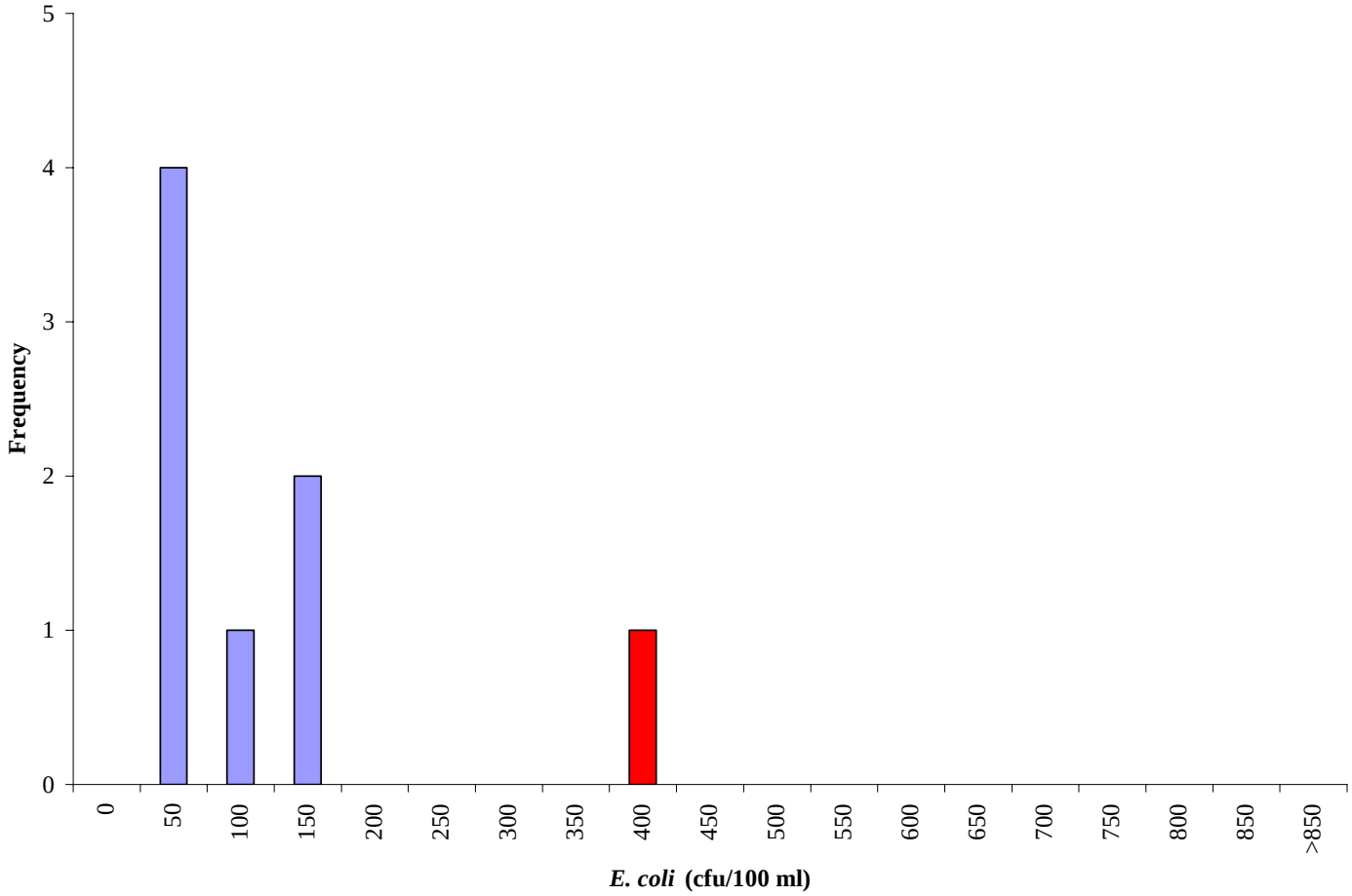

Figure A.14 Frequency analysis of *E.coli* concentrations at station 5AMSW006.77 in the Mill Swamp impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

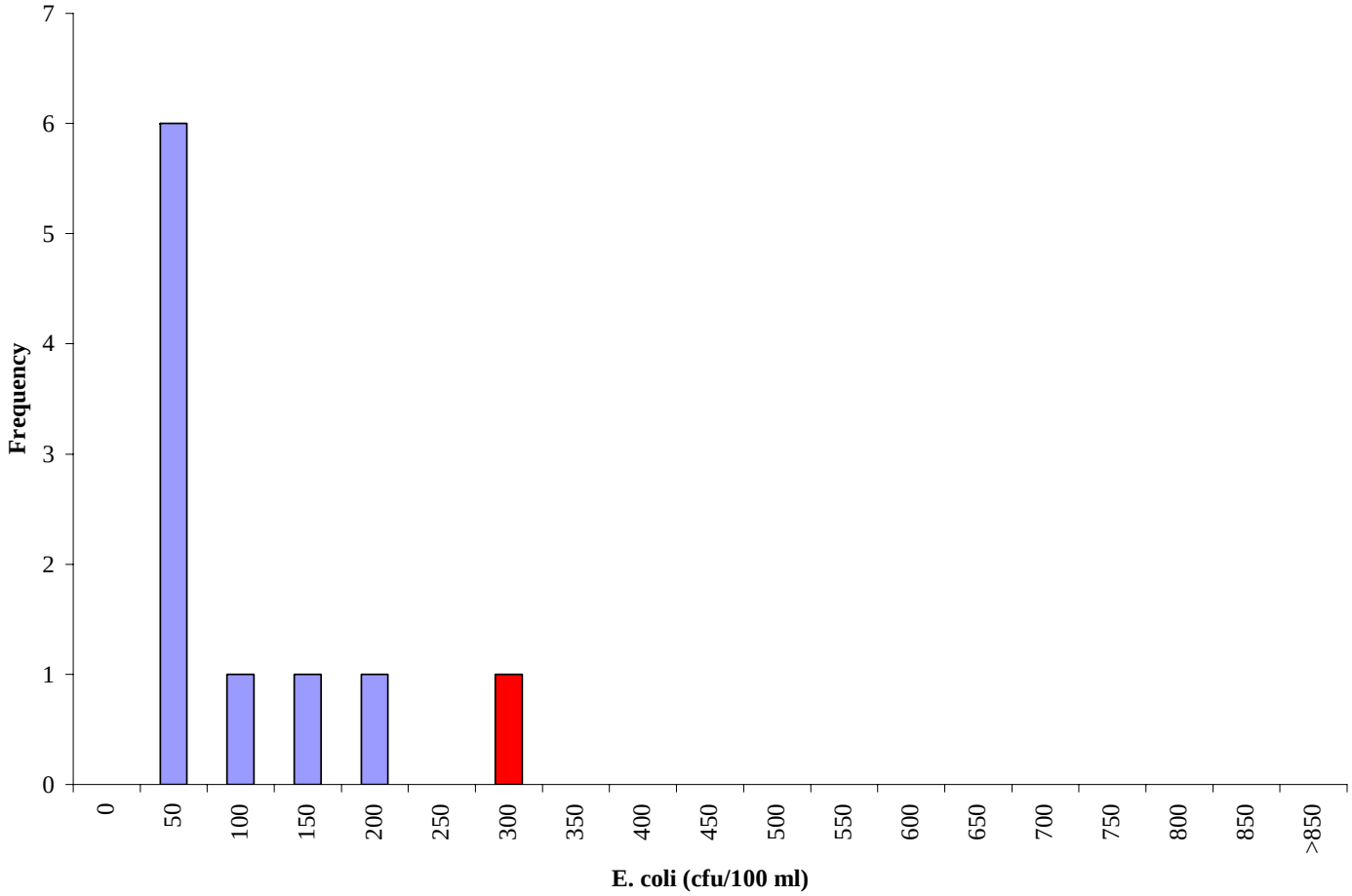

Figure A.15 Frequency analysis of *E.coli* concentrations at station 5ANTW155.06 in the Nottoway River impairment for period July 2002 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

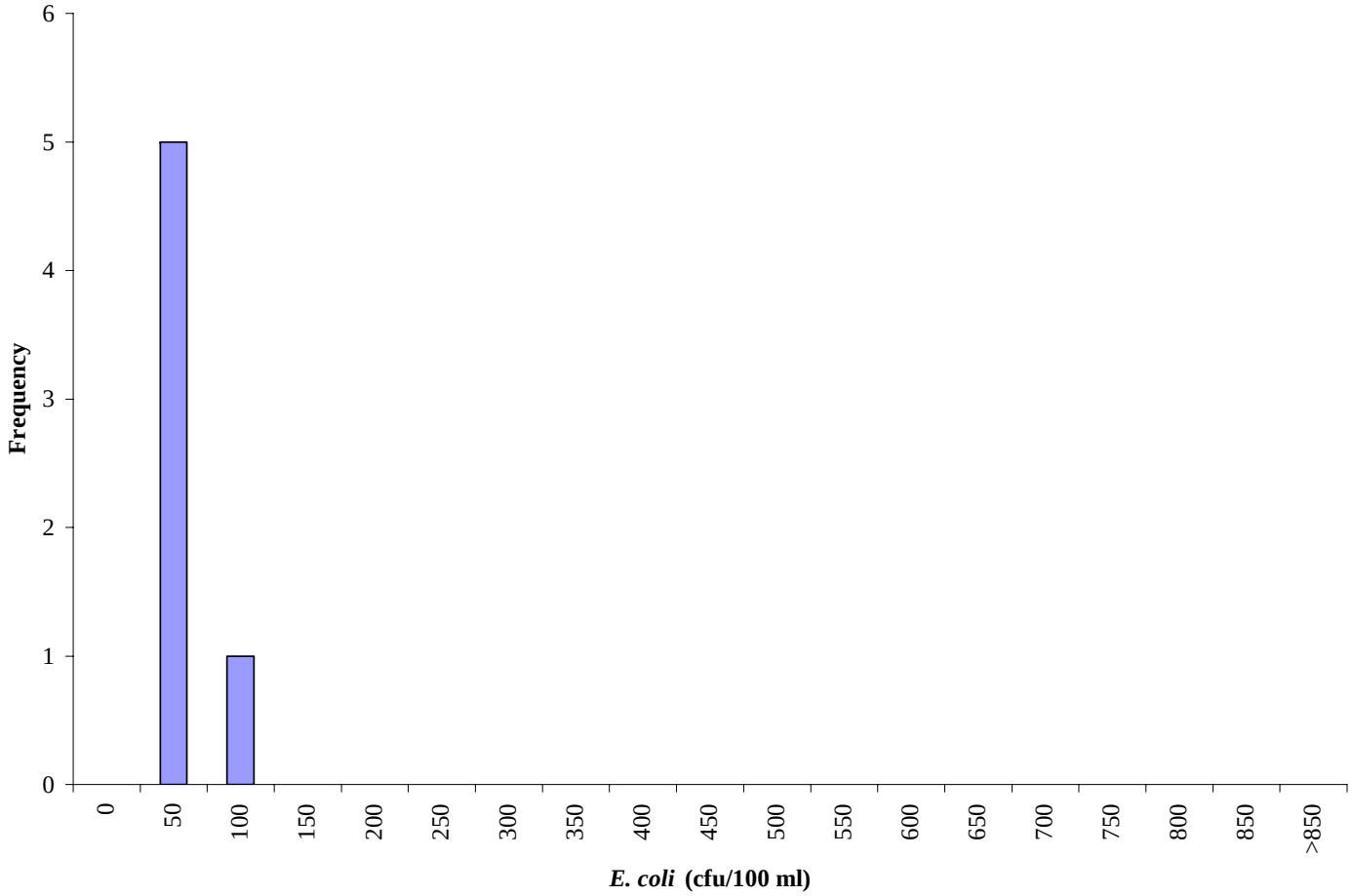

Figure A.16 Frequency analysis of *E.coli* concentrations at station 5ARCN003.36 in the Raccoon Creek impairment for period September 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

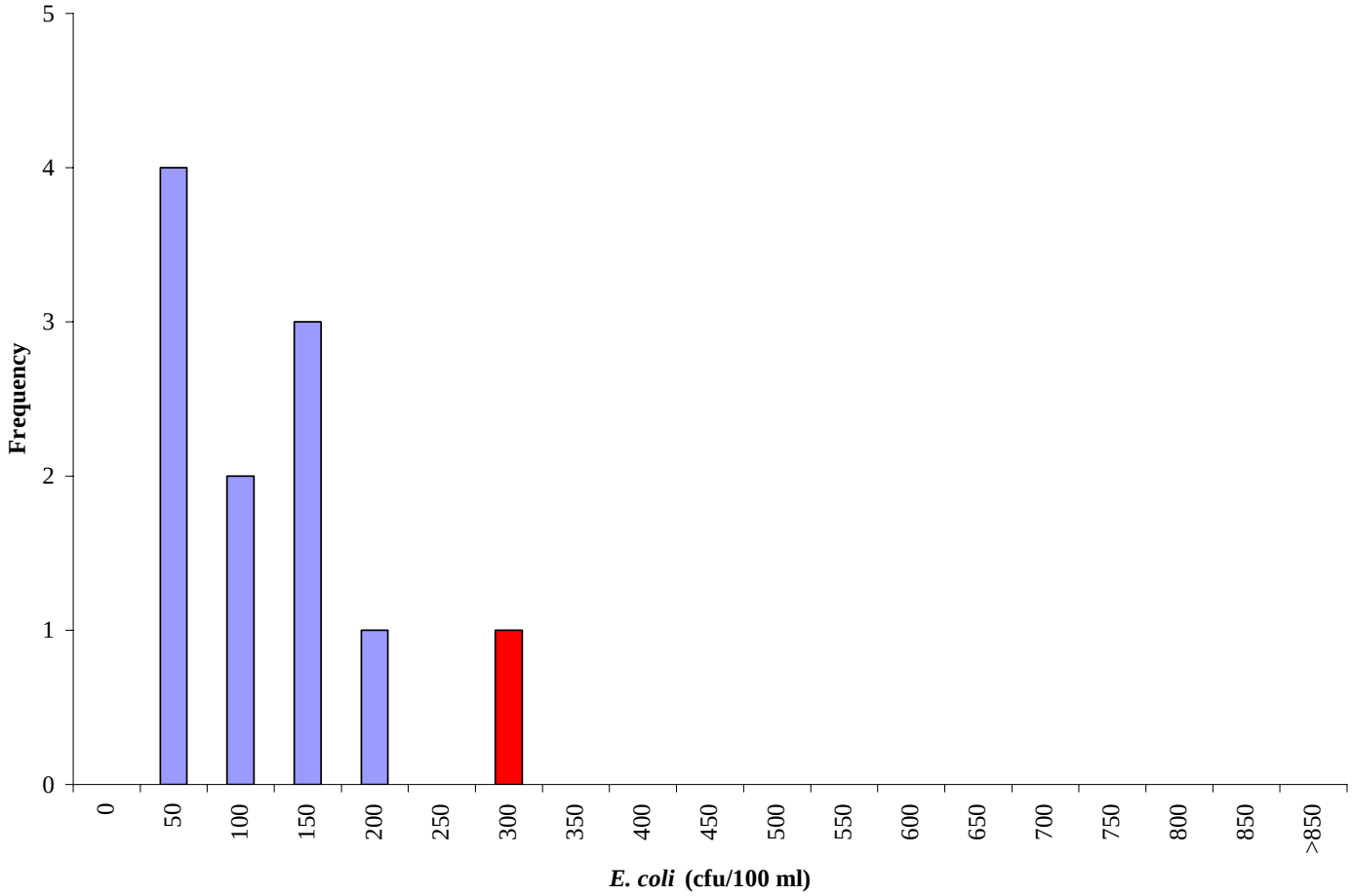

Figure A.17 Frequency analysis of *E.coli* concentrations at station 5ARKN006.40 in the Rattlesnake (Creek) Swamp impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

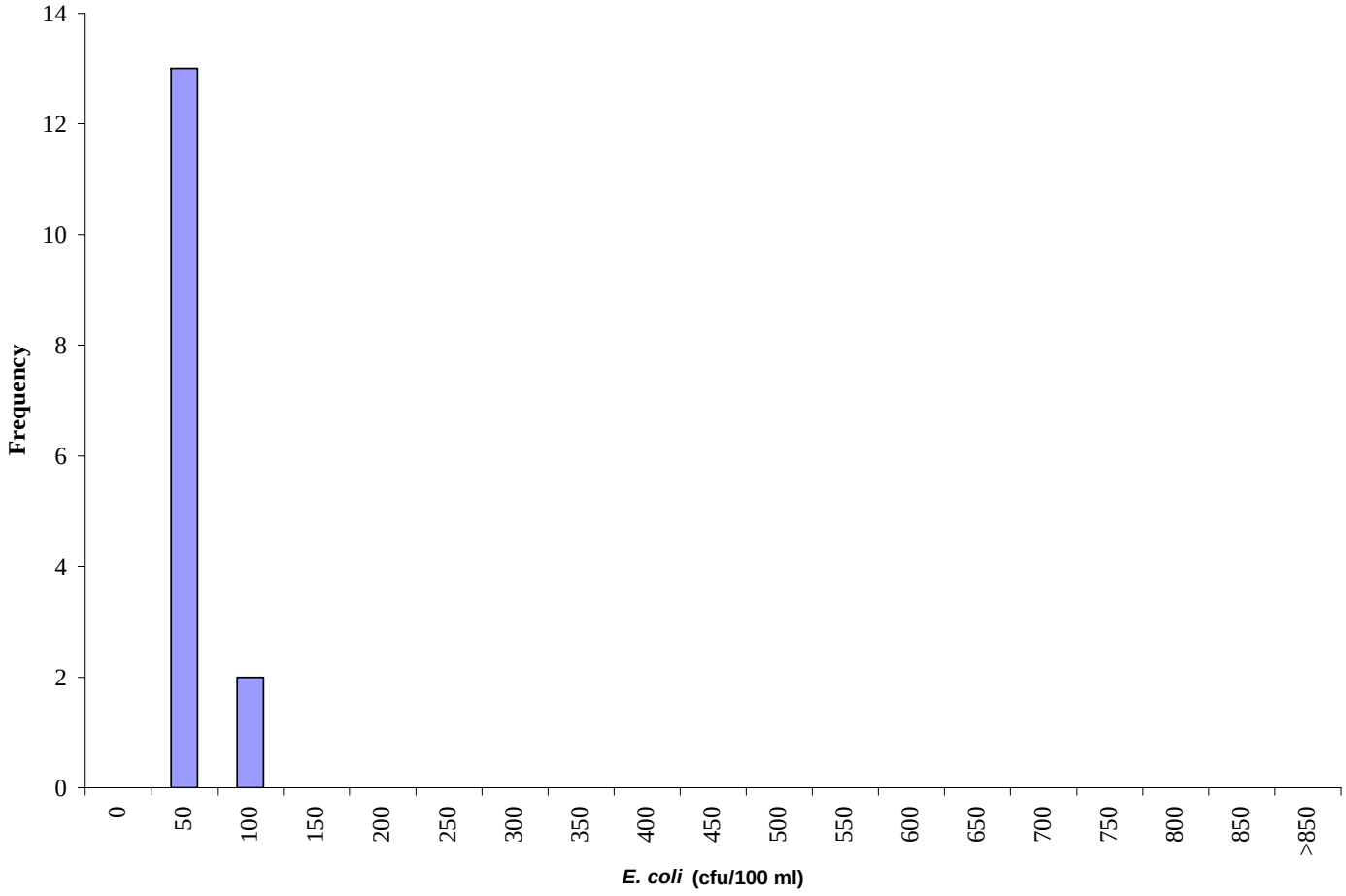

Figure A.18 Frequency analysis of *E.coli* concentrations at station 5ASAP013.69 in the Sappony Creek impairment for period July 2003 to March 2004.

*Red indicates a value which violates the listing standard of 235 cfu/100 ml.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions of land applied fecal coliform load for Big Hounds Creek Impairment - All Contributors by landuse (Subwatersheds 32, 33, 34, 35).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	2.14E+11	2.99E+11	2.07E+11	6.23E+11	2.19E+13	5.44E+12	8.51E+11	1.36E+13
February	1.93E+11	2.70E+11	1.87E+11	6.95E+11	2.47E+13	5.09E+12	7.68E+11	1.22E+13
March	2.14E+11	2.99E+11	2.07E+11	1.05E+12	2.70E+13	5.12E+12	8.51E+11	1.36E+13
April	2.07E+11	2.89E+11	2.00E+11	1.36E+12	2.57E+13	4.85E+12	8.23E+11	1.31E+13
May	2.14E+11	2.99E+11	2.07E+11	1.40E+12	2.66E+13	5.22E+12	8.51E+11	1.36E+13
June	2.07E+11	2.89E+11	2.00E+11	1.62E+12	2.54E+13	4.65E+12	8.23E+11	1.31E+13
July	2.14E+11	2.99E+11	2.07E+11	1.68E+12	2.63E+13	4.59E+12	8.51E+11	1.36E+13
August	2.14E+11	2.99E+11	2.07E+11	1.68E+12	2.63E+13	4.59E+12	8.51E+11	1.36E+13
September	2.07E+11	2.89E+11	2.00E+11	1.36E+12	2.57E+13	4.45E+12	8.23E+11	1.31E+13
October	2.14E+11	2.99E+11	2.07E+11	1.05E+12	2.70E+13	4.49E+12	8.51E+11	1.36E+13
November	2.07E+11	2.89E+11	2.00E+11	1.01E+12	2.61E+13	4.45E+12	8.23E+11	1.31E+13
December	2.14E+11	2.99E+11	2.07E+11	7.69E+11	2.73E+13	5.01E+12	8.51E+11	1.36E+13
Annual Total Loads (cfu/yr)	2.52E+12	3.52E+12	2.43E+12	1.43E+13	3.10E+14	5.79E+13	1.00E+13	1.60E+14

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Big Hounds Creek Impairment - All Contributors (Reaches 32, 33, 34, 35).

