Fecal Bacteria Total Maximum Daily Load Development for Mattox Creek

Primary Contact Recreational Use and Shellfish Harvesting Use

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EXECUTIVE SUMMARY

Background and Applicable Standards

The Mattox Creek watershed is in USGS Hydrologic Unit Code 02070011, and located in Virginia's King George and Westmoreland counties. Mattox Creek is part of the Potomac and Shenandoah River basins; it drains to the Potomac River.

There are two impairments in Mattox Creek, a tidal impairment violating primary contact fecal coliform standards for tidally influenced waters as well as enterococci standards for shellfish. This impairment will be referred to in this report as the tidal segment. The second impairment will be referred to as the free-flowing segment, which is violating the primary contact fecal coliform standards in fresh water. Mattox Creek tidal segment was initially on the 1996 *303(d) TMDL Priority List* (VADEQ, 1997). A 2.1 mile segment was cited for violations of the fecal coliform bacteria standard; the impaired segment begins at the Route 205 bridge over Mattox Creek (river mile 4.1) and extends downstream to Columbia Cove at river mile 2.0. This segment remained on the Virginia *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998) and the Virginia *2002 303(d) Report on Impaired Waters* (VADEQ, 2002). The impaired segment was adjusted during the 2002 cycle to an upstream limit at river mile 4.10 and a downstream limit at river mile 1.00. This expansion was to incorporate the segment affected by the Virginia Department of Health (VDH), Division of Shellfish Sanitation (DSS) Shellfish Condemnation 001B, 6/29/1999. The 3.10 mile segment was adjusted during the 2004 cycle to be coincident with VDH-DSS Shellfish Condemnation 001B. The free-flowing segment of the impairment was added to the Virginia 2002 Section 303(d) Report and it begins at the headwaters at river mile 12.60 and extends to the tidal limit at river mile 4.10. This free-flowing segment was assessed during the 2002 cycle based on fecal coliform violations. Both segments remained on the Virginia *2004 305(b)/303(d) Water Quality Integrated Report* (VADEQ, 2004).

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.

The 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 e*nterococci* 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.

For shellfish, the criteria used for developing TMDLs are outlined in 9 VAC 25-260-160 and read as follows.

> *In all open ocean or estuarine waters capable of propagating shellfish or in specific areas where public or leased private shellfish beds are present, and including those waters on which condemnation or restriction classifications are established by the State Department of Health, the following criteria for fecal coliform bacteria shall apply:*
>
> *The geometric mean fecal coliform value for a sampling station shall not exceed an MPN (most probable number) of 14 per 100 milliliters. The 90th percentile shall not exceed an MPN of 43 for a 5-tube, 3-dilution test or 49 for a 3-tube, 3-dilution test.*

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.). In the Mattox Creek watershed, there are two point sources permitted through the Virginia Pollutant Discharge Elimination System (VPDES). Currently, these permitted discharges are expected not to exceed the 126 cfu/100 mL *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.

For the free-flowing segment violating the primary contact fecal coliform standards, 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. 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*. For the tidal segment violating primary contact and shellfish standards, 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 35-cfu/100 ml *enterococci* in estuarine waters. Additionally, for shellfish impairment in the tidal segment, the fecal coliform 30-Month geometric mean

shall not exceed a maximum allowable level of 14 MPN. The 30-Month 90th percentile of fecal coliform levels in the shellfish impairment (tidal segment) shall not exceed 49 MPN. Translator equations developed by VADEQ were used to convert fecal coliform values to *E. coli* and *enterococci* values.

Water Quality Modeling

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 both the non-tidal and tidal 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, climat, 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. To adequately represent the spatial variation in the watershed, the Mattox Creek drainage area was divided into six subwatersheds for the purpose of modeling hydrology. The non-tidal portion of the stream system is represented in subwatersheds 1, 2, 3, 5, and 6, and the tidal portion of Mattox River is subwatershed 4. The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model.

The Steady State Tidal Prism Model, which is currently used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. MapTech's implementation of the Tidal Prism Model uses the same basic principle of a control volume with ebb and flood tides based on monitored tide data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody.

The paired watershed approach was used to calibrate the HSPF model. Through this approach, the HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow is available. Several watersheds were compared with Mattox Creek watershed and, in consultation with VADEQ, Piscataway

Creek in Essex County, Virginia was selected as the paired watershed. The Piscataway Creek watershed is similar in size to the Mattox Creek watershed and is located in the same ecoregion (Southeastern Plains). The two watersheds have similar soils, climate, geology, and land use, and the Piscataway Creek gaging station was chosen to develop the surrogate hydrology model for Mattox Creek. The water quality calibration period of October 1992 through September 1997 was selected based on the availability of water quality data to calibrate the HSPF model for the free flowing segment using monitored data collected at VADEQ monitoring stations. For the tidal segment, water quality calibration was conducted from October 1996 to September 1999 using data collected by VADEQ and VDH.

Existing Conditions

Wildlife populations and ranges; 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 Mattox Creek 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, and direct deposition by wildlife.

Contributions from all of these sources were updated to 2006 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record. Under existing conditions in 2006, 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 the EPA requires a zero percent violation load allocation in TMDLs, modeling was first conducted on the free-flowing segment since the outflow from this segment contributes to the tidal segment. The modeling target for the free-flowing segment was a value of 0% exceedance of the 126-cfu/100 mL geometric mean standard and 0% exceedance of the single 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 ES.1. Scenario four would generally be adopted as the targets for Stage I implementation goal for the free flowing segment. The last scenario shows the reductions necessary to achieve zero percent violation compliance for the free flowing segment.

Table ES.1 Allocation scenarios for bacterial concentration with current loading estimates in Mattox free-flowing segment.

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	NPS Res. Com.	NPS Tran.	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	0	91.7	39.5
2	0	0	100	100	100	100	0	0	4.0
3	0	0	90	50	100	50	0	5	17.9
4[1]	0	0	100	90	100	90	0	0	7.2
5	0	0	100	99	100	99	0	0	4.2
6	50	50	99	99	100	99	50	0	1.7
7[2]	50	94	98	99	100	99	94	0	0

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

Modeling was then conducted on the tidal segment with following standards to meet:

- 0% exceedance of the *enterococci* single sample of 104-cfu/100 ml,
- 0% exceedances of the *enterococci* geometric mean of 35-cfu/100 ml,
- 0% exceedances of the fecal coliform 30-month geometric mean of 14 MPN, and,
- 0% exceedances of the 30-month 90th percentile of fecal coliform of 49 MPN.

Modeling results indicated that when running the existing conditions in both the tidal and free flowing segments, two out of four standards were met at the outlet of the tidal segment. All standards were met when running the allocated scenario in which the free flowing inputs were the allocated loads and only eliminating the straight pipes loadings from the tidal segment as shown in Table ES.2.

Tables ES.3 and ES.4 show the TMDL tables for the free-flowing segment, and the tidal segment, respectively. The TMDL table gives the number of corresponding bacteria counts 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 nonpoint sources existing in the watershed.

Table ES.2 Allocation scenarios for bacterial concentration with current loading estimates in Mattox tidal segment and allocated loads from Mattox free-flowing segment.

Scenario	Percent Reduction in Loading from Existing Conditions							Percent Violations			
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe	NPS Res. Com.	NPS Tran.	*Enterococci* geo. Mean > 35cfu/100mL	*Enterococci* instantaneous. > 104cfu/100mL	Fecal coliform geo. Mean > 14 MPN	Fecal coliform 90th percentile > 49 MPN
Existing	0	0	0	0	0	0	0	0	1	0	10
Allocated	0	0	0	0	100	0	0	0	0	0	0

Table ES.3 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Mattox free-flowing segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox Creek – Free-Flowing	*E. coli*	2.2E+06	5.0E+12	*Implicit*	5.0E+12

Table ES.4 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Mattox tidal segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox – Tidal Segment	*Enterococci*	1.7E+05	1.0E+14	*Implicit*	1.0E+14
Mattox – Tidal Segment	*Fecal coliform*	3.0E+05	2.6E+13		2.6E+13

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 bacterial impairments in the Mattox Creek watershed. The second step is to develop a TMDL implementation plan (IP). The final step is to implement the TMDL IP, 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 IP. 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 Virginia Department of Environmental Quality (VADEQ) and Virginia Department of Conservation and Recreation (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 Mattox Creek watershed, public involvement was possible through two meetings (Table ES.4).

Table ES.4 Public meetings for the Mattox Creek watershed.

Type	Date	Location
1st Public meeting	2/7/2006	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA
Technical Advisory Committee meeting	3/14/2006	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA
Final Public meeting	4/11/2006	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA

1. INTRODUCTION

1.1 Background

The need for TMDLs to be conducted in the Mattox Creek watershed is based on provisions of the Clean Water Act (CWA). The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 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 Mattox Creek watershed, which is contained in USGS Hydrologic Unit Code 02070011, is located in Virginia's King George and Westmoreland counties. Mattox Creek is part of the Potomac and Shenandoah River basins; it drains to the Potomac River basin (Figure 1.1). A 2.1 mile segment was cited in the 1996 *303(d) TMDL Priority List* (VADEQ, 1997) for violations of the fecal coliform bacteria standard; the impaired segment begins at the Route 205 bridge over Mattox Creek (river mile 4.1) and extends downstream to Columbia Cove at river mile 2.0 (Figure 1.2). The violations were recorded at Virginia Department of Environmental Quality (VADEQ) monitoring station 1-AMAO004.08, which is located at the Route 205 bridge.

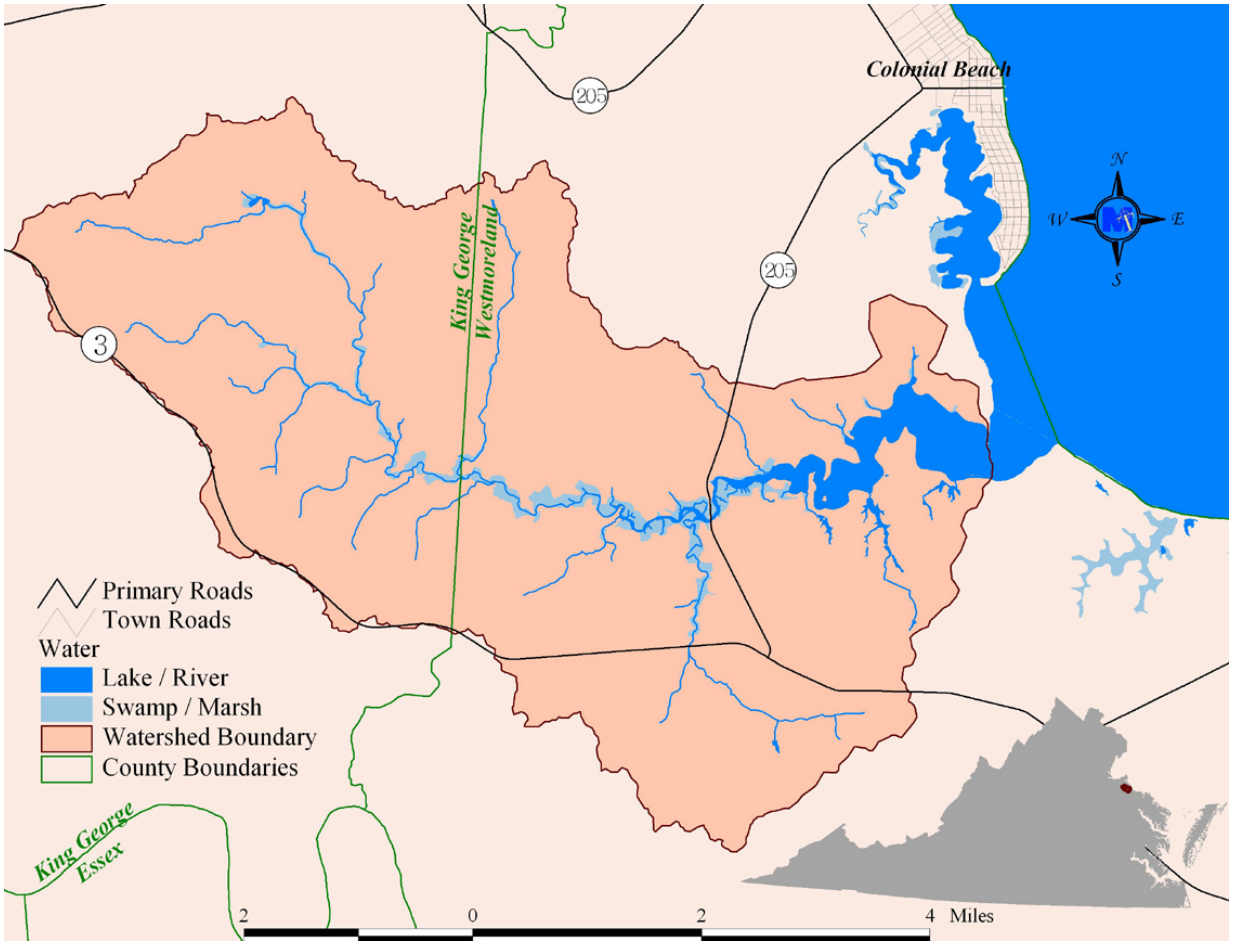

Figure 1.1 Location of the Mattox Creek watershed.

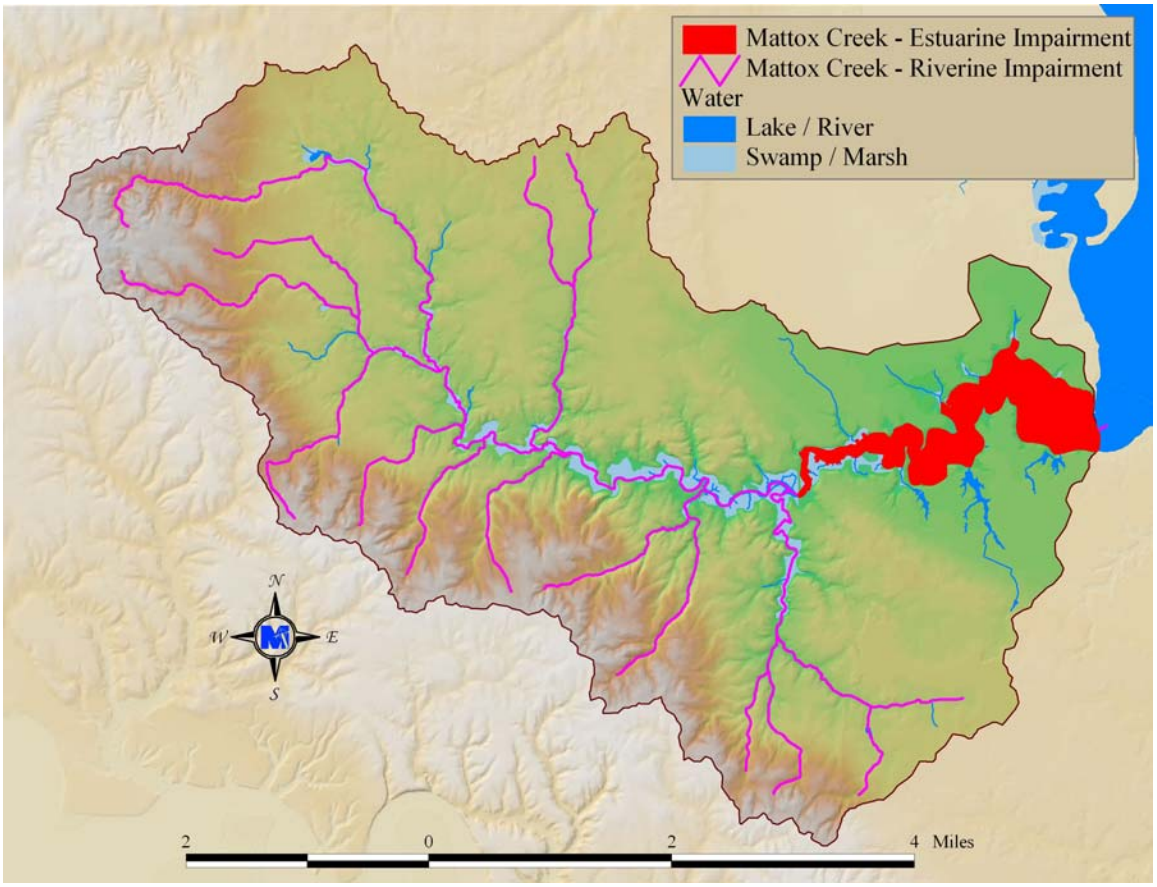

Figure 1.2 Impaired stream segments in the Mattox Creek watershed.

In the 1998 *303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998), Mattox Creek was cited for excessive violations of the fecal bacteria standard. Seven violations were noted in 31 samples taken at the Route 205 bridge station (1-AMAO004.08). The recorded violations resulted in an assessment of "partially supporting" of the CWA's Swimming Use support goal.

The impairment was also listed in the 2002 *303(d) Report on Impaired Waters* (VADEQ, 2002) for continued fecal coliform violations as well as a Virginia Department of Health (VDH) Shellfish Restriction. The impaired segment was adjusted during the 2002 cycle to an upstream limit at river mile 4.10 and a downstream limit at river mile 1.00. This expansion was to incorporate the segment affected by the VDH, Division of Shellfish Sanitation (DSS) Shellfish Condemnation 001B, 6/29/1999. The impaired segment was

listed as partially supporting for swimmable use and partially supporting for shellfish harvesting use.

The *Report on Impaired Waters* (VADEQ, 2002) also lists an additional impaired segment that begins at the headwaters at river mile 12.60 and extends to the tidal limit at river mile 4.10. This free-flowing segment was assessed during the 2002 cycle based on a fecal coliform violation rate of 8/26 at station 1-AMAO007.46. It is listed as not supporting for swimmable use.

The 2004 *305(b)/303(d) Water Quality Assessment Integrated Report* (VADEQ, 2004) lists the 3.10 mile segment (from river mile 4.10 to river mile 1.00) for not supporting shellfish use. The segment was adjusted during the 2004 cycle to be coincident with VDH-DSS Shellfish Condemnation 001B, 7/5/2002. This same tidal segment was also designated as not supporting for recreation use based on excessive fecal coliform standards at station 1-AMAO004.08.

In addition, the 2004 *305(b)/303(d) Water Quality Assessment Integrated Report* (VADEQ, 2004) lists the free-flowing segment from the headwaters at river mile 12.60 to the tidal limit at river mile 4.10 as not supporting for recreation use due to fecal coliform violations in seven out of 20 samples at station 1-AMAO007.46. The source of the fecal coliform violations was unknown.

Tables 1.1 and 1.2 list the type of impairment (*i.e.*, fecal coliform or shellfish) along with the listing years, segment sizes, and locations.

Table 1.1 Impairments within the free-flowing portion of the Mattox Creek watershed.

Year of Listing	Impairment Type	Miles Affected	Location	Listing Station ID
2002	Primary Contact	8.5	River mile 12.6 – 4.1	1-AMAO007.46
2004	Primary Contact	34.03	River mile 12.6 – 4.1	1-AMAO007.46

Table 1.2 Impairments within the tidal portion of the Mattox Creek watershed.

Year of Listing	Impairment Type	Miles Affected	Location	Listing Station ID
1996	Primary Contact	2.1	River mile 4.1 – 2.0	1-AMAO004.08
1998	Primary Contact	2.1	River mile 4.1 – 2.0	1-AMAO004.08
2002	Shellfish	3.1	River mile 4.1 – 1.0	1-AMAO004.08
2002	Primary Contact	3.1	River mile 4.1 – 1.0	1-AMAO004.08
2004	Shellfish	3.1	River mile 4.1 – 1.0	1-AMAO004.08
2004	Primary Contact	3.1	River mile 4.1 – 1.0	1-AMAO004.08

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 Mattox Creek.

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.*

If the waterbody had an exceedance rate > 10.5% and had at least two 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. These were the criteria used for listing the impairments included in this study. Sufficient fecal coliform bacterial standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

The EPA recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The 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 tracts 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 in Virginia on January 15, 2003.

For non-shellfish, 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.

For shellfish, the criteria used for developing TMDLs are outlined in 9 VAC 25-260-160 and read as follows.

In all open ocean or estuarine waters capable of propagating shellfish or in specific areas where public or leased private shellfish beds are present, and including those waters on which condemnation or restriction classifications are established by the State Department of Health, the following criteria for fecal coliform bacteria shall apply:

The geometric mean fecal coliform value for a sampling station shall not exceed an MPN (most probable number) of 14 per 100 milliliters. The 90th percentile shall not exceed an MPN of 43 for a 5-tube, 3-dilution test or 49 for a 3-tube, 3-dilution test.

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 Mattox Creek 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 CWA requires compliance with that state's water quality standard. For the free-flowing segment of Mattox Creek, assessment of the TMDL was made using the primary contact recreation criterion in freshwater, meeting both the geometric mean standard and the instantaneous 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 the free-flowing TMDL 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 impairment in Mattox Creek.

Stream Name	Listing Criterion	TMDL Endpoint
Mattox Creek – upstream of bridge on Rt. 205	Fecal coliform	*E. coli*
Mattox Creek –downstream of bridge on Rt. 205	Fecal coliform	*Enterococci, Fecal coliform*

Since the tidally-influenced segment of Mattox Creek below the Rt. 205 bridge violates the VADEQ primary contact recreation use in estuarine waters and modeling provided simulated output of *enterococci* concentrations at 1-hour intervals, assessments of the TMDLs were made using both the geometric mean standard of 35 cfu/100 mL and the 90th percentile of 104 cfu/100 mL. Therefore, the in-stream *enterococci* targets for these TMDLs were a monthly geometric mean not exceeding 35 cfu/100 mL and a 90th percentile not exceeding 104 cfu/100 mL.

The Virginia Department of Health (VDH) shellfish harvesting use impairments will be assessed using both the fecal coliform standard of 14 MPN and the 90th percentile of 49 MPN. Therefore, the in-stream fecal coliform targets for these TMDLs were a 30-month geometric mean not exceeding 14 MPN and a 30-month 90th percentile not exceeding 49 MPN.

2.3 Selection of a TMDL Critical Condition.

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs 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 Mattox Creek 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 Mattox Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint 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. In this context, point sources also include nonpoint sources that are not precipitation-driven (*e.g.*, fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and flow duration intervals showed that there was no obvious critical flow level (Figure 2.1). That is, the analysis showed no obvious dominance of either nonpoint sources or point sources. High concentrations were recorded in all flow regimes at monitoring stations where data were collected during all flow regimes. 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 (see section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this watershed. The resulting periods for calibration and validation for each impaired water body are presented in Chapter 4.

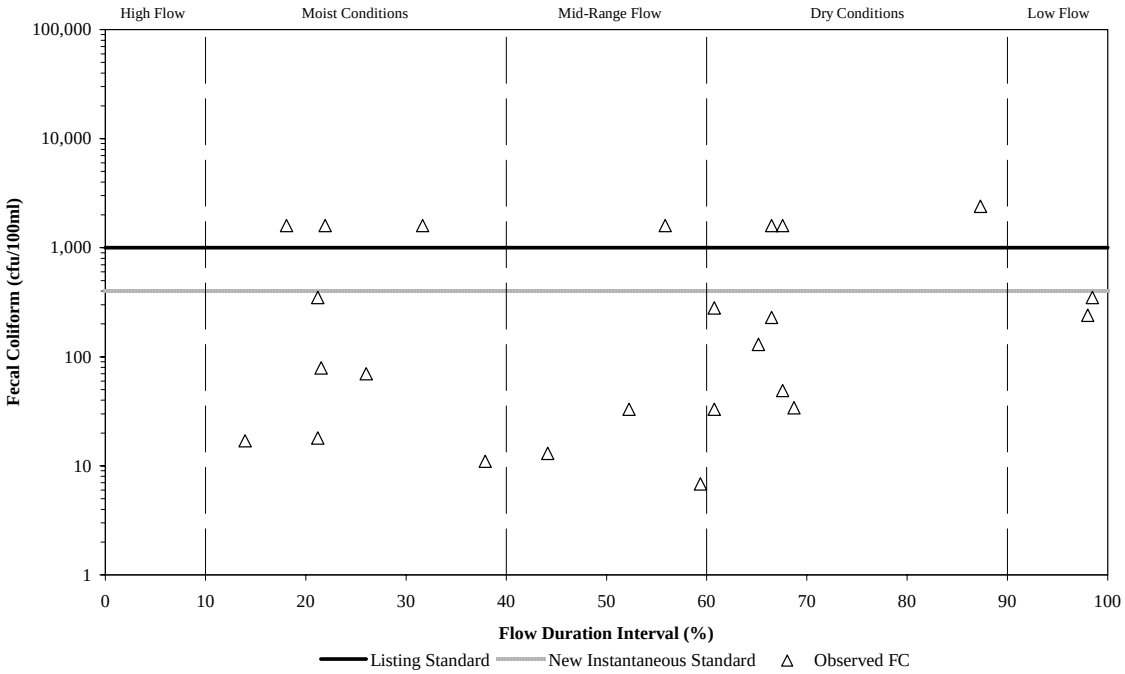

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 1-AMAO004.08) and discharge (HSPF simulated flow) in the Mattox Creek impairment.

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 Mattox Creek watershed. 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 three VADEQ in-stream monitoring stations used for TMDL assessment (Figure 2.2, Tables 2.2 through 2.4);
- Bacteria enumerations and bacterial source tracking from two VADEQ in-stream monitoring stations analyzed during TMDL development; and

- Bacteria enumerations from eight VDH monitoring stations within shellfish condemnation zone 001B (Figure 2.4 and Table 2.5).

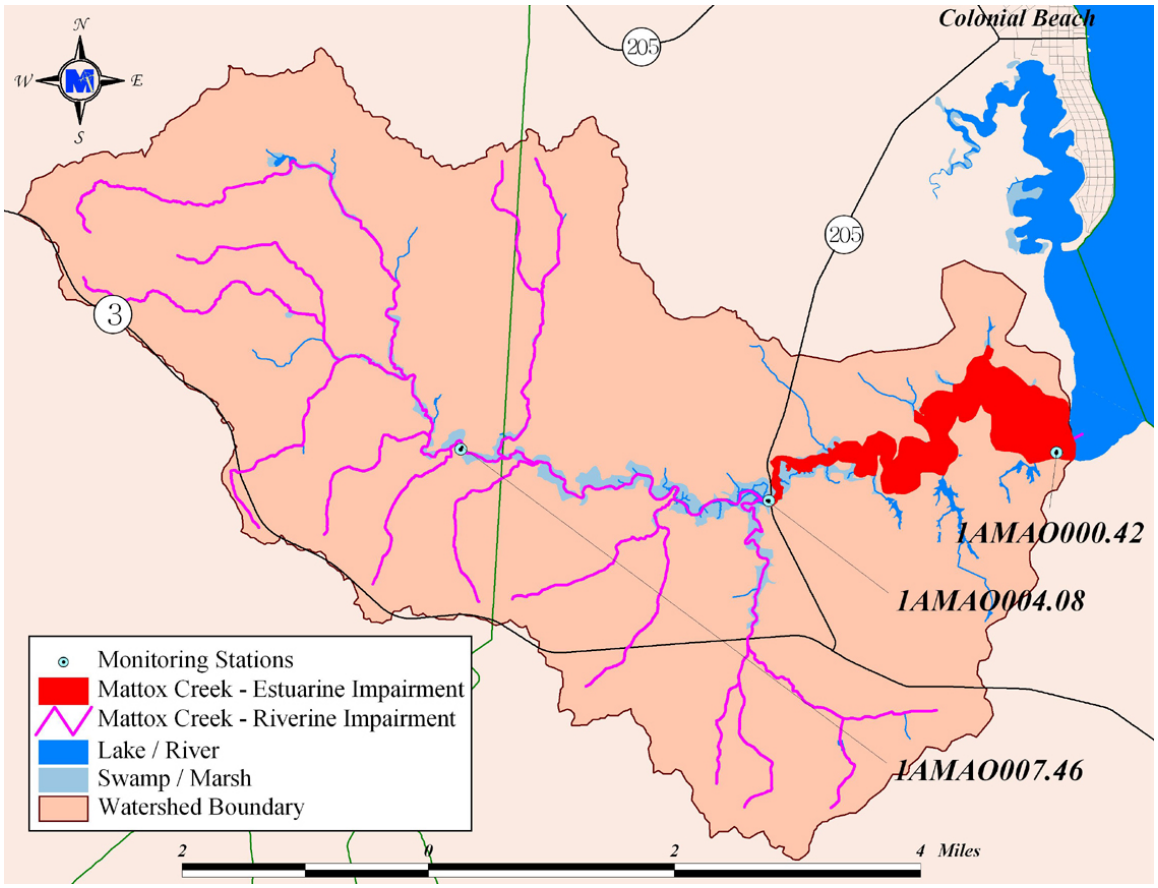

Figure 2.2 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Mattox Creek watershed.

2.4.2 Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples collected by VADEQ were analyzed from November 1992 through June 2004 (Table 2.2) and are included in the analysis. Samples were taken for the express purpose of determining compliance with the state's 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 analyzed further 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. *E. coli* samples were collected to evaluate compliance with the state's current bacterial standard for freshwater, as well as for bacterial source tracking (BST) analysis (Table 2.3). The current instantaneous standard for *E. coli* is 235 cfu/100 mL. *Enterococci* samples were collected to evaluate compliance with the state's current bacterial standard for saltwater and transition zones (Table 2.4). The current instantaneous standard for *enterococci* is 104 cfu/100 mL.

The Division of Shellfish Sanitation (DSS) of the VDH conducted its own fecal coliform sampling in the tidal segment of Mattox Creek below the Rt. 205 bridge. This data is also included in the analysis and is summarized in Table 2.5.