Reach	Source Type	January	February	March	April	May	June
32	Human/Pet	1.15E+11	1.04E+11	1.15E+11	1.12E+11	1.15E+11	1.12E+11
	Livestock	1.05E+10	1.23E+10	1.82E+10	2.64E+10	2.72E+10	3.08E+10
	Wildlife	8.95E+10	8.09E+10	8.95E+10	8.66E+10	8.95E+10	8.66E+10
33	Human/Pet	8.57E+10	7.74E+10	8.57E+10	8.30E+10	8.57E+10	8.30E+10
	Livestock	2.77E+10	3.25E+10	4.80E+10	6.96E+10	7.20E+10	8.12E+10
	Wildlife	1.65E+11	1.49E+11	1.65E+11	1.60E+11	1.65E+11	1.60E+11
34	Human/Pet	2.26E+10	2.04E+10	2.26E+10	2.19E+10	2.26E+10	2.19E+10
	Livestock	1.19E+10	1.39E+10	2.06E+10	2.98E+10	3.08E+10	3.48E+10
	Wildlife	1.17E+11	1.05E+11	1.17E+11	1.13E+11	1.17E+11	1.13E+11
35	Human/Pet	5.99E+10	5.41E+10	5.99E+10	5.79E+10	5.99E+10	5.79E+10
	Livestock	5.73E+09	6.73E+09	9.94E+09	1.44E+10	1.49E+10	1.68E+10
	Wildlife	6.38E+10	5.76E+10	6.38E+10	6.18E+10	6.38E+10	6.18E+10
Reach	**Source Type**	**July**	**August**	**September**	**October**	**November**	**December**
32	Human/Pet	1.15E+11	1.15E+11	1.12E+11	1.15E+11	1.12E+11	1.15E+11
	Livestock	3.18E+10	3.18E+10	2.64E+10	1.82E+10	1.76E+10	1.36E+10
	Wildlife	8.95E+10	8.95E+10	8.66E+10	8.95E+10	8.66E+10	8.95E+10
33	Human/Pet	8.57E+10	8.57E+10	8.30E+10	8.57E+10	8.30E+10	8.57E+10
	Livestock	8.40E+10	8.40E+10	6.96E+10	4.80E+10	4.64E+10	3.60E+10
	Wildlife	1.65E+11	1.65E+11	1.60E+11	1.65E+11	1.60E+11	1.65E+11
34	Human/Pet	2.26E+10	2.26E+10	2.19E+10	2.26E+10	2.19E+10	2.26E+10
	Livestock	3.60E+10	3.60E+10	2.98E+10	2.06E+10	1.99E+10	1.54E+10
	Wildlife	1.17E+11	1.17E+11	1.13E+11	1.17E+11	1.13E+11	1.17E+11
35	Human/Pet	5.99E+10	5.99E+10	5.79E+10	5.99E+10	5.79E+10	5.99E+10
	Livestock	1.74E+10	1.74E+10	1.44E+10	9.94E+09	9.62E+09	7.45E+09
	Wildlife	6.38E+10	6.38E+10	6.18E+10	6.38E+10	6.18E+10	6.38E+10

Table B.3 Existing annual loads from land-based sources for the Big Hounds Creek Impairment - All Contributors (Subwatersheds 32, 33, 34, 35).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	1.27E+13	2.65E+14	0.00E+00	1.41E+12	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.22E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	4.11E+11	0.00E+00	5.16E+11	5.48E+10	4.58E+12	1.92E+11	0.00E+00	3.60E+11	1.94E+13
dogs	0.00E+00	3.27E+12	0.00E+00	0.00E+00	0.00E+00	3.30E+13	0.00E+00	0.00E+00	0.00E+00
duck	5.35E+07	7.24E+05	2.76E+07	6.82E+07	3.13E+08	9.89E+06	0.00E+00	4.01E+08	3.95E+09
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
goose	8.14E+10	1.24E+09	5.41E+10	1.36E+11	5.79E+11	1.62E+10	0.00E+00	7.79E+11	7.00E+12
hogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.06E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	8.96E+11	1.21E+10	4.63E+11	1.14E+12	5.25E+12	1.66E+11	0.00E+00	6.73E+12	6.62E+13
raccoon	1.13E+12	2.39E+11	1.40E+12	2.79E+11	1.41E+13	1.45E+12	0.00E+00	2.15E+12	6.70E+13
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+13	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.84E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
stp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.34E+12	0.00E+00	0.00E+00
turkey	1.58E+08	0.00E+00	4.96E+07	5.28E+06	4.41E+08	0.00E+00	0.00E+00	1.39E+08	7.47E+09

Table B.4 Existing annual loads from direct-deposition sources for the Big Hounds Creek Impairment - All Contributors (Reaches 32, 33, 34, 35).

Source	Annual Total Loads (cfu/yr)
beaver	1.40E+09
beef	1.41E+12
broilers	0.00E+00
dairy	0.00E+00
deer	2.58E+11
duck	2.16E+08
goose	2.54E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	4.39E+12
raccoon	2.23E+11
stp	0.00E+00
straightpipe density	3.34E+12
turkey	4.13E+06

Table B.5 Current conditions of land applied fecal coliform load for Little Nottoway River Impairment - All Contributors by land-use (Subwatersheds 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	6.47E+11	7.25E+11	4.79E+13	4.81E+12	1.68E+14	1.43E+13	1.15E+13	4.11E+13
February	5.84E+11	6.55E+11	5.57E+13	5.18E+12	1.83E+14	1.31E+13	1.04E+13	3.71E+13
March	6.47E+11	7.25E+11	5.36E+14	7.87E+12	2.00E+14	1.32E+13	1.15E+13	4.11E+13
April	6.26E+11	7.01E+11	5.36E+14	1.03E+13	1.90E+14	1.25E+13	1.11E+13	3.98E+13
May	6.47E+11	7.25E+11	5.36E+14	1.06E+13	1.97E+14	1.31E+13	1.15E+13	4.11E+13
June	6.26E+11	7.01E+11	6.80E+11	1.23E+13	2.43E+14	1.18E+13	1.11E+13	3.98E+13
July	6.47E+11	7.25E+11	7.02E+11	1.27E+13	2.50E+14	1.15E+13	1.15E+13	4.11E+13
August	6.47E+11	7.25E+11	7.02E+11	1.27E+13	2.50E+14	1.15E+13	1.15E+13	4.11E+13
September	6.26E+11	7.01E+11	1.58E+14	1.03E+13	1.90E+14	1.11E+13	1.11E+13	3.98E+13
October	6.47E+11	7.25E+11	5.36E+14	7.87E+12	2.00E+14	1.11E+13	1.15E+13	4.11E+13
November	6.26E+11	7.01E+11	5.36E+14	7.62E+12	1.94E+14	1.11E+13	1.11E+13	3.98E+13
December	6.47E+11	7.25E+11	4.79E+13	5.73E+12	2.02E+14	1.29E+13	1.15E+13	4.11E+13
Annual Total Loads (cfu/yr)	7.61E+12	8.53E+12	2.99E+15	1.08E+14	2.47E+15	1.47E+14	1.35E+14	4.84E+14

Table B.6 Monthly, directly deposited fecal coliform loads in each reach of the Little Nottoway River Impairment - All Contributors (Reaches 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31).

Reach ID	Source Type	January	February	March	April	May	June
19	Human/Pet	5.05E+10	4.56E+10	5.05E+10	4.89E+10	5.05E+10	4.89E+10
	Livestock	5.93E+10	6.96E+10	1.03E+11	1.49E+11	1.54E+11	1.74E+11
	Wildlife	1.55E+11	1.40E+11	1.55E+11	1.50E+11	1.55E+11	1.50E+11
20	Human/Pet	9.60E+10	8.67E+10	9.60E+10	9.29E+10	9.60E+10	9.29E+10
	Livestock	4.17E+10	4.90E+10	7.23E+10	1.05E+11	1.08E+11	1.22E+11
	Wildlife	1.84E+11	1.66E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11
21	Human/Pet	2.36E+10	2.13E+10	2.36E+10	2.29E+10	2.36E+10	2.29E+10
	Livestock	2.10E+10	2.46E+10	3.63E+10	5.27E+10	5.45E+10	6.15E+10
	Wildlife	1.14E+11	1.03E+11	1.14E+11	1.10E+11	1.14E+11	1.10E+11
22	Human/Pet	1.01E+10	9.14E+09	1.01E+10	9.80E+09	1.01E+10	9.80E+09
	Livestock	3.93E+10	4.62E+10	6.82E+10	9.90E+10	1.02E+11	1.15E+11
	Wildlife	9.91E+10	8.95E+10	9.91E+10	9.59E+10	9.91E+10	9.59E+10
23	Human/Pet	1.00E+10	9.06E+09	1.00E+10	9.71E+09	1.00E+10	9.71E+09
	Livestock	4.61E+10	5.41E+10	7.98E+10	1.16E+11	1.20E+11	1.35E+11
	Wildlife	1.82E+11	1.64E+11	1.82E+11	1.76E+11	1.82E+11	1.76E+11
24	Human/Pet	3.82E+09	3.45E+09	3.82E+09	3.70E+09	3.82E+09	3.70E+09
	Livestock	1.62E+10	1.90E+10	2.81E+10	4.08E+10	4.21E+10	4.76E+10
	Wildlife	8.93E+10	8.07E+10	8.93E+10	8.65E+10	8.93E+10	8.65E+10
25	Human/Pet	1.93E+11	1.74E+11	1.93E+11	1.87E+11	1.93E+11	1.87E+11
	Livestock	2.55E+10	2.99E+10	4.42E+10	6.42E+10	6.63E+10	7.49E+10
	Wildlife	1.37E+11	1.24E+11	1.37E+11	1.33E+11	1.37E+11	1.33E+11
26	Human/Pet	8.17E+10	7.38E+10	8.17E+10	7.90E+10	8.17E+10	7.90E+10
	Livestock	1.32E+10	1.56E+10	2.30E+10	3.33E+10	3.44E+10	3.89E+10
	Wildlife	1.04E+11	9.38E+10	1.04E+11	1.00E+11	1.04E+11	1.00E+11
27	Human/Pet	4.95E+09	4.47E+09	4.95E+09	4.79E+09	4.95E+09	4.79E+09
	Livestock	1.38E+10	1.62E+10	2.40E+10	3.48E+10	3.60E+10	4.06E+10
	Wildlife	7.35E+10	6.64E+10	7.35E+10	7.12E+10	7.35E+10	7.12E+10
28	Human/Pet	1.64E+10	1.49E+10	1.64E+10	1.59E+10	1.64E+10	1.59E+10
	Livestock	5.93E+09	6.96E+09	1.03E+10	1.49E+10	1.54E+10	1.74E+10
	Wildlife	6.33E+10	5.72E+10	6.33E+10	6.13E+10	6.33E+10	6.13E+10
29	Human/Pet	1.31E+10	1.18E+10	1.31E+10	1.27E+10	1.31E+10	1.27E+10
	Livestock	1.10E+11	1.02E+11	1.51E+11	2.20E+11	2.27E+11	2.56E+11
	Wildlife	8.28E+10	7.48E+10	8.28E+10	8.01E+10	8.28E+10	8.01E+10
30	Human/Pet	5.66E+10	5.12E+10	5.66E+10	5.48E+10	5.66E+10	5.48E+10
	Livestock	2.99E+10	3.51E+10	5.17E+10	7.51E+10	7.76E+10	8.76E+10
	Wildlife	2.03E+11	1.84E+11	2.03E+11	1.97E+11	2.03E+11	1.97E+11
31	Human/Pet	9.00E+09	8.13E+09	9.00E+09	8.71E+09	9.00E+09	8.71E+09
	Livestock	3.02E+10	3.55E+10	5.24E+10	7.61E+10	7.86E+10	8.88E+10
	Wildlife	1.60E+11	1.45E+11	1.60E+11	1.55E+11	1.60E+11	1.55E+11

Table B.6 Monthly, directly deposited fecal coliform loads in each reach of the Little Nottoway River Impairment - All Contributors (Reaches 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31). (cont.)

Reach ID	Source Type	July	August	September	October	November	December
19	Human/Pet	5.05E+10	5.05E+10	4.89E+10	5.05E+10	4.89E+10	5.05E+10
	Livestock	1.80E+11	1.80E+11	1.49E+11	1.03E+11	9.95E+10	7.71E+10
	Wildlife	1.55E+11	1.55E+11	1.50E+11	1.55E+11	1.50E+11	1.55E+11
20	Human/Pet	9.60E+10	9.60E+10	9.29E+10	9.60E+10	9.29E+10	9.60E+10
	Livestock	1.27E+11	1.27E+11	1.05E+11	7.23E+10	7.00E+10	5.42E+10
	Wildlife	1.84E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11	1.84E+11
21	Human/Pet	2.36E+10	2.36E+10	2.29E+10	2.36E+10	2.29E+10	2.36E+10
	Livestock	6.36E+10	6.36E+10	5.27E+10	3.63E+10	3.52E+10	2.72E+10
	Wildlife	1.14E+11	1.14E+11	1.10E+11	1.14E+11	1.10E+11	1.14E+11
22	Human/Pet	1.01E+10	1.01E+10	9.80E+09	1.01E+10	9.80E+09	1.01E+10
	Livestock	1.19E+11	1.19E+11	9.90E+10	6.82E+10	6.60E+10	5.11E+10
	Wildlife	9.91E+10	9.91E+10	9.59E+10	9.91E+10	9.59E+10	9.91E+10
23	Human/Pet	1.00E+10	1.00E+10	9.71E+09	1.00E+10	9.71E+09	1.00E+10
	Livestock	1.40E+11	1.40E+11	1.16E+11	7.98E+10	7.73E+10	5.99E+10
	Wildlife	1.82E+11	1.82E+11	1.76E+11	1.82E+11	1.76E+11	1.82E+11
24	Human/Pet	3.82E+09	3.82E+09	3.70E+09	3.82E+09	3.70E+09	3.82E+09
	Livestock	4.92E+10	4.92E+10	4.08E+10	2.81E+10	2.72E+10	2.11E+10
	Wildlife	8.93E+10	8.93E+10	8.65E+10	8.93E+10	8.65E+10	8.93E+10
25	Human/Pet	1.93E+11	1.93E+11	1.87E+11	1.93E+11	1.87E+11	1.93E+11
	Livestock	7.74E+10	7.74E+10	6.42E+10	4.42E+10	4.28E+10	3.32E+10
	Wildlife	1.37E+11	1.37E+11	1.33E+11	1.37E+11	1.33E+11	1.37E+11
26	Human/Pet	8.17E+10	8.17E+10	7.90E+10	8.17E+10	7.90E+10	8.17E+10
	Livestock	4.02E+10	4.02E+10	3.33E+10	2.30E+10	2.22E+10	1.72E+10
	Wildlife	1.04E+11	1.04E+11	1.00E+11	1.04E+11	1.00E+11	1.04E+11
27	Human/Pet	4.95E+09	4.95E+09	4.79E+09	4.95E+09	4.79E+09	4.95E+09
	Livestock	4.20E+10	4.20E+10	3.48E+10	2.40E+10	2.32E+10	1.80E+10
	Wildlife	7.35E+10	7.35E+10	7.12E+10	7.35E+10	7.12E+10	7.35E+10
28	Human/Pet	1.64E+10	1.64E+10	1.59E+10	1.64E+10	1.59E+10	1.64E+10
	Livestock	1.80E+10	1.80E+10	1.49E+10	1.03E+10	9.95E+09	7.71E+09
	Wildlife	6.33E+10	6.33E+10	6.13E+10	6.33E+10	6.13E+10	6.33E+10
29	Human/Pet	1.31E+10	1.31E+10	1.27E+10	1.31E+10	1.27E+10	1.31E+10
	Livestock	2.65E+11	2.65E+11	2.20E+11	1.51E+11	1.46E+11	1.13E+11
	Wildlife	8.28E+10	8.28E+10	8.01E+10	8.28E+10	8.01E+10	8.28E+10
30	Human/Pet	5.66E+10	5.66E+10	5.48E+10	5.66E+10	5.48E+10	5.66E+10
	Livestock	9.06E+10	9.06E+10	7.51E+10	5.17E+10	5.01E+10	3.88E+10
	Wildlife	2.03E+11	2.03E+11	1.97E+11	2.03E+11	1.97E+11	2.03E+11
31	Human/Pet	9.00E+09	9.00E+09	8.71E+09	9.00E+09	8.71E+09	9.00E+09
	Livestock	9.18E+10	9.18E+10	7.61E+10	5.24E+10	5.07E+10	3.93E+10
	Wildlife	1.60E+11	1.60E+11	1.55E+11	1.60E+11	1.55E+11	1.60E+11

Table B.7 Existing annual loads from land-based sources for the Little Nottoway River Impairment - All Contributors (Subwatersheds 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.56E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	8.01E+13	1.67E+15	0.00E+00	8.89E+12	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	2.98E+15	0.00E+00	1.65E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.23E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	1.78E+13	3.75E+14	0.00E+00	1.98E+12	0.00E+00	0.00E+00
deer	1.50E+12	0.00E+00	1.75E+12	4.40E+11	2.55E+13	4.49E+11	0.00E+00	4.65E+12	7.72E+13
dogs	0.00E+00	5.38E+12	0.00E+00	0.00E+00	0.00E+00	6.38E+13	0.00E+00	0.00E+00	0.00E+00
duck	1.04E+08	5.69E+07	1.04E+08	4.17E+08	1.76E+09	1.12E+08	0.00E+00	5.54E+09	9.48E+09
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
goose	1.78E+11	1.06E+11	1.96E+11	7.99E+11	3.20E+12	2.01E+11	0.00E+00	9.87E+12	1.68E+13
hogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	1.74E+12	9.55E+11	1.75E+12	6.99E+12	2.96E+13	1.88E+12	0.00E+00	9.29E+13	1.59E+14
raccoon	4.20E+12	2.09E+12	4.57E+12	1.95E+12	7.33E+13	4.64E+12	0.00E+00	2.79E+13	2.31E+14
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.63E+13	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.73E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
stp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.70E+12	0.00E+00	0.00E+00
turkey	5.78E+08	0.00E+00	1.68E+08	4.24E+07	2.45E+09	0.00E+00	0.00E+00	1.79E+09	2.97E+10

Table B.8 Existing annual loads from direct-deposition sources for the Little Nottoway River Impairment - All Contributors (Reaches 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31).

Source	Annual Total Loads (cfu/yr)
beaver	4.56E+09
beef	8.89E+12
broilers	0.00E+00
dairy	1.98E+12
deer	1.13E+12
duck	8.10E+08
goose	9.52E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	1.64E+13
raccoon	8.89E+11
stp	0.00E+00
straightpipe density	6.70E+12
turkey	1.74E+07

Table B.9 Current conditions of land applied fecal coliform load for Nottoway River Impairment - All Contributors by landuse (Subwatersheds 1, 2, 3, 4, 5, 6, 14, 15, 16, 17, 18).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	1.67E+12	1.73E+11	2.75E+13	1.14E+12	4.39E+13	6.17E+12	9.92E+12	3.52E+13
February	1.51E+12	1.56E+11	3.20E+13	1.29E+12	4.96E+13	5.63E+12	8.96E+12	3.18E+13
March	1.67E+12	1.73E+11	3.08E+14	1.98E+12	5.43E+13	5.67E+12	9.92E+12	3.52E+13
April	1.62E+12	1.67E+11	3.08E+14	2.59E+12	5.17E+13	5.32E+12	9.60E+12	3.41E+13
May	1.67E+12	1.73E+11	3.08E+14	2.67E+12	5.35E+13	5.56E+12	9.92E+12	3.52E+13
June	1.62E+12	1.67E+11	3.26E+11	3.12E+12	8.28E+13	5.00E+12	9.60E+12	3.41E+13
July	1.67E+12	1.73E+11	3.37E+11	3.22E+12	8.45E+13	4.83E+12	9.92E+12	3.52E+13
August	1.67E+12	1.73E+11	3.37E+11	3.22E+12	8.45E+13	4.83E+12	9.92E+12	3.52E+13
September	1.62E+12	1.67E+11	9.07E+13	2.59E+12	5.17E+13	4.67E+12	9.60E+12	3.41E+13
October	1.67E+12	1.73E+11	3.08E+14	1.98E+12	5.43E+13	4.66E+12	9.92E+12	3.52E+13
November	1.62E+12	1.67E+11	3.08E+14	1.91E+12	5.25E+13	4.67E+12	9.60E+12	3.41E+13
December	1.67E+12	1.73E+11	2.75E+13	1.43E+12	5.49E+13	5.50E+12	9.92E+12	3.52E+13
Annual Total Loads (cfu/yr)	1.97E+13	2.04E+12	1.72E+15	2.71E+13	7.18E+14	6.25E+13	1.17E+14	4.15E+14

Table B.10 Monthly, directly deposited fecal coliform loads in each reach of the Nottoway River Impairment - All Contributors (Reaches 1, 2, 3, 4, 5, 6, 14, 15, 16, 17, 18).

Reach ID	Source Type	January	February	March	April	May	June
1	Human/Pet	1.33E+11	1.20E+11	1.33E+11	1.29E+11	1.33E+11	1.29E+11
	Livestock	4.82E+10	5.66E+10	8.36E+10	1.21E+11	1.25E+11	1.42E+11
	Wildlife	2.86E+11	2.58E+11	2.86E+11	2.76E+11	2.86E+11	2.76E+11
2	Human/Pet	1.29E+09	1.17E+09	1.29E+09	1.25E+09	1.29E+09	1.25E+09
	Livestock	2.97E+09	3.48E+09	5.14E+09	7.46E+09	7.71E+09	8.70E+09
	Wildlife	3.90E+10	3.52E+10	3.90E+10	3.77E+10	3.90E+10	3.77E+10
3	Human/Pet	2.98E+10	2.69E+10	2.98E+10	2.88E+10	2.98E+10	2.88E+10
	Livestock	1.36E+10	1.60E+10	2.36E+10	3.43E+10	3.55E+10	4.00E+10
	Wildlife	1.69E+11	1.53E+11	1.69E+11	1.63E+11	1.69E+11	1.63E+11
4	Human/Pet	1.22E+09	1.10E+09	1.22E+09	1.18E+09	1.22E+09	1.18E+09
	Livestock	2.17E+09	2.55E+09	3.77E+09	5.47E+09	5.65E+09	6.38E+09
	Wildlife	4.26E+10	3.84E+10	4.26E+10	4.12E+10	4.26E+10	4.12E+10
5	Human/Pet	1.35E+10	1.22E+10	1.35E+10	1.31E+10	1.35E+10	1.31E+10
	Livestock	5.14E+09	6.04E+09	8.91E+09	1.29E+10	1.34E+10	1.51E+10
	Wildlife	7.12E+10	6.43E+10	7.12E+10	6.89E+10	7.12E+10	6.89E+10
6	Human/Pet	3.40E+09	3.07E+09	3.40E+09	3.29E+09	3.40E+09	3.29E+09
	Livestock	2.17E+09	2.55E+09	3.77E+09	5.47E+09	5.65E+09	6.38E+09
	Wildlife	4.96E+10	4.48E+10	4.96E+10	4.80E+10	4.96E+10	4.80E+10
14	Human/Pet	8.13E+09	7.35E+09	8.13E+09	7.87E+09	8.13E+09	7.87E+09
	Livestock	1.42E+10	1.67E+10	2.47E+10	3.58E+10	3.70E+10	4.18E+10
	Wildlife	1.46E+11	1.32E+11	1.46E+11	1.41E+11	1.46E+11	1.41E+11
15	Human/Pet	1.13E+09	1.02E+09	1.13E+09	1.10E+09	1.13E+09	1.10E+09
	Livestock	9.88E+08	1.16E+09	1.71E+09	2.49E+09	2.57E+09	2.90E+09
	Wildlife	3.95E+10	3.56E+10	3.95E+10	3.82E+10	3.95E+10	3.82E+10
16	Human/Pet	6.97E+09	6.29E+09	6.97E+09	6.74E+09	6.97E+09	6.74E+09
	Livestock	3.95E+08	4.64E+08	6.85E+08	9.95E+08	1.03E+09	1.16E+09
	Wildlife	7.07E+10	6.38E+10	7.07E+10	6.84E+10	7.07E+10	6.84E+10
17	Human/Pet	2.40E+10	2.17E+10	2.40E+10	2.32E+10	2.40E+10	2.32E+10
	Livestock	1.58E+10	1.86E+10	2.74E+10	3.98E+10	4.11E+10	4.64E+10
	Wildlife	1.15E+11	1.04E+11	1.15E+11	1.11E+11	1.15E+11	1.11E+11
18	Human/Pet	1.09E+10	9.81E+09	1.09E+10	1.05E+10	1.09E+10	1.05E+10
	Livestock	7.71E+09	9.05E+09	1.34E+10	1.94E+10	2.00E+10	2.26E+10
	Wildlife	1.45E+11	1.31E+11	1.45E+11	1.41E+11	1.45E+11	1.41E+11

Table B.10 Monthly, directly deposited fecal coliform loads in each reach of the Nottoway River Impairment - All Contributors (Reaches 1, 2, 3, 4, 5, 6, 14, 15, 16, 17, 18), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
1	Human/Pet	1.33E+11	1.33E+11	1.29E+11	1.33E+11	1.29E+11	1.33E+11
	Livestock	1.46E+11	1.46E+11	1.21E+11	8.36E+10	8.09E+10	6.27E+10
	Wildlife	2.86E+11	2.86E+11	2.76E+11	2.86E+11	2.76E+11	2.86E+11
2	Human/Pet	1.29E+09	1.29E+09	1.25E+09	1.29E+09	1.25E+09	1.29E+09
	Livestock	9.00E+09	9.00E+09	7.46E+09	5.14E+09	4.97E+09	3.86E+09
	Wildlife	3.90E+10	3.90E+10	3.77E+10	3.90E+10	3.77E+10	3.90E+10
3	Human/Pet	2.98E+10	2.98E+10	2.88E+10	2.98E+10	2.88E+10	2.98E+10
	Livestock	4.14E+10	4.14E+10	3.43E+10	2.36E+10	2.29E+10	1.77E+10
	Wildlife	1.69E+11	1.69E+11	1.63E+11	1.69E+11	1.63E+11	1.69E+11
4	Human/Pet	1.22E+09	1.22E+09	1.18E+09	1.22E+09	1.18E+09	1.22E+09
	Livestock	6.60E+09	6.60E+09	5.47E+09	3.77E+09	3.65E+09	2.83E+09
	Wildlife	4.26E+10	4.26E+10	4.12E+10	4.26E+10	4.12E+10	4.26E+10
5	Human/Pet	1.35E+10	1.35E+10	1.31E+10	1.35E+10	1.31E+10	1.35E+10
	Livestock	1.56E+10	1.56E+10	1.29E+10	8.91E+09	8.62E+09	6.68E+09
	Wildlife	7.12E+10	7.12E+10	6.89E+10	7.12E+10	6.89E+10	7.12E+10
6	Human/Pet	3.40E+09	3.40E+09	3.29E+09	3.40E+09	3.29E+09	3.40E+09
	Livestock	6.60E+09	6.60E+09	5.47E+09	3.77E+09	3.65E+09	2.83E+09
	Wildlife	4.96E+10	4.96E+10	4.80E+10	4.96E+10	4.80E+10	4.96E+10
14	Human/Pet	8.13E+09	8.13E+09	7.87E+09	8.13E+09	7.87E+09	8.13E+09
	Livestock	4.32E+10	4.32E+10	3.58E+10	2.47E+10	2.39E+10	1.85E+10
	Wildlife	1.46E+11	1.46E+11	1.41E+11	1.46E+11	1.41E+11	1.46E+11
15	Human/Pet	1.13E+09	1.13E+09	1.10E+09	1.13E+09	1.10E+09	1.13E+09
	Livestock	3.00E+09	3.00E+09	2.49E+09	1.71E+09	1.66E+09	1.29E+09
	Wildlife	3.95E+10	3.95E+10	3.82E+10	3.95E+10	3.82E+10	3.95E+10
16	Human/Pet	6.97E+09	6.97E+09	6.74E+09	6.97E+09	6.74E+09	6.97E+09
	Livestock	1.20E+09	1.20E+09	9.95E+08	6.85E+08	6.63E+08	5.14E+08
	Wildlife	7.07E+10	7.07E+10	6.84E+10	7.07E+10	6.84E+10	7.07E+10
17	Human/Pet	2.40E+10	2.40E+10	2.32E+10	2.40E+10	2.32E+10	2.40E+10
	Livestock	4.80E+10	4.80E+10	3.98E+10	2.74E+10	2.65E+10	2.06E+10
	Wildlife	1.15E+11	1.15E+11	1.11E+11	1.15E+11	1.11E+11	1.15E+11
18	Human/Pet	1.09E+10	1.09E+10	1.05E+10	1.09E+10	1.05E+10	1.09E+10
	Livestock	2.34E+10	2.34E+10	1.94E+10	1.34E+10	1.29E+10	1.00E+10
	Wildlife	1.45E+11	1.45E+11	1.41E+11	1.45E+11	1.41E+11	1.45E+11

Table B.11 Existing annual loads from land-based sources for the Nottoway River Impairment - All Contributors (Sub-watersheds 1, 2, 3,4, 5, 6, 14, 15, 16, 17, 18).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	2.50E+13	5.39E+14	0.00E+00	2.87E+12	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	8.97E+14	0.00E+00	4.97E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.37E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	4.95E+12	0.00E+00	9.36E+11	1.49E+11	8.74E+12	8.34E+10	0.00E+00	4.87E+12	7.89E+13
dogs	0.00E+00	1.58E+12	0.00E+00	0.00E+00	0.00E+00	2.43E+13	0.00E+00	0.00E+00	0.00E+00
duck	1.67E+08	5.96E+06	4.14E+07	7.56E+07	4.02E+08	2.19E+07	0.00E+00	4.55E+09	6.98E+09
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.84E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
goose	3.28E+11	1.49E+10	7.15E+10	1.72E+11	7.09E+11	4.04E+10	0.00E+00	8.22E+12	1.23E+13
hogs	0.00E+00	0.00E+00	8.16E+14	0.00E+00	4.52E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	2.80E+12	9.99E+10	6.94E+11	1.27E+12	6.74E+12	3.67E+11	0.00E+00	7.63E+13	1.17E+14
raccoon	1.16E+13	3.44E+11	2.27E+12	5.52E+11	2.20E+13	8.40E+11	0.00E+00	2.73E+13	2.06E+14
septic_ density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E+13	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
stp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+12	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E+12	0.00E+00	0.00E+00
turkey	1.91E+09	0.00E+00	9.01E+07	1.44E+07	8.40E+08	0.00E+00	0.00E+00	1.87E+09	3.04E+10

Table B.12 Existing annual loads from direct-deposition sources for the Nottoway River Impairment - All Contributors (Reaches 1, 2, 3, 4, 5, 6, 14, 15, 16, 17, 18).

Source	Annual Total Loads (cfu/yr)
beaver	3.85E+09
beef	2.87E+12
broilers	0.00E+00
dairy	0.00E+00
deer	9.96E+11
duck	5.65E+08
goose	6.64E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	1.15E+13
raccoon	6.90E+11
stp	1.11E+12
straightpipe density	1.64E+12
turkey	1.76E+07

Table B.13 Current conditions of land applied fecal coliform load for Beaverpond Creek by landuse (Subwatersheds 38, 39, 40).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	5.36E+10	1.86E+10	2.15E+12	5.17E+11	1.32E+13	3.20E+12	2.58E+11	6.21E+12
February	4.84E+10	1.68E+10	2.30E+12	5.31E+11	1.43E+13	2.87E+12	2.33E+11	5.61E+12
March	5.36E+10	1.86E+10	1.61E+13	7.48E+11	1.57E+13	3.14E+12	2.58E+11	6.21E+12
April	5.18E+10	1.80E+10	1.60E+13	9.22E+11	1.49E+13	3.02E+12	2.50E+11	6.01E+12
May	5.36E+10	1.86E+10	1.61E+13	9.53E+11	1.54E+13	3.11E+12	2.58E+11	6.21E+12
June	5.18E+10	1.80E+10	7.78E+11	1.08E+12	1.63E+13	2.99E+12	2.50E+11	6.01E+12
July	5.36E+10	1.86E+10	8.04E+11	1.11E+12	1.68E+13	3.06E+12	2.58E+11	6.21E+12
August	5.36E+10	1.86E+10	8.04E+11	1.11E+12	1.68E+13	3.06E+12	2.58E+11	6.21E+12
September	5.18E+10	1.80E+10	5.27E+12	9.22E+11	1.49E+13	2.96E+12	2.50E+11	6.01E+12
October	5.36E+10	1.86E+10	1.61E+13	7.48E+11	1.57E+13	3.04E+12	2.58E+11	6.21E+12
November	5.18E+10	1.80E+10	1.60E+13	7.24E+11	1.51E+13	2.96E+12	2.50E+11	6.01E+12
December	5.36E+10	1.86E+10	2.15E+12	5.88E+11	1.58E+13	3.13E+12	2.58E+11	6.21E+12
Annual Total Loads (cfu/yr)	6.31E+11	2.19E+11	9.46E+13	9.96E+12	1.85E+14	3.65E+13	3.04E+12	7.31E+13

Table B.14 Monthly, directly deposited fecal coliform loads in each reach of the Beaverpond Creek (Reaches 38, 39, 40).

Reach ID	Source Type	January	February	March	April	May	June
38	Human/Pet	1.75E+10	1.58E+10	1.75E+10	1.69E+10	1.75E+10	1.69E+10
	Livestock	1.49E+10	1.67E+10	2.46E+10	3.57E+10	3.69E+10	4.17E+10
	Wildlife	1.08E+11	9.76E+10	1.08E+11	1.05E+11	1.08E+11	1.05E+11
39	Human/Pet	7.59E+09	6.86E+09	7.59E+09	7.35E+09	7.59E+09	7.35E+09
	Livestock	1.57E+10	1.77E+10	2.62E+10	3.80E+10	3.93E+10	4.44E+10
	Wildlife	7.24E+10	6.54E+10	7.24E+10	7.01E+10	7.24E+10	7.01E+10
40	Human/Pet	8.72E+09	7.88E+09	8.72E+09	8.44E+09	8.72E+09	8.44E+09
	Livestock	3.19E+09	3.42E+09	5.04E+09	7.32E+09	7.57E+09	8.54E+09
	Wildlife	6.13E+10	5.53E+10	6.13E+10	5.93E+10	6.13E+10	5.93E+10
Reach ID	**Source Type**	**July**	**August**	**September**	**October**	**November**	**December**
38	Human/Pet	1.75E+10	1.75E+10	1.69E+10	1.75E+10	1.69E+10	1.75E+10
	Livestock	4.31E+10	4.31E+10	3.57E+10	2.46E+10	2.38E+10	1.85E+10
	Wildlife	1.08E+11	1.08E+11	1.05E+11	1.08E+11	1.05E+11	1.08E+11
39	Human/Pet	7.59E+09	7.59E+09	7.35E+09	7.59E+09	7.35E+09	7.59E+09
	Livestock	4.58E+10	4.58E+10	3.80E+10	2.62E+10	2.53E+10	1.96E+10
	Wildlife	7.24E+10	7.24E+10	7.01E+10	7.24E+10	7.01E+10	7.24E+10
40	Human/Pet	8.72E+09	8.72E+09	8.44E+09	8.72E+09	8.44E+09	8.72E+09
	Livestock	8.83E+09	8.83E+09	7.32E+09	5.04E+09	4.88E+09	3.78E+09
	Wildlife	6.13E+10	6.13E+10	5.93E+10	6.13E+10	5.93E+10	6.13E+10

Table B.15 Existing annual loads from land-based sources for the Beaverpond Creek (Subwatersheds 38, 39, 40).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	6.16E+12	1.29E+14	0.00E+00	6.84E+11	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Canada goose	2.70E+10	1.75E+10	2.99E+11	2.12E+11	9.54E+11	9.47E+09	0.00E+00	2.59E+11	3.52E+12
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.54E+06	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	7.09E+10	0.00E+00	1.88E+12	9.17E+10	3.99E+12	8.35E+09	0.00E+00	7.31E+10	9.21E+12
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E+13	0.00E+00	0.00E+00	0.00E+00
duck	2.07E+07	1.34E+07	2.29E+08	1.62E+08	7.31E+08	7.25E+06	0.00E+00	1.98E+08	2.69E+09
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
hogs	0.00E+00	0.00E+00	8.51E+13	0.00E+00	4.71E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	1.18E+12	2.49E+13	0.00E+00	1.31E+11	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	2.40E+11	1.55E+11	2.66E+12	1.88E+12	8.46E+12	8.40E+10	0.00E+00	2.30E+12	3.12E+13
raccoon	2.93E+11	4.63E+10	4.63E+12	4.36E+11	1.33E+13	1.37E+11	0.00E+00	4.14E+11	2.92E+13
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E+12	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.98E+11	0.00E+00	0.00E+00
turkey	2.04E+07	0.00E+00	1.62E+08	7.22E+06	3.44E+08	0.00E+00	0.00E+00	2.62E+07	3.17E+09

Table B.16 Existing annual loads from direct-deposition sources for the Beaverpond Creek (Reaches 38, 39, 40).

Source	Annual Total Loads (cfu/yr)
beaver	3.24E+09
beef	6.84E+11
broilers	0.00E+00
Canada goose	1.57E+11
dairy	0.00E+00
deer	7.66E+09
duck	1.82E+08
hogs	0.00E+00
horse	1.31E+11
layers	0.00E+00
muskrat	2.55E+12
raccoon	1.23E+11
sheep	0.00E+00
straightpipe density	3.98E+11
turkey	1.87E+06

Table B.17 Current conditions of land applied fecal coliform load for Raccoon Creek Impairment - All Contributors by landuse (Subwatersheds 18, 19, 20, 21, 22, 23, 24, 25, 26).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	1.16E+12	1.45E+11	3.87E+13	2.17E+11	2.23E+13	2.74E+12	2.76E+13	3.68E+13
February	1.05E+12	1.31E+11	4.37E+13	2.36E+11	2.49E+13	2.43E+12	2.49E+13	3.32E+13
March	1.16E+12	1.45E+11	3.81E+14	3.47E+11	2.72E+13	2.57E+12	2.76E+13	3.68E+13
April	1.13E+12	1.40E+11	3.81E+14	4.40E+11	2.60E+13	2.43E+12	2.67E+13	3.56E+13
May	1.16E+12	1.45E+11	3.81E+14	4.55E+11	2.69E+13	2.46E+12	2.76E+13	3.68E+13
June	1.13E+12	1.40E+11	5.38E+12	5.22E+11	6.44E+13	2.32E+12	2.67E+13	3.56E+13
July	1.16E+12	1.45E+11	5.56E+12	5.39E+11	6.52E+13	2.28E+12	2.76E+13	3.68E+13
August	1.16E+12	1.45E+11	5.56E+12	5.39E+11	6.52E+13	2.28E+12	2.76E+13	3.68E+13
September	1.13E+12	1.40E+11	1.16E+14	4.40E+11	2.60E+13	2.21E+12	2.67E+13	3.56E+13
October	1.16E+12	1.45E+11	3.81E+14	3.47E+11	2.72E+13	2.23E+12	2.76E+13	3.68E+13
November	1.13E+12	1.40E+11	3.81E+14	3.35E+11	2.64E+13	2.21E+12	2.67E+13	3.56E+13
December	1.16E+12	1.45E+11	3.87E+13	2.62E+11	2.75E+13	2.51E+12	2.76E+13	3.68E+13
Annual Total Loads (cfu/yr)	1.37E+13	1.71E+12	2.16E+15	4.68E+12	4.29E+14	2.87E+13	3.25E+14	4.33E+14

Table B.18 Monthly, directly deposited fecal coliform loads in each reach of the Raccoon Creek Impairment - All Contributors (Reaches 18, 19, 20, 21, 22, 23, 24, 25, 26).

Reach ID	Source Type	January	February	March	April	May	June
18	Human/Pet	9.57E+09	8.64E+09	9.57E+09	9.26E+09	9.57E+09	9.26E+09
	Livestock	4.94E+09	5.80E+09	8.57E+09	1.24E+10	1.29E+10	1.45E+10
	Wildlife	1.53E+11	1.39E+11	1.53E+11	1.48E+11	1.53E+11	1.48E+11
19	Human/Pet	1.59E+10	1.43E+10	1.59E+10	1.54E+10	1.59E+10	1.54E+10
	Livestock	3.95E+09	4.64E+09	6.85E+09	9.95E+09	1.03E+10	1.16E+10
	Wildlife	2.65E+11	2.40E+11	2.65E+11	2.57E+11	2.65E+11	2.57E+11
20	Human/Pet	7.02E+08	6.34E+08	7.02E+08	6.80E+08	7.02E+08	6.80E+08
	Livestock	2.27E+10	2.67E+10	3.94E+10	5.72E+10	5.91E+10	6.67E+10
	Wildlife	1.52E+11	1.38E+11	1.52E+11	1.48E+11	1.52E+11	1.48E+11
21	Human/Pet	9.07E+07	8.20E+07	9.07E+07	8.78E+07	9.07E+07	8.78E+07
	Livestock	4.94E+09	5.80E+09	8.57E+09	1.24E+10	1.29E+10	1.45E+10
	Wildlife	2.57E+11	2.32E+11	2.57E+11	2.49E+11	2.57E+11	2.49E+11
22	Human/Pet	8.42E+09	7.60E+09	8.42E+09	8.15E+09	8.42E+09	8.15E+09
	Livestock	1.98E+09	2.32E+09	3.43E+09	4.97E+09	5.14E+09	5.80E+09
	Wildlife	1.25E+11	1.13E+11	1.25E+11	1.21E+11	1.25E+11	1.21E+11
23	Human/Pet	4.47E+10	4.04E+10	4.47E+10	4.33E+10	4.47E+10	4.33E+10
	Livestock	5.54E+09	6.50E+09	9.59E+09	1.39E+10	1.44E+10	1.62E+10
	Wildlife	3.56E+11	3.21E+11	3.56E+11	3.44E+11	3.56E+11	3.44E+11
24	Human/Pet	8.04E+08	7.26E+08	8.04E+08	7.78E+08	8.04E+08	7.78E+08
	Livestock	7.51E+09	8.82E+09	1.30E+10	1.89E+10	1.95E+10	2.21E+10
	Wildlife	6.19E+10	5.59E+10	6.19E+10	5.99E+10	6.19E+10	5.99E+10
25	Human/Pet	1.57E+10	1.42E+10	1.57E+10	1.52E+10	1.57E+10	1.52E+10
	Livestock	2.57E+09	3.02E+09	4.45E+09	6.47E+09	6.68E+09	7.54E+09
	Wildlife	3.10E+11	2.80E+11	3.10E+11	3.00E+11	3.10E+11	3.00E+11
26	Human/Pet	4.59E+09	4.15E+09	4.59E+09	4.44E+09	4.59E+09	4.44E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.85E+11	1.68E+11	1.85E+11	1.80E+11	1.85E+11	1.80E+11

Table B.18 Monthly, directly deposited fecal coliform loads in each reach of the Raccoon Creek Impairment - All Contributors (Reaches 18, 19, 20, 21, 22, 23, 24, 25, 26), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
18	Human/Pet	9.57E+09	9.57E+09	9.26E+09	9.57E+09	9.26E+09	9.57E+09
	Livestock	1.50E+10	1.50E+10	1.24E+10	8.57E+09	8.29E+09	6.43E+09
	Wildlife	1.53E+11	1.53E+11	1.48E+11	1.53E+11	1.48E+11	1.53E+11
19	Human/Pet	1.59E+10	1.59E+10	1.54E+10	1.59E+10	1.54E+10	1.59E+10
	Livestock	1.20E+10	1.20E+10	9.95E+09	6.85E+09	6.63E+09	5.14E+09
	Wildlife	2.65E+11	2.65E+11	2.57E+11	2.65E+11	2.57E+11	2.65E+11
20	Human/Pet	7.02E+08	7.02E+08	6.80E+08	7.02E+08	6.80E+08	7.02E+08
	Livestock	6.90E+10	6.90E+10	5.72E+10	3.94E+10	3.81E+10	2.96E+10
	Wildlife	1.52E+11	1.52E+11	1.48E+11	1.52E+11	1.48E+11	1.52E+11
21	Human/Pet	9.07E+07	9.07E+07	8.78E+07	9.07E+07	8.78E+07	9.07E+07
	Livestock	1.50E+10	1.50E+10	1.24E+10	8.57E+09	8.29E+09	6.43E+09
	Wildlife	2.57E+11	2.57E+11	2.49E+11	2.57E+11	2.49E+11	2.57E+11
22	Human/Pet	8.42E+09	8.42E+09	8.15E+09	8.42E+09	8.15E+09	8.42E+09
	Livestock	6.00E+09	6.00E+09	4.97E+09	3.43E+09	3.32E+09	2.57E+09
	Wildlife	1.25E+11	1.25E+11	1.21E+11	1.25E+11	1.21E+11	1.25E+11
23	Human/Pet	4.47E+10	4.47E+10	4.33E+10	4.47E+10	4.33E+10	4.47E+10
	Livestock	1.68E+10	1.68E+10	1.39E+10	9.59E+09	9.29E+09	7.20E+09
	Wildlife	3.56E+11	3.56E+11	3.44E+11	3.56E+11	3.44E+11	3.56E+11
24	Human/Pet	8.04E+08	8.04E+08	7.78E+08	8.04E+08	7.78E+08	8.04E+08
	Livestock	2.28E+10	2.28E+10	1.89E+10	1.30E+10	1.26E+10	9.77E+09
	Wildlife	6.19E+10	6.19E+10	5.99E+10	6.19E+10	5.99E+10	6.19E+10
25	Human/Pet	1.57E+10	1.57E+10	1.52E+10	1.57E+10	1.52E+10	1.57E+10
	Livestock	7.80E+09	7.80E+09	6.47E+09	4.45E+09	4.31E+09	3.34E+09
	Wildlife	3.10E+11	3.10E+11	3.00E+11	3.10E+11	3.00E+11	3.10E+11
26	Human/Pet	4.59E+09	4.59E+09	4.44E+09	4.59E+09	4.44E+09	4.59E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.85E+11	1.85E+11	1.80E+11	1.85E+11	1.80E+11	1.85E+11

Table B.19 Existing annual loads from land-based sources for the Raccoon Creek Impairment - All Contributors (Subwatersheds 18, 19, 20, 21, 22, 23, 24, 25, 26).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.09E+10	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	3.87E+12	2.57E+14	0.00E+00	1.37E+12	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	3.89E+12	0.00E+00	1.69E+13	7.04E+10	8.08E+12	3.66E+10	0.00E+00	1.50E+13	8.71E+13
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E+13	0.00E+00	0.00E+00	0.00E+00
duck	2.96E+08	4.55E+07	1.49E+09	6.11E+07	5.19E+08	1.56E+06	0.00E+00	2.59E+10	1.49E+10
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
goose	2.11E+11	3.25E+10	1.07E+12	4.36E+10	3.70E+11	1.11E+09	0.00E+00	1.85E+13	1.06E+13
hogs	0.00E+00	0.00E+00	1.19E+15	0.00E+00	6.61E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	9.01E+14	0.00E+00	4.99E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	2.63E+12	4.05E+11	1.33E+13	5.43E+11	4.61E+12	1.38E+10	0.00E+00	2.30E+14	1.33E+14
raccoon	6.96E+12	1.27E+12	3.42E+13	1.55E+11	1.59E+13	2.02E+11	0.00E+00	6.17E+13	2.02E+14
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E+13	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E+12	0.00E+00	0.00E+00
turkey	1.46E+09	0.00E+00	1.59E+09	6.61E+06	7.59E+08	0.00E+00	0.00E+00	5.62E+09	3.27E+10

Table B.20 Existing annual loads from direct-deposition sources for the Raccoon Creek Impairment - All Contributors (Reaches 18, 19, 20, 21, 22, 23, 24, 25, 26).