Table 2.2 Summary of fecal coliform monitoring conducted by VADEQ for Mattox Creek from November 1992 through June 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] (%)
Mattox Creek	1-AMAO000.42	36	18	790	92	100	126	3
Mattox Creek	1-AMAO004.08	49	7	2,400	538	180	700	29
Mattox Creek	1-AMAO007.46	34	20	16,000	929	210	2,725	29

[1]Violations are based on the current fecal coliform instantaneous standard (400 cfu/100mL)

Table 2.3 Summary of *E. coli* monitoring conducted by VADEQ for Mattox Creek from July 2003 through December 2005.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] (%)
Mattox Creek	1-AMAO004.08	12	10	200	71	60	64	0
Mattox Creek	1-AMAO007.46	10	1	90	46	50	29	0

Table 2.4 Summary of *enterococci* monitoring conducted by VADEQ for Mattox Creek from July 2003 through June 2004.

Stream	VADEQ Station	Count (#)	Minimum (cfu/100mL)	Maximum (cfu/100mL)	Mean (cfu/100mL)	Median (cfu/100mL)	Standard Deviation	Violations[1] (%)
Mattox Creek	1-AMAO004.08	12	10	420	117	70	122	42

Table 2.5 Summary of fecal coliform monitoring conducted by VDH from April 1990 through February 2006.

Stream	VDH Station	Count (#)	Minimum (MPN)	Maximum (MPN)	Mean (MPN)	Median (MPN)	Geomean[1] (MPN)	90th Percentile[2] (MPN)
Mattox Creek	2-2	169	2.90	1,100	20.42	7.2	7.58	39.80
Mattox Creek	2-3	168	2.90	1,100	21.86	3.6	7.43	43.00
Mattox Creek	2-3.5	19	2.90	240	25.13	3.6	8.35	46.20
Mattox Creek	2-4	169	2.90	1,200	28.73	9.1	10.07	43.00
Mattox Creek	2-5	168	2.90	1,200	42.16	9.1	12.52	**52.60**
Mattox Creek	2-5.5	19	2.90	1,200	90.48	15	**15.70**	**82.40**
Mattox Creek	2-6	168	2.90	1,200	61.44	23	**17.71**	**93.00**
Mattox Creek	2-7	164	2.90	1,200	52.31	23	**18.26**	**93.00**
Mattox Creek	2-8	158	2.90	1,200	63.16	23	**20.94**	**93.00**
Mattox Creek	2-9	158	2.90	1,200	77.97	23	**25.58**	**93.00**

[1]Violations marked in **bold** are based on the current fecal coliform geomean standard (14 MPN).
[2]Violations marked in **bold** are based on the current fecal coliform 90th percentile standard (49 MPN).

2.4.3 Analysis of Water Quality 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.

2.4.3.1 Bacterial Source Tracking

MapTech, Inc. was contracted to perform an analysis of fecal coliform and *E. coli* concentrations as well as bacterial source tracking. 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 water quality solutions solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's Environmental Diagnostics Laboratory (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 one ambient station (1-AMAO007.46) and one VDH shellfish station (2-8) in the Mattox Creek drainage area (Figure 2.3) are reported in Table 2.6. 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 two 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 2.7 summarizes the results for the BST study at the ambient station (1-AMAO007.46) and VDH Station 2-8. The averages per station and type of contributor

shown are weighted by 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. The results at the ambient station indicate a strong impact of wildlife; however, anthropogenic sources combined account for more than wildlife. Human impact was the least at this site, which is expected since most of the heavily populated areas of the watershed are downstream of this station. The results at VDH Station 2-8 indicate the increased human contribution from the more populated areas toward the watershed outlet. No single source dominated contributions, as measured by the BST technique at this station.

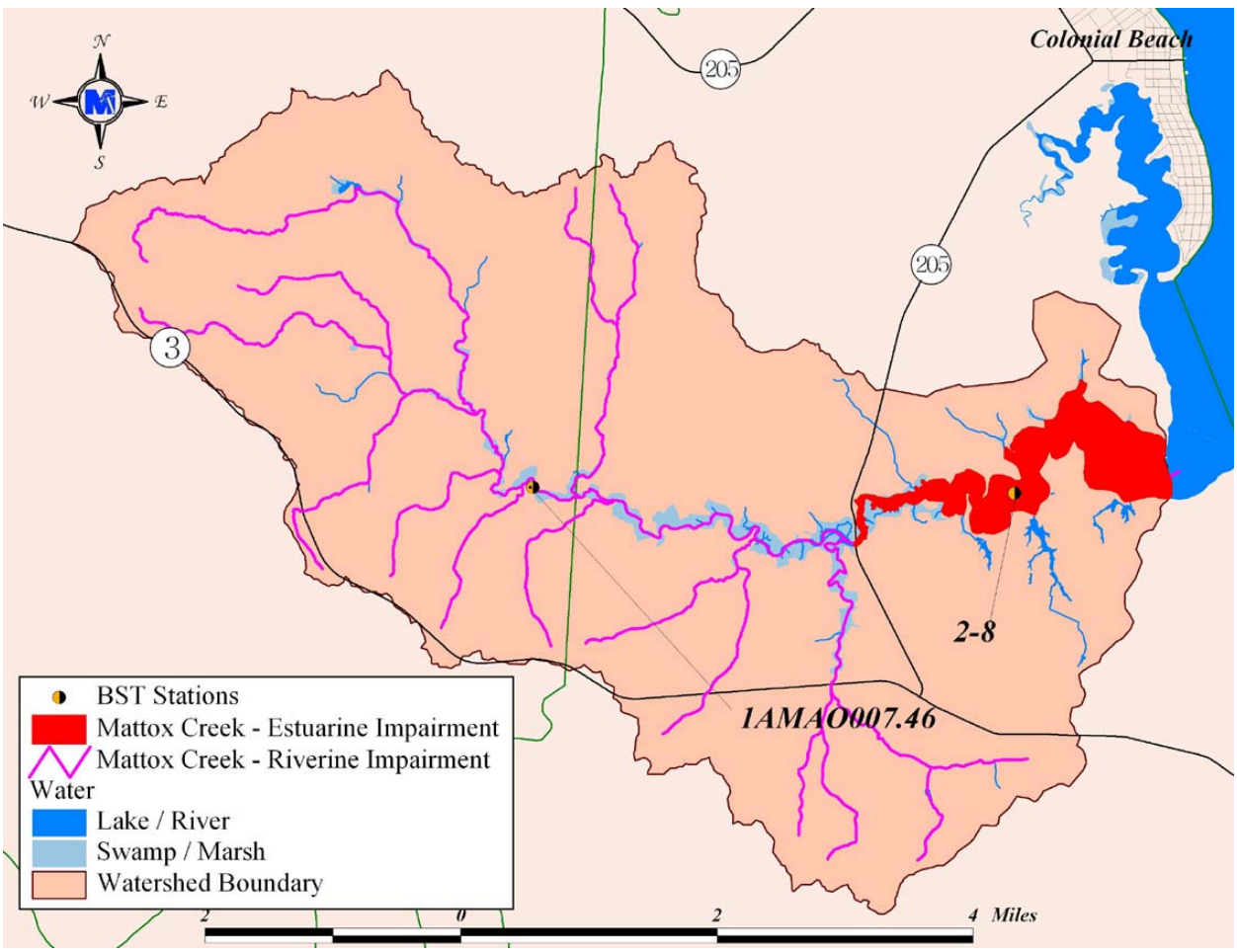

Figure 2.3 Location of BST water quality monitoring stations in the Mattox Creek watershed.

Table 2.6 Summary of bacterial source tracking results from water samples collected in the Mattox Creek impairment.

Station	Date	*E. coli* (cfu/100mL)	Percent Isolates classified as: Wildlife	Human	Livestock	Pet
VDH Station 2-8	10/16/2003	35	**71%**	0%	4%	**25%**
	11/17/2003	50	**12%**	8%	**80%**	0%
	12/16/2003	162	**38%**	**12%**	**25%**	**25%**
	1/13/2004	6	**55%**	**20%**	5%	**20%**
	2/25/2004	2	62%	38%	0%	0%
	3/11/2004	26	**25%**	4%	**71%**	0%
	4/8/2004	29	**50%**	**21%**	**12%**	**17%**
	5/24/2004	16	**80%**	**12%**	8%	0%
	6/23/2004	10	**44%**	**50%**	6%	0%
	7/20/2004	16	**88%**	0%	0%	**12%**
	8/19/2004	34	**42%**	**12%**	4%	**42%**
	9/20/2004	181	**21%**	**71%**	8%	0%
1-AMAO007.46	7/28/2003	42	38%	50%	0%	12%
	8/19/2003	96	**21%**	4%	**42%**	**33%**
	9/10/2003	90	**71%**	0%	8%	**21%**
	10/1/2003	30	**17%**	0%	**71%**	**12%**
	11/5/2003	40	**42%**	0%	**58%**	0%
	12/9/2003	50	**59%**	8%	4%	**29%**
	1/12/2004	0	0%	0%	0%	0%
	2/18/2004	0	0%	0%	0%	0%
	3/8/2004	28	**53%**	**33%**	**14%**	0%
	5/24/2004	60	67%	0%	0%	33%
	6/7/2004	90	22%	0%	0%	**78%**
	7/21/2004	60	**67%**	0%	0%	**33%**

BOLD type indicates a statistically significant value.

Table 2.7 Load weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.

Station ID	Weighted Averages: Wildlife	Human	Livestock	Pet
1-AMAO007.46	45%	5%	30%	20%
VDH Station 2-8	35%	30%	22%	13%

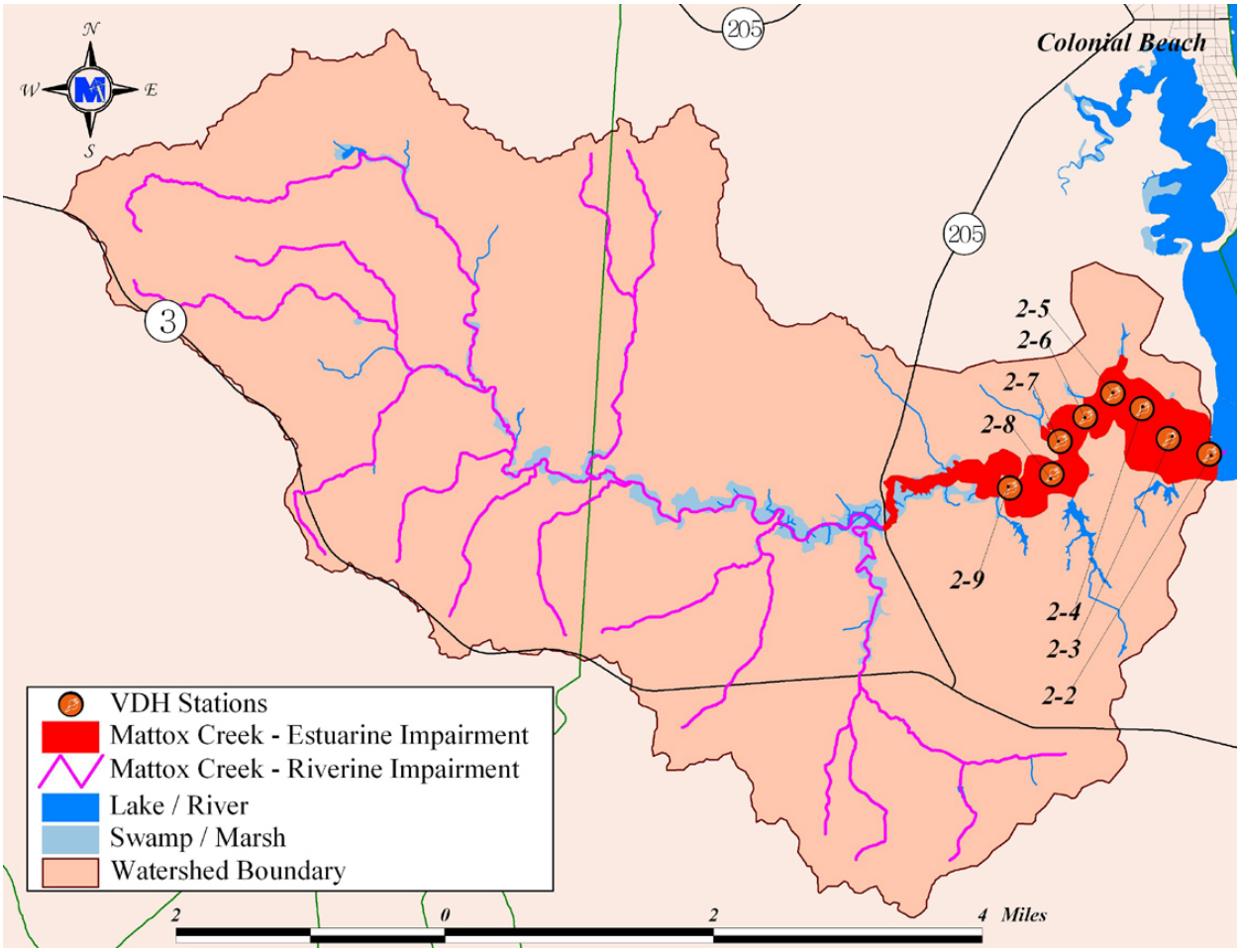

Figure 2.4 Location of VDH water quality monitoring stations in the Mattox Creek watershed.

2.4.4 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 was conducted using the Mood's 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.

2.4.4.1 Precipitation

The total monthly precipitation measured at NCDC station #441913 (in Colonial Beach, Westmoreland County) was analyzed and no overall, long-term trend was found (Table 2.8).

Table 2.8 Summary of trend analysis on precipitation (in).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
441913	3.677	3.360	12.890	0.040	2.084	410	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

A significant seasonality effect was found at station #441913. Differences in mean monthly precipitation are indicated in Table 2.9. 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, March, April, June, August, September, October, November, and December is classified in both median group "A" and "B" and is not significantly different than either group.

Table 2.9 Summary of the Mood's Median Test on mean monthly precipitation at station 441913 (p=0.007).

Month	Mean	Min	Max	Median Group	
January	3.187143	0.41	8	A	B
February	3.116571	0.63	7.15	A	
March	4.153235	1.34	8.11	A	B
April	3.220294	0.21	8.7	A	B
May	4.347353	1.07	7.71		B
June	3.571765	0.41	11.91	A	B
July	4.639706	1.12	9.22		B
August	3.703235	0.44	8.45	A	B
September	4.056765	0.47	12.89	A	B
October	3.553235	0.04	8.44	A	B
November	3.165294	0.5	7.93	A	B
December	3.436471	0.48	7.27	A	B

2.4.4.2 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ and VDH were described in Section 2.4.2. The trend analysis was conducted on data collected at stations used in TMDL assessment. As indicated in Table 2.10, there was insufficient data available to determine a significant trend in fecal coliform values at VADEQ stations 1-AMAO000.42, 1-AMAO004.08, and 1-AMAO007.46, and there were no overall, long-term trends in fecal coliform values found at VDH stations 2-2 through 2-9.

Table 2.10 Summary of trend analysis on fecal coliform.

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
1-AMAO000.42	92.306	100.0	790	18.0	125.873	36	--
1-AMAO004.08	395.317	140.0	24,00	6.8	618.473	42	--
1-AMAO007.46	929.059	210.0	16,000	20.0	2,725.422	34	--
VDH 2-2	20.493	7.3	1,100	2.9	88.257	165	No Trend
VDH 2-3	22.250	3.6	1,100	2.9	90.647	164	No Trend
VDH 2-4	28.963	9.1	1,200	0.0	100.114	166	No Trend
VDH 2-5	42.973	9.1	1,200	2.9	136.904	164	No Trend
VDH 2-6	62.551	23.0	1,200	2.9	169.445	164	No Trend
VDH 2-7	52.309	23.0	1,200	2.9	154.990	164	No Trend
VDH 2-8	63.506	23.0	1,200	2.9	170.643	157	No Trend
VDH 2-9	77.972	23.0	1,200	2.9	204.507	158	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

Mood's Median tests were performed on each station to identify any seasonality effect within the fecal coliform data collected by VADEQ and VDH. Significant seasonality effects were found at VDH stations 2-2, 2-4, 2-5, 2-6, 2-7, and 2-9. Differences in mean monthly fecal coliform values are indicated in Tables 2.11 through 2.16. Fecal coliform values at a given station, in months with the same median group letter, are not significantly different from each other at a 95% significance level. For example, at station 2-2 (Table 2.11), fecal coliform values in April, May, and September are all in median group "B" and are not significantly different from each other. In months with multiple groups, fecal coliform values are the result of the 95% confidence interval, for that month, overlapping more than one median group. For example, at station 2-2, fecal coliform values during the months of March, June, July, August, October, November, and December are classified in both median group "A" and "B" and are not significantly different than either group. VADEQ stations 1-AMAO000.42, 1-AMAO004.08, and 1-AMAO007.46 did not have significant seasonality effects. VDH stations 2-3 and 2-8 did not have significant seasonality effects.

Table 2.11 Summary of the Mood's Median Test on fecal coliform at station VDH 2-2 (p=0.013).

Month	Mean	Min	Max	Median Group	
January	3.169	2.900	3.600	A	
February	20.959	2.900	150.000	A	
March	94.400	2.900	1,100.000	A	B
April	11.354	2.900	43.000		B
May	7.092	2.900	23.000		B
June	21.640	2.900	75.000	A	B
July	10.427	2.900	43.000	A	B
August	17.347	3.600	43.000	A	B
September	12.079	2.900	43.000		B
October	7.347	2.900	23.000	A	B
November	12.287	2.900	43.000	A	B
December	33.346	2.900	240.000	A	B

Table 2.12 Summary of the Mood's Median Test on fecal coliform at station VDH 2-4 (p=0.031).

Month	Mean	Min	Max	Median Group	
January	5.669	2.900	23.000	A	
February	19.641	2.900	93.000	A	B
March	117.241	2.900	1,200.000	A	B
April	30.189	2.900	240.000	A	B
May	5.981	0.000	15.000	A	B
June	28.573	3.600	93.000	A	B
July	10.347	2.900	23.000	A	B
August	34.760	3.600	240.000		B
September	33.921	3.600	240.000		B
October	18.773	3.600	43.000		B
November	14.580	2.900	43.000	A	B
December	31.785	2.900	240.000	A	B

Table 2.13 Summary of the Mood's Median Test on fecal coliform at station VDH 2-5 (p=0.004).

Month	Mean	Min	Max	Median Group	
January	3.700	2.900	9.100	A	
February	14.8	2.9	93	A	
March	119.3949	2.9	1,200	A	B
April	95.78929	2.9	1,100	A	B
May	15.15	2.9	43	A	B
June	40.32	2.9	210		B
July	26.55	3.6	93		B
August	31.32	3.6	150		B
September	58.06429	7.3	460		B
October	24.41333	2.9	93	A	
November	29.63333	3	150	A	
December	53.21538	2.9	460	A	

Table 2.14 Summary of the Mood's Median Test on fecal coliform at station VDH 2-6 (p=0.022).

Month	Mean	Min	Max	Median Group	
January	6.784615	2.9	23	A	
February	114.3818	2.9	1,100	A	B
March	195.1538	2.9	1,200	A	B
April	54.58571	3.6	460	A	B
May	18.49167	3.6	43	A	B
June	80.50667	2.9	460		B
July	20.12143	3	43	A	B
August	34.47333	9.1	75		B
September	67.65714	9.1	460		B
October	39.21333	2.9	240	A	B
November	24.92	2.9	93	A	B
December	113.3308	2.9	1,100	A	B

Table 2.15 Summary of the Mood's Median Test on fecal coliform at station VDH 2-7 (p=0.001).

Month	Mean	Min	Max	Median Group	
January	10.56923	2.9	35	A	
February	30.74545	2.9	240	A	B
March	125.7154	2.9	1,200	A	B
April	93.86429	2.9	1,100	A	B
May	25.63333	3.6	43	A	B
June	38.78667	3.6	210	A	B
July	26.95	9.1	93	A	B
August	42.38	3.6	93		B
September	111.8071	7.3	1,100		B
October	45.87333	3.6	240	A	B
November	26.21333	2.9	93	A	B
December	46.58462	2.9	240	A	B

Table 2.16 Summary of the Mood's Median Test on fecal coliform at station VDH 2-9 (p=0.004).

Month	Mean	Min	Max	Median Group	
January	16.70833	2.9	93	A	
February	31.4	2.9	240	A	B
March	208.9615	2.9	1,200	A	B
April	110.5429	3.6	1,200		B
May	26.425	3.6	93	A	B
June	37.53333	2.9	150	A	B
July	73.92857	20	240		B
August	50.54	9.1	150		B
September	145.8	7.3	1,200		B
October	42.64286	2.9	150		B
November	47.57143	3.6	150	A	B
December	142.45	2.9	1,100	A	B

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal coliform in the Mattox Creek watershed 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 Chapter 4.

3.1 Watershed Characterization

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and the 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 Figure 3.1.

Table 3.1 Contributing land use area for free-flowing and tidal impairments of Mattox Creek watershed.

Impaired Segment	Land use								
	Water (acres)	Residential (acres)	Commercial (acres)	Transitional (acres)	Woodland (acres)	Pasture (acres)	Cropland (acres)	Wetlands (acres)	Livestock Access (acres)
Free-flowing segment	56.71	249.75	38.92	98.08	9,732.43	1,094.13	2,160.34	466.36	17.17
Tidal segment	632.05	423.44	30.69	85.4	1,466.70	407.53	699.43	187.26	4.57
Sum	*688.76*	*673.19*	*69.61*	*183.48*	*11,199.13*	*1,501.66*	*2,859.77*	*653.62*	*21.75*

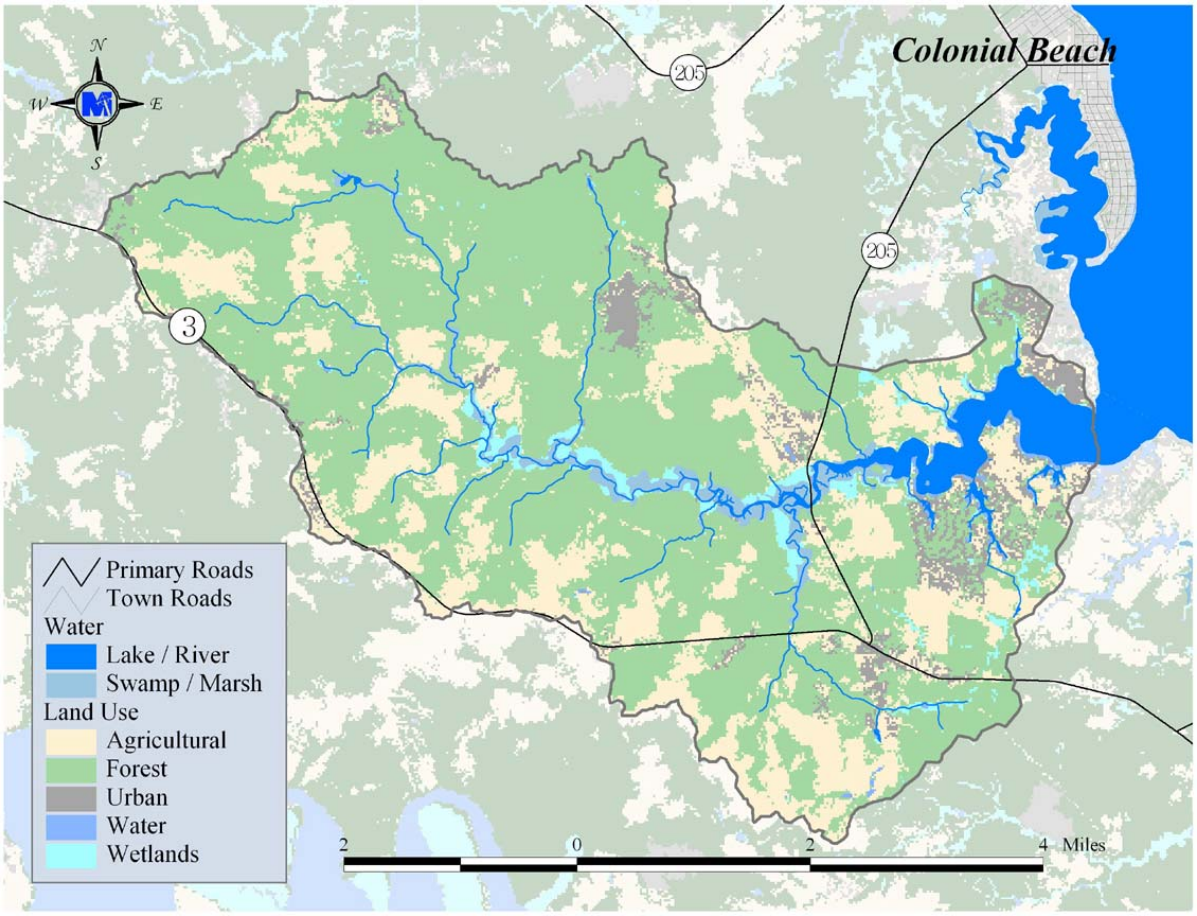

Figure 3.1 Land uses in the Mattox Creek watershed.

The estimated human population within the impaired drainage area in 2006 is 1,336 in the free-flowing segment and 1,763 in the tidal segment. The area also houses 757 dogs (326 in free-flowing segment and 431 in tidal segment) and 847 cats (365 in free-flowing segment and 482 in tidal segment). The counties of King George and Westmoreland are home to numerous species of wildlife, including mammals (*e.g.*, beaver, raccoon, deer) and birds (*e.g.*, duck, wild turkey, goose) (VDGIF, 2006) (Table 3.2).

Table 3.2 Number of wildlife species, mammal types, and bird types inhabiting counties and cities within the Mattox Creek watershed*.

County / City	Number of Wildlife Species	Number of Mammal Types	Number of Bird Types
King George	383	43	192
Westmoreland	382	42	198

*VDGIF, 2006.

For the period from 1963 to 2002, the Colonial Beach area of Virginia received an average annual precipitation of approximately 41.18 inches, with 54% of the precipitation occurring during the May through October growing season (SERCC, 2006). Average annual snowfall is 1.6 inches, with the highest snowfall occurring during December (SERCC, 2006). Average annual daily temperature is 58.5 ºF. The highest average daily temperature of 90.4 ºF occurs in July, while the lowest average daily temperature of 27.1 ºF occurs in January (SERCC, 2006).

3.2 Assessment of Point Sources

In the Mattox Creek watershed, there are two point sources permitted through the Virginia Pollutant Discharge Elimination System (VPDES) (Table 3.3). Figure 3.2 shows 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/100 mL *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 3.3 Summary of VPDES permitted point sources in the Mattox Creek watershed.

Receiving Water	Facility Name	Permit No	Design Flow (MGD)	Permitted For Fecal Control	Data Availability
Mattox Creek UT	Washington District Elementary School	VA0082058	N/A	Yes	5/99 to 1/06
Mattox Creek	Outdoor World Harborview	VA0089087	N/A	Yes	6/99 to 1/06

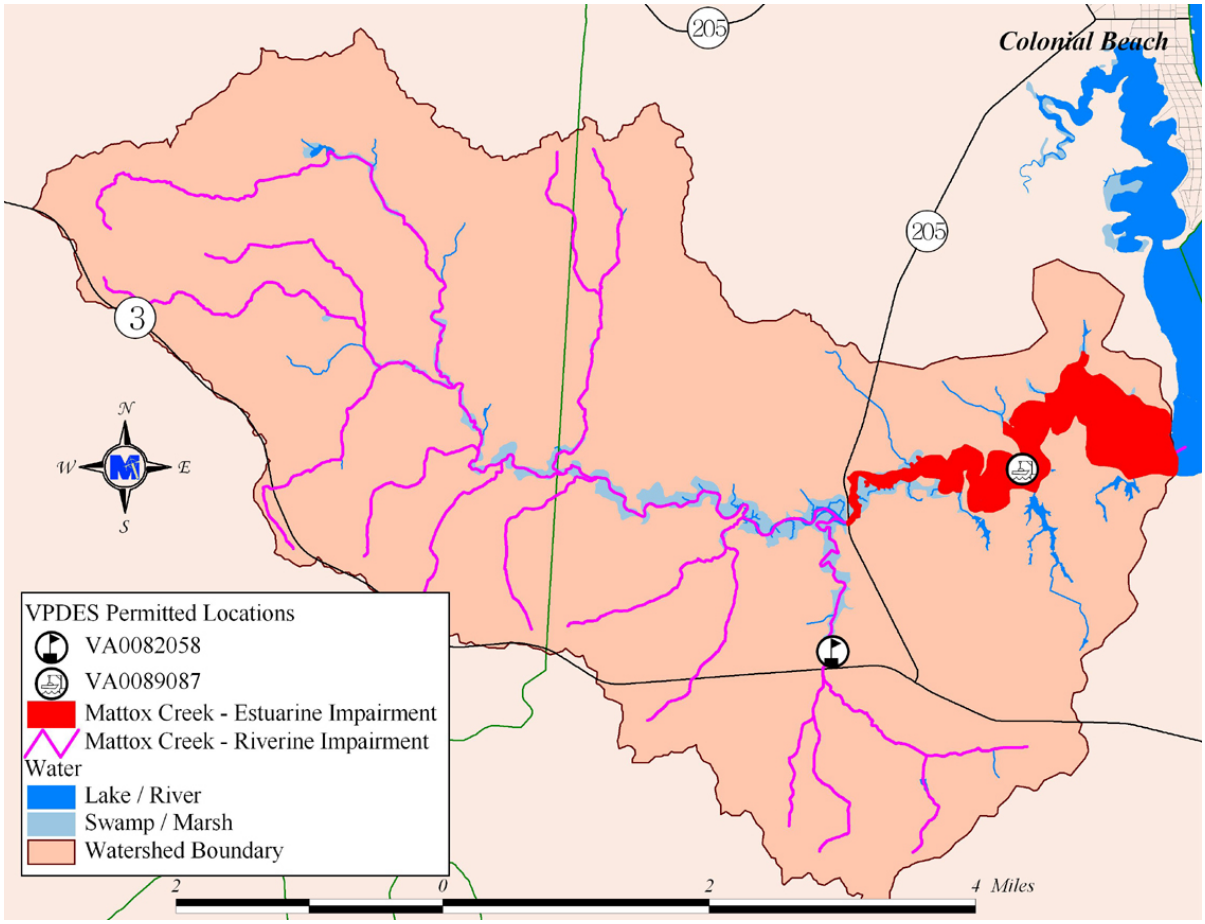

Figure 3.2 Location of VPDES permitted point sources in the Mattox Creek watershed.