Source	Annual Total Loads (cfu/yr)
beaver	2.09E+10
beef	1.37E+12
broilers	0.00E+00
dairy	0.00E+00
deer	6.55E+10
duck	1.88E+09
goats	0.00E+00
goose	8.82E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	2.02E+13
raccoon	8.17E+11
sheep	0.00E+00
straightpipe density	1.18E+12
turkey	2.11E+07

Table B.21 Current conditions of land applied fecal coliform load for Cypress Swamp Impairment - All contributors by landuse (Subwatersheds 12, 13, 14, 15, 16, 17, 18, 19, 20).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	2.33E+12	2.36E+10	5.70E+12	6.63E+10	4.21E+12	1.45E+12	3.12E+13	3.88E+13
February	2.11E+12	2.14E+10	5.34E+12	6.45E+10	3.98E+12	1.28E+12	2.82E+13	3.51E+13
March	2.33E+12	2.36E+10	1.31E+13	8.19E+10	4.41E+12	1.35E+12	3.12E+13	3.88E+13
April	2.26E+12	2.29E+10	1.30E+13	9.23E+10	4.26E+12	1.27E+12	3.02E+13	3.76E+13
May	2.33E+12	2.36E+10	1.31E+13	9.54E+10	4.41E+12	1.28E+12	3.12E+13	3.88E+13
June	2.26E+12	2.29E+10	4.82E+12	1.02E+11	5.10E+12	1.20E+12	3.02E+13	3.76E+13
July	2.33E+12	2.36E+10	4.99E+12	1.06E+11	5.24E+12	1.17E+12	3.12E+13	3.88E+13
August	2.33E+12	2.36E+10	4.99E+12	1.06E+11	5.24E+12	1.17E+12	3.12E+13	3.88E+13
September	2.26E+12	2.29E+10	7.22E+12	9.23E+10	4.26E+12	1.14E+12	3.02E+13	3.76E+13
October	2.33E+12	2.36E+10	1.31E+13	8.19E+10	4.41E+12	1.14E+12	3.12E+13	3.88E+13
November	2.26E+12	2.29E+10	1.30E+13	7.93E+10	4.27E+12	1.14E+12	3.02E+13	3.76E+13
December	2.33E+12	2.36E+10	5.70E+12	7.14E+10	4.41E+12	1.31E+12	3.12E+13	3.88E+13
Annual Total Loads (cfu/yr)	2.75E+13	2.78E+11	1.04E+14	1.04E+12	5.42E+13	1.49E+13	3.67E+14	4.57E+14

Table B.22 Monthly, directly deposited fecal coliform loads in each reach of the Cypress Swamp Impairment - All contributors (Reaches 12, 13, 14, 15, 16, 17, 18, 19, 20).

Reach ID	Source Type	January	February	March	April	May	June
12	Human/Pet	2.87E+10	2.59E+10	2.87E+10	2.78E+10	2.87E+10	2.78E+10
	Livestock	4.35E+07	3.93E+07	5.81E+07	8.43E+07	8.71E+07	9.83E+07
	Wildlife	1.57E+11	1.42E+11	1.57E+11	1.52E+11	1.57E+11	1.52E+11
13	Human/Pet	1.64E+10	1.48E+10	1.64E+10	1.59E+10	1.64E+10	1.59E+10
	Livestock	1.98E+09	2.32E+09	3.43E+09	4.97E+09	5.14E+09	5.80E+09
	Wildlife	5.08E+11	4.59E+11	5.08E+11	4.92E+11	5.08E+11	4.92E+11
14	Human/Pet	3.92E+09	3.54E+09	3.92E+09	3.79E+09	3.92E+09	3.79E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.56E+11	2.32E+11	2.56E+11	2.48E+11	2.56E+11	2.48E+11
15	Human/Pet	4.54E+10	4.10E+10	4.54E+10	4.40E+10	4.54E+10	4.40E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.52E+11	2.28E+11	2.52E+11	2.44E+11	2.52E+11	2.44E+11
16	Human/Pet	3.28E+09	2.97E+09	3.28E+09	3.18E+09	3.28E+09	3.18E+09
	Livestock	4.35E+07	3.93E+07	5.81E+07	8.43E+07	8.71E+07	9.83E+07
	Wildlife	4.06E+11	3.67E+11	4.06E+11	3.93E+11	4.06E+11	3.93E+11
17	Human/Pet	3.61E+09	3.26E+09	3.61E+09	3.50E+09	3.61E+09	3.50E+09
	Livestock	6.53E+07	5.90E+07	8.71E+07	1.26E+08	1.31E+08	1.48E+08
	Wildlife	6.08E+10	5.49E+10	6.08E+10	5.88E+10	6.08E+10	5.88E+10
18	Human/Pet	9.74E+09	8.80E+09	9.74E+09	9.43E+09	9.74E+09	9.43E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.93E+11	1.74E+11	1.93E+11	1.86E+11	1.93E+11	1.86E+11
19	Human/Pet	3.18E+10	2.87E+10	3.18E+10	3.07E+10	3.18E+10	3.07E+10
	Livestock	2.18E+07	1.97E+07	2.90E+07	4.21E+07	4.35E+07	4.92E+07
	Wildlife	3.36E+11	3.04E+11	3.36E+11	3.25E+11	3.36E+11	3.25E+11
20	Human/Pet	9.02E+09	8.15E+09	9.02E+09	8.73E+09	9.02E+09	8.73E+09
	Livestock	2.18E+07	1.97E+07	2.90E+07	4.21E+07	4.35E+07	4.92E+07
	Wildlife	1.55E+11	1.40E+11	1.55E+11	1.50E+11	1.55E+11	1.50E+11

Table B.22 Monthly, directly deposited fecal coliform loads in each reach of the Cypress Swamp Impairment - All contributors (Reaches 12, 13, 14, 15, 16, 17, 18, 19, 20), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
12	Human/Pet	2.87E+10	2.87E+10	2.78E+10	2.87E+10	2.78E+10	2.87E+10
	Livestock	1.02E+08	1.02E+08	8.43E+07	5.81E+07	5.62E+07	4.35E+07
	Wildlife	1.57E+11	1.57E+11	1.52E+11	1.57E+11	1.52E+11	1.57E+11
13	Human/Pet	1.64E+10	1.64E+10	1.59E+10	1.64E+10	1.59E+10	1.64E+10
	Livestock	6.00E+09	6.00E+09	4.97E+09	3.43E+09	3.32E+09	2.57E+09
	Wildlife	5.08E+11	5.08E+11	4.92E+11	5.08E+11	4.92E+11	5.08E+11
14	Human/Pet	3.92E+09	3.92E+09	3.79E+09	3.92E+09	3.79E+09	3.92E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.56E+11	2.56E+11	2.48E+11	2.56E+11	2.48E+11	2.56E+11
15	Human/Pet	4.54E+10	4.54E+10	4.40E+10	4.54E+10	4.40E+10	4.54E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.52E+11	2.52E+11	2.44E+11	2.52E+11	2.44E+11	2.52E+11
16	Human/Pet	3.28E+09	3.28E+09	3.18E+09	3.28E+09	3.18E+09	3.28E+09
	Livestock	1.02E+08	1.02E+08	8.43E+07	5.81E+07	5.62E+07	4.35E+07
	Wildlife	4.06E+11	4.06E+11	3.93E+11	4.06E+11	3.93E+11	4.06E+11
17	Human/Pet	3.61E+09	3.61E+09	3.50E+09	3.61E+09	3.50E+09	3.61E+09
	Livestock	1.52E+08	1.52E+08	1.26E+08	8.71E+07	8.43E+07	6.53E+07
	Wildlife	6.08E+10	6.08E+10	5.88E+10	6.08E+10	5.88E+10	6.08E+10
18	Human/Pet	9.74E+09	9.74E+09	9.43E+09	9.74E+09	9.43E+09	9.74E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.93E+11	1.93E+11	1.86E+11	1.93E+11	1.86E+11	1.93E+11
19	Human/Pet	3.18E+10	3.18E+10	3.07E+10	3.18E+10	3.07E+10	3.18E+10
	Livestock	5.08E+07	5.08E+07	4.21E+07	2.90E+07	2.81E+07	2.18E+07
	Wildlife	3.36E+11	3.36E+11	3.25E+11	3.36E+11	3.25E+11	3.36E+11
20	Human/Pet	9.02E+09	9.02E+09	8.73E+09	9.02E+09	8.73E+09	9.02E+09
	Livestock	5.08E+07	5.08E+07	4.21E+07	2.90E+07	2.81E+07	2.18E+07
	Wildlife	1.55E+11	1.55E+11	1.50E+11	1.55E+11	1.50E+11	1.55E+11

Table B.23 Existing annual loads from land-based sources for the Cypress Swamp Impairment - All contributors (Subwatersheds 12, 13, 14, 15, 16, 17, 18, 19, 20).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+10	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	4.50E+11	9.89E+12	0.00E+00	4.99E+10	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	8.22E+12	1.39E+10	1.63E+13	3.81E+10	6.10E+12	4.06E+10	0.00E+00	6.94E+12	9.00E+13
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.08E+12	0.00E+00	0.00E+00	0.00E+00
duck	6.57E+08	1.86E+07	1.37E+09	4.20E+07	4.29E+08	1.82E+06	0.00E+00	3.45E+10	1.90E+10
goats	0.00E+00	0.00E+00	0.00E+00	3.08E+10	7.31E+11	0.00E+00	3.85E+09	0.00E+00	0.00E+00
goose	4.46E+11	1.26E+10	9.28E+11	2.85E+10	2.92E+11	1.23E+09	0.00E+00	2.34E+13	1.29E+13
hogs	0.00E+00	0.00E+00	4.54E+13	0.00E+00	2.51E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	5.97E+12	1.69E+11	1.24E+13	3.82E+11	3.91E+12	1.65E+10	0.00E+00	3.13E+14	1.73E+14
raccoon	1.28E+13	8.32E+10	2.91E+13	1.10E+11	1.09E+13	1.70E+11	0.00E+00	2.32E+13	1.81E+14
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.57E+12	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
stp	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E+11	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+12	0.00E+00	0.00E+00
turkey	3.78E+09	5.70E+06	2.33E+09	7.47E+06	8.27E+08	6.39E+06	0.00E+00	3.18E+09	4.11E+10

Table B.24 Existing annual loads from direct-deposition sources for the Cypress Swamp Impairment - All contributors (Reaches 12, 13, 14, 15, 16, 17, 18, 19, 20).

Source	Annual Total Loads (cfu/yr)
beaver	1.88E+10
beef	4.99E+10
broilers	0.00E+00
dairy	0.00E+00
deer	6.43E+10
duck	2.33E+09
goats	3.85E+09
goose	1.04E+12
hogs	0.00E+00
layers	0.00E+00
muskrat	2.56E+13
raccoon	6.54E+11
sheep	0.00E+00
stp	3.59E+11
straightpipe density	1.43E+12
turkey	2.58E+07

Table B.25 Current conditions of land applied fecal coliform load for Mill Swamp Impairment - All contributors by landuse (Subwatersheds 21, 22, 23, 24, 25, 26, 27, 28).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	1.01E+11	3.84E+10	2.07E+13	4.07E+11	1.46E+13	1.71E+12	1.64E+13	1.60E+13
February	9.15E+10	3.47E+10	2.28E+13	4.42E+11	1.59E+13	1.51E+12	1.49E+13	1.45E+13
March	1.01E+11	3.84E+10	1.83E+14	6.29E+11	1.76E+13	1.59E+12	1.64E+13	1.60E+13
April	9.80E+10	3.71E+10	1.83E+14	8.78E+11	1.69E+13	1.50E+12	1.59E+13	1.55E+13
May	1.01E+11	3.84E+10	1.83E+14	9.07E+11	1.75E+13	1.51E+12	1.64E+13	1.60E+13
June	9.80E+10	3.71E+10	4.83E+12	1.01E+12	3.52E+13	1.43E+12	1.59E+13	1.55E+13
July	1.01E+11	3.84E+10	4.99E+12	1.05E+12	3.58E+13	1.39E+12	1.64E+13	1.60E+13
August	1.01E+11	3.84E+10	4.99E+12	1.05E+12	3.58E+13	1.39E+12	1.64E+13	1.60E+13
September	9.80E+10	3.71E+10	5.72E+13	8.78E+11	1.69E+13	1.35E+12	1.59E+13	1.55E+13
October	1.01E+11	3.84E+10	1.83E+14	6.29E+11	1.76E+13	1.35E+12	1.64E+13	1.60E+13
November	9.80E+10	3.71E+10	1.83E+14	6.09E+11	1.70E+13	1.35E+12	1.59E+13	1.55E+13
December	1.01E+11	3.84E+10	2.07E+13	4.90E+11	1.76E+13	1.55E+12	1.64E+13	1.60E+13
Annual Total Loads (cfu/yr)	1.19E+12	4.52E+11	1.05E+15	8.97E+12	2.58E+14	1.77E+13	1.94E+14	1.89E+14

Table B.26 Monthly, directly deposited fecal coliform loads in each reach of the Mill Swamp Impairment - All contributors (Reaches 21, 22, 23, 24, 25, 26, 27, 28).

Reach ID	Source Type	January	February	March	April	May	June
21	Human/Pet	1.15E+10	1.04E+10	1.15E+10	1.11E+10	1.15E+10	1.11E+10
	Livestock	8.71E+07	7.87E+07	1.16E+08	1.69E+08	1.74E+08	1.97E+08
	Wildlife	9.23E+10	8.33E+10	9.23E+10	8.93E+10	9.23E+10	8.93E+10
22	Human/Pet	1.65E+09	1.49E+09	1.65E+09	1.60E+09	1.65E+09	1.60E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.20E+10	6.50E+10	7.20E+10	6.97E+10	7.20E+10	6.97E+10
23	Human/Pet	7.40E+09	6.68E+09	7.40E+09	7.16E+09	7.40E+09	7.16E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.47E+11	1.33E+11	1.47E+11	1.42E+11	1.47E+11	1.42E+11
24	Human/Pet	1.18E+10	1.07E+10	1.18E+10	1.14E+10	1.18E+10	1.14E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.47E+11	2.23E+11	2.47E+11	2.39E+11	2.47E+11	2.39E+11
25	Human/Pet	9.31E+09	8.41E+09	9.31E+09	9.01E+09	9.31E+09	9.01E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.84E+11	1.66E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11
26	Human/Pet	1.93E+10	1.74E+10	1.93E+10	1.86E+10	1.93E+10	1.86E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.11E+11	1.00E+11	1.11E+11	1.08E+11	1.11E+11	1.08E+11
27	Human/Pet	3.14E+10	2.84E+10	3.14E+10	3.04E+10	3.14E+10	3.04E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.44E+11	1.30E+11	1.44E+11	1.40E+11	1.44E+11	1.40E+11
28	Human/Pet	4.76E+09	4.30E+09	4.76E+09	4.61E+09	4.76E+09	4.61E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.18E+10	7.39E+10	8.18E+10	7.92E+10	8.18E+10	7.92E+10

Table B.26 Monthly, directly deposited fecal coliform loads in each reach of the Mill Swamp Impairment - All contributors (Reaches 21, 22, 23, 24, 25, 26, 27, 28), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
21	Human/Pet	1.15E+10	1.15E+10	1.11E+10	1.15E+10	1.11E+10	1.15E+10
	Livestock	2.03E+08	2.03E+08	1.69E+08	1.16E+08	1.12E+08	8.71E+07
	Wildlife	9.23E+10	9.23E+10	8.93E+10	9.23E+10	8.93E+10	9.23E+10
22	Human/Pet	1.65E+09	1.65E+09	1.60E+09	1.65E+09	1.60E+09	1.65E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.20E+10	7.20E+10	6.97E+10	7.20E+10	6.97E+10	7.20E+10
23	Human/Pet	7.40E+09	7.40E+09	7.16E+09	7.40E+09	7.16E+09	7.40E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.47E+11	1.47E+11	1.42E+11	1.47E+11	1.42E+11	1.47E+11
24	Human/Pet	1.18E+10	1.18E+10	1.14E+10	1.18E+10	1.14E+10	1.18E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.47E+11	2.47E+11	2.39E+11	2.47E+11	2.39E+11	2.47E+11
25	Human/Pet	9.31E+09	9.31E+09	9.01E+09	9.31E+09	9.01E+09	9.31E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.84E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11	1.84E+11
26	Human/Pet	1.93E+10	1.93E+10	1.86E+10	1.93E+10	1.86E+10	1.93E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.11E+11	1.11E+11	1.08E+11	1.11E+11	1.08E+11	1.11E+11
27	Human/Pet	3.14E+10	3.14E+10	3.04E+10	3.14E+10	3.04E+10	3.14E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.44E+11	1.44E+11	1.40E+11	1.44E+11	1.40E+11	1.44E+11
28	Human/Pet	4.76E+09	4.76E+09	4.61E+09	4.76E+09	4.61E+09	4.76E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	8.18E+10	8.18E+10	7.92E+10	8.18E+10	7.92E+10	8.18E+10

Table B.27 Existing annual loads from land-based sources for the Mill Swamp Impairment - All contributors (Subwatersheds 21, 22, 23, 24, 25, 26, 27, 28).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.57E+09	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	6.99E+12	1.51E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	6.30E+11	2.51E+10	1.92E+13	7.00E+10	8.47E+12	6.01E+10	0.00E+00	1.73E+13	4.08E+13
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.30E+12	0.00E+00	0.00E+00	0.00E+00
duck	0.00E+00	3.62E+07	1.51E+09	7.93E+07	7.93E+08	2.97E+07	0.00E+00	1.90E+10	9.94E+09
goats	0.00E+00	0.00E+00	0.00E+00	1.54E+10	3.25E+11	0.00E+00	1.71E+09	0.00E+00	0.00E+00
goose	0.00E+00	2.44E+10	1.02E+12	5.34E+10	5.35E+11	2.00E+10	0.00E+00	1.28E+13	6.70E+12
hogs	0.00E+00	0.00E+00	9.92E+14	0.00E+00	5.50E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	1.11E+12	2.49E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	0.00E+00	2.68E+11	1.12E+13	5.86E+11	5.86E+12	2.19E+11	0.00E+00	1.40E+14	7.35E+13
raccoon	5.62E+11	1.34E+11	2.73E+13	1.44E+11	1.21E+13	2.20E+11	0.00E+00	2.33E+13	6.76E+13
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.84E+12	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+12	0.00E+00	0.00E+00
turkey	2.97E+08	5.36E+06	2.63E+09	1.21E+07	1.15E+09	9.10E+06	0.00E+00	8.10E+09	1.87E+10

Table B.28 Existing annual loads from direct-deposition sources for the Mill Swamp Impairment - All contributors (Reaches 21, 22, 23, 24, 25, 26, 27, 28).

Source	Annual Total Loads (cfu/yr)
beaver	9.57E+09
broilers	0.00E+00
dairy	0.00E+00
deer	4.35E+10
duck	1.31E+09
goats	1.71E+09
goose	5.82E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	1.17E+13
Raccoon	3.34E+11
sheep	0.00E+00
straightpipe density	1.14E+12
turkey	1.56E+07

Table B.29 Current conditions of land applied fecal coliform load for Rattlesnake Creek Swamp - All contributors (minus Mill Swamp) by landuse (Subwatersheds 29, 30, 31, 32, 33, 34, 35, 36).