3.3 Assessment of Nonpoint Sources

There are no major towns or cities within the Mattox Creek watershed area. Both residential and rural 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 2.4.3.1). 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 3.4).

Table 3.4 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2006 in areas contributing to the impaired segment in Mattox Creek.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Free-flowing segment	1,336	594	0	565	29
Tidal segment	1,763	808	0	793	15

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

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).

3.3.2 Biosolids

Biosolids from five wastewater sources (Tables 3.5 and Table 3.6) have been applied to agricultural lands in the Mattox Creek watershed. Wastewater plants used to supply biosolids to the Mattox Creek watershed are Dale City, Piscataway, Blue Plains, Back River, and Little Falls Run. Between 1997 and 2001, an average of 1,211 and 520 dry tons per year were applied to the free-flowing segment and the tidal segment, respectively. 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 3.5 Source and application of dry biosolids within the Mattox Creek free-flowing segment.

Source of Biosolids	Dry Tons Applied In				
	1997	**1998**	**1999**	**2000**	**2001**
Blue Plains	115.9	295.1	878.1	686.6	429.3
Back River	777.8				126.8
Dale City	321.5	619.1	205.1	486.9	208.7
Piscataway			557.5	252.8	
Little Falls Run					93
Total	1,215.2	914.2	1,640.7	1,426.3	857.8

Table 3.6 Source and application of dry biosolids within the Mattox Creek tidal segment.

Source of Biosolids	Dry Tons Applied In				
	1997	1998	1999	2000	2001
Blue Plains	137.9	269.2	569.2		
Dale City			171.9		
Piscataway		155.2	257.5		
Total	137.9	424.4	998.6		

3.3.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Mattox Creek watershed 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. 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 3.7. Table 3.8 lists the domestic animal populations for impairments in the Mattox Creek watershed.

Table 3.7 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 3.8 Estimated domestic animal populations in areas contributing to impaired segments in the Mattox Creek watershed.

Impaired Segment	Dogs	Cats
Mattox Free-flowing Segment	326	365
Mattox Tidal Segment	431	482

3.3.4 Livestock

The Mattox Creek watershed is not known for being a major producer of livestock. The predominant types of livestock in the watershed are beef and dairy cattle, although all types

of livestock identified were considered in modeling the watershed. There were no Confined Animal Feeding Operations (CAFOs) permitted under Virginia Pollutant Abatement (VPA) regulations. Table 3.9 gives a summary of livestock populations in the Mattox Creek watershed during the period for source assessment, organized by impairment. Animal populations were based on communication with Virginia Cooperative Extension Service (VCE), Natural Resources Conservation Service (NRCS), Northern Neck Soil and Water Conservation District (NNSWCD), Tri-County/City Soil and Water Conservation District (TCCSWCD), local extension agents, and watershed visits. 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 (ASAE, 1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.10.

Table 3.9 Livestock populations in areas contributing to impaired segments in the Mattox Creek watershed.

Impairment	All cattle	Beef	Dairy	Horse	Sheep
Mattox Creek Free-flowing Segment	430	157	150	60	11
Mattox Creek Tidal Segment	60	50	0	13	2
Total	*490*	*207*	*150*	*73*	*13*

Table 3.10 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Beef stocker (850 lb)	51.0	101,000
Beef calf (350 lb)	21.0	101,000
Dairy milker (1,400 lb)	120.4	271,329
Dairy heifer (850 lb)	70.0	271,329
Dairy calf (350 lb)	29.0	271,329
Hog (135 lb)	11.3	400,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000

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 3.11 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.

Table 3.11 Average percentage of collected livestock waste applied throughout year.

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

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 3.15 and 3.16) and local stakeholders. Horses and sheep were assumed to be in pasture 100% of the time.

Based on discussions with SWCD, it was concluded that beef cattle were not expected to make a significant contribution through direct deposition to streams in the upper subwatersheds of the free-flowing segment of the Mattox Creek watershed. Some stream access was still being reported in the lower two subwatersheds of the free-flowing segment and in the tidally influenced subwatershed. Dairy cattle had no access to streams in the Mattox Creek watershed. Table 3.12 shows the breakdown of all beef cattle with regard to stream access by impairment. 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 3.13 and Table 3.14.

Table 3.12 Livestock populations in areas contributing to impaired segments in the Mattox Creek watershed.

Impaired Segment	All Beef
Mattox Creek Free-flowing Segment with access to streams	43
Mattox Creek Free-flowing Segment with no access to streams	217
Mattox Creek Tidal Segment with access to streams	30
Mattox Creek Tidal Segment with no access to streams	30
Total	**320**

Table 3.13 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.5	0.5	0
February	23.5	0.5	0
March	23.1	0.9	0
April	22.3	1.7	0
May	22.3	1.7	0
June	22.0	2.0	0
July	22.0	2.0	0
August	22.0	2.0	0
September	22.3	1.7	0
October	23.1	0.9	0
November	23.1	0.9	0
December	23.5	0.5	0

Table 3.14 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 Mattox Creek watershed 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 3.15 (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 Mattox Creek watershed are reported in Table 3.16. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (USDA Forest Service, 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 3.17 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 3.18.

Table 3.15 Wildlife population density.

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)
0.0287	0.0124	0.0322	0.041	1.2181	0.0239	3.6

Table 3.16 Wildlife populations in the Mattox Creek watershed.

Impairment	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Mattox Free-flowing segment	404	173	75	94	2,812	321	145
Mattox Tidal segment	106	31	56	72	2,132	88	56
Total	510	204	131	166	4,944	409	201

Table 3.17 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 land use areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining land use 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

[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 3.18 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 Mattox Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are six 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

Mattox Creek contains a broad range of hydrologic systems and thus requires a very robust and versatile modeling platform. The upper portion of Mattox Creek and its

tributaries are non-tidal riverine impairments, while the downstream segment is tidally influenced and contains more swampland.

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 both the non-tidal and tidal 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, climate, 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.

4.1.1 Modeling Free-flowing Impairments

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 (IMPLNDs) and pervious land areas (PERLNDs). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses 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.

4.1.2 Modeling Tidal Impairments

The Steady State Tidal Prism Model, which is currently used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. MapTech's implementation of the Tidal Prism Model uses the same basic principle of a control volume with ebb and flood tides based on monitored

tide data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody. Allocations can then be determined based directly on the 90th percentile or geometric mean standard.

4.2 Model Setup

Daily precipitation data was available within the Mattox Creek watershed at the Colonial Beach NCDC Coop station #441913. The few missing values were filled with daily precipitation from nearby NCDC Coop stations. The resulting daily precipitation was disaggregated into hourly precipitation using the distribution from the Williamsburg NCDC Coop station #449151.

To adequately represent the spatial variation in the watershed, the Mattox Creek drainage area was divided into six subwatersheds (Figure 4.1) for the purpose of modeling hydrology. The non-tidal portion of the stream system is represented in subwatersheds 1,2,3,4, and 6, and the tidal portion of Mattox River is subwatershed 4. The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF 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. 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.

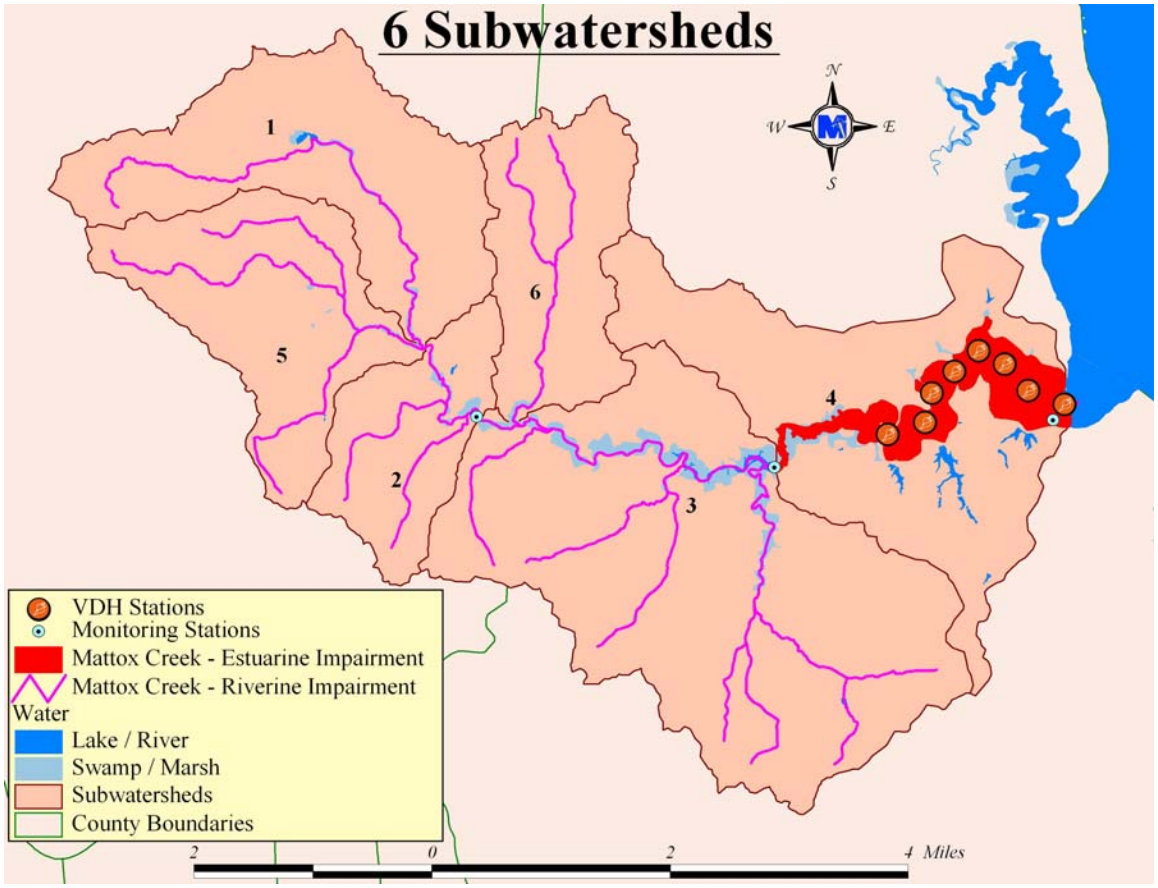

Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations in the Mattox Creek drainage area.

The methodology used to identify the land use types in the Mattox Creek watershed is described in section 3.1. The 12 land use types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 4.1). Within each subwatershed, up to the nine land use types were represented. Each land use 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 4.2 shows the consolidated land use types and the area existing in each impairment. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in four IMPLND types, while there are eight PERLND types, each with parameters describing a particular land use (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 4.1 Consolidation of MRLC land use categories for the Mattox Creek drainage area.

TMDL Land Use Categories	Pervious/Impervious (Percentage)	MRLC Land use Classifications (Class No.)
Water	Impervious (100%)	Open Water (11)
Residential	Pervious (80%) Impervious (20%)	Low Intensity Residential (21)
Commercial and Services	Pervious (50%) Impervious (50%)	Commercial/Industrial/Transportation (23)
Transitional	Pervious (95%) Impervious (5%)	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 4.2 Spatial distribution of land use types in the Mattox Creek watershed.

Impaired Segment	Land use								
	Water (ac)	Residential (ac)	Commercial & Services (ac)	Barren (ac)	Woodland (ac)	Pasture (ac)	Cropland (ac)	Wetlands (ac)	Livestock Access (ac)
Free-flowing segment	56.71	249.75	38.92	98.08	9,732.43	1,094.13	2,160.34	466.36	17.17
Tidal segment	632.05	423.44	30.69	85.4	1,466.70	407.53	699.43	187.26	4.57
Sum	*688.76*	*673.19*	*69.61*	*183.48*	*11,199.13*	*1,501.66*	*2,859.77*	*653.62*	*21.75*

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 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). This data are entered into HSPF via the Hydraulic Function Tables (F-tables). 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.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2006) and Digital Elevation Models (DEM) was used. The NRCS has developed an empirical formula for estimating stream top width, cross-sectional area, average depth, and flow rate, all as functions of the drainage area. Estimates were obtained at the outlet of each subwatershed. Using the NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams. However, the F-table is supposed to cover the floodplains. The floodplain information was obtained from the DEM. A profile perpendicular to the channel was generated showing the floodplain height with distance for each subwatershed outlet. An example of this profile is given in Figure 4.2. Consecutive entries to the F-table are generated by estimating the volume of

water and surface area in the reach at incremental depths (where depths are taken from the outlet profile, e.g. Figure 4.2).

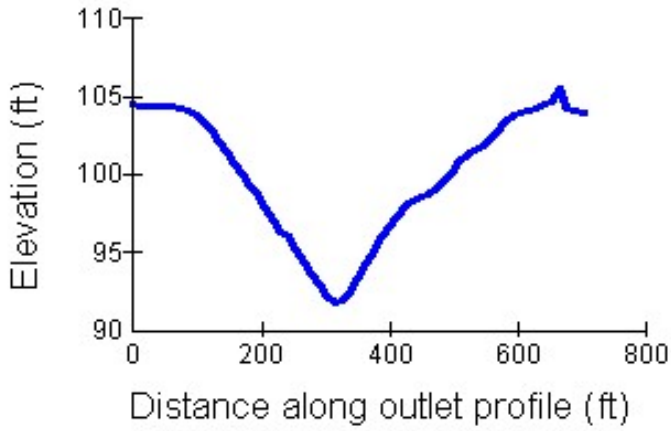

Figure 4.2 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with values for resistance to flow (Manning's *n*) assigned based on recommendations by Brater and King (1976) and shown in Table 4.3. 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). 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 based on National Hydrography Dataset (NHD) Data. 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. An example of an F-table used in HSPF is shown in Table 4.4.

Table 4.3 Summary of Manning's roughness coefficients for channel cells*.

Section	Upstream Area (ha)	Manning's *n*
Intermittent stream	18 - 360	0.06
Perennial stream	360 and up	0.05

*Brater and King (1976)

Table 4.4 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

4.4 Selection of Representative Modeling Period

Selection of the representative modeling periods was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrologic conditions. Modeling periods were selected for hydrology calibration, water quality calibration and validation, and modeling of allocation scenarios. Since there are no discharge data available for Mattox Creek, a paired watershed approach was used to set initial parameters for the model. The modeling period was selected to include the VADEQ assessment period from July 1990 through June 2003 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.

As shown in the critical conditions section (section 2.3, Figure 2.1), there is no critical flow level at VADEQ Station 1-AMAO004.08, where bacteria data was collected. This indicates that the modeling time periods must include low and high stream flow regimes.

In order to select a modeling period representative of the critical hydrological condition from the available data, the mean daily precipitation for each season was calculated for the period 1900 through 2004. The results of this analysis for the period 1970 through 2004 are shown in Figures 4.3 through 4.4. This resulted in 90 observations of 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 precipitation 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 (Table 4.5). Therefore, the period was selected

as representing the hydrologic regime of the watershed, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for hydrologic calibration was October 1991 to September 1995. For hydrologic validation, the period selected was October 1995 to September 1999.

Figure 4.3 Annual Historical Precipitation (Colonial Beach NCDC Station 441913) Data

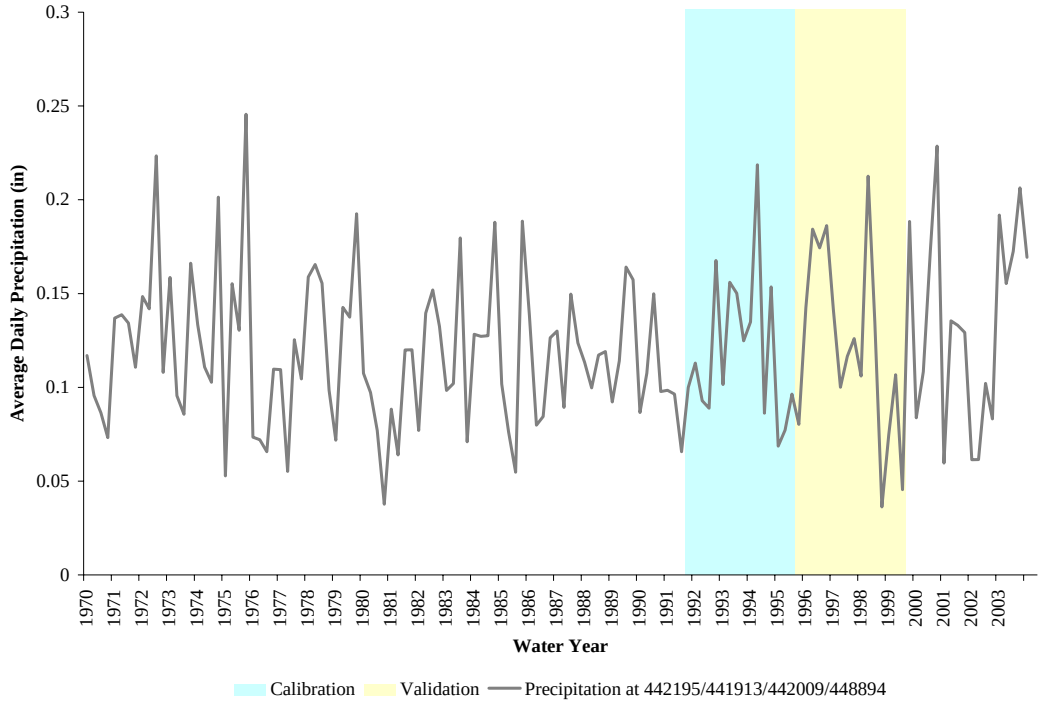

Figure 4.4 Seasonal Historical Precipitation (Colonial Beach NCDC Station 441913) Data

Table 4.5 Comparison of modeled period to historical record.

	Precipitation (441913)			
	Fall	**Winter**	**Summer**	**Spring**
	Historical Record (1900 - 2004)			
Mean	0.099	0.108	0.114	0.130
Variance	0.001	0.001	0.001	0.002
	Calibration and Validation Time Periods (10/91 - 9/95; 10/95 - 9/99)			
Mean	0.110	0.144	0.112	0.133
Variance	0.001	0.003	0.002	0.003
	p-values			
Mean	0.150	0.043	0.443	0.433
Variance	0.456	0.019	0.165	0.321

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 (10/1/1992 to 9/30/1997), was chosen as the calibration period for the free flowing segment. This period contained 35 water quality data points from VADEQ

stations 1-AMAO007.46 and 1-AMAO004.08. The period from 10/1/1997 to 9/30/2001 was chosen as the validation period, with 23 data points from the water quality sampling stations. The period selected for modeling of allocation scenarios was the water quality calibration period.

The period from 10/1/1996 to 9/30/1999 was selected for water quality calibration for the tidal segment of Mattox Creek. This period contained 48 observed data points from the VADEQ station 1-AMAO000.42 and the 8 VDH stations. For each sampling date, readings from all VDH stations within Mattox Creek and the EQ station 1-AMAO000.42 were averaged to obtain a representative value for the entire tidal segment. The selection of this period was restricted by the availability of tide stage data from the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services CO-OPS) station number 8635750 at Lewisetta, VA. The period from 10/1/1999 to 9/30/2002 was chosen as the validation period, with 34 data points from the VADEQ and VDH water quality sampling stations. The period selected for modeling of allocation scenarios was the water quality calibration period.

4.5 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 land use 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 time frame of the simulation being run, different numbers should be used. Data representing 1995 were used for the water quality calibration period (1993-1997) and data representing 1999 were used for validation period (1998-2001). Data representing 2006 were used for the allocation runs in order to represent existing conditions.

4.5.1 Point Sources

There are two point discharges in the Mattox Creek watershed permitted for fecal control (see Table 3.3). The Washington District Elementary School is located in the free-flowing segment and the Outdoor World Harborview is located in the tidal segment. No design flow capacity was available for those facilities and, therefore, the long-term average flow was used for Washington District Elementary School for the allocation run. For the Outdoor World Harborview, the maximum annual load was used since more detailed data was available for this facility. 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 the Washington District Elementary School, the available Discharge Monitoring Report (DMR) records were used for calibration and current condition runs. However, records for the Outdoor World Harborview only had flow data in the DMR; therefore, 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 stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.5.2 Private Residential Sewage Treatment

The numbers of septic systems in the free-flowing segment and the tidal segment of the Mattox Creek watershed modeled for water quality were calculated by overlaying U.S.

Census Bureau data (USCB, 1990; USCB, 2000) with the watersheds to enumerate the septic systems. Each residential land use area was assigned a number of septic systems based on census data. A total of 438 septic systems were estimated for the free-flowing segment of the Mattox Creek watershed, while the tidal segment included 668 failing septic systems in 1993. During allocation runs, the number of households was projected to 2006, based on current growth rates (USCB, 2000), resulting in 565 septic systems in the free-flowing segment and 793 septic systems in the tidal segment (Table 4.6). The number of septic systems was projected to increase to 623 septic systems in the free-flowing segment and 850 in the tidal segment by 2011.

Table 4.6 Estimated failing septic systems in 2006.

Impaired Segment	Septic Systems	Failing Septic Systems	Uncontrolled Discharges
Mattox – Free-flowing Segment	565	101	29
Mattox – Tidal Segment	793	143	15
Total	1,358	244	44

4.5.2.1 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 Mattox Creek watershed. The 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 density of people per household on a subwatershed basis 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.

4.5.2.2 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 of 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 waste load 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.

4.5.3 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. The numbers are based on data provided by VCE, NNSSWCD, and TCCSWCD as well as taking into account growth rates in King George and Westmoreland counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1992; VASS, 2002). Based on feedback from the soil and water conservation districts, livestock populations are steady and, therefore, the same populations were used for various modeling periods. 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.

4.5.3.1 Land Application of Collected Manure

Collection of livestock manure occurs on farms for dairy, beef, and horse. 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.

4.5.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a portion of the total waste produced per day. The portion 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 portion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

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

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

4.5.3.3 Direct Deposition to Streams

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

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

It was determined based on feedback from the Northern Neck and Tri-County/City Soil and Water Conservation districts that beef cattle has no access to streams in subwatersheds 1, 2, and 5. It was assumed that 50% of the beef cattle has access to streams in subwatersheds 3, 4 (tidal segment), and 6. Beef cattle were assumed to have no access to marshes and wetlands.

All adult dairy cows were assumed to be in confinement and therefore have no access to streams.

4.5.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the Mattox Creek watershed. 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. The available 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. Application data were available for the entire validation period with partial data available for the calibration period. During both model calibration and allocation runs, biosolids were modeled as having a fecal concentration of 157,835 cfu/g, the mean value of measured biosolids concentrations observed in several years of samples supplied by VDH for sources applied during 2001 to 2005. Applications were modeled as being spread onto the land surface over a six-hour period on the date of reported application. 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 doubling biosolids application increased the monthly geometric mean of *E. coli* between 0.36% and 9.88%. The total loading sensitivity analysis (see section 4.6.2, Figure 4.9) 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.

4.5.5 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 4.5. This layer was used in conjunction with the land use layer and the resulting area was calculated for each land use 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 waste load, fecal coliform densities, and number of animals for each species.

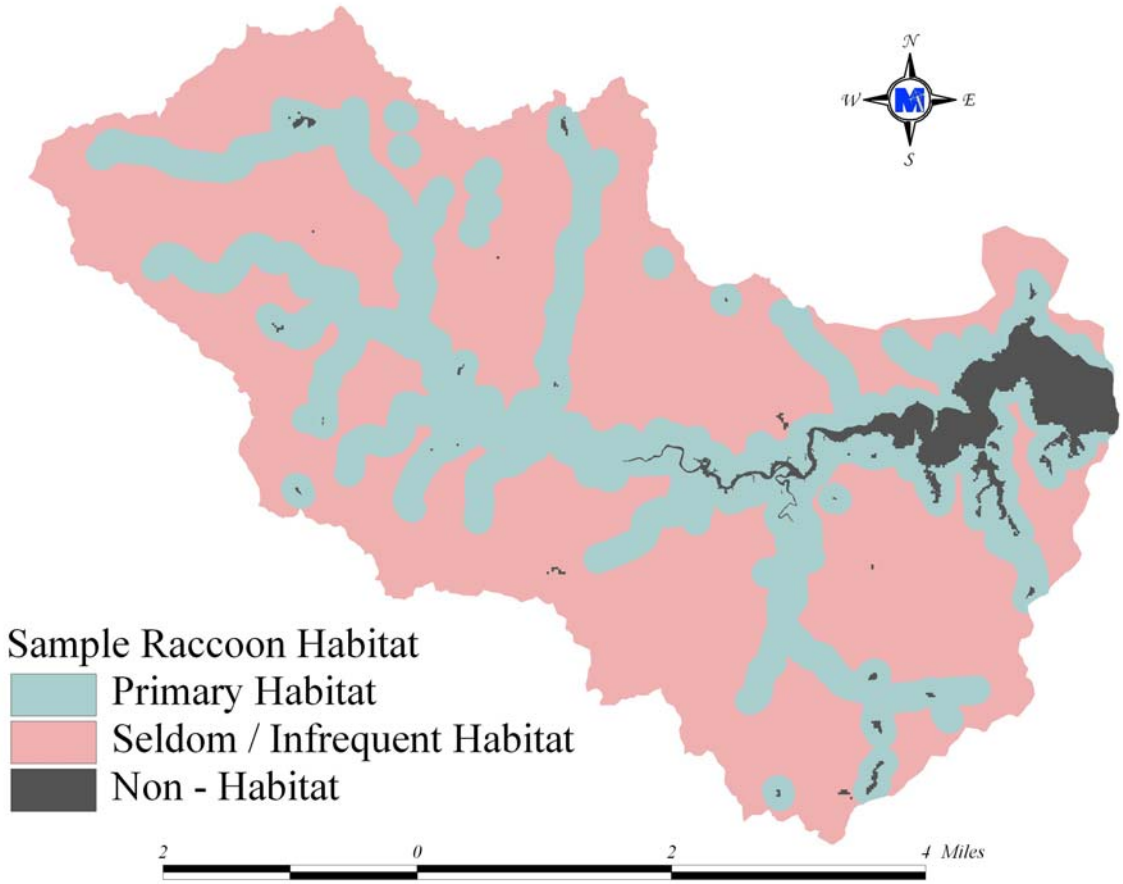

Figure 4.5 Example of raccoon habitat layer in the Mattox Creek watershed, as developed by MapTech.

Goose and duck waste loads 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 waste load 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 3.14). 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 (1992–2006) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.5.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), waste load, and fecal coliform density are reported in section 3.3.3. Waste from pets was distributed on residential land uses. The locations of households were taken from the 1990 and 2000 Census (USCB, 1990 and USCB, 2000). The land use and household layers were overlaid, which resulted in the number of households per land use. The number of animals per land use was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1995 and 2006 to coincide with modeling periods.

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 4.7, 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 1992-1995. 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 groundwater transport such as DEEPFR (Deep Recharge), AGWRC (Groundwater Recession Rate), LZSN (Lower Zone Storage), and UZSN (Upper Zone Storage), and to a lesser extent by INFILT (Infiltration) which governs infiltration, 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 DEEPFR, AGWRC, LZETP and INFILT. The responses of these and other hydrologic outputs are reported in Table 4.8.

Table 4.7 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	12.250-15.512
INFILT	Soil Infiltration Capacity	in/hr	0.0447-0.2070
AGWRC	Groundwater Recession Rate	---	0.98
BASETP	Base Flow Evapotranspiration	---	0.01
INTFW	Interflow Inflow	---	1.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.01
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.01-0.2
MON-UZSN	Monthly Upper Zone Nominal Storage	in	1.2250-1.5512
MON-MANNING	Monthly Manning's *n* for Overland Flow	---	0.05-0.37
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.1-0.8

Table 4.8 HSPF sensitivity analysis results for hydrologic model parameters.