Landuse	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Wetlands	Woodland
January	3.50E+11	4.34E+10	6.71E+12	1.96E+11	5.92E+12	3.72E+12	1.94E+13	2.30E+13
February	3.17E+11	3.92E+10	6.06E+12	2.05E+11	6.30E+12	3.28E+12	1.75E+13	2.08E+13
March	3.50E+11	4.34E+10	6.71E+12	2.74E+11	6.97E+12	3.45E+12	1.94E+13	2.30E+13
April	3.39E+11	4.20E+10	6.49E+12	3.55E+11	6.74E+12	3.26E+12	1.88E+13	2.22E+13
May	3.50E+11	4.34E+10	6.71E+12	3.67E+11	6.97E+12	3.28E+12	1.94E+13	2.30E+13
June	3.39E+11	4.20E+10	6.49E+12	4.01E+11	6.74E+12	3.09E+12	1.88E+13	2.22E+13
July	3.50E+11	4.34E+10	6.71E+12	4.14E+11	6.97E+12	3.01E+12	1.94E+13	2.30E+13
August	3.50E+11	4.34E+10	6.71E+12	4.14E+11	6.97E+12	3.01E+12	1.94E+13	2.30E+13
September	3.39E+11	4.20E+10	6.49E+12	3.55E+11	6.74E+12	2.91E+12	1.88E+13	2.22E+13
October	3.50E+11	4.34E+10	6.71E+12	2.74E+11	6.97E+12	2.92E+12	1.94E+13	2.30E+13
November	3.39E+11	4.20E+10	6.49E+12	2.65E+11	6.74E+12	2.91E+12	1.88E+13	2.22E+13
December	3.50E+11	4.34E+10	6.71E+12	2.27E+11	6.97E+12	3.36E+12	1.94E+13	2.30E+13
Annual Total Loads (cfu/yr)	4.13E+12	5.11E+11	7.90E+13	3.75E+12	8.10E+13	3.82E+13	2.29E+14	2.71E+14

Table B.30 Monthly, directly deposited fecal coliform loads in each reach of the Rattlesnake Creek Swamp - All contributors (minus Mill Swamp) (Reaches 29, 30, 31, 32, 33, 34, 35, 36).

Reach ID	Source Type	January	February	March	April	May	June
29	Human/Pet	2.56E+09	2.32E+09	2.56E+09	2.48E+09	2.56E+09	2.48E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.26E+10	6.56E+10	7.26E+10	7.02E+10	7.26E+10	7.02E+10
30	Human/Pet	2.28E+10	2.06E+10	2.28E+10	2.21E+10	2.28E+10	2.21E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.62E+11	2.37E+11	2.62E+11	2.54E+11	2.62E+11	2.54E+11
31	Human/Pet	2.34E+09	2.11E+09	2.34E+09	2.26E+09	2.34E+09	2.26E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.37E+10	5.76E+10	6.37E+10	6.17E+10	6.37E+10	6.17E+10
32	Human/Pet	1.46E+09	1.31E+09	1.46E+09	1.41E+09	1.46E+09	1.41E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.46E+10	3.12E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10
33	Human/Pet	1.62E+10	1.46E+10	1.62E+10	1.57E+10	1.62E+10	1.57E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.58E+11	4.14E+11	4.58E+11	4.43E+11	4.58E+11	4.43E+11
34	Human/Pet	6.32E+09	5.71E+09	6.32E+09	6.11E+09	6.32E+09	6.11E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.06E+11	9.53E+10	1.06E+11	1.02E+11	1.06E+11	1.02E+11
35	Human/Pet	2.73E+10	2.46E+10	2.73E+10	2.64E+10	2.73E+10	2.64E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.30E+11	2.08E+11	2.30E+11	2.22E+11	2.30E+11	2.22E+11
36	Human/Pet	1.93E+10	1.74E+10	1.93E+10	1.87E+10	1.93E+10	1.87E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.38E+11	1.25E+11	1.38E+11	1.34E+11	1.38E+11	1.34E+11

Table B.30 Monthly, directly deposited fecal coliform loads in each reach of the Rattlesnake Creek Swamp - All contributors (minus Mill Swamp) (Reaches 29, 30, 31, 32, 33, 34, 35, 36), (cont.).

Reach ID	Source Type	July	August	September	October	November	December
29	Human/Pet	2.56E+09	2.56E+09	2.48E+09	2.56E+09	2.48E+09	2.56E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	7.26E+10	7.26E+10	7.02E+10	7.26E+10	7.02E+10	7.26E+10
30	Human/Pet	2.28E+10	2.28E+10	2.21E+10	2.28E+10	2.21E+10	2.28E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.62E+11	2.62E+11	2.54E+11	2.62E+11	2.54E+11	2.62E+11
31	Human/Pet	2.34E+09	2.34E+09	2.26E+09	2.34E+09	2.26E+09	2.34E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	6.37E+10	6.37E+10	6.17E+10	6.37E+10	6.17E+10	6.37E+10
32	Human/Pet	1.46E+09	1.46E+09	1.41E+09	1.46E+09	1.41E+09	1.46E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	3.46E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10	3.46E+10
33	Human/Pet	1.62E+10	1.62E+10	1.57E+10	1.62E+10	1.57E+10	1.62E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	4.58E+11	4.58E+11	4.43E+11	4.58E+11	4.43E+11	4.58E+11
34	Human/Pet	6.32E+09	6.32E+09	6.11E+09	6.32E+09	6.11E+09	6.32E+09
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.06E+11	1.06E+11	1.02E+11	1.06E+11	1.02E+11	1.06E+11
35	Human/Pet	2.73E+10	2.73E+10	2.64E+10	2.73E+10	2.64E+10	2.73E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.30E+11	2.30E+11	2.22E+11	2.30E+11	2.22E+11	2.30E+11
36	Human/Pet	1.93E+10	1.93E+10	1.87E+10	1.93E+10	1.87E+10	1.93E+10
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.38E+11	1.38E+11	1.34E+11	1.38E+11	1.34E+11	1.38E+11

Table B.31 Existing annual loads from land-based sources for the Rattlesnake Creek Swamp - All contributors (minus Mill Swamp) (Subwatersheds 29, 30, 31, 32, 33, 34, 35, 36).

Source	Barren	Commercial	Cropland	Livestock Access	Pasture	Residential	Water	Wetlands	Woodland
beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E+10	0.00E+00	0.00E+00
beef	0.00E+00	0.00E+00	0.00E+00	2.65E+12	5.24E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
broilers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.79E+07	0.00E+00	0.00E+00	0.00E+00
dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
deer	9.81E+11	2.71E+10	2.68E+13	1.18E+11	7.67E+12	8.68E+10	0.00E+00	2.60E+13	5.42E+13
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E+13	0.00E+00	0.00E+00	0.00E+00
duck	1.89E+08	3.82E+07	2.00E+09	8.22E+07	8.72E+08	2.95E+06	0.00E+00	2.11E+10	1.56E+10
goats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
goose	1.27E+11	2.58E+10	1.35E+12	5.54E+10	5.88E+11	1.99E+09	0.00E+00	1.42E+13	1.05E+13
hogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
horse	0.00E+00	0.00E+00	0.00E+00	7.95E+10	1.51E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
layers	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
muskrat	1.40E+12	2.83E+11	1.48E+13	6.08E+11	6.45E+12	2.18E+10	0.00E+00	1.56E+14	1.15E+14
raccoon	1.62E+12	1.76E+11	3.61E+13	2.41E+11	1.24E+13	2.04E+11	0.00E+00	3.21E+13	9.08E+13
septic density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+13	0.00E+00	0.00E+00	0.00E+00
sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
straightpipe density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E+12	0.00E+00	0.00E+00
turkey	4.61E+08	5.91E+06	3.66E+09	1.96E+07	1.04E+09	1.60E+07	0.00E+00	1.22E+10	2.50E+10

Table B.32 Existing annual loads from direct-deposition sources for the Rattlesnake Creek Swamp - All contributors (minus Mill Swamp) (Reaches 29, 30, 31, 32, 33, 34, 35, 36).

Source	Annual Total Loads (cfu/yr)
beaver	1.16E+10
broilers	0.00E+00
dairy	0.00E+00
deer	5.83E+10
duck	1.66E+09
goats	0.00E+00
goose	7.36E+11
hogs	0.00E+00
layers	0.00E+00
muskrat	1.48E+13
Raccoon	4.40E+11
sheep	0.00E+00
straightpipe density	1.16E+12
turkey	2.14E+07

APPENDIX C

VALIDATION RESULTS

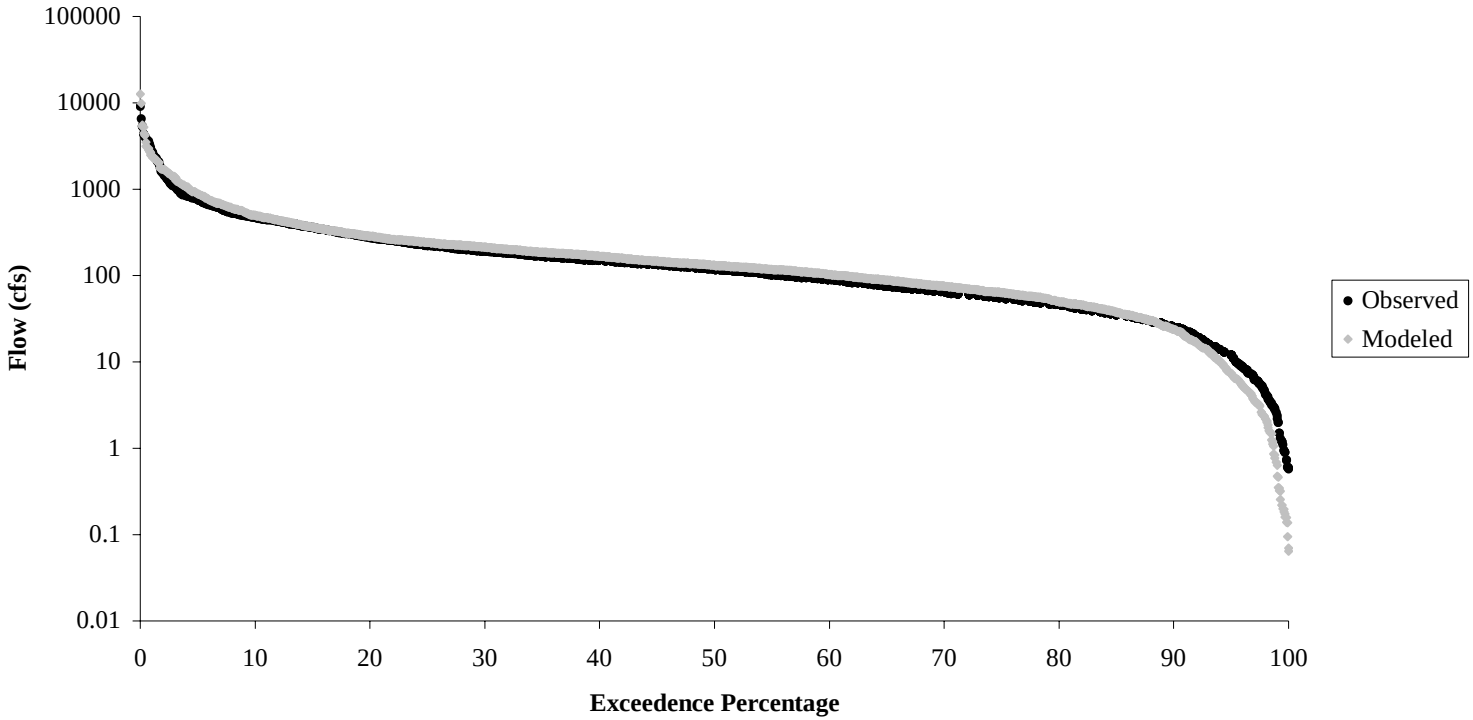

Figure C.1 Nottoway River flow duration at USGS Station 02044500 for validation period 10/1/1997 through 9/30/2002 (model segment 2, subshed 13).

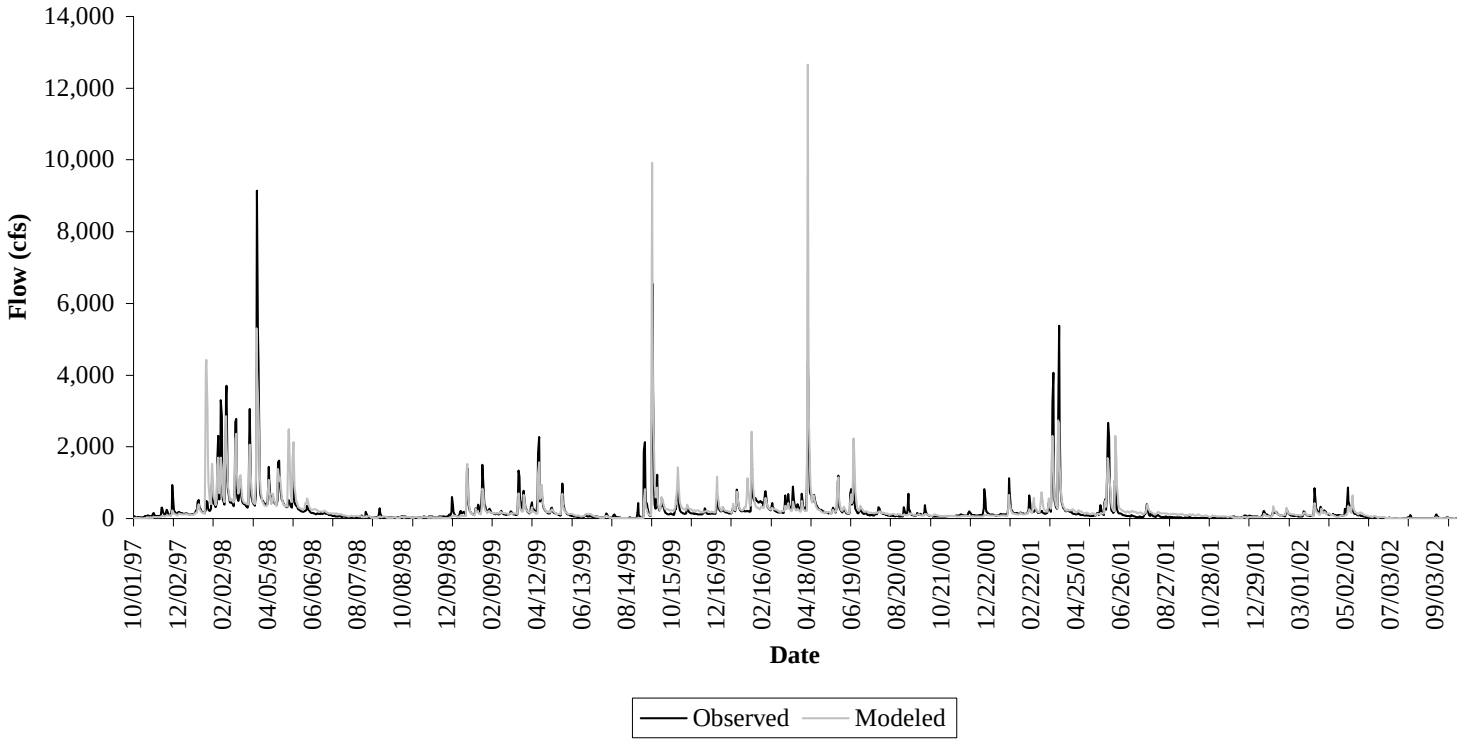

Figure C.2 Validation results for period 10/1/1997 through 9/30/2002 at USGS Station 02044500 on Upper Nottoway River (model segment 2, subshed 13).

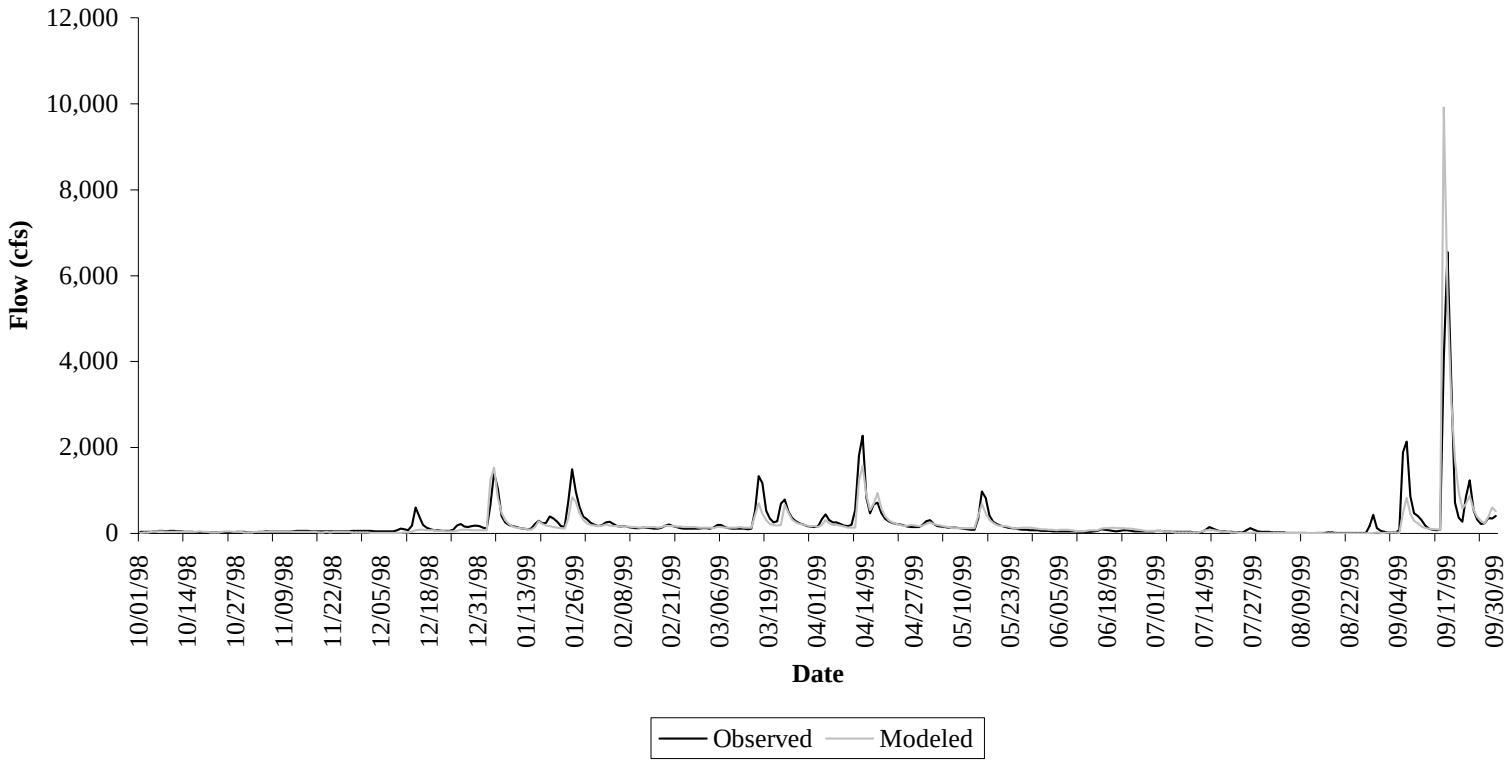

Figure C.3 Validation results for period 10/01/98 through 09/30/99 for USGS Station 02044500 on Upper Nottoway River (model segment 2, subshed 13).

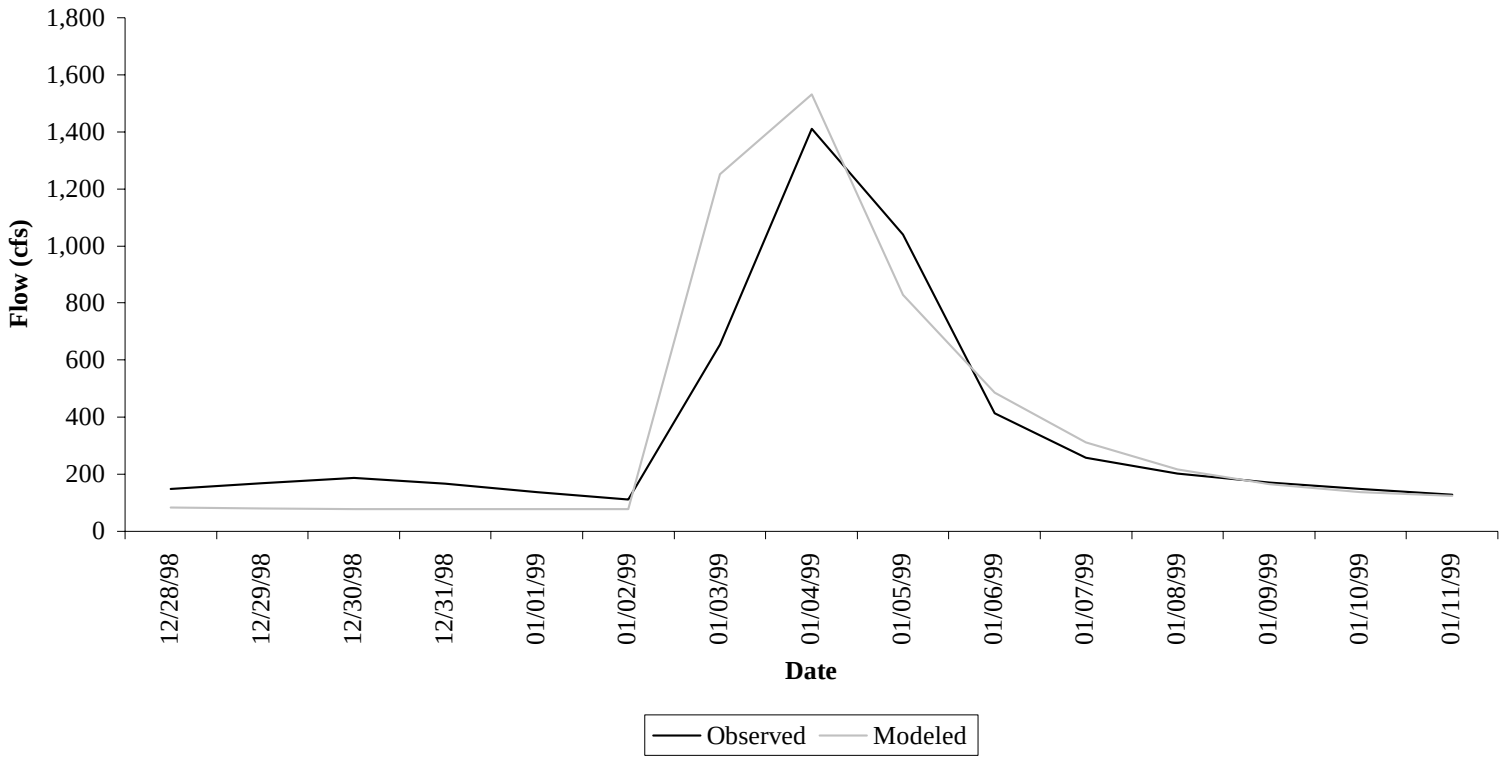

Figure C.4 Validation results for a single storm event at USGS Station 02044500 on Upper Nottoway River (model segment 2, subshed 13).