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	0.24	10.32	-38.72	4.38	-18.61	-5.89	17.98	4.32
AGWRC[1]	0.92	0.12	5.32	-21.78	3.60	-12.29	-7.63	11.68	3.14
AGWRC[1]	0.96	0.02	0.82	-3.85	0.93	-2.09	-2.83	1.92	0.31
AGWRC[1]	0.999	-28.01	-22.57	-7.75	-36.19	-36.17	26.93	-22.65	-27.82
BASETP	-50	0.50	-0.29	3.66	-0.14	1.19	3.86	-0.45	-0.66
BASETP	-10	0.09	-0.06	0.69	-0.03	0.24	0.69	-0.09	-0.07
BASETP	10	-0.10	0.06	-0.72	0.03	-0.24	-0.75	0.09	0.09
BASETP	50	-0.47	0.29	-3.54	0.13	-1.19	-3.64	0.46	0.42
DEEPFR	-50	-6.25	-3.28	-10.12	-5.37	-7.46	-7.89	-6.06	-5.90
DEEPFR	-10	-15.61	-8.14	-25.42	-13.44	-18.64	-19.68	-15.15	-14.70
DEEPFR	10	-31.20	-16.05	-51.10	-26.87	-37.27	-39.09	-30.27	-29.46
DEEPFR	50	-60.73	-31.61	-98.56	-53.74	-71.71	-68.58	-60.04	-58.99
INFILT	-50	-1.78	11.57	-22.28	2.07	-9.94	-13.31	4.94	-0.05
INFILT	-10	-0.32	1.71	-3.65	0.38	-1.64	-2.39	0.64	-0.03
INFILT	10	0.31	-1.55	3.40	-0.37	1.55	2.24	-0.53	0.04
INFILT	50	1.50	-6.45	15.09	-1.72	7.01	10.41	-1.95	0.38
INTFW	10	0.04	0.15	-0.17	0.07	-0.05	0.00	0.08	0.04
INTFW	50	0.14	0.60	-0.65	0.28	-0.22	-0.01	0.31	0.17
INTFW	100	0.21	1.01	-1.02	0.45	-0.39	-0.05	0.52	0.25
INTFW	200	0.28	1.50	-1.42	0.65	-0.62	-0.10	0.75	0.34
LZSN	-50	6.74	15.53	-4.52	10.45	-2.15	-12.16	18.39	6.43
LZSN	-10	0.90	2.10	-1.27	1.79	-0.10	-2.69	1.75	0.84
LZSN	10	-0.82	-1.81	1.15	-1.68	0.01	2.37	-1.26	-0.91
LZSN	50	-3.66	-7.41	4.19	-7.41	-0.79	8.81	-3.94	-4.15
MON-INTERCEP	-50	2.62	0.12	10.52	0.56	5.57	9.85	0.43	1.81
MON-INTERCEP	-10	0.42	-0.02	1.94	0.10	0.95	2.08	-0.28	0.27
MON-INTERCEP	10	-0.37	-0.02	-1.59	-0.11	-0.85	-1.75	0.26	-0.23
MON-INTERCEP	50	-1.91	-0.07	-7.97	-0.41	-4.26	-7.92	0.32	-1.41
MON-LZETP	-50	13.61	10.46	28.03	7.55	0.78	35.27	35.94	8.87
MON-LZETP	-10	1.27	0.96	2.48	0.85	0.21	2.54	3.16	0.92
MON-LZETP	10	-1.17	-0.89	-2.33	-0.79	-0.19	-2.29	-2.89	-0.94
MON-LZETP	50	-6.45	-4.94	-12.61	-4.48	-1.00	-12.54	-15.89	-5.71
MON-MANNING	-50	0.07	0.94	-0.54	0.21	-0.38	-0.16	0.45	0.08
MON-MANNING	-10	0.01	0.12	-0.06	0.02	-0.04	-0.02	0.07	0.01
MON-MANNING	10	-0.01	-0.09	0.05	-0.02	0.03	0.01	-0.04	-0.01
MON-MANNING	50	-0.03	-0.42	0.22	-0.04	0.13	0.06	-0.27	-0.04
MON-UZSN	-50	5.43	13.14	-3.50	8.05	-1.67	5.02	8.47	5.56
MON-UZSN	-10	0.82	1.89	-0.70	1.43	-0.27	0.20	1.01	0.88
MON-UZSN	10	-0.74	-1.66	0.67	-1.33	0.23	-0.03	-0.89	-0.81
MON-UZSN	50	-3.20	-7.07	3.27	-6.20	0.54	0.60	-2.40	-3.47

[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 1997, and model parameters established for 1995 conditions. (See section 4.4 for a complete explanation of selected model time periods.) The three HSPF parameters impacting the model's water quality response were increased and decreased by amounts that were consistent with the range of values for the parameter (Table 4.9). FSTDEC (First Order Decay) was the parameter with the greatest influence on monthly geometric mean concentration, although MON-SQOLIM and WSQOP also showed significant potential to influence this value (Table 4.10). Graphical depictions of the results of this sensitivity analysis can be seen in Figures 4.6 through 4.8.

Table 4.9 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0-1.8E+11
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0-1.4
FSTDEC	In-stream First Order Decay Rate	1/day	4.00

Table 4.10 Percent change in average monthly *E. coli* geometric mean for the years 1992-1997.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1992-1997											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	63.97	61.80	62.88	64.17	62.05	61.24	61.70	58.90	56.22	62.44	63.12	61.88
FSTDEC	-10	8.79	8.56	8.68	8.81	8.56	8.52	8.55	8.23	7.91	8.61	8.70	8.57
FSTDEC	10	-7.58	-7.41	-7.50	-7.60	-7.39	-7.38	-7.40	-7.15	-6.89	-7.44	-7.52	-7.42
FSTDEC	50	-29.66	-29.14	-29.47	-29.76	-29.02	-29.08	-29.11	-28.30	-27.38	-29.22	-29.50	-29.16
MON-SQOLIM	-50	-7.16	-4.58	-5.07	-4.85	-5.34	-3.54	-3.98	-2.35	-2.21	-5.18	-7.20	-5.65
MON-SQOLIM	-25	-3.24	-2.04	-2.03	-1.90	-2.17	-1.55	-1.85	-1.05	-0.89	-2.13	-3.04	-2.56
MON-SQOLIM	50	3.07	1.86	1.67	1.53	1.71	1.26	1.59	0.91	0.73	1.85	2.80	2.55
MON-SQOLIM	100	10.05	6.39	5.36	4.65	5.16	3.87	5.16	2.96	2.32	6.14	9.16	8.44
WSQOP	-50	6.46	6.43	6.04	5.09	7.00	3.64	3.71	1.81	2.32	6.62	8.54	5.78
WSQOP	-10	0.78	0.73	0.71	0.58	0.73	0.37	0.40	0.21	0.22	0.68	0.86	0.61
WSQOP	10	-1.02	-1.05	-1.13	-0.92	-1.15	-0.56	-0.58	-0.30	-0.35	-1.10	-1.35	-0.86
WSQOP	50	-3.57	-3.56	-3.96	-3.20	-3.79	-1.80	-1.95	-1.04	-1.12	-3.62	-4.36	-2.85

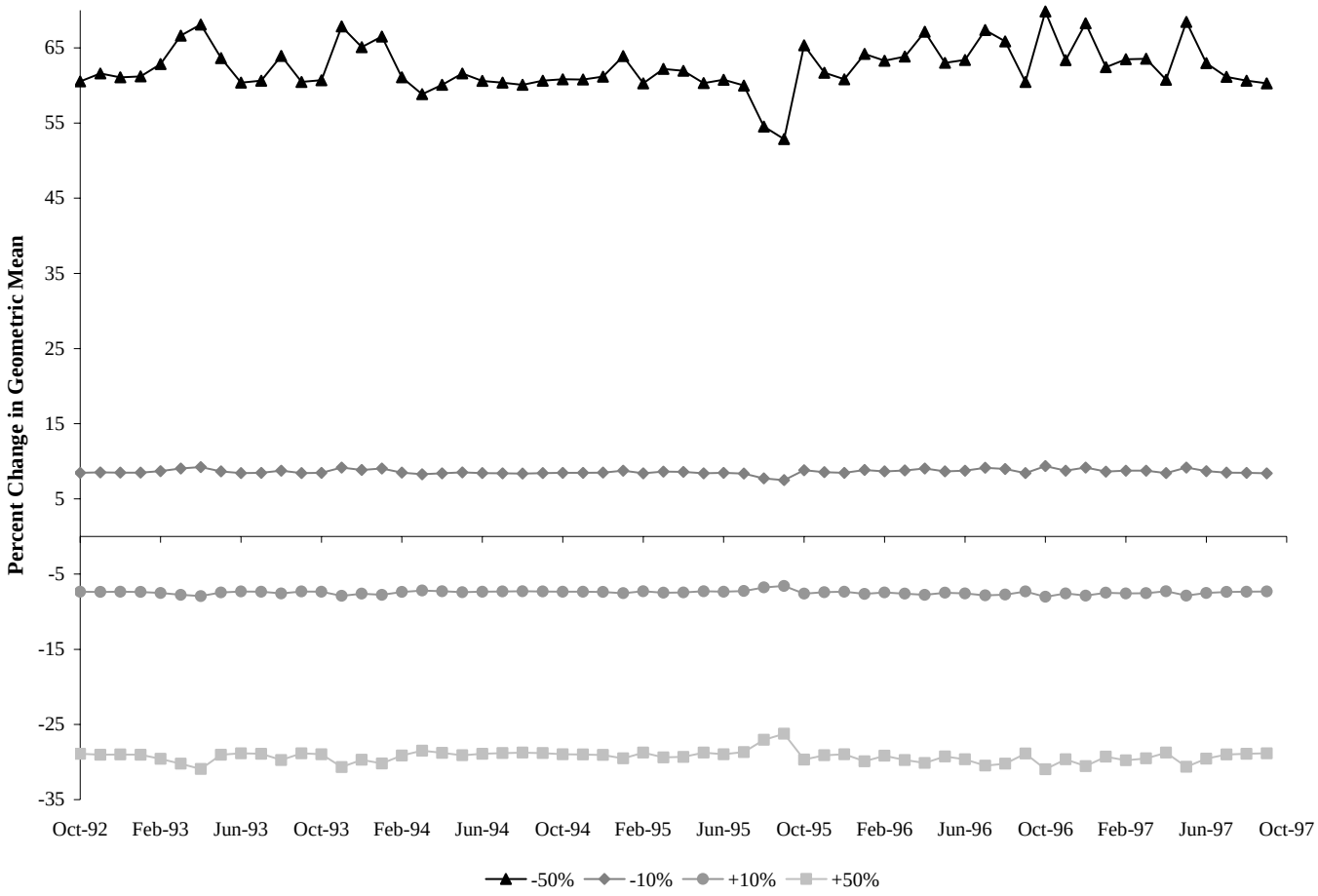

Figure 4.6 Results of sensitivity analysis on monthly geometric-mean concentrations, as affected by changes in the in-stream first-order decay rate (FSTDEC).

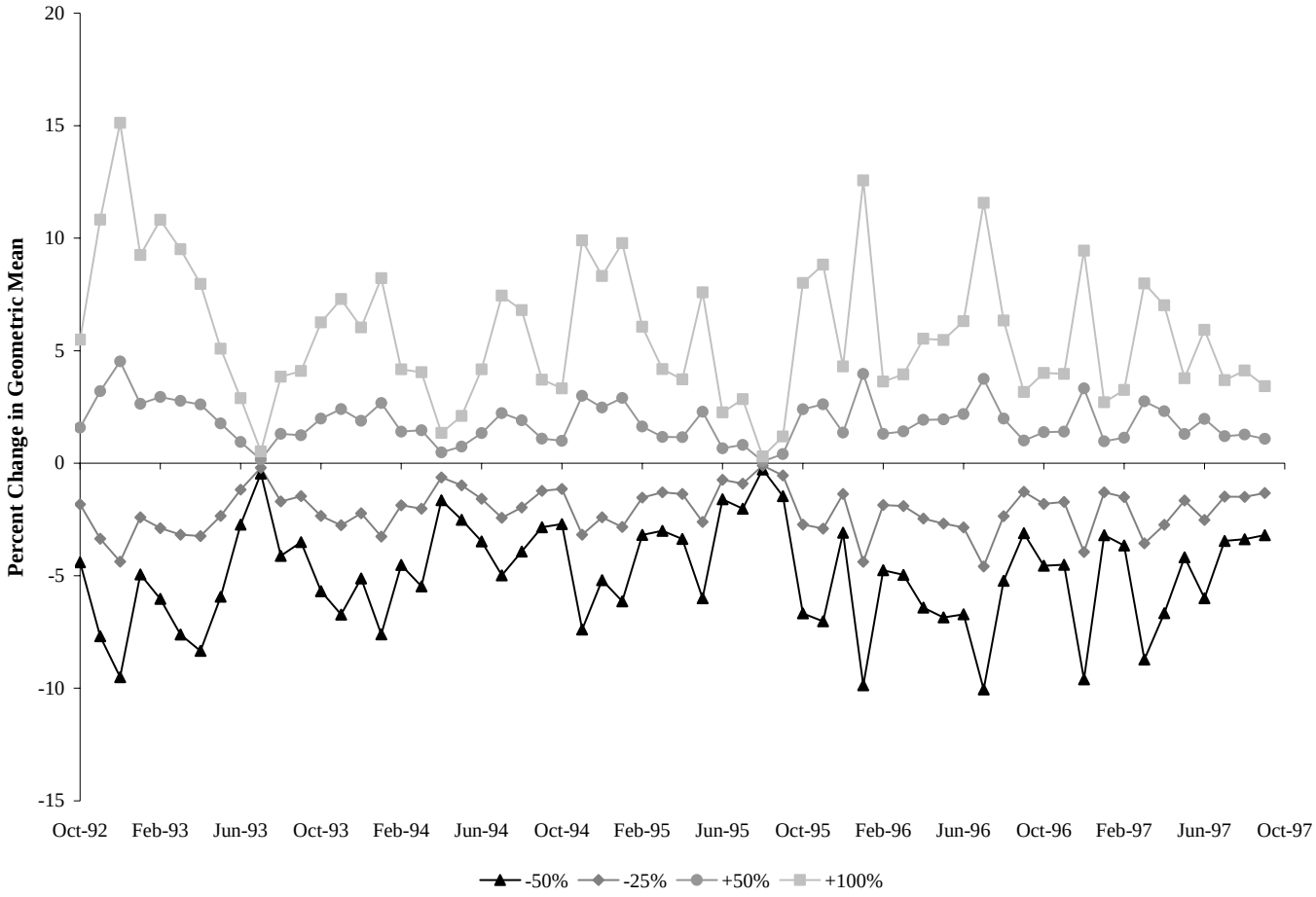

Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

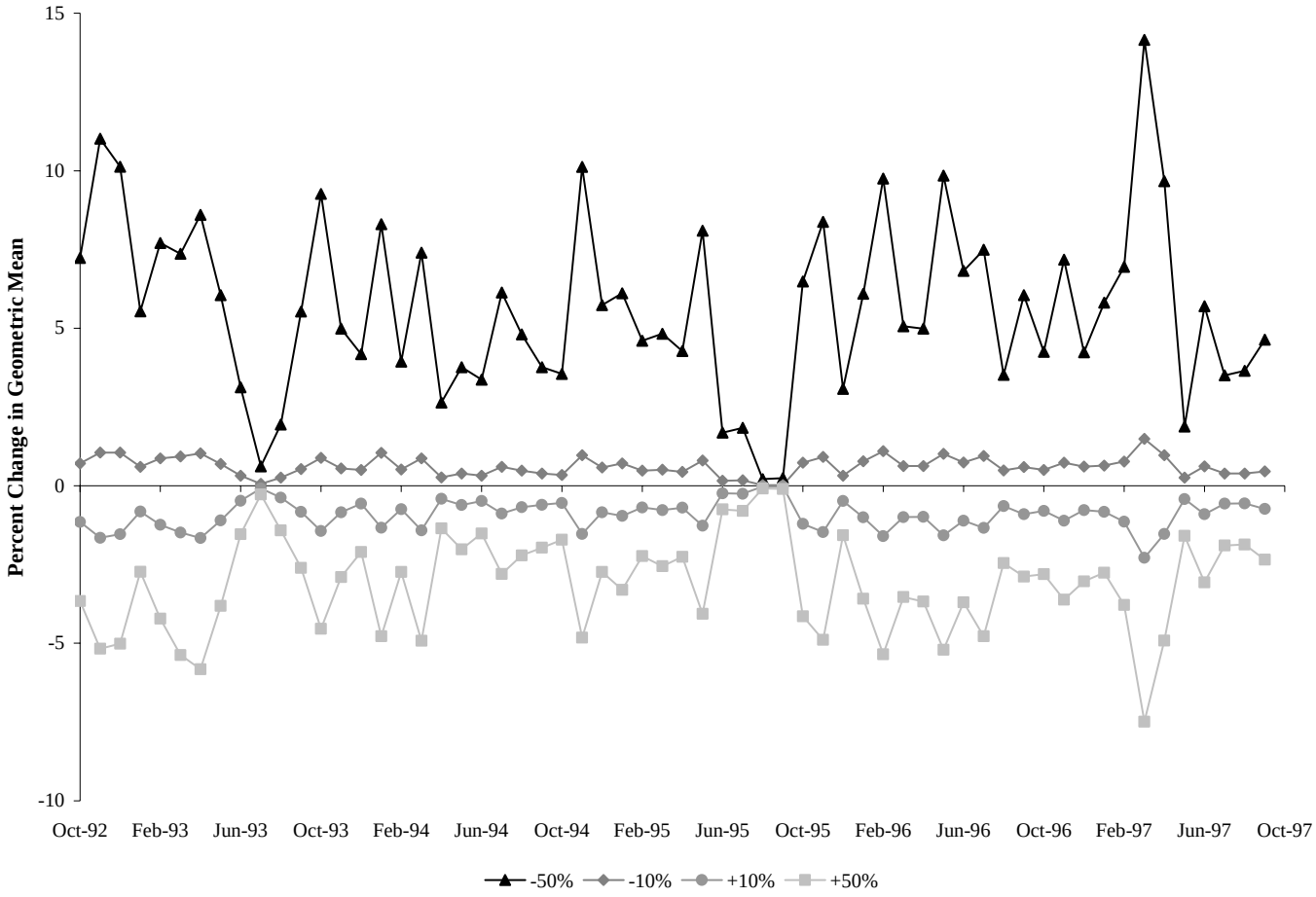

Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations, as affected by changes in the wash-off rate from land surfaces (WSQOP).

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 Figure 4.9 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 between land applied and direct loadings; a 100% increase in the land applied loads results in an increase of over 60% in stream loads, while a 100% increase in direct loads results in less than a 5% increase in stream loads. However, the sensitivity analysis of geometric mean concentrations showed that direct loads had a considerable impact, with land applied loads having a lesser, but still significant impact (Figures 4.10 and 4.11).

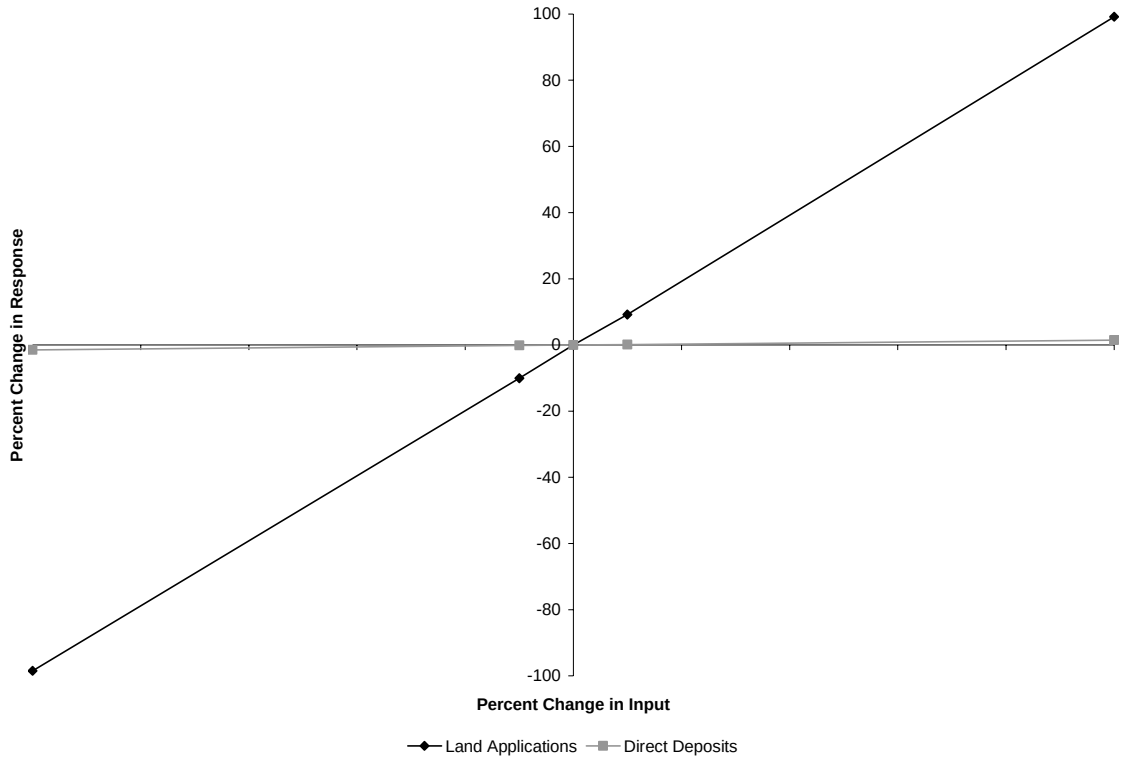

Figure 4.9 Results of total loading sensitivity analysis.

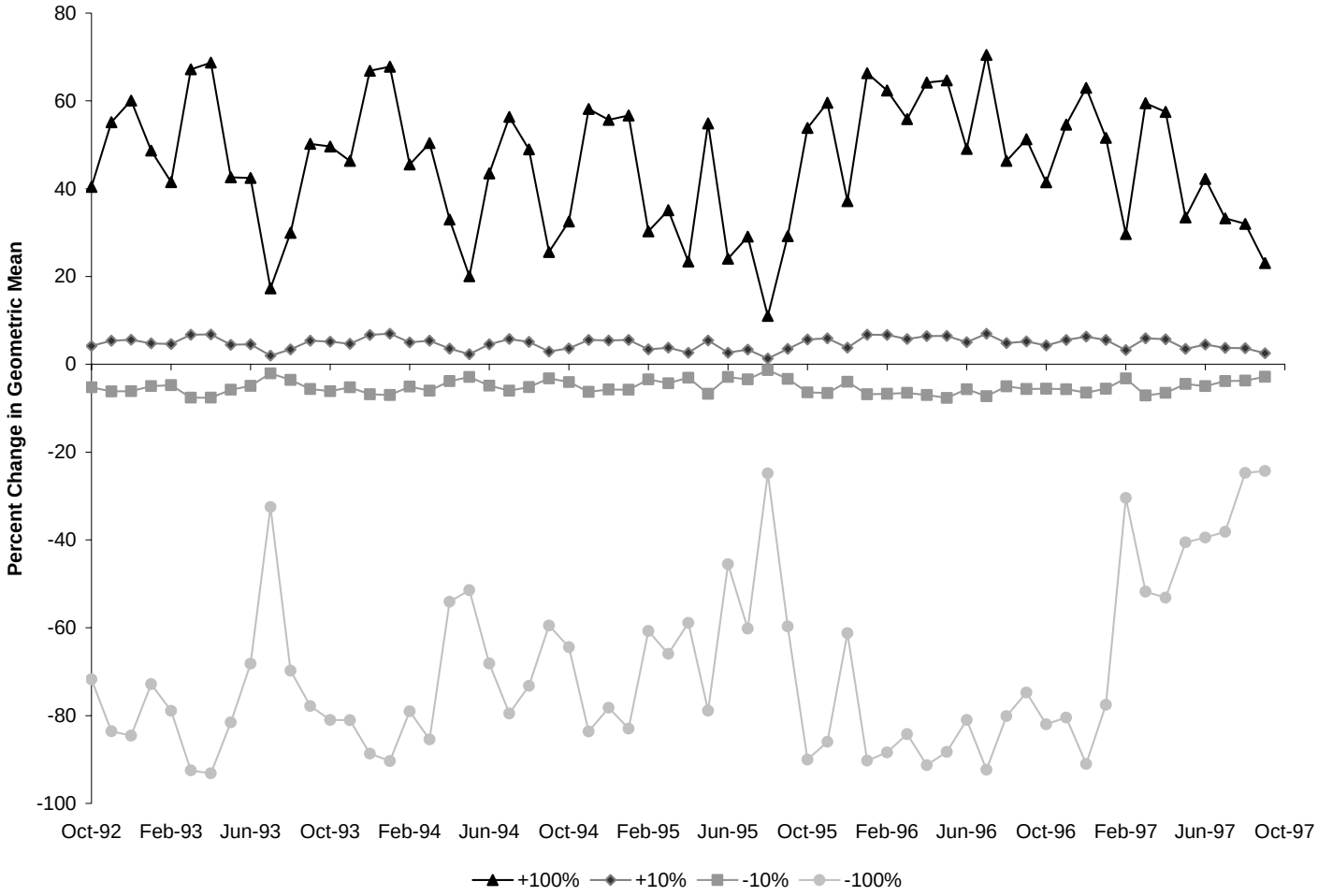

Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations as affected by changes in land-based loadings.

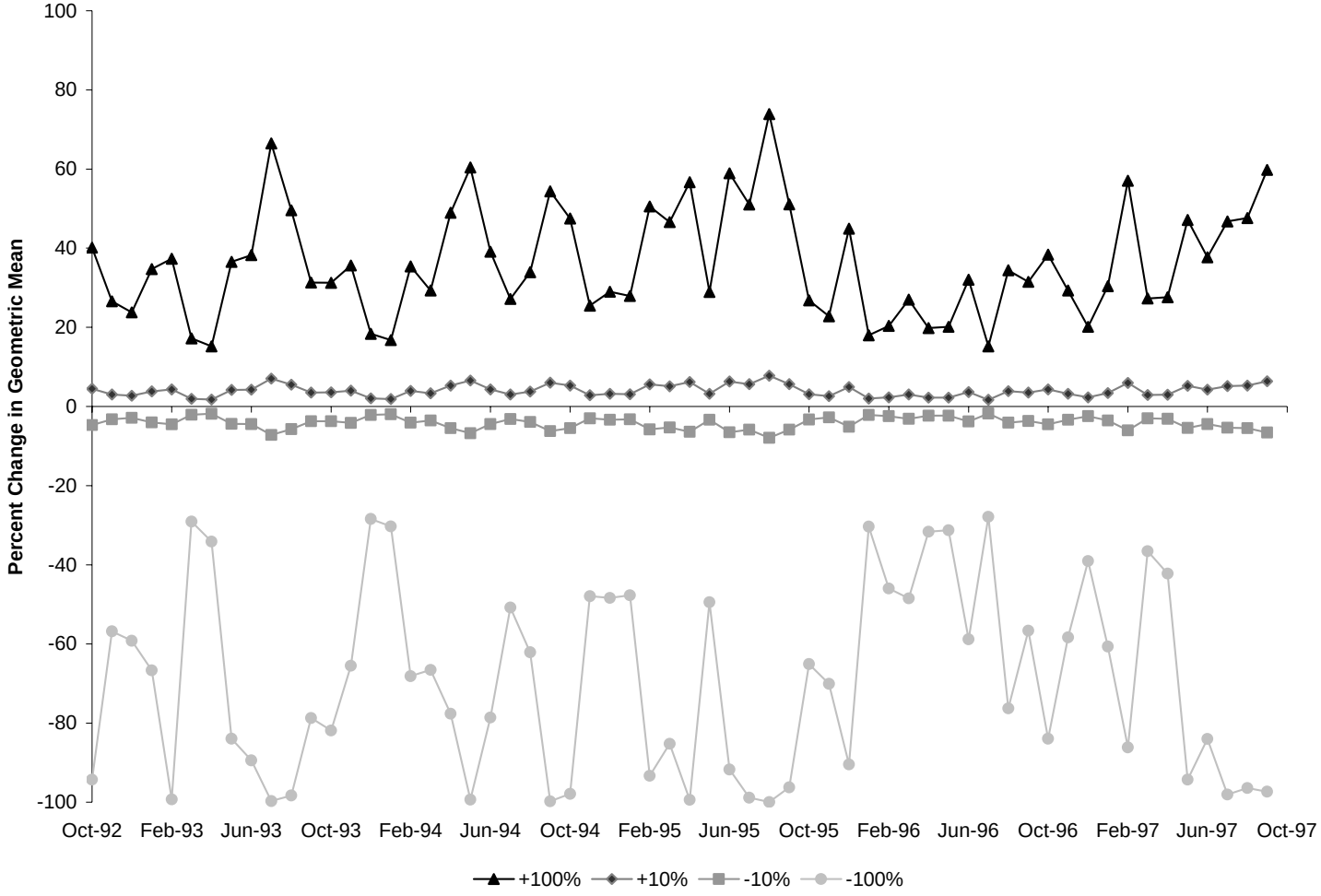

Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations as affected by changes in loadings from direct nonpoint sources.

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. Due to the lack of continuous stream flow data for Mattox Creek, the model's hydrologic parameters were set based on a paired watershed analysis, with consideration for available soils, land use, and topographic data. Qualities of fecal coliform sources were modeled as described in section 4.5. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

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. During validation, no adjustments are made to model parameters. The goal of validation is to assess the capability of the model in hydrologic conditions other than those used during calibration.

4.7.1 Hydrologic Calibration

The paired watershed approach was used to calibrate the HSPF model. Through this approach, the HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow is available. The changes between the initial estimated and final calibrated parameters from the paired watershed model (*e.g.*, lower zone storage) are noted. Then the estimated parameters in the impaired watershed HSPF model are changed by the same percentages.

There are many factors to consider when finding a best-fit paired watershed. Drainage area, shape, proximity to the impaired watershed, land use, hydrologic soil group, ecoregion, and slope are among the most important. Several watersheds were compared with Mattox Creek watershed and, in consultation with VADEQ, Piscataway Creek in Essex County, Virginia was selected as the paired watershed.

The Piscataway Creek watershed is similar in size to the Mattox Creek watershed and is located in the same ecoregion (Southeastern Plains). The two watersheds have similar soils, climate, geology, and land use, and the Piscataway Creek gaging station was chosen to

develop the surrogate hydrology model for Mattox Creek. The hydrologic comparison of the watersheds was established by examining the land use distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group.

The first action taken to implement the paired watershed approach was examining the similarities between the Piscataway Creek and Mattox Creek watersheds. The land use distribution is shown in Table 4.11. The four major land use categories were Agricultural, Urban, Natural, and Other. The natural land use category included forested and wetlands areas, which accounted for 72% of the Piscataway Creek watershed and 66% of the Mattox Creek watershed.

Table 4.11 Land use distribution for Mattox Creek and Piscataway Creek watersheds.