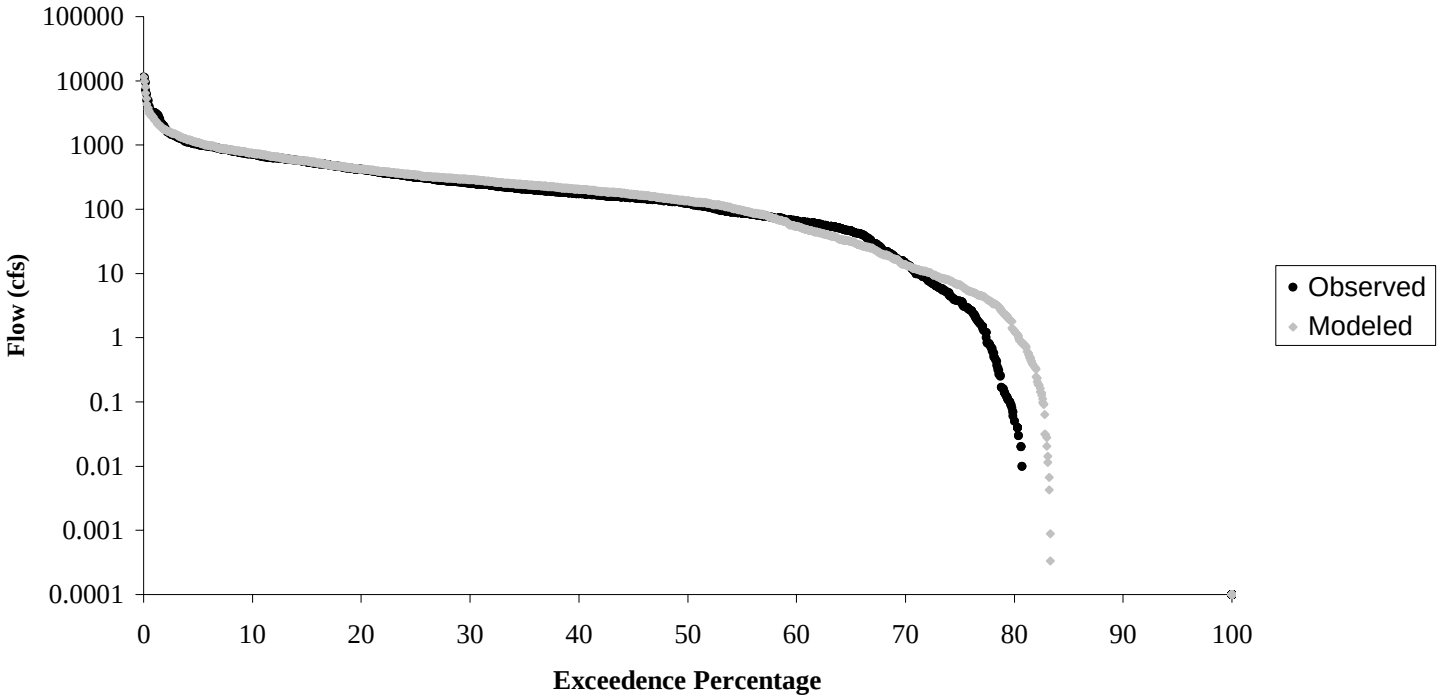

Figure C.5 Upper Blackwater River flow duration at USGS Station 02047500 for validation period 10/1/1997 through 9/30/2002 (model segment 5, subshed 6).

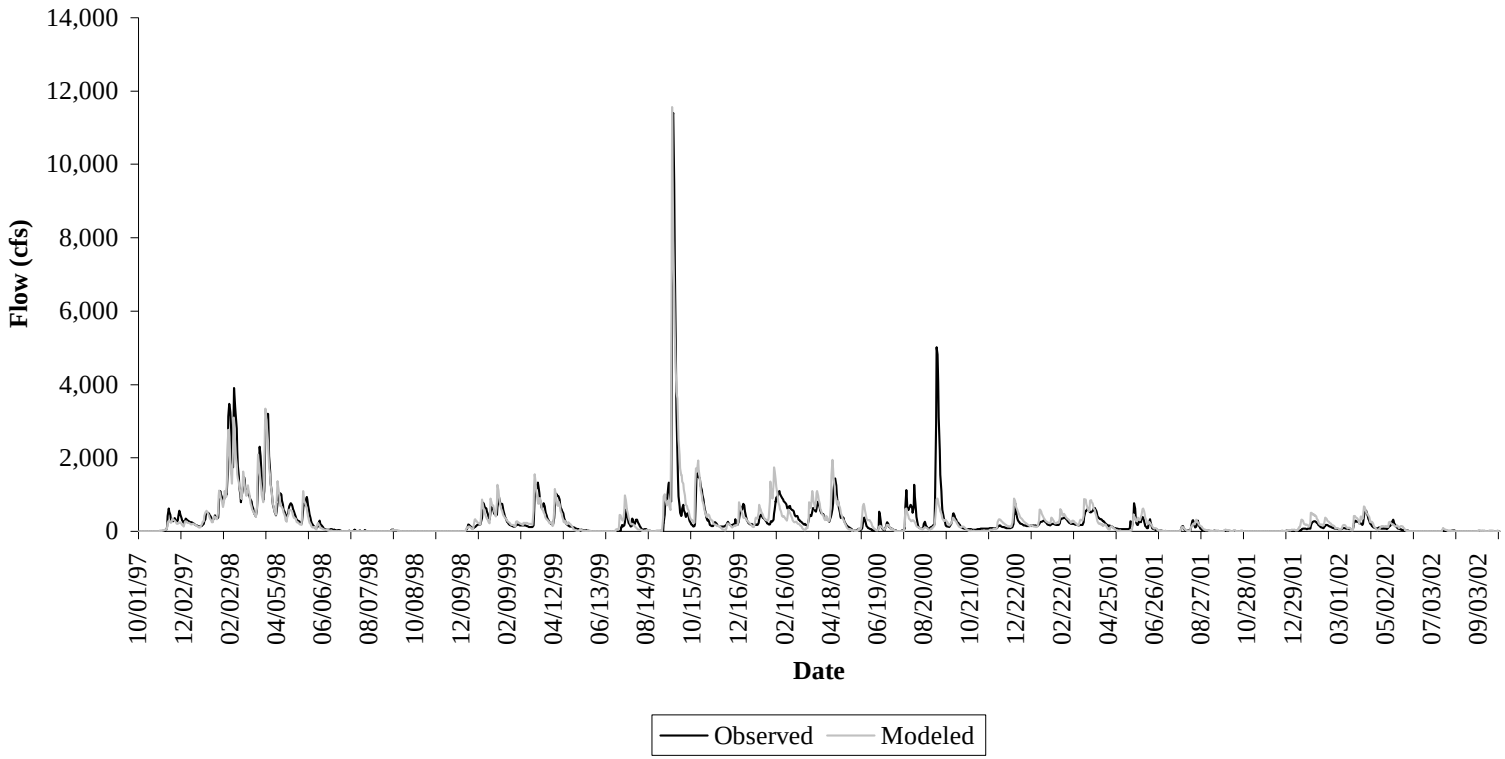

Figure C.6 Validation results for period 10/1/1997 through 9/30/2002 at USGS Station 02047500 on Upper Blackwater River (model segment 5, subshed 6).

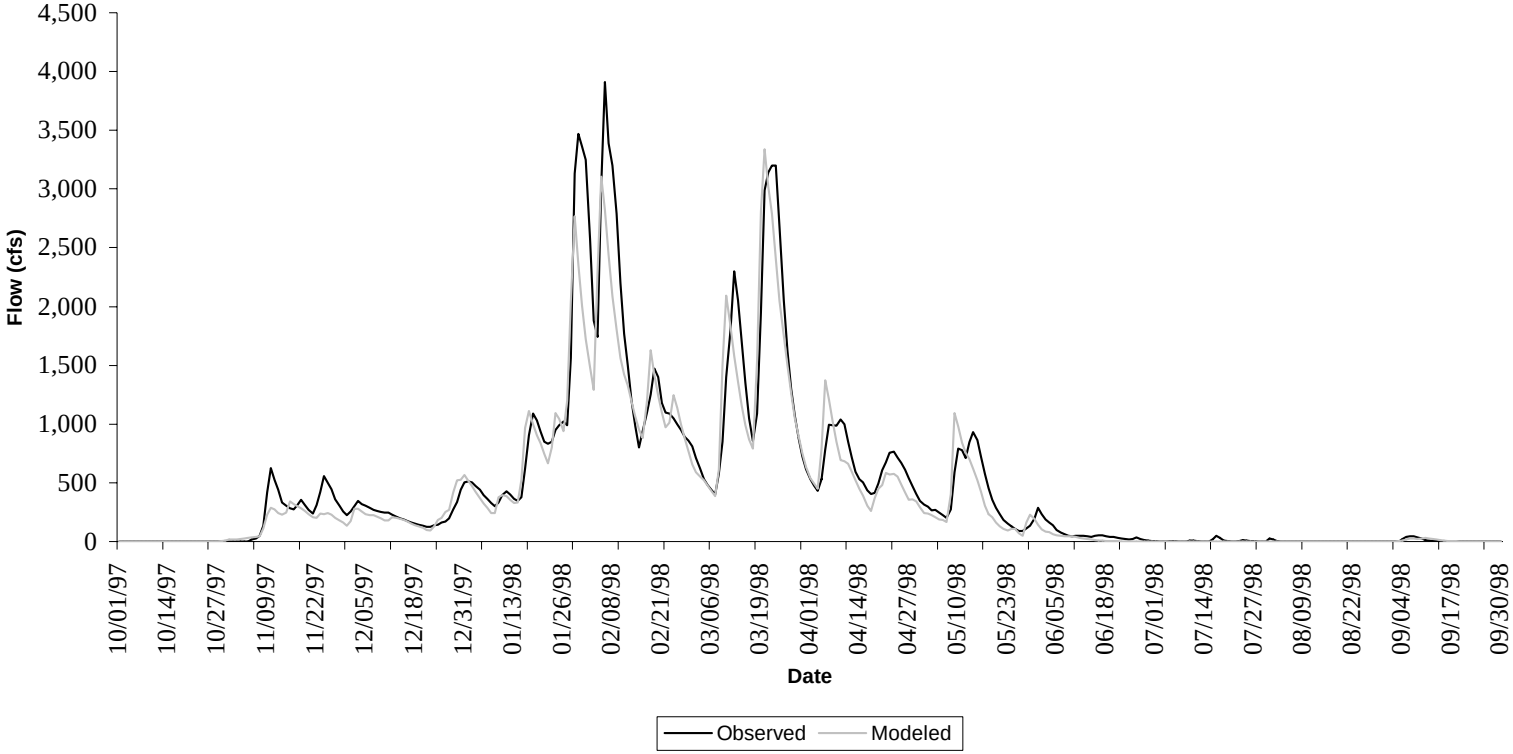

Figure C.7 Validation results for period 10/01/97 through 09/30/98 for USGS Station 02047500 on Upper Blackwater River (model segment 5, subshed 6).

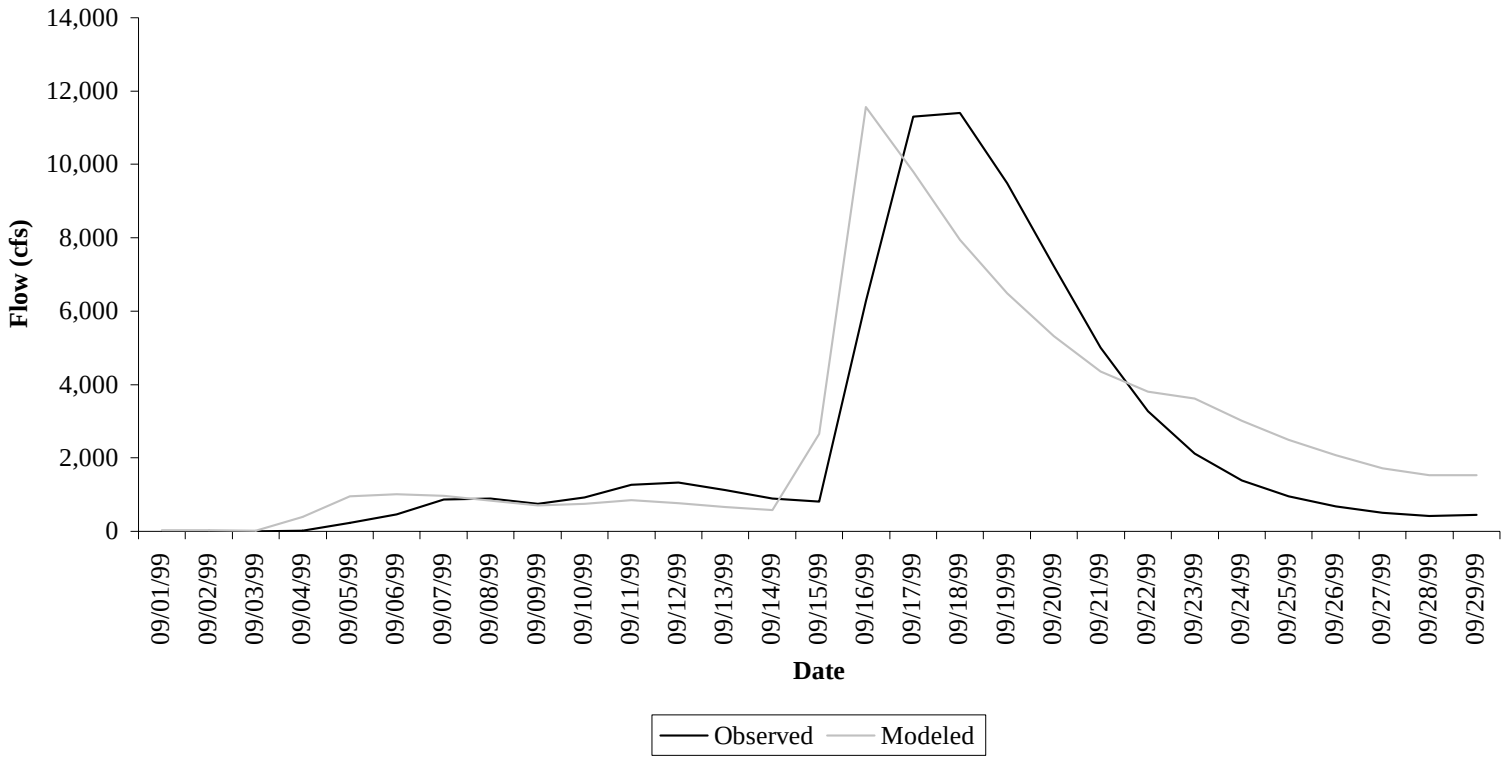

Figure C.8 Validation results for a single storm event at USGS Station 02047500 on Upper Blackwater River (model segment 5, subshed 6).

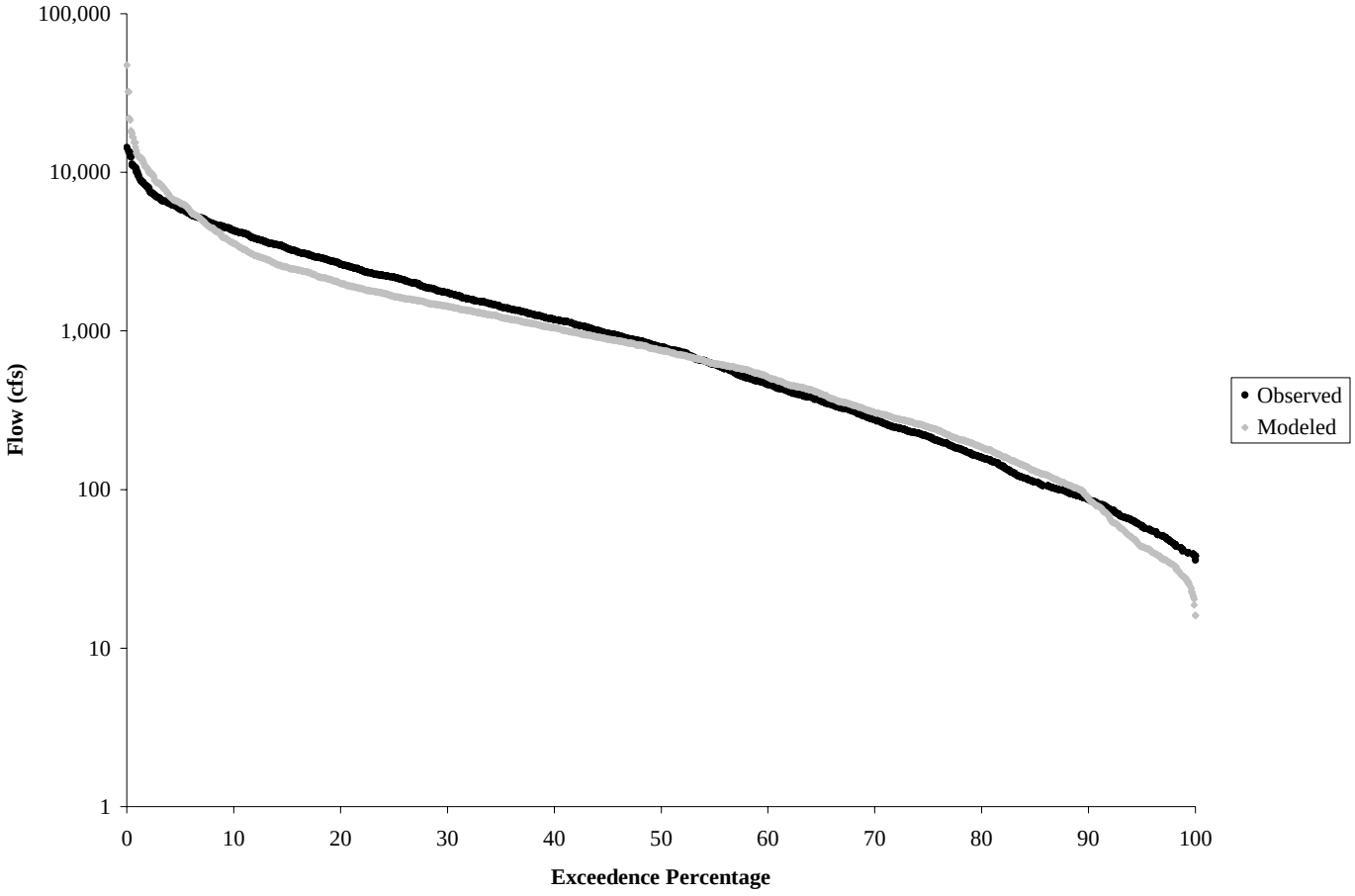

Figure C.9 Nottoway River flow duration at USGS Station 02047000 for validation period 10/1/1982 through 9/30/1987 for Raccoon and Sappony Creeks (model segment 4, subshed 8).

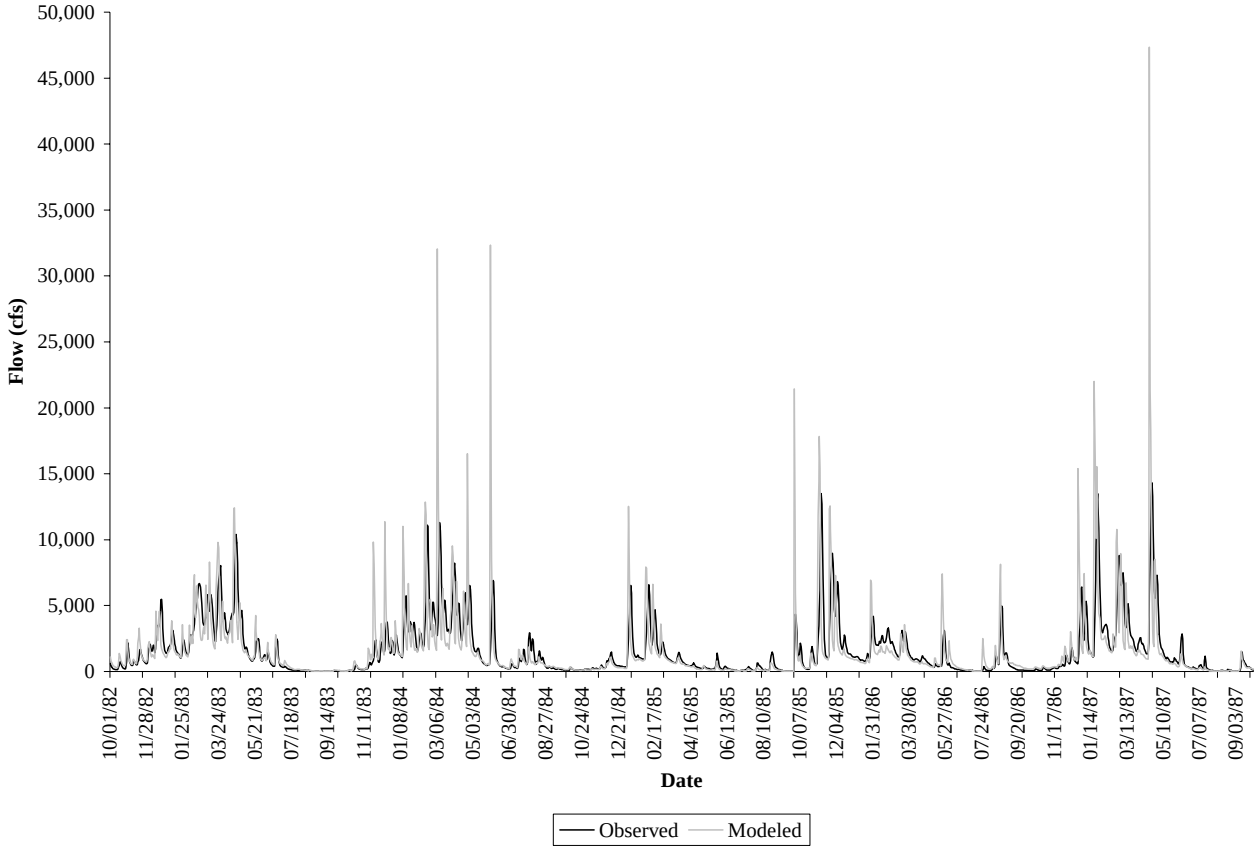

Figure C.10 Validation results for period 10/1/1982 through 9/30/1987 at USGS Station 02047000 on Nottoway River for Raccoon and Sappony Creek (model segment 4, subshed 8).