Land use Categories	Land use	Mattox Creek		Piscataway Creek	
		acres	%	acres	%
Agricultural	Cropland and Pasture	4,413	24.73	4339	26.62
Urban	Commercial and Residential	744	4.16	19	0.12
Natural	Forest and Wetlands	11,824	66.25	11,677	71.63
Other	Water and Transitional	868	4.86	267	1.63
Total		**17,849**	**100**	**16,302**	**100**

The soil hydrologic groups in both watersheds were examined. The soils present in the Mattox Creek watershed consist of clay loam and fine sandy loam; the soils in the Piscataway Creek watershed consist of fine sandy loam. Based on the hydrologic soil group classification, the soil series present in the two watersheds predominantly range from “B” to “C”, with "C" being the predominant series in Mattox Creek, and “B” the predominant series in Piscataway Creek.

Watershed characteristics of Mattox Creek and Piscataway Creek, including the drainage area, channel slope, channel length, and the drainage density, were compared. The data,

presented in Table 4.12, indicates that these physical characteristics of the watershed are similar.

Table 4.12 Comparison of Mattox Creek and Piscataway Creek watershed characteristics.

Watershed	Drainage Area (acre)	Channel Slope (degrees)	Channel Length (ft)	Drainage Density (ft/acre)
Mattox Creek	17,849	2.02	411,712	23.1
Piscataway Creek	16,302	3.11	382,273	23.4

Based on the land use distribution, soil types, and the watershed's physical characteristics, the Piscataway Creek watershed is hydrologically similar to the Mattox Creek watershed. An HSPF model was calibrated and validated for the Piscataway Creek watershed using daily continuous stream flow data from USGS station #01669000 (Piscataway Creek near Tappahannock, VA) and precipitation data from Colonial Beach NCDC Coop station #441913.

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), interflow (IRC), 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 (DEEPFR), active groundwater storage PET (AGWETP), and Manning's *n* for overland flow plane (NSUR). Table 4.13 contains the typical range for these 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.

Table 4.13 Model parameters utilized for hydrologic calibration of Piscataway Creek.

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	15.00	5.25
INFILT	in/hr	0.001 – 0.50	0.1242-0.2070	0.0745-0.1242
LSUR	ft	100 – 700	210.38-675.18	210.38-675.18
SLSUR	---	0.001 – 0.30	0.0355-0.0679	0.0355-0.0679
KVARY	l/in	0.0 – 5.0	0.0	0.0
AGWRC	l/day	0.85 – 0.999	0.98	0.965
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	0.00
BASETP	---	0.0 – 0.20	0.01	0.01
AGWETP	---	0.0 – 0.20	0.0	0.0 – 0.1
CEPSC	in	0.01 - 0.40	0.01 – 0.20	0.01 – 0.40
UZSN	in	0.05 – 2.0	0.05–1.65	1.36– 2.33
NSUR	---	0.10 – 0.50	0.01 – 0.50	0.01 – 0.44
INTFW	---	1.0 – 10.0	1	3.5
IRC	l/day	0.30 – 0.85	0.5	0.4
LZETP	---	0.1 – 0.9	0.0 – 0.8	0.0 – 0.7
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

The results of hydrology calibration for Piscataway Creek are presented in Table 4.14 and Figures 4.12 through 4.14. Table 4.14 shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating a well-calibrated model.

Table 4.14 Hydrology calibration criteria and model performance for period 10/1/1991 through 9/30/1995 at USGS Gaging Station 01669000 on Piscataway Creek.

Criterion	Observed	Modeled	Error
Total In-stream Flow	53.14	52.32	-1.55%
Upper 10% Flow Values	17.45	18.17	4.13%
Lower 50% Flow Values	11.17	10.06	-9.89%
Winter Flow Volume	20.75	22.18	6.90%
Spring Flow Volume	15.99	13.26	-17.08%
Summer Flow Volume	7.35	9.52	29.65%
Fall Flow Volume	9.05	7.35	-18.79%
Total Storm Volume	49.50	49.31	-0.38%
Winter Storm Volume	19.84	21.43	8.03%
Spring Storm Volume	15.08	12.51	-17.04%
Summer Storm Volume	6.45	8.76	35.80%
Fall Storm Volume	8.13	6.61	-18.71%

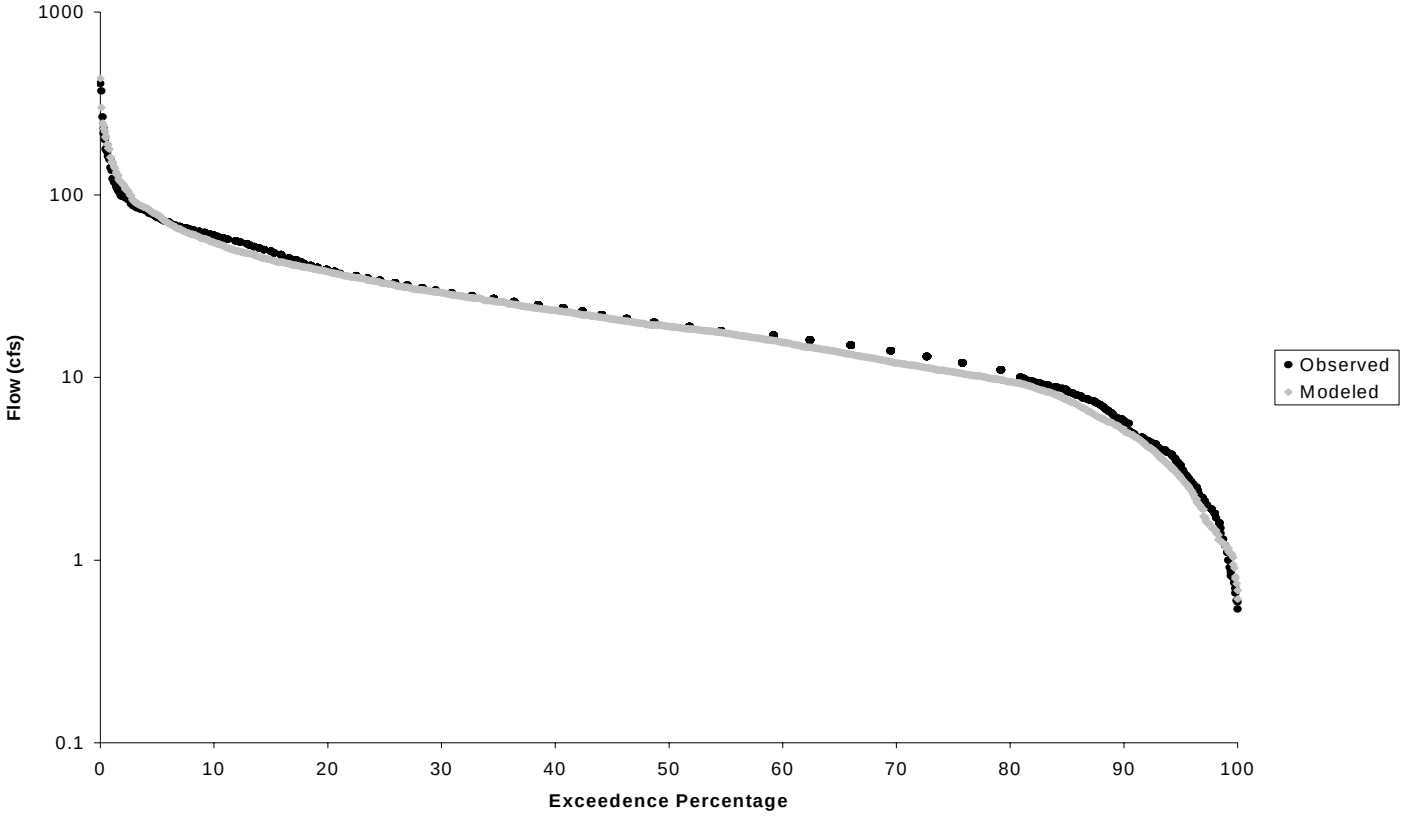

Figure 4.12 Piscataway Creek flow duration at USGS Gaging Station 01669000 for calibration period 10/01/1991 through 09/30/1995.

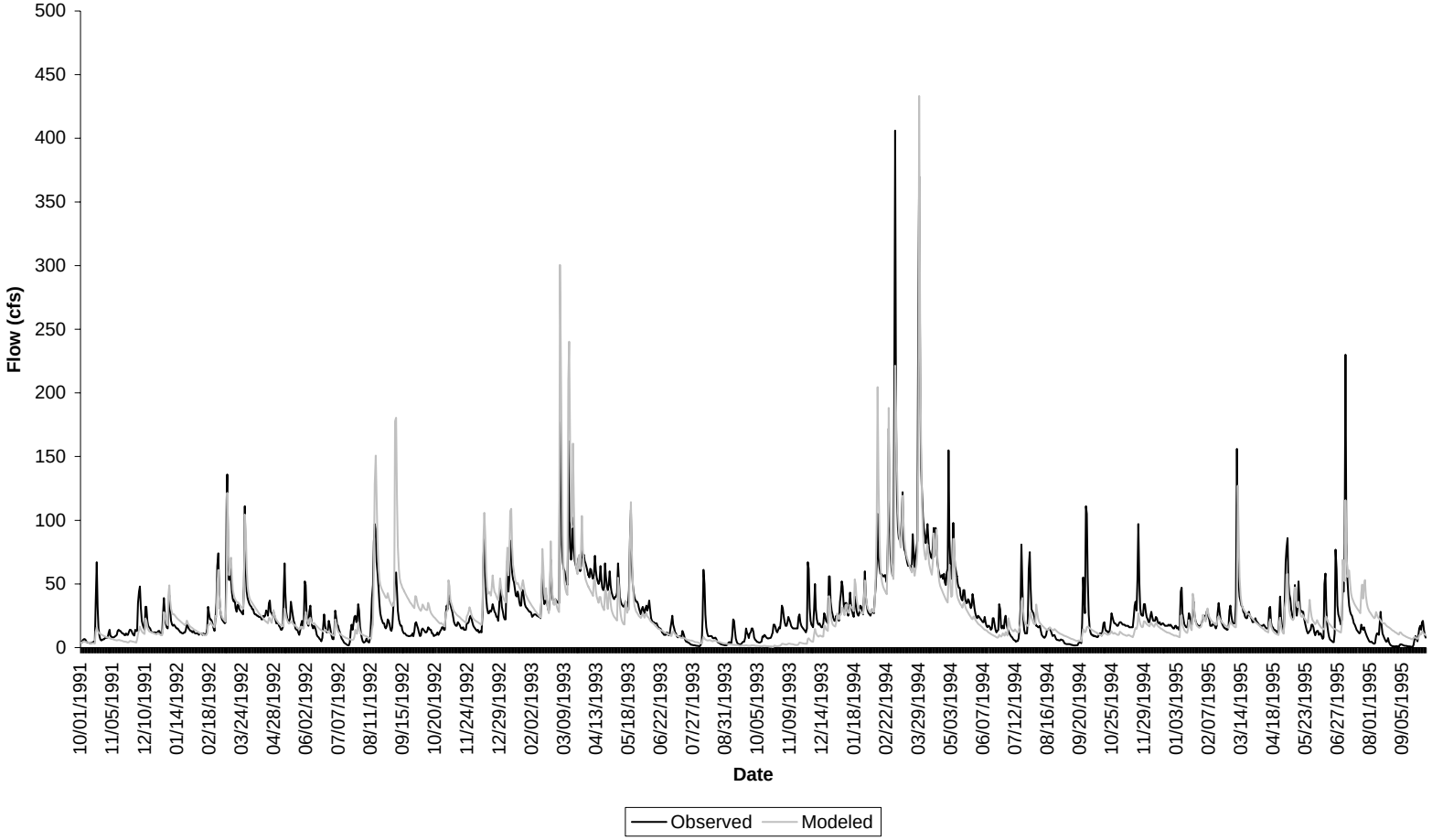

Figure 4.13 Calibration results for period 10/01/1991 through 09/30/1995 at USGS Gaging Station 01669000 on Piscataway Creek.

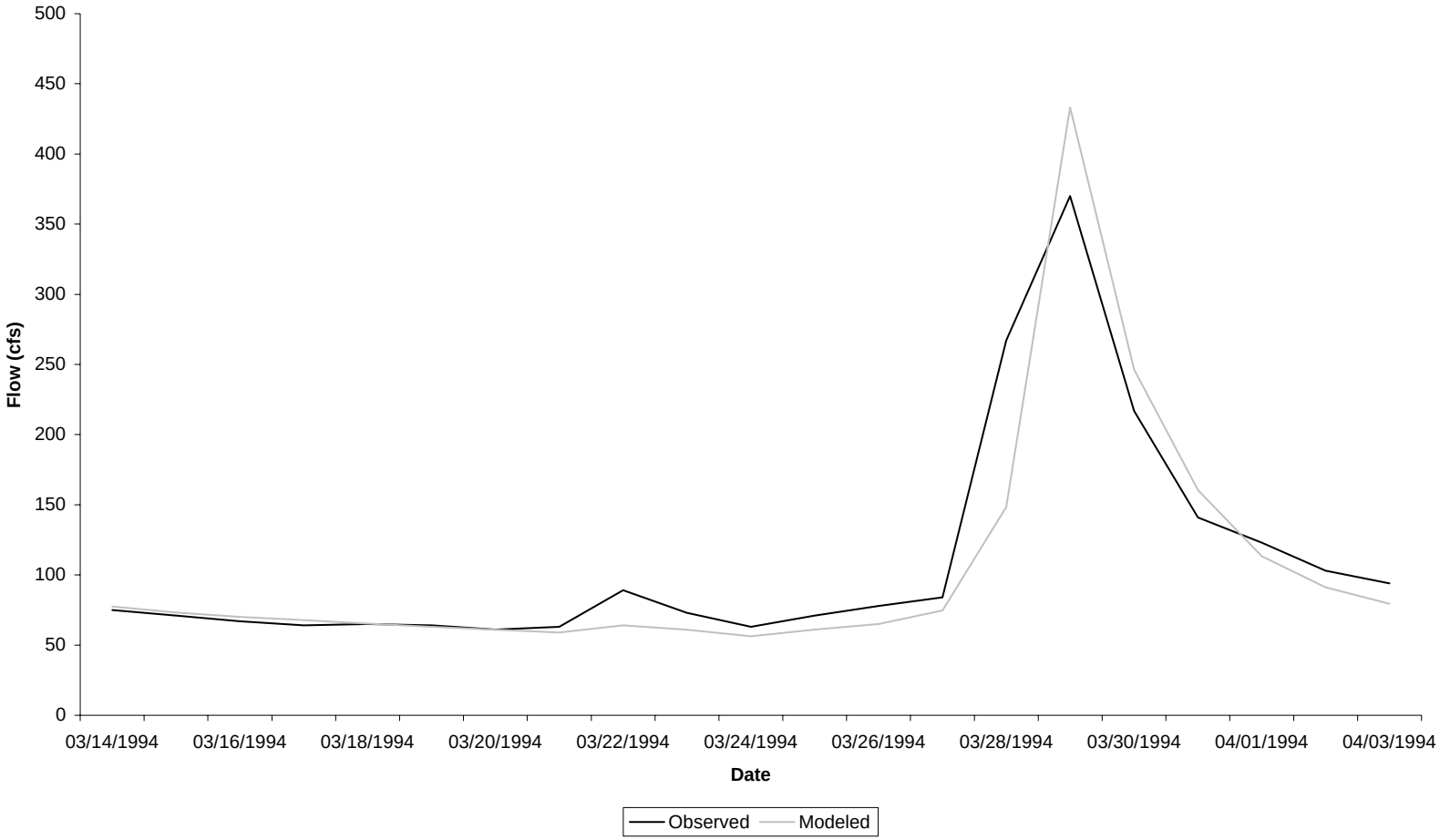

Figure 4.14 Calibration results for a single storm event at USGS Gaging Station 01669000 on Piscataway Creek during March 1994.

4.7.2 HSPF Hydrologic Validation

The hydrologic model was verified using stream flow data from 10/1/1995 to 9/30/1998. The resulting statistics are shown in Table 4.15. The percent error is within acceptable ranges for model validation. The hydrology validation results are shown in Figures 4.15 to 4.17.

Table 4.15 Hydrology validation criteria and model performance for Piscataway Creek for the period 10/01/1995 through 9/30/1999.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	55.56	48.00	-13.61%
Upper 10% Flow Values:	17.01	16.36	-3.84%
Lower 50% Flow Values:	10.03	9.24	-7.91%
Winter Flow Volume	23.79	22.49	-5.47%
Spring Flow Volume	14.56	10.68	-26.63%
Summer Flow Volume	5.30	3.65	-31.04%
Fall Flow Volume	11.92	11.18	-6.22%
Total Storm Volume	52.18	45.90	-12.04%
Winter Storm Volume	22.96	21.97	-4.29%
Spring Storm Volume	13.71	10.15	-25.95%
Summer Storm Volume	4.45	3.13	-29.71%
Fall Storm Volume	11.07	10.65	-3.78%

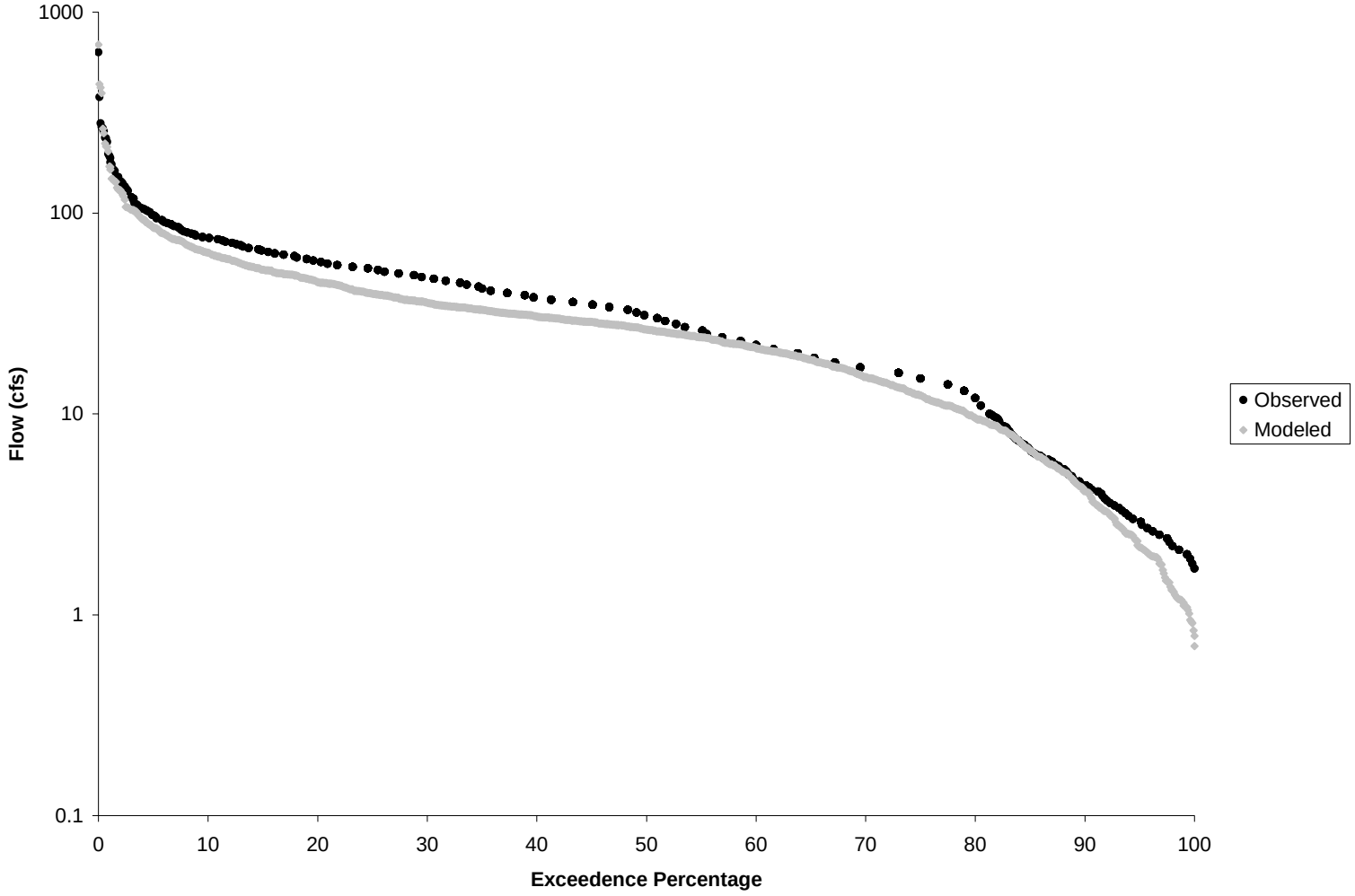

Figure 4.15 Piscataway Creek flow duration (10/01/1995 through 09/30/1998).

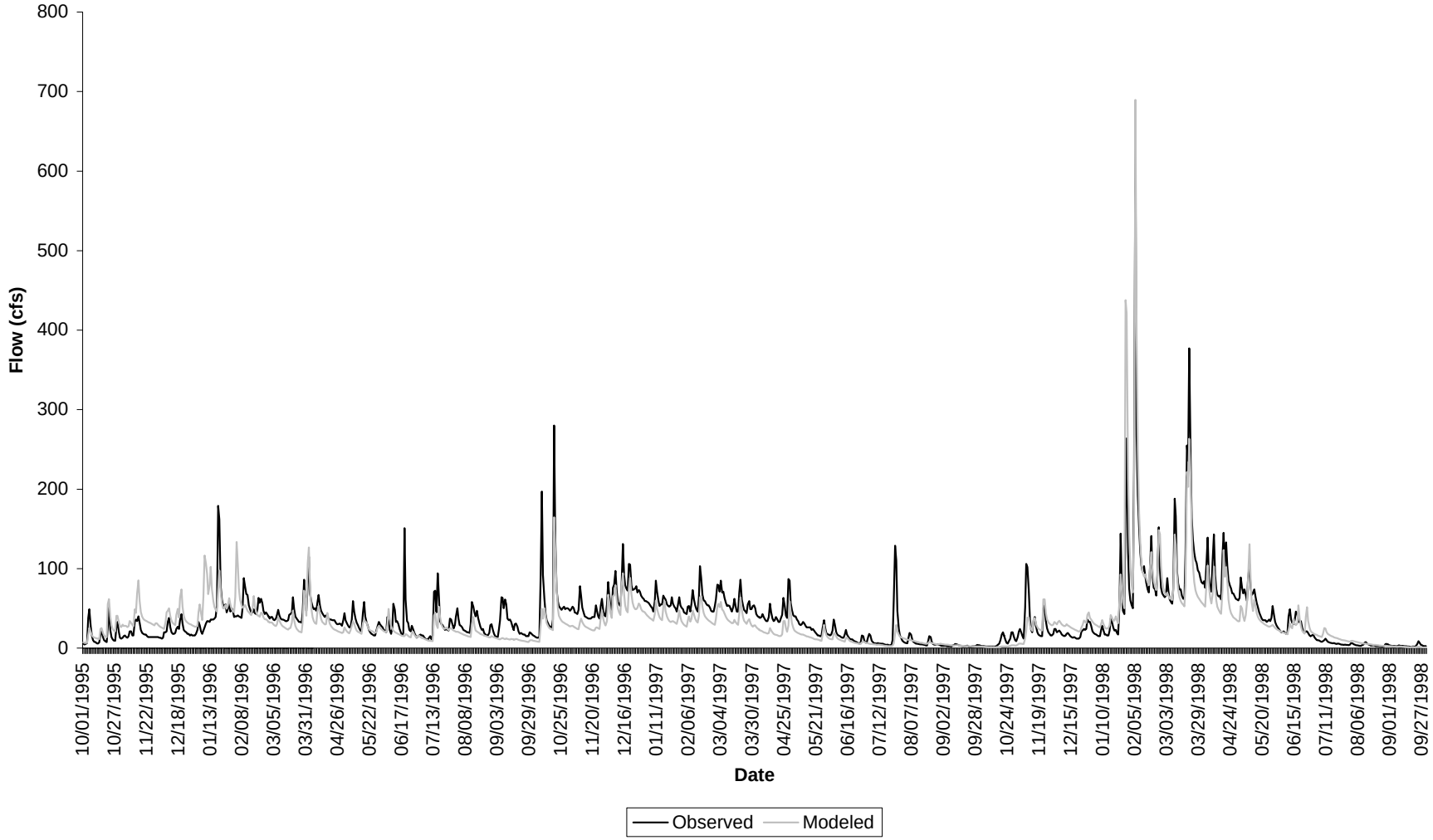

Figure 4.16 Hydrology validation results for Piscataway Creek (10/01/1995 through 09/30/1998).

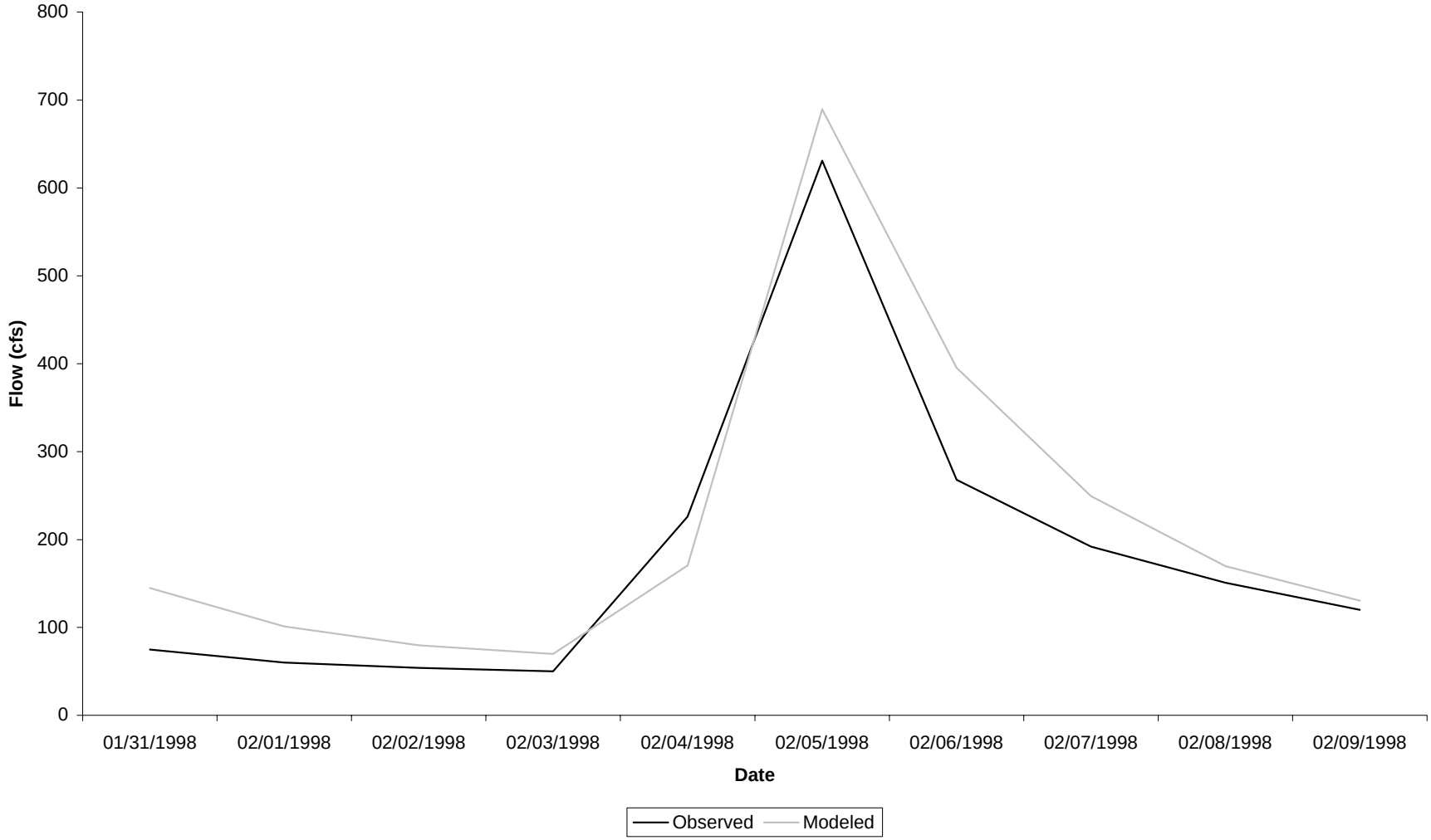

Figure 4.17 Hydrology validation results for a single storm event for Piscataway Creek during February 1998.

4.7.3 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/100 mL and, at other times, at 16,000 cfu/100 mL. 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 mlL) concentrations impede the calibration process.

Based on availability of data, water quality calibration was conducted from 10/1/1992 through 9/30/1997 for the free-flowing segment of Mattox Creek, and from 10/1/1996 through 9/30/1999 for the tidal segment of Mattox Creek. 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 4.16 and Table 4.17). Figure 4.18 through Figure 4.20 show the results of calibration.

Table 4.16 Model parameters utilized for water quality calibration of the free-flowing segment of Mattox Creek.

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	1.9E+07 to 5.9E+09
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	8E+6 to 1E+11	5.9E+8 to 1.7E+11
WSQOP	in/hr	0.05 – 3.00	0.2 – 3.0	0.08 – 1.4
FSTDEC	1/day	0.01 – 10.00	1.15	3.25
THFST	---	1.0 – 2.0	1.07	1.07

Table 4.17 Model parameters utilized for water quality calibration for the tidal segment of Mattox Creek.

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	7.2E+07 to 1.6E+09
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	8E+6 to 1E+11	3.2E+9 to 7.3E+10
WSQOP	in/hr	0.05 – 3.00	0.2 – 3.0	0.4 – 1.4
FSTDEC	1/day	0.01 – 10.00	1.15	0.1 – 10
THFST	---	1.0 – 2.0	1.07	1.07

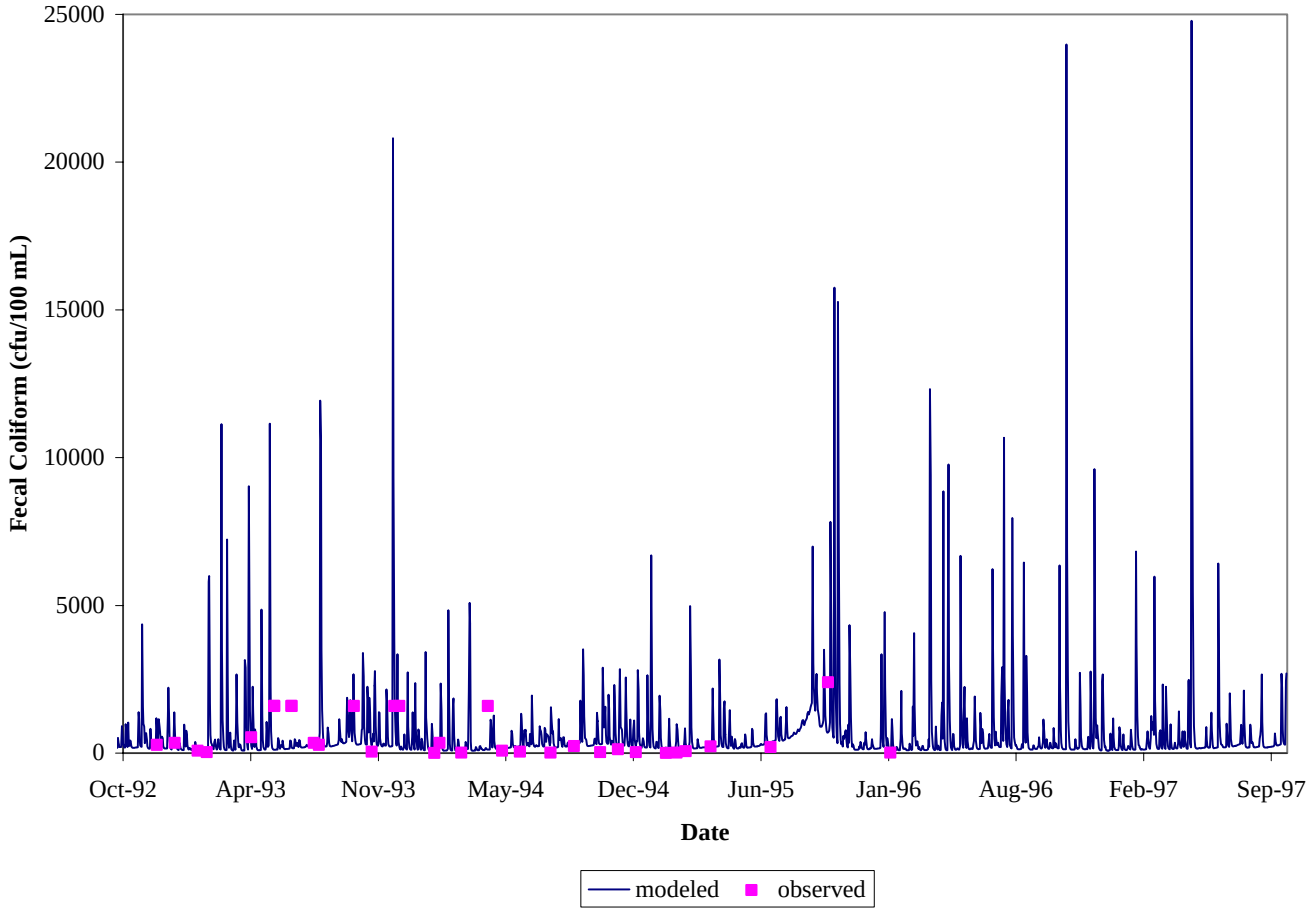

Figure 4.18 Quality calibration results for period 10/1/1992 to 9/30/1997 Mattox Creek free flowing segment at subshed 3 (VADEQ Station ID 1-AMAO004.08).

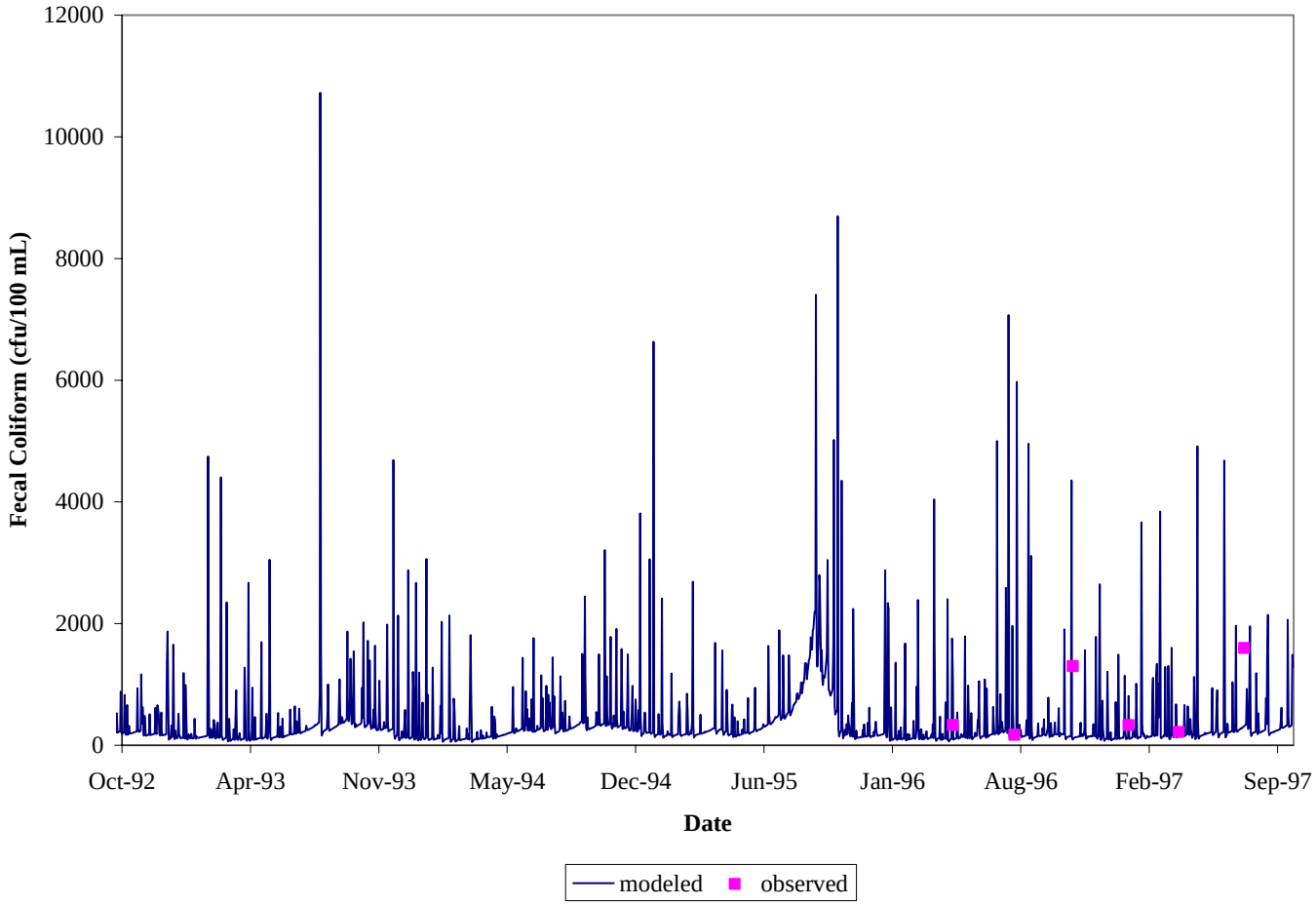

Figure 4.19 Quality calibration results for period 10/1/1992 to 9/30/1997 for the free-flowing segment of Mattox Creek at subshed 2 (VADEQ Station ID 1-AMAO007.46).

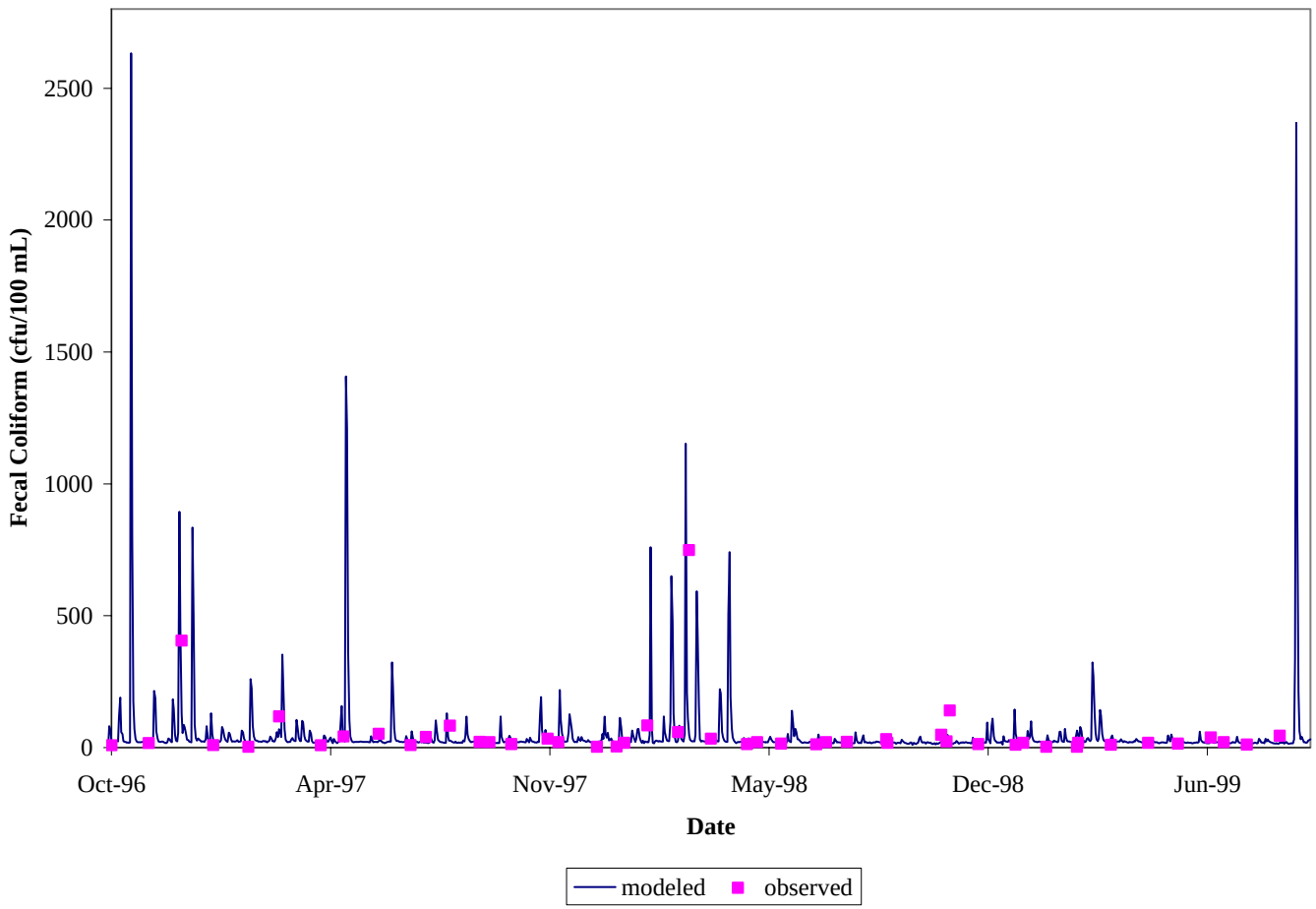

Figure 4.20 Quality calibration results for period 10/1/1996 to 9/30/1999 for the tidal segment of Mattox Creek. (Average fecal coliform of VDH stations 2-2 to 2-9 and VADEQ Station ID 1-AMAO000.42.)

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 4.18).

The standard errors in Table 4.18 range from a low of about 16 to a high of about 56. Even the highest value in this range can be considered quite reasonable when taking into account the censoring of maximum values that is practiced in the collection of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 2,400 or 16,000 cfu is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.18 Results of analyses on calibration runs.

WQ Monitoring Station	Mean Standard Error (cfu/100ml)	Maximum Observed Value (cfu/100ml)	Maximum Simulated Value (cfu/100ml)
VADEQ station 1-AMAO000.42 plus average of VDH stations 2-2 to 2-9	16.05	749	2,632
1-AMAO004.08	42.26	2,400	24,781.28
1-AMAO007.46	56.08	16,000	10,726.37

A comparison between the geometric mean of observed fecal coliform data and the modeled fecal coliform values is shown in Table 4.19. The results shown in Table 4.19 indicate a good agreement between observed and predicted values of fecal coliform during the calibration period.

Table 4.19 Comparison of modeled and observed standard violations for the fecal coliform calibration model for the Mattox Creek watershed.

Station ID	Modeled Calibration Load Fecal Coliform 10/1/92 - 9/30/97			Monitored Fecal Coliform 10/1/92-9/30/97		
	n	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**	***n***	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**
VADEQ station 1-AMAO000.42 plus average of VDH stations 2-2 to 2-9	1825	27.85	1.64%	48	21.49	4.17%
1-AMAO004.08	1826	343.08	34.14%	33	173.67	30.30%
1-AMAO007.46	1826	250.53	20.55%	7	751.64	42.86%

4.7.4 Fecal Coliform Water Quality Validation

Fecal coliform water quality model validation was performed on data from 10/1/1999 to 9/30/2002 for the tidal segment of Mattox Creek and from 10/1/1997 to 9/30/2001 for the free-flowing segment. Observed data was available at the outlet of subwatershed 2 in the free-flowing segment and at the outlet of the tidal segment. The results are shown in Tables 4.20 and 4.21 and Figures 4.21 and 4.22. The standard error was 167.59 in the Mattox Creek free-flowing model validation and 8.76 in the tidal segment.

Table 4.20 Mean standard error of the fecal coliform validated model for Mattox free-flowing segment (10/1/1997 through 9/30/2001).

Subwatershed	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
2	1-AMAO007.46	167.59	11,723	2,200

Table 4.21 Mean standard error of the fecal coliform validated model for Mattox tidal segment (10/1/1999 through 9/30/2002).

Subwatershed	Station	Mean Standard Error (cfu/100 mL)	Maximum Simulated Value (cfu/100 mL)	Maximum Monitored Value (cfu/100 mL)
Main outlet	1-AMAO000.42 and average VDH stations	8.76	2,628.15	61.89

A comparison between the geometric mean of observed fecal coliform data and the modeled fecal coliform values is shown in Table 4.22. The results show good agreement between observed and predicted fecal coliform values.

Table 4.22 Comparison of modeled and observed standard violations for the fecal coliform validation model for the Mattox Creek watershed.

Station ID	Modeled Calibration Load Fecal Coliform 10/1/92 - 9/30/97			Monitored Fecal Coliform 10/1/92-9/30/97		
	n	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**	***n***	**Geometric Mean (cfu/100ml)**	**Exceedances of Instantaneous Standard**
VADEQ station 1-AMAO000.42 plus average of VDH stations 2-2 to 2-9	1095	13.63	0.00%	34	30.88	2.28%
1-AMAO007.46	1095	299.02	33.33%	21	239.79	29.73%

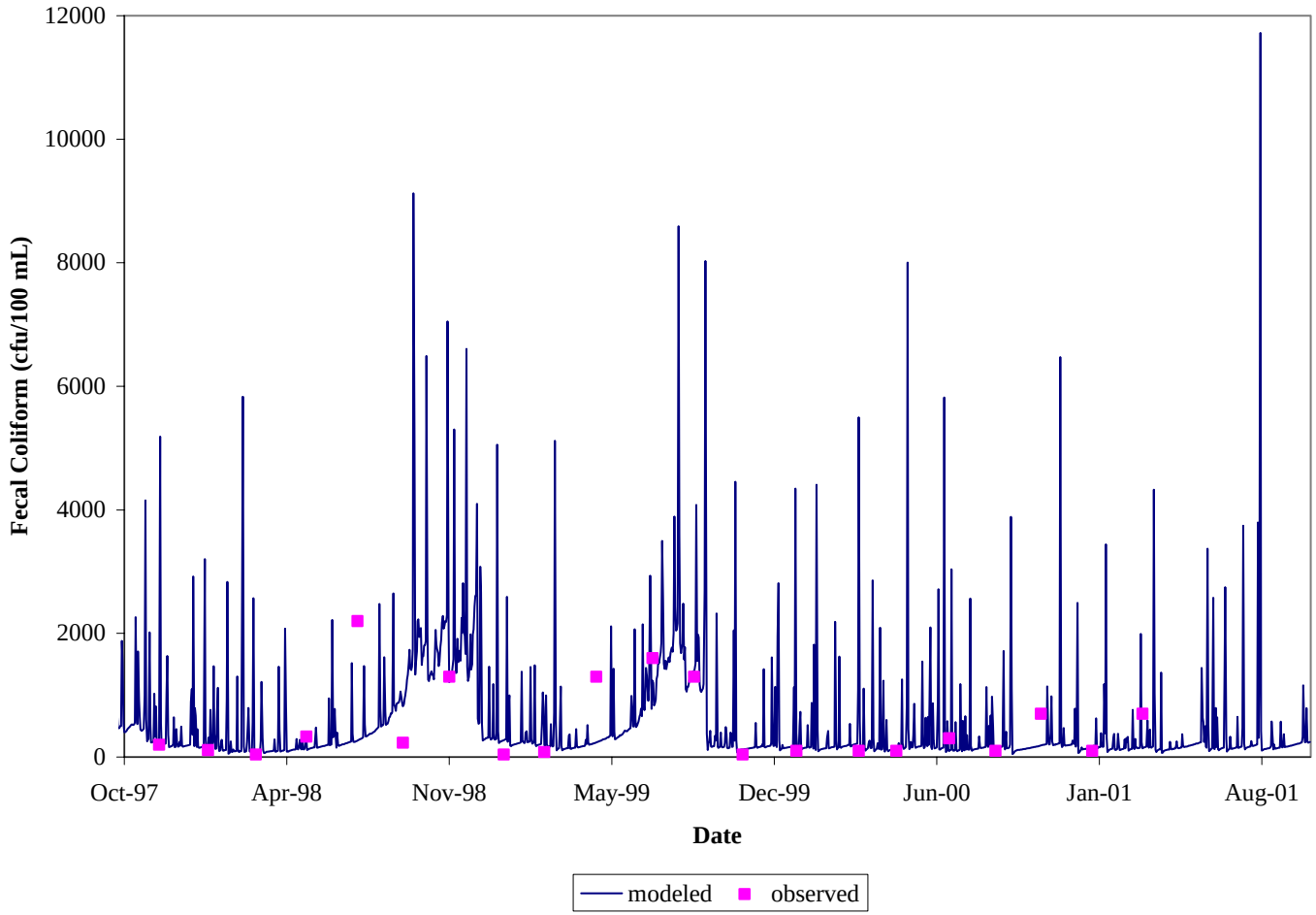

Figure 4.21 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations at outlet of subwatershed 2 in the free-flowing segment of Mattox Creek (VADEQ Station ID 1-AMAO007.46) for the period from October 1997 to August 2001.

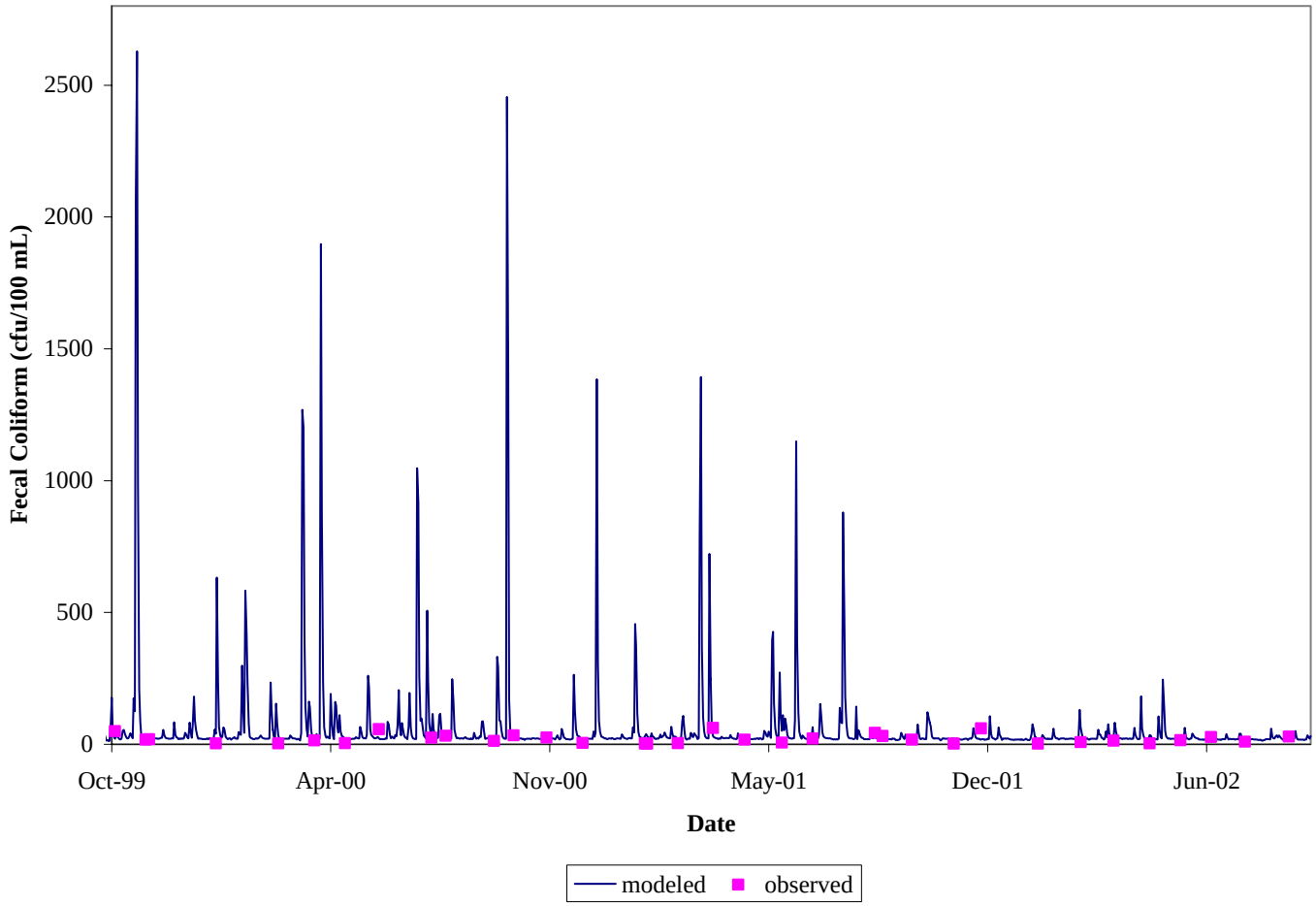

Figure 4.22 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations at outlet of the tidal segment of Mattox Creek (subwatershed 4) (10/1/1999 through 9/30/2002).

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, nonpoint 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

- Assuming all biosolids applied in a given time period to be applied on the first day of the period.

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. As detailed in Section 2.1, for the free-flowing segment, 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. For the tidal segment, 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. Also, for the shellfish standards in the tidal segment, the fecal coliform 30-month geometric mean shall not excess 14 MPN and the 30-month 90th percentile shall not exceed 49 MPN. According to the guidelines put forth by the VADEQ (VADEQ, 2003), the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* and *enterococci* through the use of the following equations:

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc}) \qquad \textit{E. coli}$$

$$\log_2(C_{ent}) = 1.2375 + 0.59984 \cdot \log_2(C_{fc}) \qquad \textit{Enterococci}$$

where C_{ec} is the concentration of *E. coli* in cfu/100 mL, C_{ent} is the concentration of *enterococci* 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 5.6). 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 two point sources currently permitted to discharge fecal, one into the free-flowing segment and one into the Mattox tidal segment (Figure 3.4 and Table 3.3). The

allocation for the sources permitted for fecal control is equivalent to their current permit levels or maximum annual reported load.

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from land uses and directly applied loads in the stream (*e.g.*, livestock, 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. Bacterial source tracking (BST) confirmed the presence of human, pet, livestock and wildlife contamination.

5.2.2.1 Free-flowing segment

Model results indicate that wildlife direct deposits and overland loads are significant in the watershed. Other sources contributed to various degrees including livestock and human sources. This is in agreement with the results of BST analysis presented in Chapter 2. Allocation scenarios for the free-flowing segment of Mattox Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed.

Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard and 0% exceedance of the single sample maximum *E. coli* standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality.

The first objective of the reduction scenarios was to explore the role of anthropogenic sources in standards violations. First, scenarios were explored to determine the feasibility of meeting standards without wildlife reductions. Following this theme, Scenario 2 resulted from a 100% reduction in uncontrolled direct residential discharges (*i.e.*, straight pipes), livestock direct and overland discharges. A significant decrease in the violations was observed. This scenario improved conditions in the stream, but failed to eliminate the exceedances of either standard.

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Mattox free-flowing segment.

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	NPS Res. Com.	NPS Tran.	GM > 126 cfu/100ml	Single Sample > 235 cfu / 100ml
1	0	0	0	0	0	0	0	91.7	39.5
2	0	0	100	100	100	100	0	0	4.0
3	0	0	90	50	100	50	0	5	17.9
4	0	0	100	90	100	90	0	0	7.2
5	0	0	100	99	100	99	0	0	4.2
6	50	50	99	99	100	99	50	0	1.7
7	50	94	98	99	100	99	94	0	0

Scenario 3 had a 90% reduction in direct livestock deposition, and 50% reductions to land loads from urban and agricultural lands, as well as a 100% reduction of straight pipes. Loads from wildlife were not addressed. This scenario showed less improvement than Scenario 2 did and the standards were still not met.

Scenarios 4 and 5 show different combination of reductions to anthropogenic sources with Scenario 5 having significant reductions. However, even with those significant reductions, the standards were not met.

Scenario 6 shows some reductions from wildlife sources, on top of the previous reductions but still was not enough to meet the standards. Standards were finally met in Scenario 7 which requires 50% reductions from wildlife direct deposition and 94% reduction from forested areas.

Figure 5.1 shows the monthly geometric mean concentrations, and the daily concentrations for existing and allocated conditions for the impairments in the Mattox Creek watershed. This graph shows 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 5.2 shows the daily instantaneous values for existing and allocated

conditions for the impairment in the Mattox Creek watershed. This graph shows allocated conditions in black, with existing conditions overlaid in gray.

Table 5.2 Land-based and direct nonpoint source fecal coliform load reductions in the Mattox free-flowing segment 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			
Commercial	2.34E+12	2.34E+10	99
Forest	2.40E+14	1.44E+13	94
LAX	4.18E+12	4.18E+10	99
LIR	2.75E+13	2.75E+11	99
Pasture/Hay	2.87E+14	2.87E+12	99
Row crops	7.61E+14	7.61E+12	99
Transitional	8.86E+11	5.32E+09	94
Water	0.00E+00	0.00E+00	0
Wetland	5.89E+13	3.53E+12	94
Direct			
Human	6.59E+13	0.00E+00	100
Livestock	5.33E+11	1.07E+10	98
Wildlife	9.63E+12	4.81E+12	50

Table 5.2 contains the existing and allocated loads for the free-flowing impairment in Mattox Creek, 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 5.3 is 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) from the Washington District Elementary School (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 nonpoint sources existing in the watershed.

Table 5.3 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Mattox free-flowing segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox Creek – Free-flowing	*E. coli*	2.2E+06	5.0E+12	*Implicit*	5.0E+12

A TMDL table accounting for future growth in the WLA (Expansion Matrix) is given in Appendix C.

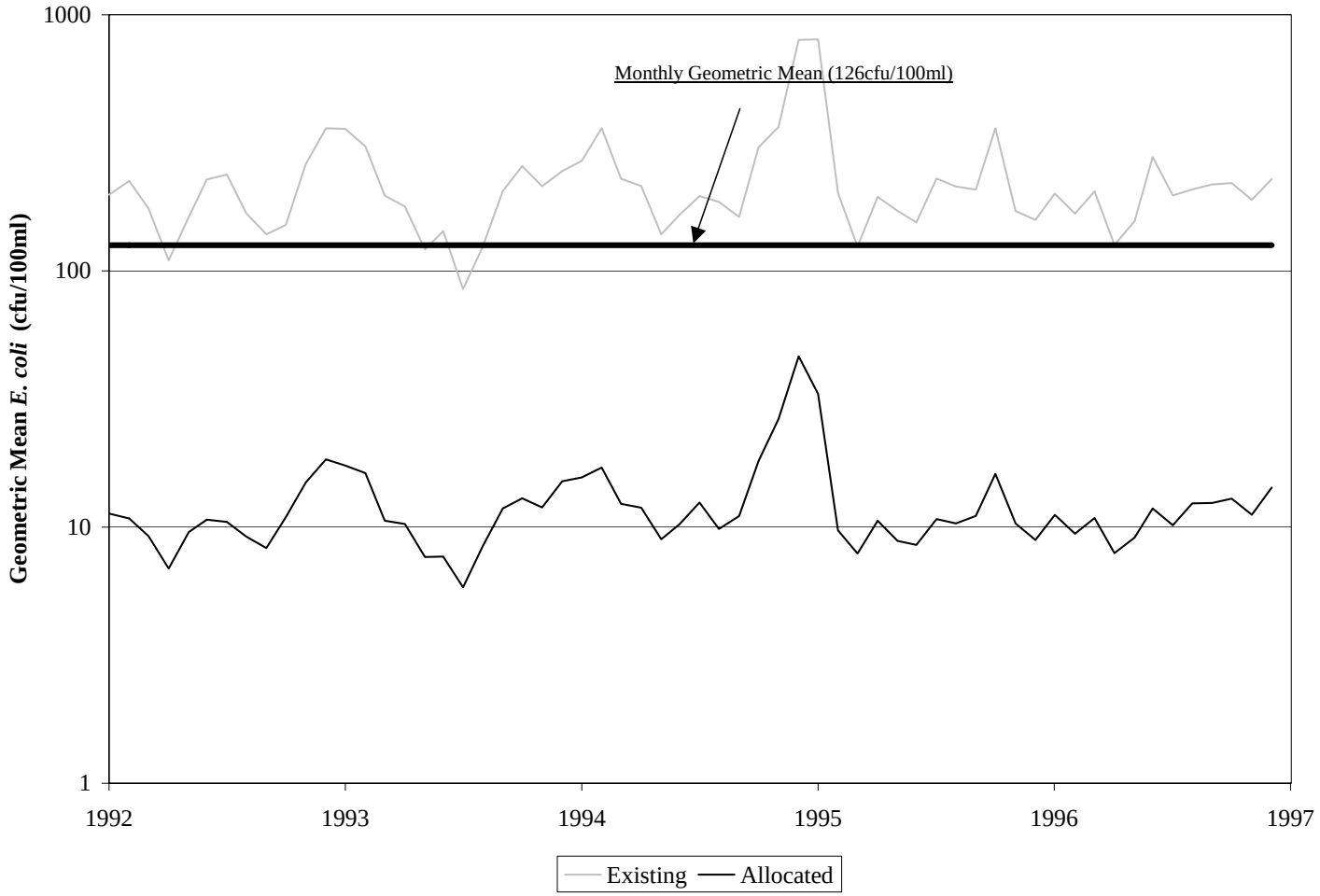

Figure 5.1 Existing and allocation scenarios of *E. coli* geometric mean concentrations at the outlet of the free-flowing segment of Mattox Creek.