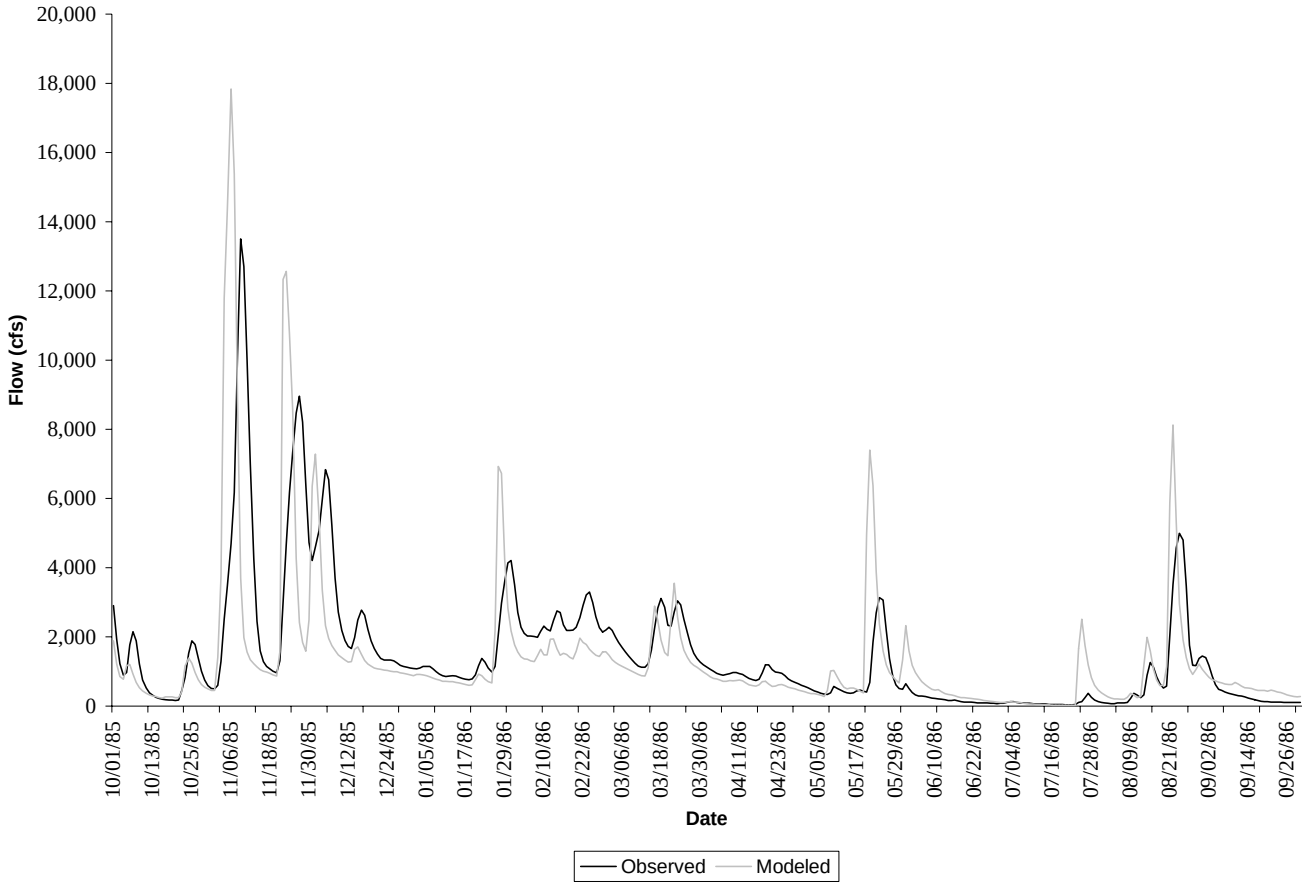

Figure C.11 Validation results for period 10/01/85 through 09/30/86 for USGS Station 02047000 on Nottoway River for Raccoon and Sappony Creek (model segment 4, subshed 8).

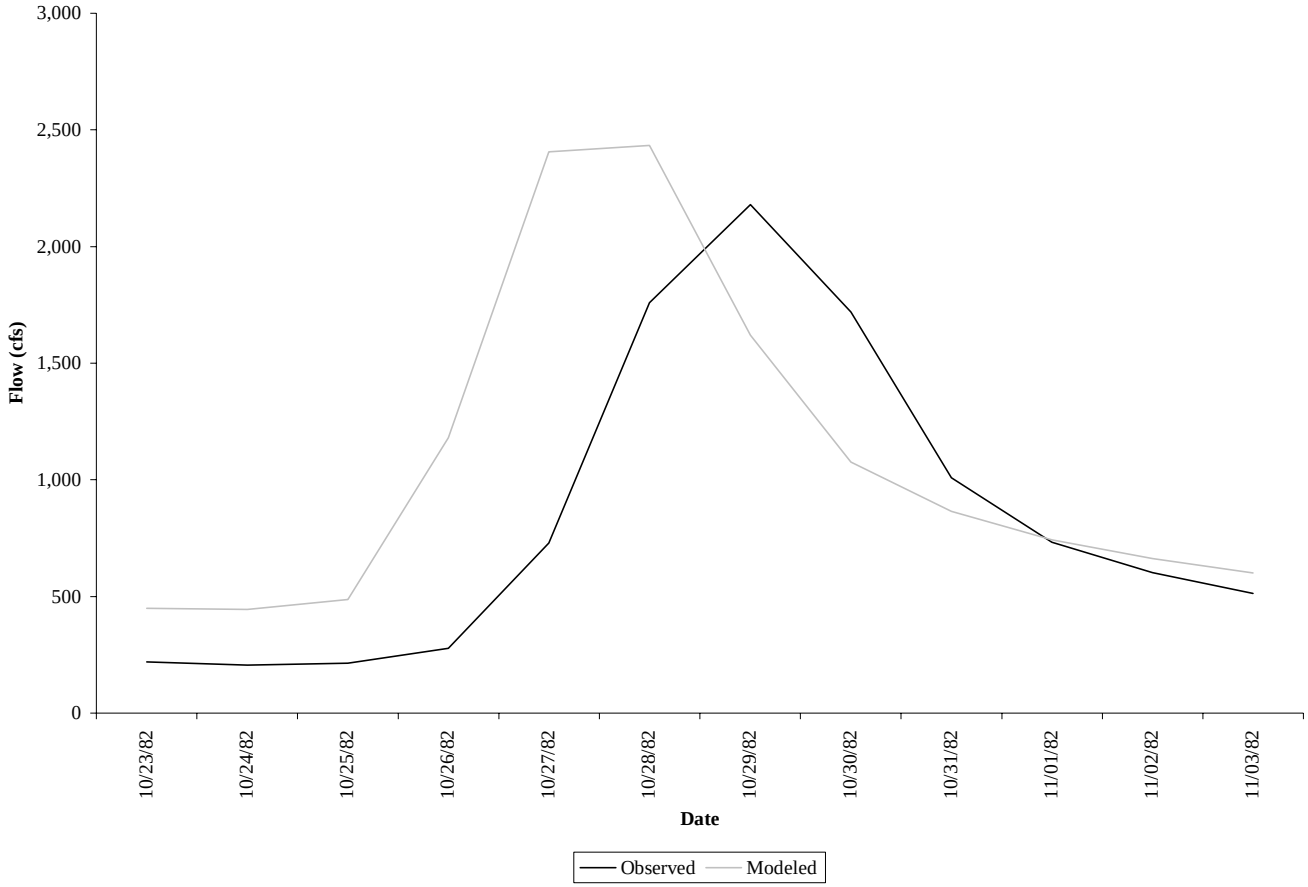

Figure C.12 Validation results for a single storm event at USGS Station 02047000 on Nottoway River for Raccoon and Sappony Creek (model segment 4, subshed 8).

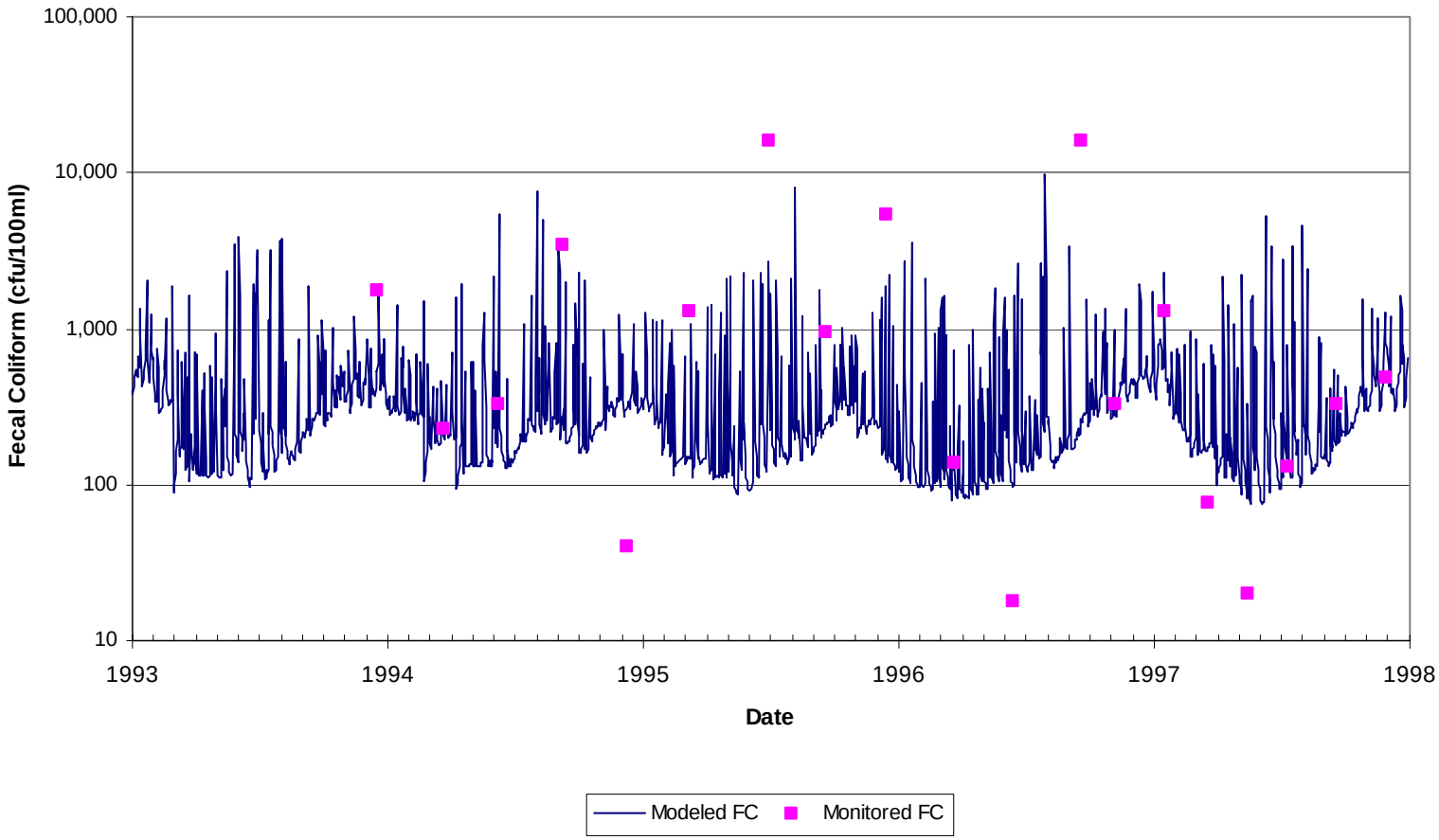

Figure C.13 Quality validation results for period 10/1/1993 to 9/30/1998 Beaverpond Creek, model segment 2, subshed 39.

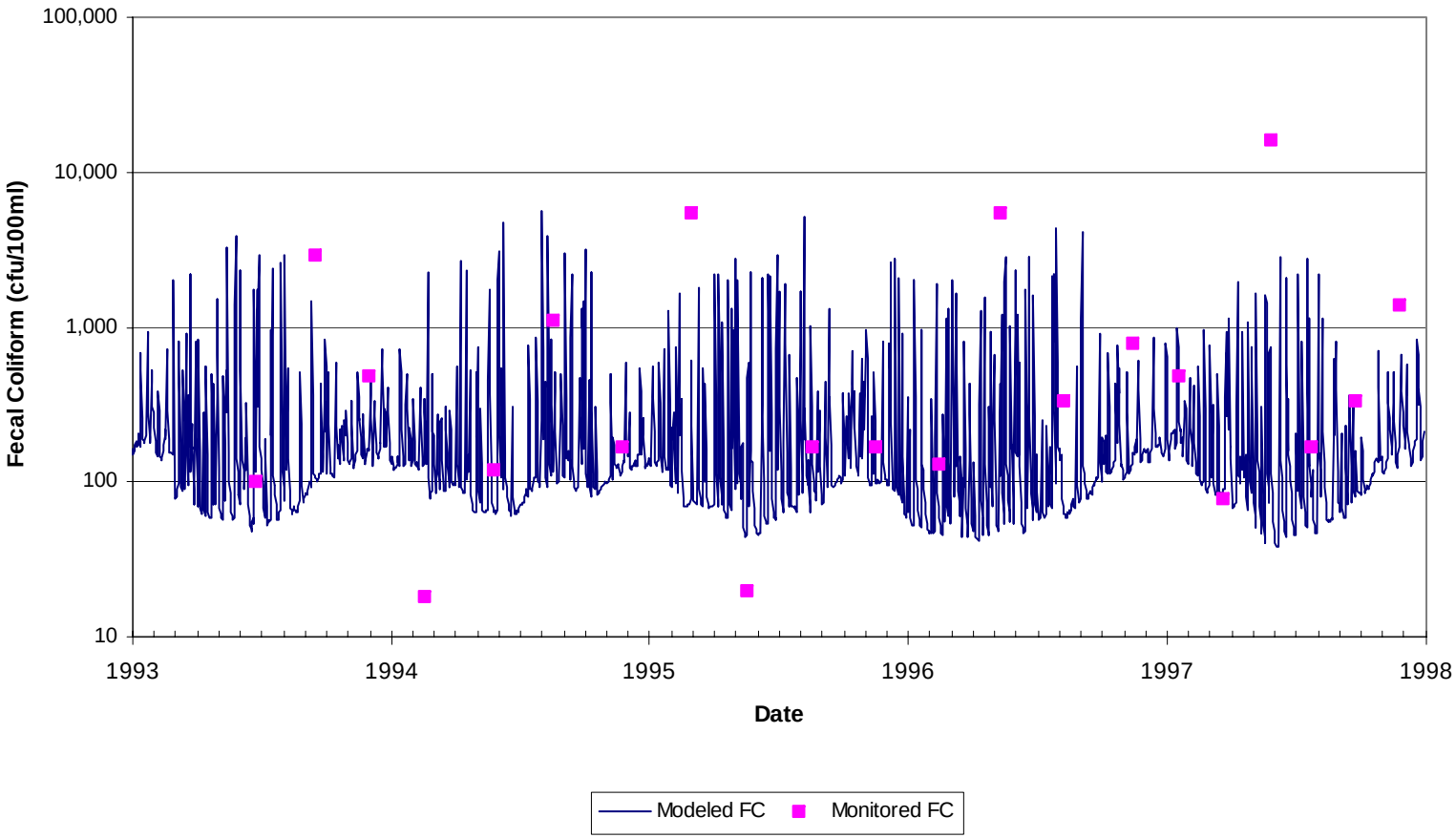

Figure C.14 Quality validation results for period 10/1/1993 to 9/30/1998 Big Hounds Creek, model segment 1, subshed 33.

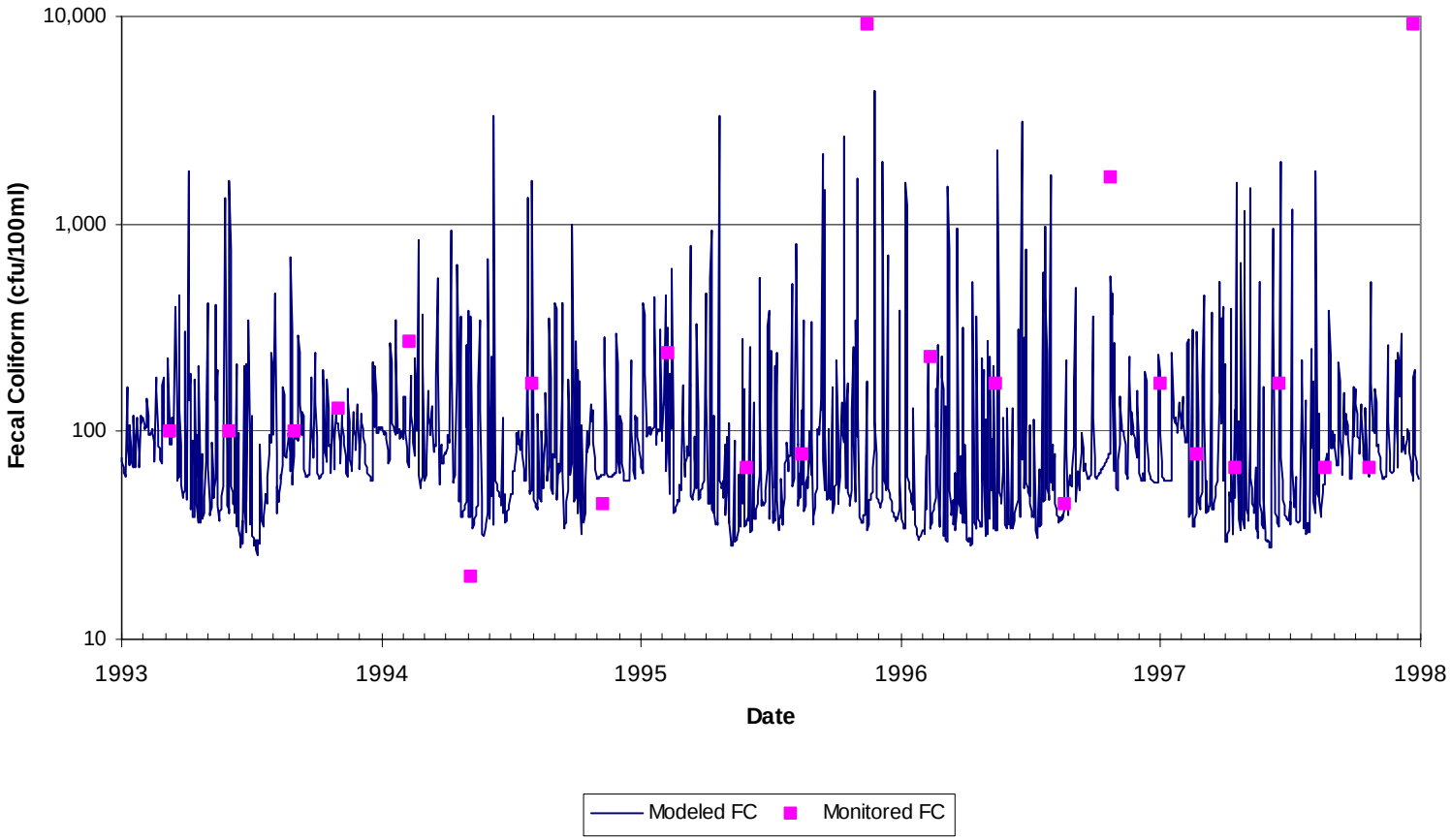

Figure C.15 Quality validation results for period 10/1/1993 to 9/30/1998 Cypress Swamp, model segment 5, subshed 15.

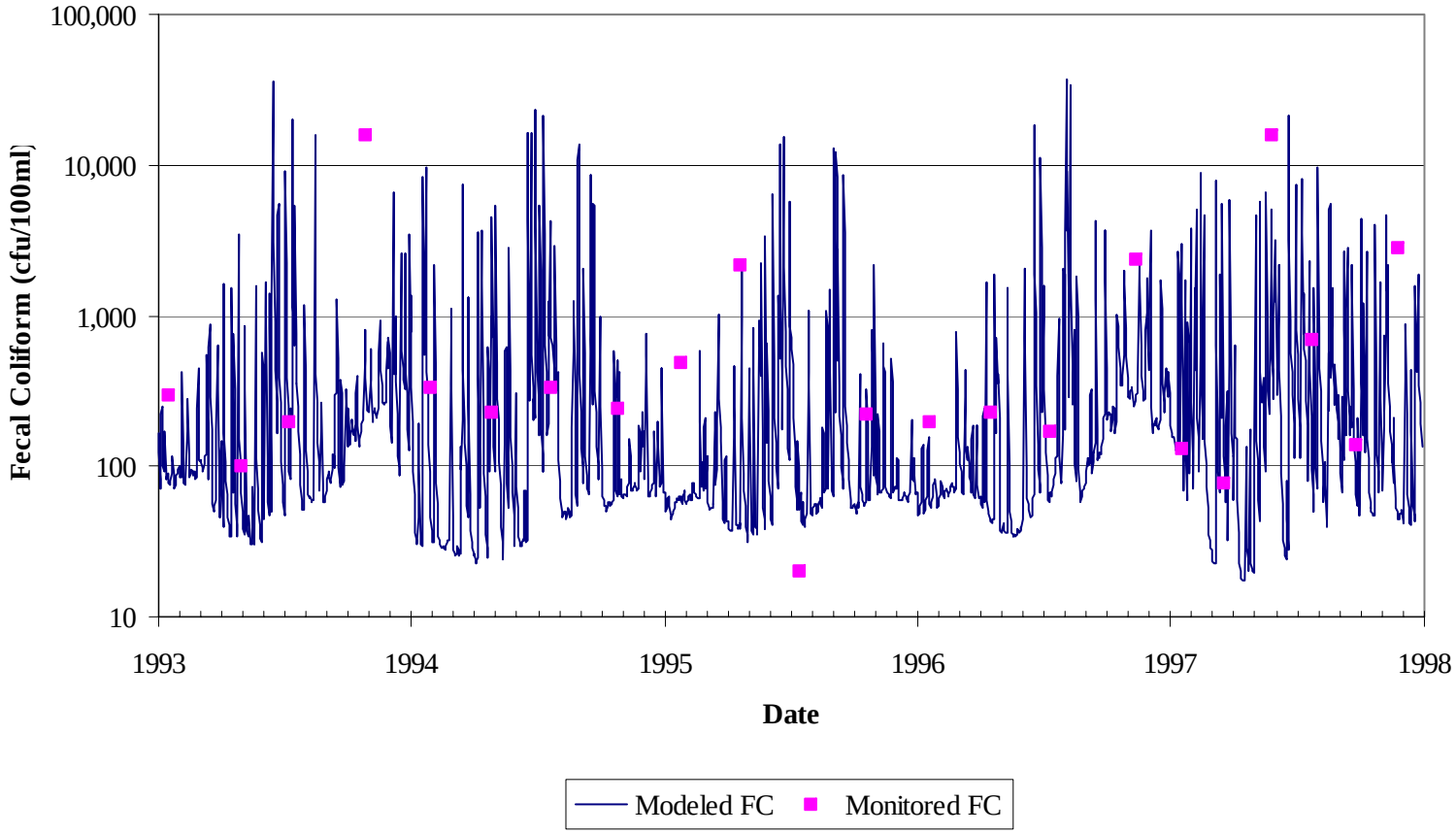

Figure C.16 Quality validation results for period 10/1/1993 to 9/30/1998 Little Nottoway River, model segment 1, subshed 22.