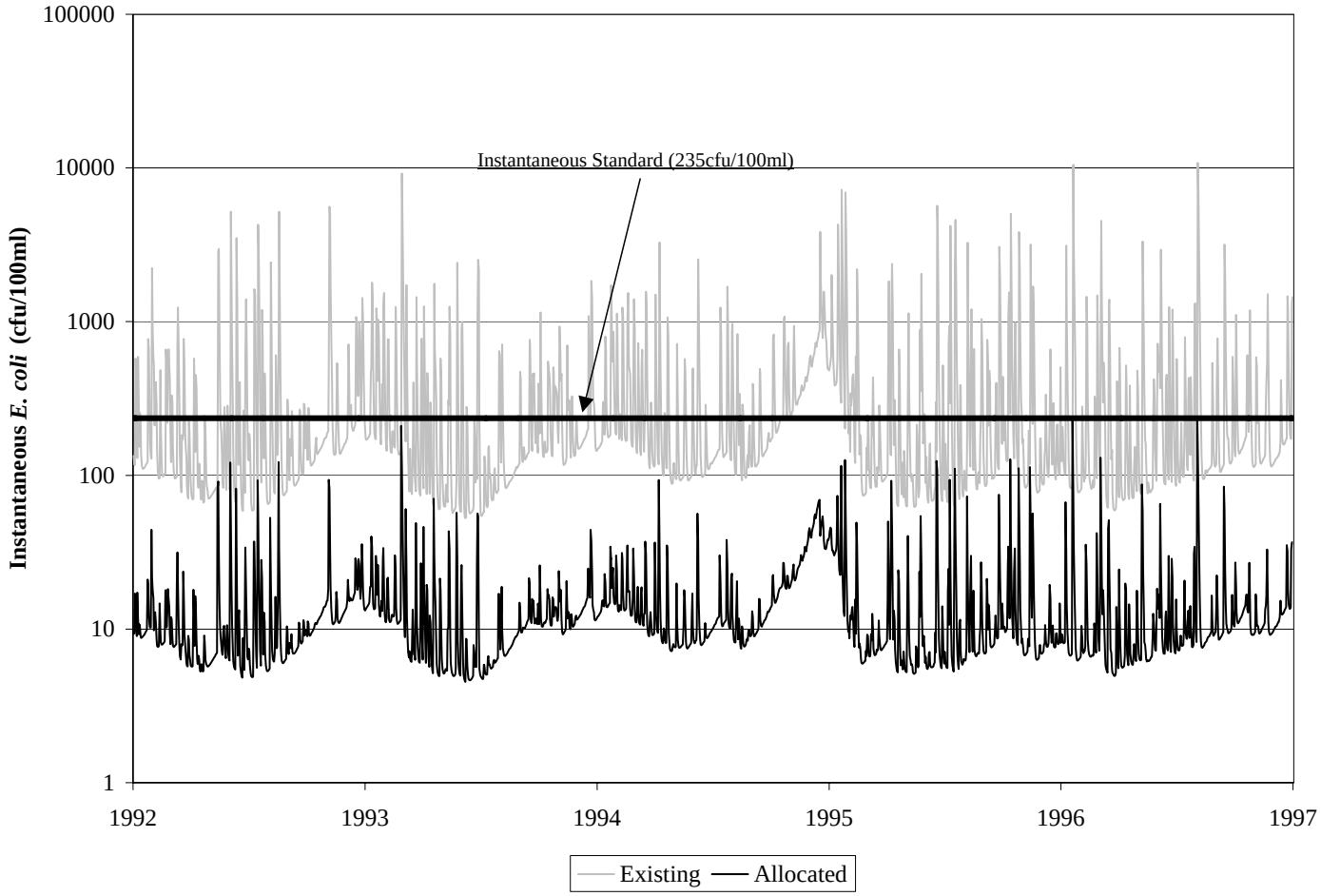

Figure 5.2 Existing and allocation scenarios of *E. coli* instantaneous concentrations at the outlet of the free-flowing segment of Mattox Creek.

5.2.2.2 Tidal Segment

Model results indicated that after allocating for the free-flowing segment of Mattox Creek and eliminating the straight pipes loadings from the tidal segment, no further reductions were needed to meet the water quality standards at the outlet of the tidal segment. This can be attributed to the reductions of incoming loads of bacteria from upstream (the free-flowing segment) and also to the tidal influence. Tidal water has less concentration of bacteria and can work as a dilution medium to incoming concentrations. Direct discharge from human sources is illegal and should be eliminated as indicated in the "Allocated" scenario in Table 5.4. Since management practices conserve water quality and protect human health, and even though reductions are only required from straight pipes in the tidal segment, it is recommended to apply the management practices during the implementation phase of the Mattox Creek TMDL processes to the entire watershed, including the tidal segment.

In Figures 5.3 through 5.6, the existing concentrations are those resulting from running the model with the existing conditions in both impairments, while the allocated concentrations are the concentrations resulting from allocated free-flowing loads and existing loads from the tidal segment minus the straight pipes loadings.

Table 5.4 Allocation scenarios for bacterial concentration with current loading estimates in Mattox tidal segment and allocated loads from Mattox free-flowing segment.

Scenario	Percent Reduction in Loading from Existing Conditions							Percent Violations			
	Direct Wildlife	NPS Forest / Wetland	Direct Livestock	NPS Pasture / Livestock Access / Crops	Straight Pipe	NPS Res. Com.	NPS Tran.	*Enterococci* geo. Mean > 35cfu/100mL	*Enterococci* instantaneous. > 104cfu/100mL	Fecal coliform geo. Mean > 14 MPN	Fecal coliform 90th percentile > 49 MPN
Existing	0	0	0	0	0	0	0	0	1	0	10
Allocated	0	0	0	0	100	0	0	0	0	0	0

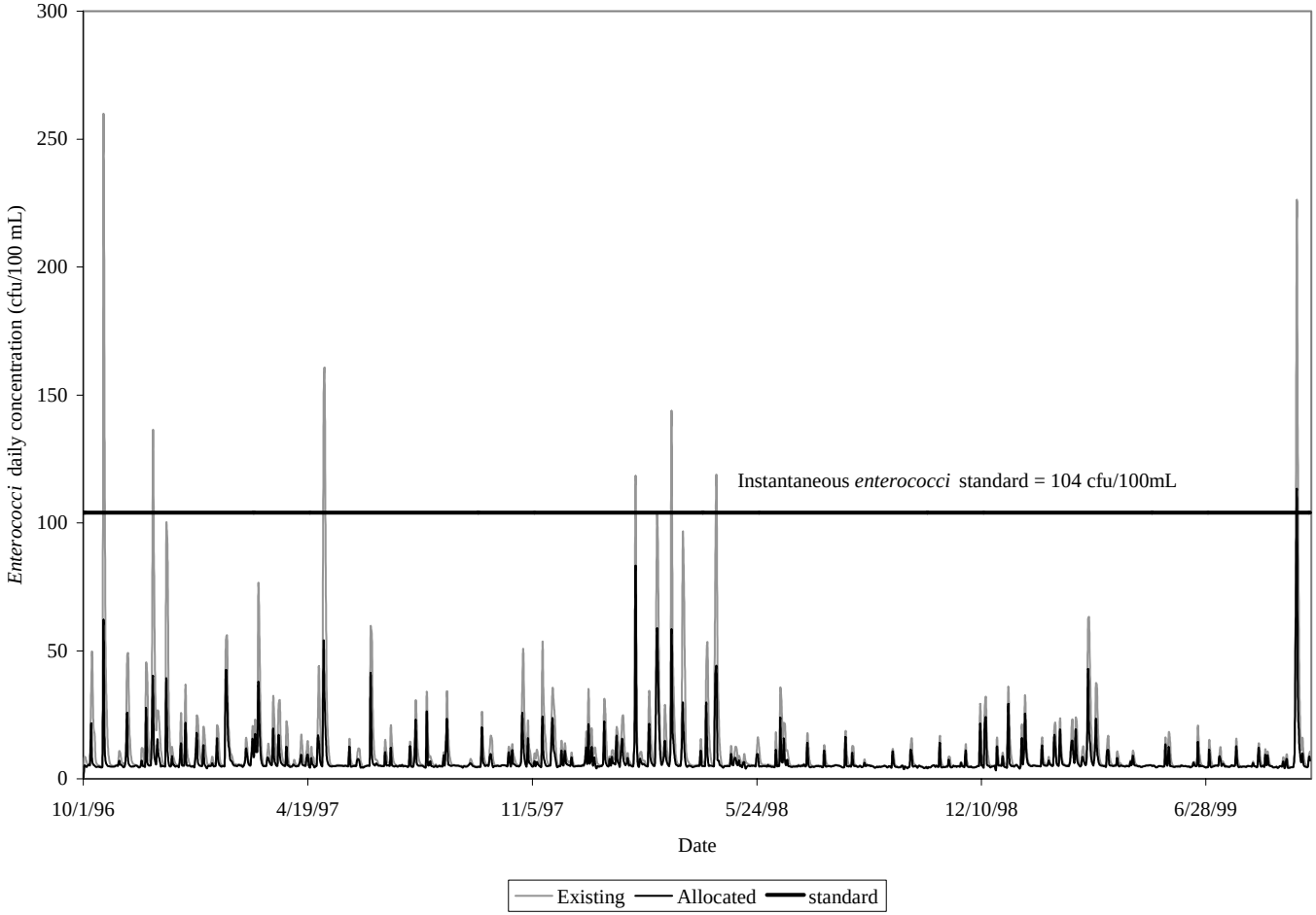

Figure 5.3 Existing and allocation scenarios of *enterococci* instantaneous concentrations at the tidal segment outlet of Mattox Creek.

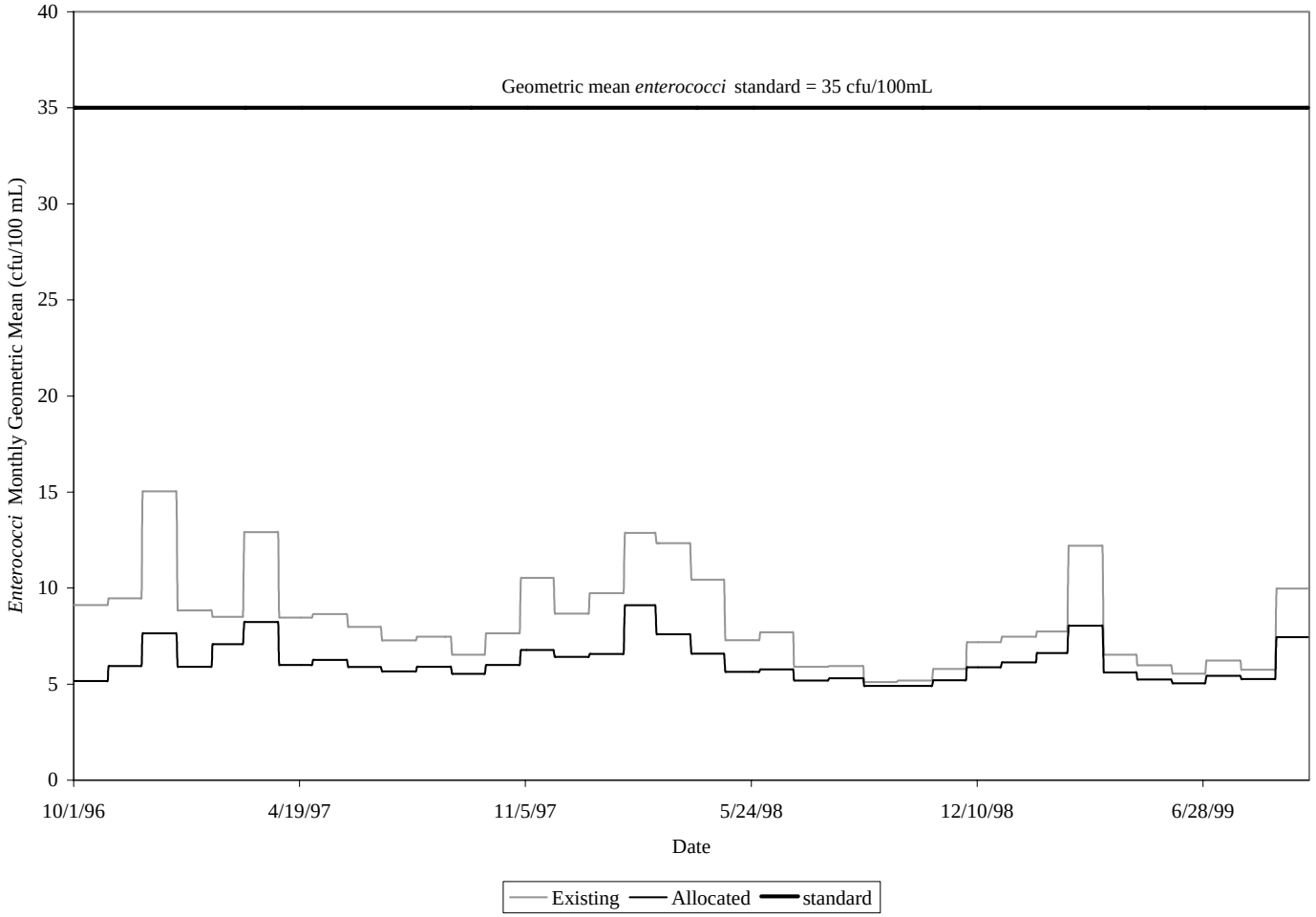

Figure 5.4 Existing and allocation scenarios of enterococci geometric mean concentrations at the tidal segment outlet of Mattox Creek.

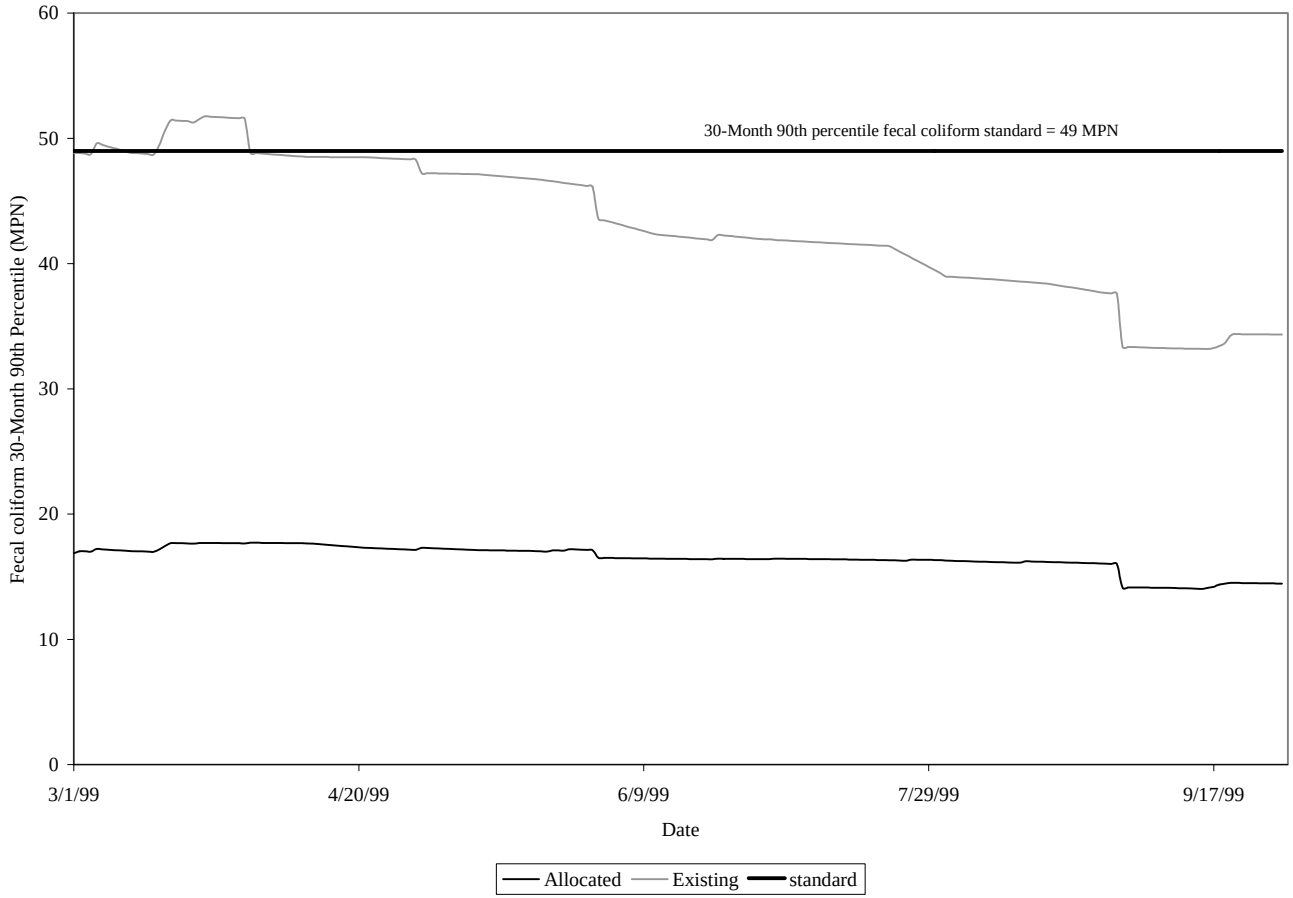

Figure 5.5 Existing and allocation scenarios of fecal coliform 30-month 90th percentile concentrations at the tidal segment outlet of Mattox Creek.

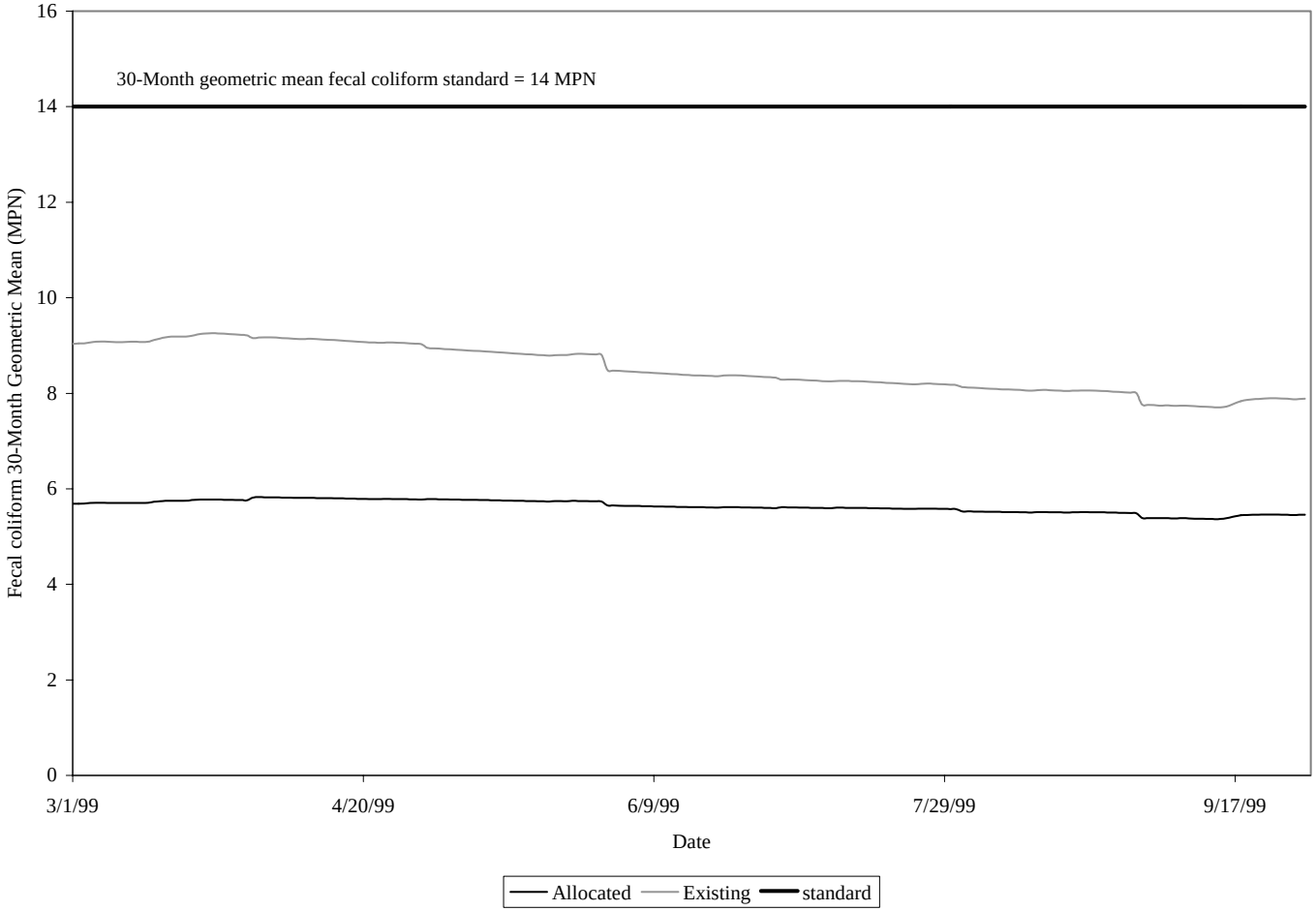

Figure 5.6 Existing and allocation scenarios of fecal coliform 30-month geometric mean concentrations at outlet of tidal segment of Mattox Creek.

Table 5.5 is known as the TMDL table, which gives the number of cfu of fecal coliform and *enterococci* 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) from the Outdoor World Harborview is located in the tidal segment (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 nonpoint sources existing in the watershed.

Table 5.5 Average annual bacterial loads (cfu/year) modeled after TMDL allocation in the Mattox tidal segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox – Tidal Segment	*Enterococci*	1.7E+05	1.0E+14	Implicit	1.0E+14
Mattox – Tidal Segment	*Fecal coliform*	3.0E+05	2.6E+13		2.6E+13

A TMDL table accounting for future growth in the WLA (Expansion Matrix) is given in Appendix C.

6. IMPLEMENTATION

Once a TMDL has been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream (see section 6.3.2). For point sources, all new or revised VPDES/NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR '122.44 (d)(1)(vii)(B) and must be submitted to the EPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan (IP). The process for developing an IP has been described in the *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.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of IPs, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is typically 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.

Best Management Practices that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

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

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

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

6.2 Stage 1 Scenario

The goal of the Stage 1 scenario is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the single sample maximum criterion (235 cfu/100mL) are less than 10.5 percent. The Stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios.

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	% Single Samples Exceeding Standard
Mattox Creek Watershed							
Free-Flowing Segment	0	0	100	90	90	100	7.2
Tidal Segment	0	0	0	0	0	100	0.0

During modeling, it was determined that Stage I load reductions needed for the free-flowing impaired segment of Mattox Creek were adequate to meet the Stage I needs in the tidal impaired segement. However, 100% reduction to straight pipes is included in Table 6.1 to recognize that direct sewage discharge to the state's waters is illegal and should be corrected. Table 6.2 details the load reductions required to meet the Stage I Implementation described in Table 6.1.

Table 6.2 Nonpoint source allocations in the Mattox Creek free-flowing 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	2.59E+12	2.59E+11	90
Barren	1.91E+10	1.91E+10	0
Commercial	1.32E+12	1.32E+11	90
Cropland	7.44E+14	7.44E+13	90
Pasture	1.02E+14	1.02E+13	90
Residential	1.09E+13	1.09E+12	90
Water	0.00E+00	0.00E+00	0
Wetlands	4.18E+13	4.18E+13	0
Woodland	9.02E+13	9.02E+13	0
Direct			
Human	6.59E+13	0.00E+00	100
Livestock	5.33E+11	0.00E+00	100
Wildlife	9.63E+12	9.63E+12	0

6.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to ongoing water quality improvement efforts aimed at restoring water quality in Virginia's streams. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of

the Tributary Strategy for the Shenandoah and Potomac River basin. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. Up-to-date information on the tributary strategy implementation process can be found at the tributary strategy web site under: http://www.naturalresources.virginia.gov/WaterQuality/FinalizedTribStrats/shenandoah.pdf

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-Up Monitoring

Following the development of the TMDL, the VADEQ and VDH (Division of Shellfish Sanitation) will make every effort to continue to monitor the impaired stream in accordance with their existing monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with Guidance Memo No. 03-2004 (VADEQ, 2003), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

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

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

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

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

6.4.2 Regulatory Framework

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

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board (SWCB) 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 IP 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. The EPA outlines the minimum elements of an approvable IP 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, and monitoring plans and milestones for attaining water quality standards.

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

For the implementation of the TMDL's LA component, a TMDL IP addressing the WQMIRA requirements, at a minimum, will be developed. The municipal separate storm sewer systems (MS4s) are covered by NPDES permits and are an exception; they are expected to be included in TMDL implementation plans, as described in the stormwater permit section below.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL IP. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

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

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

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

6.4.3 Implementation Funding Sources

Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the IP in accordance with the *Guidance Manual for Total Maximum Daily Load Implementation Plans*. Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits, and landowner contributions. The *Guidance*

Manual for Total Maximum Daily Load Implementation Plans also 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.

6.4.4 Attainability of Primary Contact Recreation Use

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

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

To address the overall issue of attainability of the primary contact criteria, during its latest triennial water quality standards review Virginia proposed a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia SWCB adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria became effective on February 12, 2004 and can be found at http://www.deq.virginia.gov/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 contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable BMPs for nonpoint source control (9 VAC 25-260-10). This and other information is collected through 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 the EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a Stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the Stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife (except for cases of nuisance populations). During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 6.1 above. The VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable BMPs can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

7. PUBLIC PARTICIPATION

The development of the Mattox Creek TMDL did not receive the benefit of much public participation. Table 7.1 details the public participation throughout the project.

The first public meeting was held at the Abraham and William Cooper Memorial Branch Library in Colonial Beach, Virginia on February 7, 2006. The meeting was published in the *Virginia Register* and it was attended by one agency staffer and two consultants. There was a 30 day-public comment period and 1 written comment was received.

Table 7.1 Public participation during TMDL development for the Mattox Creek watershed.

Date	Location	Attendance	Type	Format
2/7/06	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA	3	1st public meeting	Open to public at large
3/14/06	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA	2	Technical Advisory Committee Meeting	Invited local officials
4/11/06	Abraham and William Cooper Memorial Branch Library 20 Washington Avenue Colonial Beach, VA	24	Final public meeting	Open to public at large

A Technical Advisory Committee (TAC) meeting was held on March 14, 2006 in Colonial Beach, Virginia. The meeting, which was advertised via personal contacts and a notice in the Virginia Register, was attended by one agency representative and a town councilperson from the Town of Colonial Beach. The issues discussed were the basic premises of the project, population numbers, sewered areas, and planned expansions in the future.

The final public meeting was held on April 11, 2006 in Colonial Beach. The meeting was attended by 24 individuals, including the mayor of Colonial Beach, two Colonial

Beach Town Council members, one representative from the Board of Supervisors, a member of the Colonial Beach Foundation, a newspaper reporter, two consultants, and one state agency representative. Among the issues discussed were failing septic tanks near beach areas and biosolids applications.

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 committee will consist of, but not be limited to, representatives from the VADEQ, VADCR, VDH, the 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.

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GLOSSARY

Note: Entries in italics are taken from http://www.deq.virginia.gov/tmdl/glossary.html

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 waste load 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.*

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.*

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

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

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.*

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).

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.*

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.

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.

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.

E. coli (Escherichia coli) – one of the groups of fecal coliform bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms

indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

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

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).*

Enterococci – a subgroup of fecal streptococcal bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

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).*

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.

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.*

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.

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.*

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.*

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

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

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)).*

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).*

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.*

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

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.

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.

Nonpoint source. *Pollution that originates from diffuse 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.

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 waste load 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.*

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).*

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.*

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.

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)

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).

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.*

Tidal Prism Model – a steady state model that uses mass balance equations to calculate the volume of water in a tidal water system and the associated pollutant load (*e.g.*, fecal coliform concentration).

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).

Total Maximum Daily Load (TMDL). *The sum of the individual waste load 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.

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.

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.

Waste load 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 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

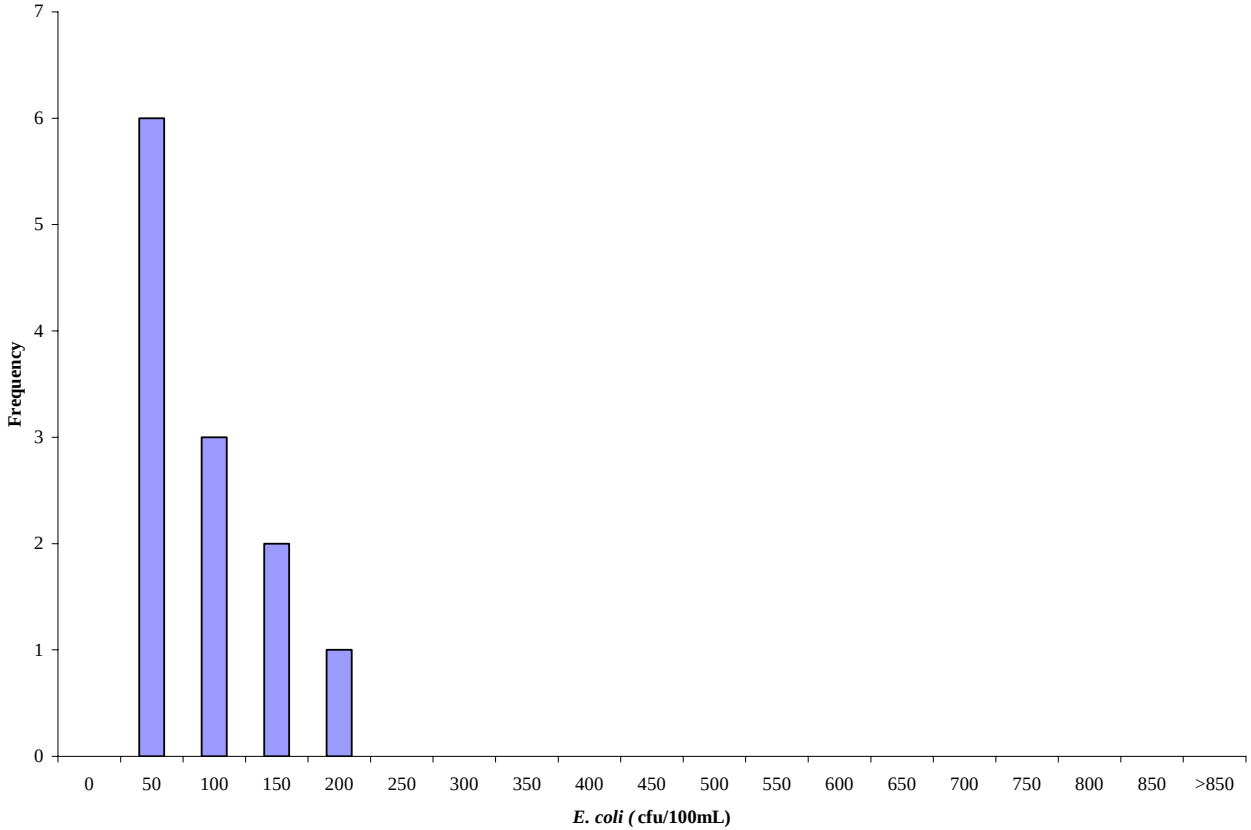

Figure A.1 Frequency analysis of *E. coli* concentrations at station 1-AMAO004.08 in the Mattox Creek watershed for the period July 2003 to June 2004.

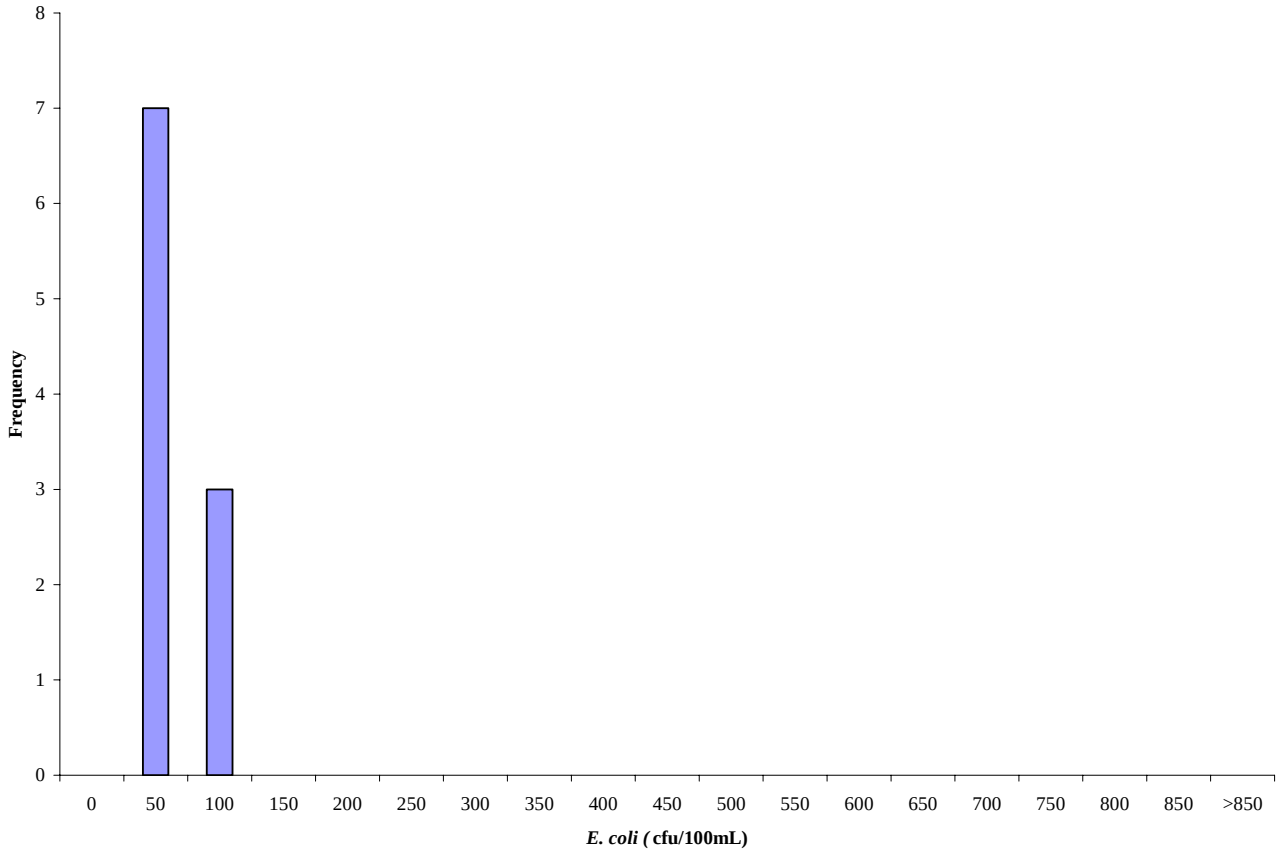

Figure A.2 Frequency analysis of *E. coli* concentrations at station 1-AMAO007.46 in the Mattox Creek watershed for the period December 2003 to December 2005.

Figure A.3 Frequency analysis of fecal coliform concentrations at station 1-AMAO000.42 in the Mattox Creek watershed for the period July 1997 to April 2003.

Figure A.4 Frequency analysis of fecal coliform concentrations at station 1-AMAO004.08 in the Mattox Creek watershed for the period November 1992 to June 2004.

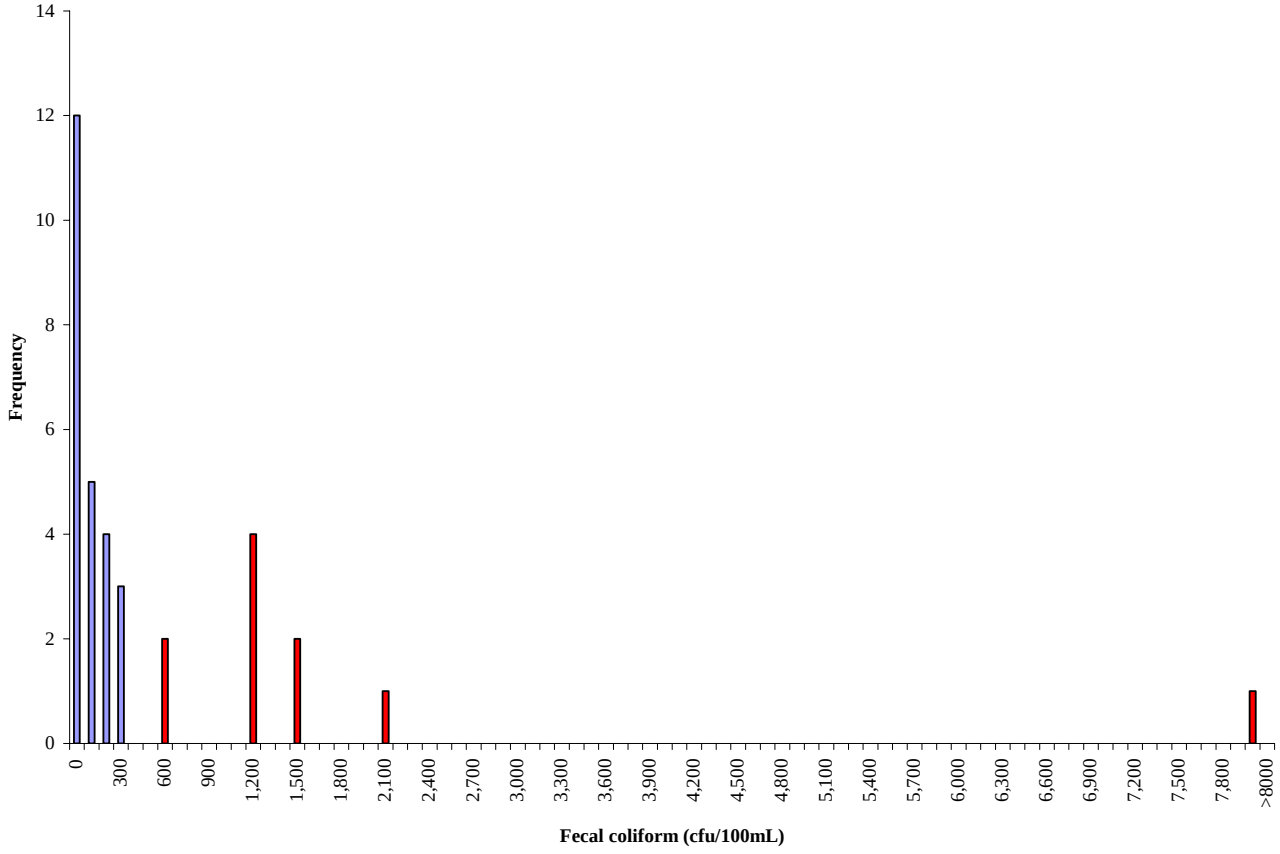

Figure A.5 Frequency analysis of fecal coliform concentrations at station 1-AMAO007.46 in the Mattox Creek watershed for the period April 1996 to December 2005.

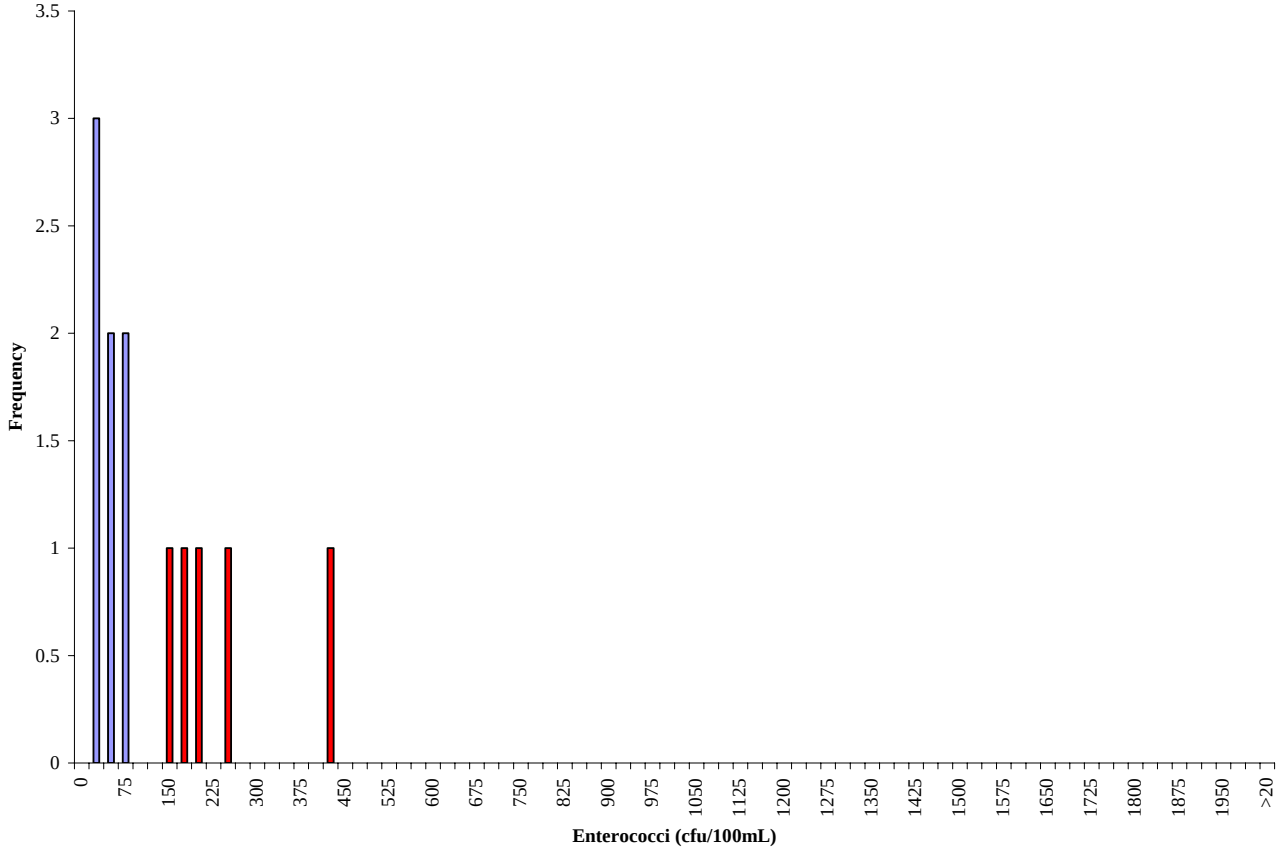

Figure A.6 Frequency analysis of enterococci concentrations at station 1-AMAO004.08 in the Mattox Creek watershed.

APPENDIX B

Table B.1 Current conditions of land applied fecal coliform load for the free-flowing segment by land use (sub-watersheds 1,2,3,5,6).

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Commercial	2.71E+11	2.44E+11	2.71E+11	2.62E+11	2.71E+11	2.62E+11	2.71E+11	2.71E+11	2.62E+11	2.71E+11	2.62E+11	2.71E+11	3.19E+12
Forest	2.05E+13	1.85E+13	2.05E+13	1.99E+13	2.05E+13	1.99E+13	2.05E+13	2.05E+13	1.99E+13	2.05E+13	1.99E+13	2.05E+13	2.42E+14
Livestock Access	2.26E+11	2.04E+11	3.07E+11	3.98E+11	4.11E+11	4.77E+11	4.93E+11	4.93E+11	3.98E+11	3.07E+11	2.97E+11	2.26E+11	4.24E+12
Low Intensity Residential	2.48E+12	2.24E+12	2.48E+12	2.40E+12	2.48E+12	2.40E+12	2.48E+12	2.48E+12	2.40E+12	2.48E+12	2.40E+12	2.48E+12	2.92E+13
Pasture	2.14E+13	1.93E+13	2.13E+13	2.05E+13	2.11E+13	3.39E+13	3.46E+13	3.46E+13	2.05E+13	2.13E+13	2.06E+13	2.14E+13	2.91E+14
Row crops	1.43E+13	1.60E+13	1.34E+14	1.34E+14	1.34E+14	2.63E+12	2.71E+12	2.71E+12	4.14E+13	1.34E+14	1.34E+14	1.43E+13	7.64E+14
Transitional	7.78E+10	7.03E+10	7.78E+10	7.53E+10	7.78E+10	7.53E+10	7.78E+10	7.78E+10	7.53E+10	7.78E+10	7.53E+10	7.78E+10	9.16E+11
Wetland	5.04E+12	4.55E+12	5.04E+12	4.87E+12	5.04E+12	4.87E+12	5.04E+12	5.04E+12	4.87E+12	5.04E+12	4.87E+12	5.04E+12	5.93E+13

Table B.2 Current conditions of land applied fecal coliform loads for the tidal impairment by land use (sub-watershed 4).

Land use	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Commercial	1.71E+11	1.55E+11	1.71E+11	1.66E+11	1.71E+11	1.66E+11	1.71E+11	1.71E+11	1.66E+11	1.71E+11	1.66E+11	1.71E+11	2.02E+12
Forest	3.59E+12	3.24E+12	3.59E+12	3.47E+12	3.59E+12	3.47E+12	3.59E+12	3.59E+12	3.47E+12	3.59E+12	3.47E+12	3.59E+12	4.22E+13
Livestock Access	1.16E+11	1.05E+11	1.50E+11	1.89E+11	1.96E+11	2.23E+11	2.30E+11	2.30E+11	1.89E+11	1.50E+11	1.45E+11	1.16E+11	2.04E+12
Low Intensity Residential	3.86E+12	3.49E+12	3.86E+12	3.74E+12	3.86E+12	3.74E+12	3.86E+12	3.86E+12	3.74E+12	3.86E+12	3.74E+12	3.86E+12	4.55E+13
Pasture	5.47E+12	4.94E+12	5.44E+12	5.22E+12	5.39E+12	5.18E+12	5.36E+12	5.36E+12	5.22E+12	5.44E+12	5.26E+12	5.47E+12	6.37E+13
Row crops	1.57E+12	1.42E+12	1.57E+12	1.52E+12	1.57E+12	1.52E+12	1.57E+12	1.57E+12	1.52E+12	1.57E+12	1.52E+12	1.57E+12	1.85E+13
Transitional	2.01E+11	1.81E+11	2.01E+11	1.94E+11	2.01E+11	1.94E+11	2.01E+11	2.01E+11	1.94E+11	2.01E+11	1.94E+11	2.01E+11	2.37E+12
Wetland	1.44E+12	1.30E+12	1.44E+12	1.40E+12	1.44E+12	1.40E+12	1.44E+12	1.44E+12	1.40E+12	1.44E+12	1.40E+12	1.44E+12	1.70E+13

Table B.3 Monthly, directly deposited fecal coliform loads in each reach of the free-flowing segment (reaches 1,2,3,5,6).

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	1	3.83E+11	3.46E+11	3.83E+11	3.71E+11	3.83E+11	3.71E+11	3.83E+11	3.83E+11	3.71E+11	3.83E+11	3.71E+11	3.83E+11	4.51E+12
Livestock	1	1.30E+09	1.17E+09	1.73E+09	2.52E+09	2.60E+09	2.94E+09	3.03E+09	3.03E+09	2.52E+09	1.73E+09	1.68E+09	1.30E+09	2.56E+10
Wildlife	1	1.50E+11	1.35E+11	1.50E+11	1.45E+11	1.50E+11	1.45E+11	1.50E+11	1.50E+11	1.45E+11	1.50E+11	1.45E+11	1.50E+11	1.77E+12
Human/Pet	2	5.58E+11	5.04E+11	5.58E+11	5.40E+11	5.58E+11	5.40E+11	5.58E+11	5.58E+11	5.40E+11	5.58E+11	5.40E+11	5.58E+11	6.57E+12
Livestock	2	2.76E+09	2.50E+09	3.69E+09	5.35E+09	5.53E+09	6.24E+09	6.45E+09	6.45E+09	5.35E+09	3.69E+09	3.57E+09	2.76E+09	5.43E+10
Wildlife	2	9.40E+10	8.49E+10	9.40E+10	9.10E+10	9.40E+10	9.10E+10	9.40E+10	9.40E+10	9.10E+10	9.40E+10	9.10E+10	9.40E+10	1.11E+12
Human/Pet	3	2.22E+12	2.00E+12	2.22E+12	2.14E+12	2.22E+12	2.14E+12	2.22E+12	2.22E+12	2.14E+12	2.22E+12	2.14E+12	2.22E+12	2.61E+13
Livestock	3	1.28E+10	1.15E+10	1.70E+10	2.47E+10	2.55E+10	2.88E+10	2.98E+10	2.98E+10	2.47E+10	1.70E+10	1.65E+10	1.28E+10	2.51E+11
Wildlife	3	3.96E+11	3.58E+11	3.96E+11	3.83E+11	3.96E+11	3.83E+11	3.96E+11	3.96E+11	3.83E+11	3.96E+11	3.83E+11	3.96E+11	4.66E+12
Human/Pet	5	2.04E+12	1.84E+12	2.04E+12	1.97E+12	2.04E+12	1.97E+12	2.04E+12	2.04E+12	1.97E+12	2.04E+12	1.97E+12	2.04E+12	2.40E+13
Livestock	5	4.21E+09	3.80E+09	5.61E+09	8.14E+09	8.41E+09	9.50E+09	9.82E+09	9.82E+09	8.14E+09	5.61E+09	5.43E+09	4.21E+09	8.27E+10
Wildlife	5	1.06E+11	9.61E+10	1.06E+11	1.03E+11	1.06E+11	1.03E+11	1.06E+11	1.06E+11	1.03E+11	1.06E+11	1.03E+11	1.06E+11	1.25E+12
Human/Pet	6	4.04E+11	3.65E+11	4.04E+11	3.91E+11	4.04E+11	3.91E+11	4.04E+11	4.04E+11	3.91E+11	4.04E+11	3.91E+11	4.04E+11	4.76E+12
Livestock	6	6.14E+09	5.55E+09	8.19E+09	1.19E+10	1.23E+10	1.39E+10	1.43E+10	1.43E+10	1.19E+10	8.19E+09	7.93E+09	6.14E+09	1.21E+11
Wildlife	6	7.18E+10	6.49E+10	7.18E+10	6.95E+10	7.18E+10	6.95E+10	7.18E+10	7.18E+10	6.95E+10	7.18E+10	6.95E+10	7.18E+10	8.46E+11

Table B.4 Monthly, directly deposited fecal coliform loads in reach 4 of the tidal impairment.

Source Type	Reach ID	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total Loads (cfu/yr)
Human/Pet	4	3.07E+12	2.77E+12	3.07E+12	2.97E+12	3.07E+12	2.97E+12	3.07E+12	3.07E+12	2.97E+12	3.07E+12	2.97E+12	3.07E+12	3.61E+13
Livestock	4	8.47E+09	7.65E+09	1.13E+10	1.64E+10	1.69E+10	1.91E+10	1.98E+10	1.98E+10	1.64E+10	1.13E+10	1.09E+10	8.47E+09	1.67E+11
Wildlife	4	6.08E+11	5.49E+11	6.08E+11	5.88E+11	6.08E+11	5.88E+11	6.08E+11	6.08E+11	5.88E+11	6.08E+11	5.88E+11	6.08E+11	7.16E+12

Table B.5 Existing annual loads from land-based sources for the free-flowing segments (sub-watersheds 1,2,3,5,6).

Source	Commercial	Forest	Livestock Access	Low Intensity Residential	Pasture	Row crops	Transitional	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E+10	0.00E+00
Beef_Calf_access	0.00E+00	0.00E+00	5.28E+10	0.00E+00	2.67E+12	0.00E+00	0.00E+00	1.41E+10	0.00E+00
Beef_Calf_non_access	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef_Stocker_Access	0.00E+00	0.00E+00	4.27E+11	0.00E+00	2.84E+13	0.00E+00	0.00E+00	1.49E+11	0.00E+00
Beef_Stocker_non_access	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	2.31E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dairy_calf	0.00E+00	0.00E+00	1.17E+12	0.00E+00	2.47E+13	0.00E+00	0.00E+00	1.30E+11	0.00E+00
Dairy_Heifer	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
Dairy_Milker	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.07E+13	7.34E+14	0.00E+00	0.00E+00	0.00E+00
Deer	0.00E+00	3.07E+13	5.41E+10	1.97E+11	3.45E+12	6.81E+12	3.09E+11	0.00E+00	1.47E+12
Dogs	0.00E+00	0.00E+00	0.00E+00	2.58E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Duck	2.18E+08	9.95E+09	2.25E+07	1.29E+08	1.72E+08	9.05E+08	5.67E+06	0.00E+00	3.87E+09
Goose	2.95E+11	1.34E+13	3.04E+10	1.74E+11	2.33E+11	1.22E+12	7.66E+09	0.00E+00	5.23E+12
Hog	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	2.11E+12	0.00E+00	4.54E+13	0.00E+00	0.00E+00	2.39E+11	0.00E+00
Muskrat	2.57E+12	1.17E+14	2.64E+11	1.51E+12	2.03E+12	1.06E+13	6.66E+10	0.00E+00	4.55E+13
Raccoon	3.26E+11	8.06E+13	1.17E+11	1.54E+12	6.49E+12	1.33E+13	5.33E+11	0.00E+00	7.11E+12
Sheep	0.00E+00	0.00E+00	8.78E+09	0.00E+00	1.88E+11	0.00E+00	0.00E+00	9.93E+08	0.00E+00
Straight_pipe_density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.59E+13	0.00E+00
Turkey	0.00E+00	2.35E+10	1.04E+07	0.00E+00	6.59E+08	1.30E+09	2.36E+08	0.00E+00	1.12E+09

Table B.6 Existing annual loads from land-based sources for the tidal impairment (sub-watershed 4).

Source	Commercial	Forest	Livestock Access	Low Intensity Residential	Pasture	Row crops	Transitional	Water	Wetland
Beaver	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.10E+09	0.00E+00
Beef_Calf_access	0.00E+00	0.00E+00	8.79E+10	0.00E+00	1.67E+12	0.00E+00	0.00E+00	8.79E+09	0.00E+00
Beef_Calf_non_access	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.76E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef_Stocker_Access	0.00E+00	0.00E+00	1.07E+12	0.00E+00	2.03E+13	0.00E+00	0.00E+00	1.07E+11	0.00E+00
Beef_Stocker_non_access	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	3.10E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dairy_calf	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
Dairy_Heifer	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
Dairy_Milker	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	0.00E+00	4.62E+12	1.44E+10	3.34E+11	1.28E+12	2.20E+12	2.69E+11	0.00E+00	5.90E+11
Dogs	0.00E+00	0.00E+00	0.00E+00	3.46E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Duck	1.33E+08	1.88E+09	2.72E+07	5.17E+08	2.84E+08	7.95E+08	9.45E+07	0.00E+00	1.08E+09
Goose	1.80E+11	2.54E+12	3.67E+10	6.99E+11	3.83E+11	1.07E+12	1.28E+11	0.00E+00	1.46E+12
Hog	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	4.58E+11	0.00E+00	9.65E+12	0.00E+00	0.00E+00	5.09E+10	0.00E+00
Muskrat	1.56E+12	2.21E+13	3.19E+11	6.07E+12	3.33E+12	9.33E+12	1.11E+12	0.00E+00	1.27E+13
Raccoon	2.72E+11	1.30E+13	5.28E+10	3.72E+12	4.08E+12	5.91E+12	8.58E+11	0.00E+00	2.20E+12
Sheep	0.00E+00	0.00E+00	1.16E+09	0.00E+00	2.44E+10	0.00E+00	0.00E+00	1.28E+08	0.00E+00
Straight_pipe_density	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.61E+13	0.00E+00
Turkey	0.00E+00	3.54E+09	2.76E+06	0.00E+00	2.46E+08	4.22E+08	2.06E+08	0.00E+00	4.51E+08

Table B.7 Existing annual loads from direct-deposition sources for the free-flowing segment (reaches 1,2,3,5,6).

Source	Annual Total Loads (cfu/yr)
Beaver	1.06E+10
Beef_Calf_access	1.41E+10
Beef_Calf_non_access	0.00E+00
Beef_Stocker_Access	1.49E+11
Beef_Stocker_non_access	0.00E+00
Dairy_calf	1.30E+11
Dairy_Heifer	0.00E+00
Dairy_Milker	0.00E+00
Deer	2.16E+10
Duck	6.18E+08
Goose	5.49E+11
Hog	0.00E+00
Horse	2.39E+11
Muskrat	8.77E+12
Raccoon	2.77E+11
Sheep	9.93E+08
Straight_pipe_density	6.59E+13
Turkey	1.34E+07

Table B.8 Existing annual loads from direct-deposition sources for the tidal impairment (reach 4).

Source	Annual Total Loads (cfu/yr)
Beaver	4.10E+09
Beef_Calf_access	8.79E+09
Beef_Calf_non_access	0.00E+00
Beef_Stocker_Access	1.07E+11
Beef_Stocker_non_access	0.00E+00
Dairy_calf	0.00E+00
Dairy_Heifer	0.00E+00
Dairy_Milker	0.00E+00
Deer	5.66E+09
Duck	4.69E+08
Goose	4.17E+11
Hog	0.00E+00
Horse	5.09E+10
Muskrat	6.65E+12
Raccoon	7.58E+10
Sheep	1.28E+08
Straight_pipe_density	3.61E+13
Turkey	2.43E+06

APPENDIX C

Table C.1 Expansion Matrix showing the effect on TMDL of a 500% growth in the WLA in the Mattox free-flowing segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox Creek – Free-flowing	*E. coli*	1.1E+07	5.0E+12	*Implicit*	5.0E+12

Table C.2 Expansion Matrix showing the effect on TMDL of a 500% growth in the WLA in the Mattox tidal segment.

Impairment	TMDL Standard	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Mattox – Tidal Segment	*Enterococci*	8.5E+05	1.0E+14	*Implicit*	1.0E+14
Mattox – Tidal Segment	*Fecal coliform*	1.5E+06	2.6E+13		2.6E+13