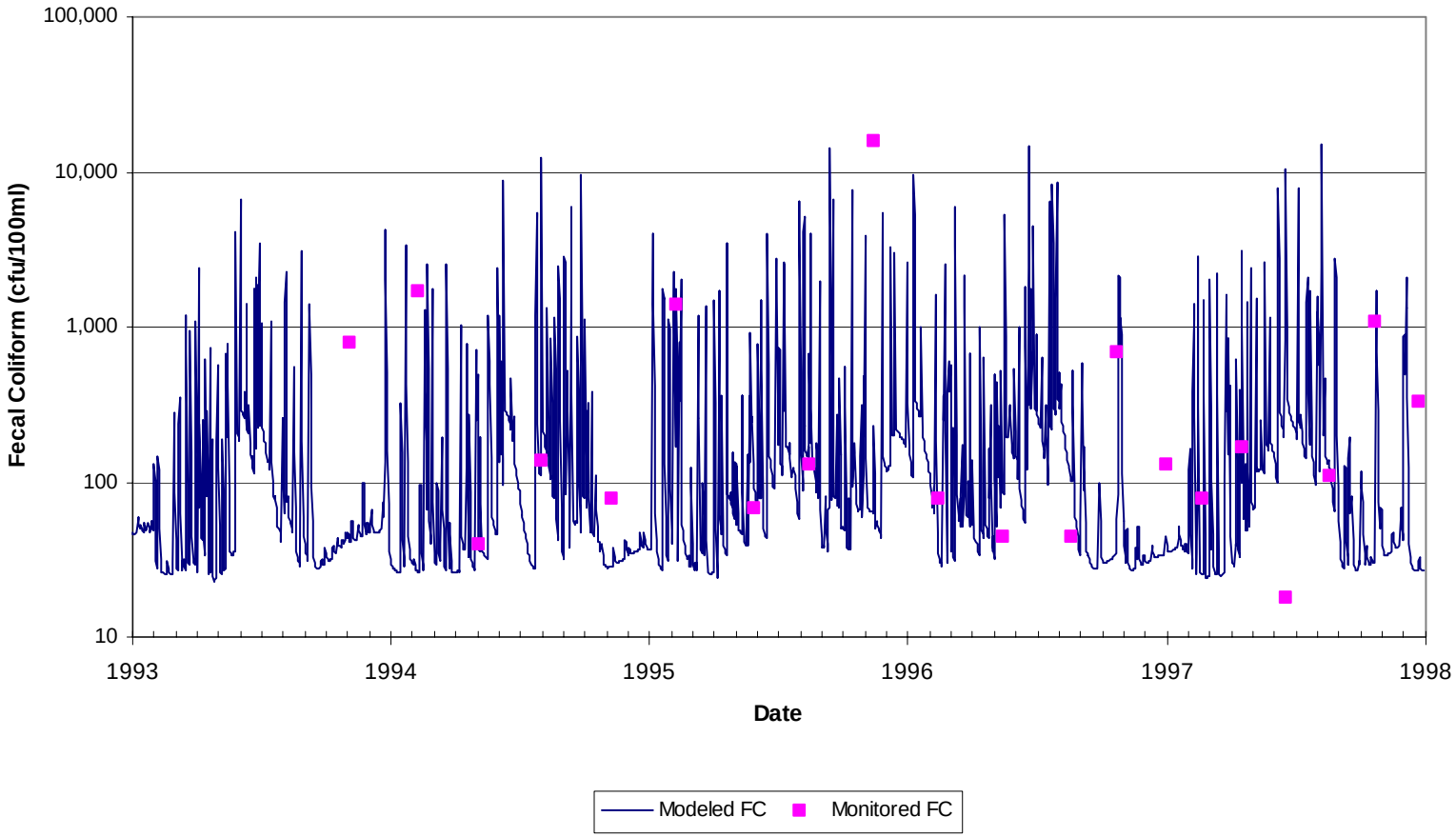

Figure C.17 Quality validation results for period 10/1/1993 to 9/30/1998 Mill Swamp, model segment 6, subshed 23.

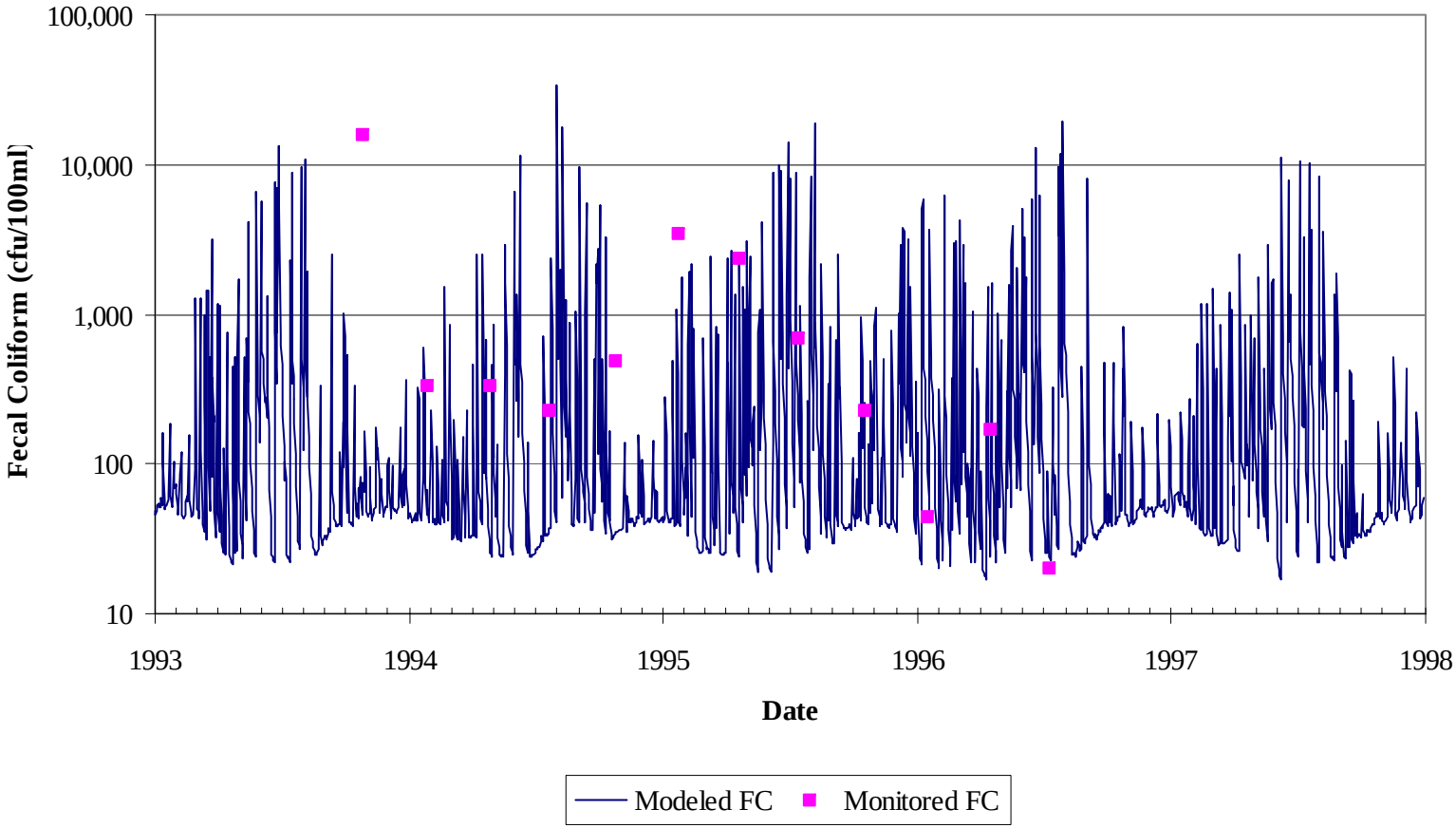

Figure C.18 Quality validation results for period 10/1/1993 to 9/30/1998 Nottoway River, model segment 1, subshed 1.

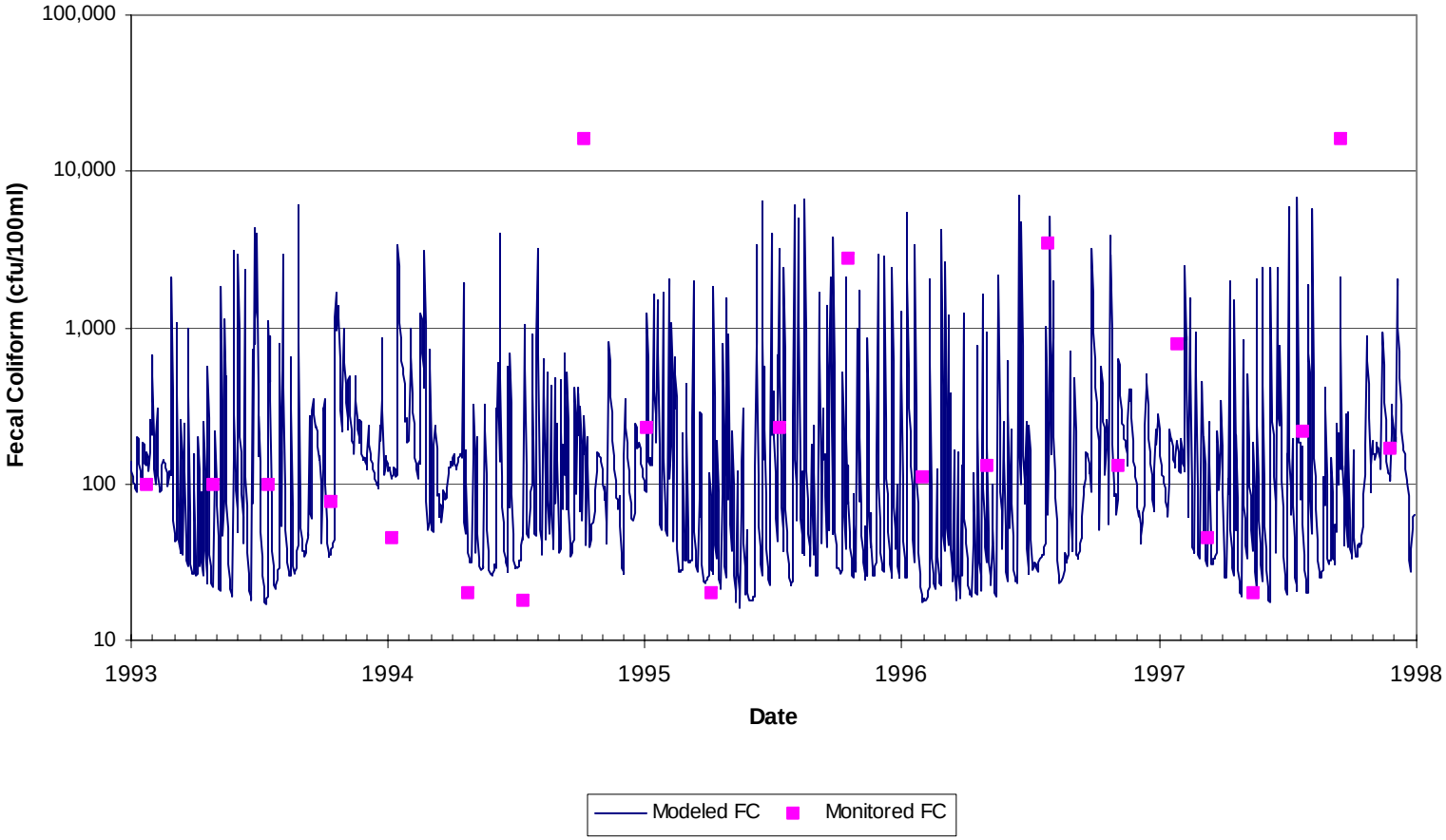

Figure C.19 Quality validation results for period 10/1/1993 to 9/30/1998 Raccoon Creek, model segment 4, subshed 20.

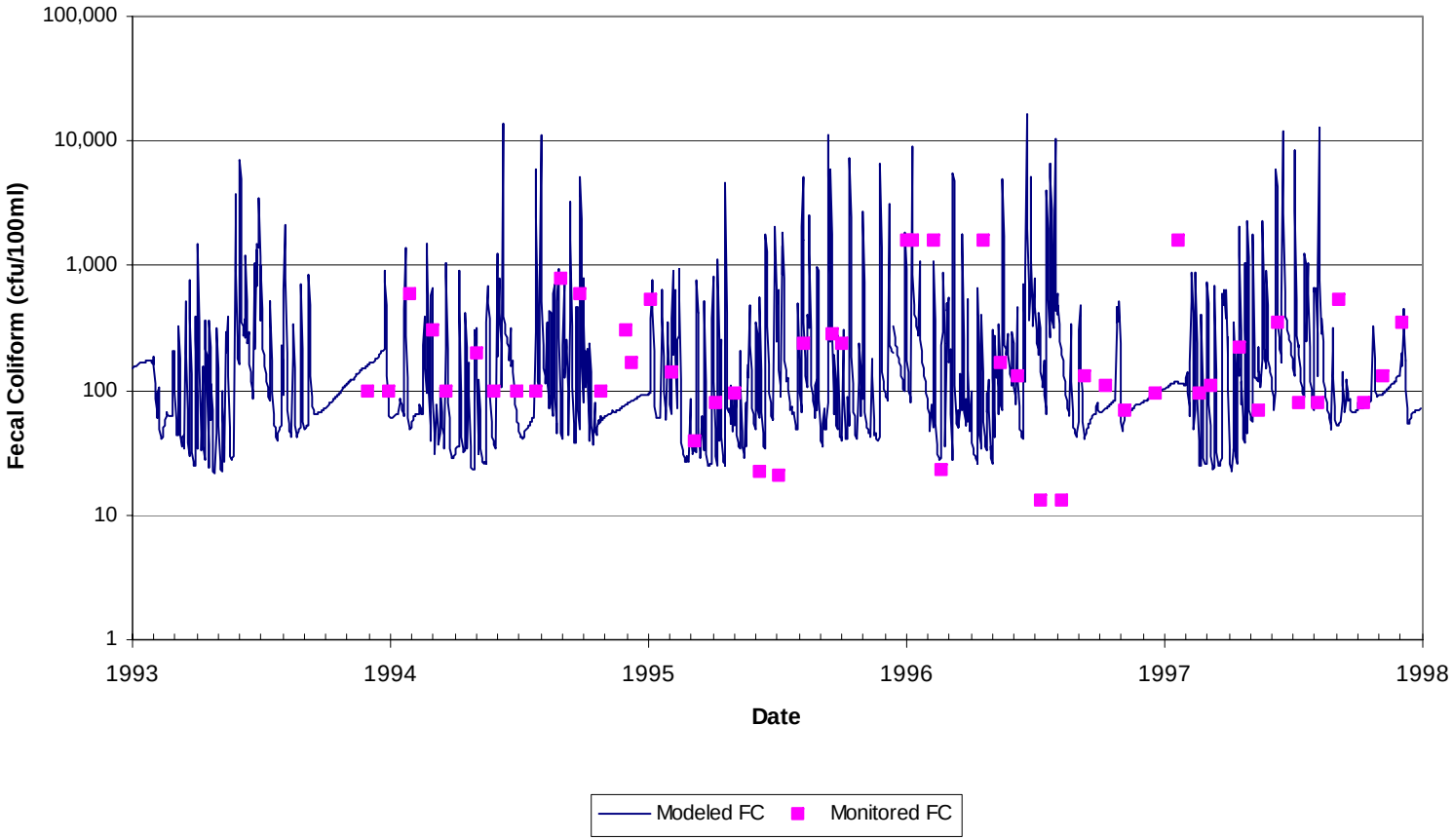

Figure C.20 Quality validation results for period 10/1/1993 to 9/30/1998 Rattlesnake (Creek) Swamp, model segment 6, subshed 31.

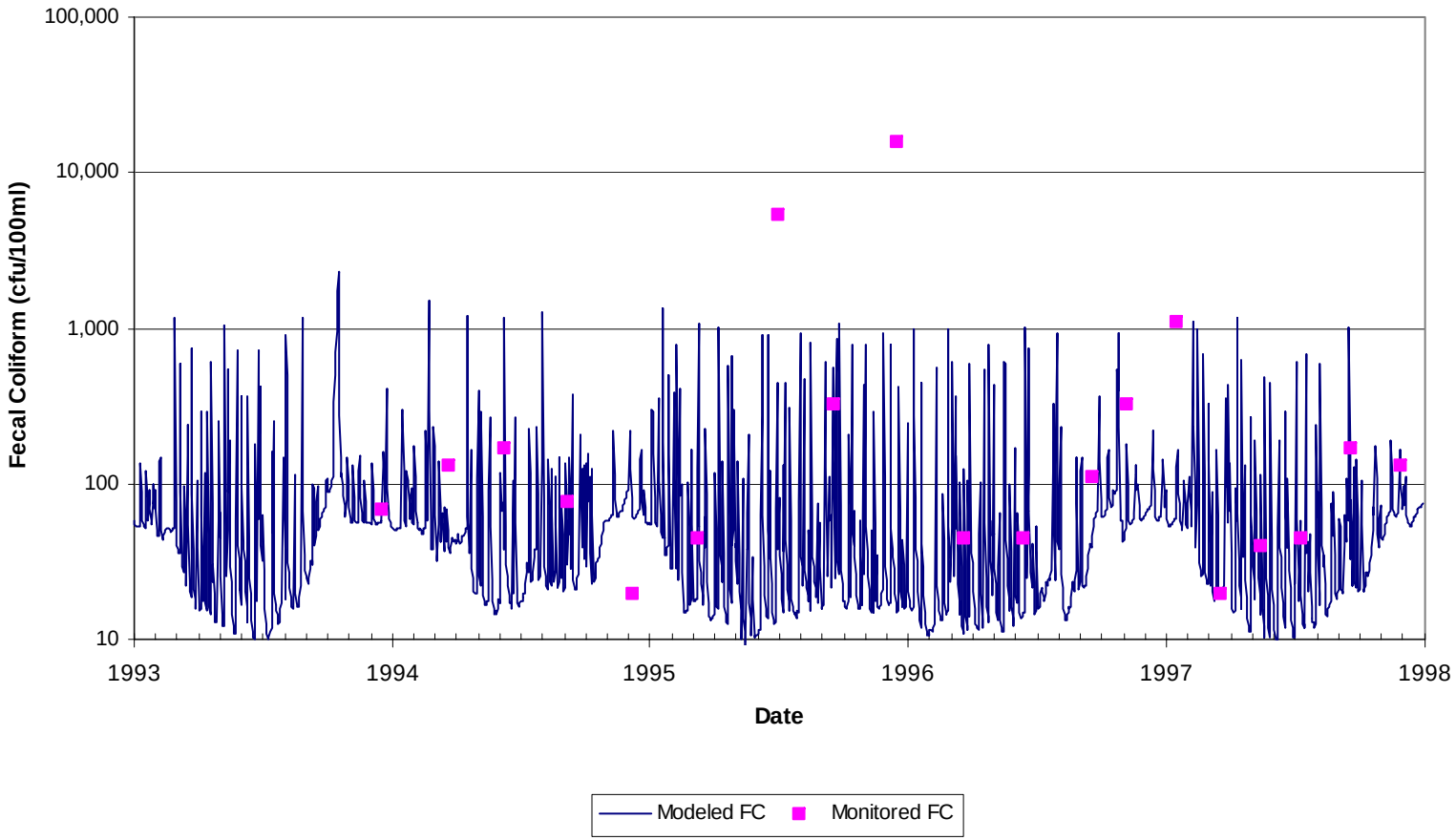

Figure C.21 Quality validation results for period 10/1/1993 to 9/30/1998 Sappony Creek, model segment 3, subshed 1.

Table C.1 Results of analyses on validation runs.

WQ Monitoring Station	Mean Standard Error (cfu/100ml)	Maximum Simulated Value (cfu/100ml)
5ANTW155.06	265	11,872
5ALNT004.68	15	15,088
5ABHC003.73	206	5,602
5ABPC000.12	303	66,764
5ASAP013.69	140	2,316
5ARCN003.36	251	7,011
5ACPP003.20	129	4,373
5AMSW006.77	152	15,217
5ARKN006.40	24	6,144

APPENDIX D

E. coli TMDL FOR FUTURE CONDITIONS

Table D.1 Average annual *E. coli* loads (cfu/year) modeled after TMDL allocation in the Chowan Study Area watershed impairments with permitted point source loads increased five times.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Big Hounds Creek	3.48E+12	1.64E+12	Implicit	5.12E+12
VA0020184	*3.48E+12*			
Cypress Swamp	1.13E+12	5.82E+12		6.95E+12
VA0088463	*1.13E+12*			
Little Nottoway	3.27E+12	9.31E+12		1.26E+13
VA0066869	*3.05E+12*			
VA0061158	*2.23E+11*			