Bacteria Total Maximum Daily Load Development for the Rappahannock River Basin

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List of Acronyms

AVMA	American Veterinary Medical Association
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMPs	Best Management Practices
BST	Bacterial Source Tracking
HSPF	Hydrologic Simulation Program – Fortran
LA	Load Allocation
MOS	Margin of Safety
MPN	Most Probable Number
MRLC	Multi-Resolution Land Characterization
MS4	Phase II Municipal Separate Storm Sewer System
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NLCD	National Land Cover Data
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
SCS	Soil Conservation Service
SERCC	Southeast Regional Climate Center
SWCD	Soil and Water Conservation District
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality
VADGIF	Virginia Department of Game and Inland Fisheries
VASS	Virginia Agriculture Statistics Service
VCE	Virginia Cooperative Extension
VDACS	Virginia Department of Agricultural and Consumer Services
VDH	Virginia Department of Health
VPDES	Virginia Pollutant Discharge Elimination System
VWCB	Virginia Water Control Board
WLA	Wasteload Allocation
WQMP	Water Quality Management Plan

Executive Summary

Background

Marsh Run (VAN-E08R-01) was first listed as impaired streams in 1996 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003a) indicating that the recreational use goal was not being met. The stream segment was further listed in 1998, 2002, 2004, and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002, 2004, 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Browns Run (VAN-E08R-02), and Rappahannock River (VAN-E01R-03) were initially listed as impaired stream on Virginia's 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b) and remained on the 2004 Section 303(d) (VADEQ, 2004) and 2006 Section 303(d) (VADEQ, 2006) list due to water quality exceedances of the bacteria standard. Hughes River (VAN-E03R-01), Rappahannock River (VAN-E08R-04), and Craig Run (VAN-E08R-03), were initially listed as impaired stream on Virginia's 2004 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2004) due to water quality exceedances of the bacteria standard. These segments remained on the 2006 Section 303(d) (VADEQ, 2006) list due to water quality exceedances of the bacteria standard. Hazel River (60076) and Rappahannock River (60081) were initially listed as impaired stream on Virginia's 2006 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006) due to water quality exceedances of the bacteria standard.

The impaired portion of Hughes River (VAN-E03R-01) delineated by VADEQ, beginning at the confluence with Kilbys Run and continuing downstream approximately 3.68 miles to the confluence with Hazel River, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HUE000.20 at Route 644.

The impaired portion of Hazel River (VAN-E04R-01) delineated by VADEQ, beginning at Route 707 bridge and continuing downstream approximately 16.67 miles to the confluence of an Unnamed Tributary to Hazel River at rivermile 16.03, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HAZ018.29 at Route 729, station 3-HAZ026.16 at Route 522, and station 3-HAZ032.54 at Route 644. A portion of the impaired section of Hazel River was listed in Attachment C (Plaintiff's list of waters that were added to the 303(d) list in 2002) of the 1999 Consent Decree for fecal coliform.

The impaired portion of Rush River (VAN-E05R-01) delineated by VADEQ, beginning at the confluence of an Unnamed Tributary to Rush River, at rivermile 8.78, and continuing downstream approximately 4.55 miles to the confluence of Big Branch, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RUS005.66 at Route 683 bridge, upstream of Route 211/522.

The impaired portion of Hazel River (60076) delineated by VADEQ, beginning at the confluence with Indian Run and continuing downstream approximately 3.32 miles to the confluence with Muddy Run, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HAZ005.98 at Route 625.

The impaired portion of Rappahannock River (VAN-E01R-03) delineated by VADEQ, beginning at the confluence with the Jordan River at rivermile 175.58 and continuing downstream approximately 2.17 miles to the confluence with Unnamed Tributary to Rappahannock River at rivermile 173.41, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP175.51 at Route 647. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected.

The impaired portion of the Rappahannock River (VAN-E08R-04) delineated by VADEQ, beginning at the confluence with Ruffans Run and continuing downstream approximately 2.02 miles to the confluence with Tinpot Run, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP147.10 at Route 15/29 Business bridge. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected. This segment of the Rappahannock River is included in Attachment C (Plaintiff's list of waters that were added to the 303(d) list in 2002) of the 1999 Consent Decree for fecal coliform.

The impaired portion of the Rappahannock River (60081) delineated by VADEQ, beginning at the confluence with Unnamed Tributary to the Rappahannock River at approximately rivermile 142.5 and continuing downstream approximately 2.85 miles to the confluence with Marsh Run, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP142.36 at Route 620. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected.

The impaired portion of Craig Run (VAN-E08R-03) delineated by VADEQ, beginning at the headwaters of Craig Run and continuing downstream approximately 3.61 miles to the confluence with Marsh Run, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-CRA000.82 at Route 656.

The impaired portion of Browns Run (VAN-E08R-02) delineated by VADEQ, beginning at the confluence with an Unnamed Tributary to Browns Run, near the Route 17 bridge and continuing downstream approximately 2.39 miles to the confluence with Marsh Run, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-BOS000.72 at Route 653.

The impaired portion of Marsh Run (VAN-E08R-01) delineated by VADEQ, beginning at the confluence with Craig Run and continuing downstream approximately 8.16 miles to the confluence with the Rappahannock River, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at stations 3-MAH000.19 at Route 651 and station 3-MAH004.18 at Route 668. This impaired segment of Marsh Run was included in Attachment A (waters listed on Part 1 of Virginia's 1998 303(d) Report) of the 1999 Consent Decree for fecal coliform.

The Hughes River (VAN-E03R-01) watershed area is approximately 45,790 acres consisting mainly of forest (74%) and pasture/cropland (25%).The remaining area is split between residential and water/wetland. The Hazel River (VAN-E04R-01) watershed is approximately 79,980 acres in size. Hazel River (VAN-E04R-01) is mainly a forested watershed (about 71%) with pasture/cropland, residential, and water/wetland comprising 28%,1%, and <1% of the area, respectively. The Rush River (VAN-E05R-01) watershed area of approximately 9,840 acres is comprised of forest (79%), pasture/cropland (20%), residential (1%), and water/wetland (<1%). The 202,410 acres in the Hazel River (60076) watershed consists of approximately 67% forest, 32% pasture/cropland, 1% residential, and <1% water/wetland land uses. The approximately 48,300 acres of Rappahannock River (VAN-E01R-03) watershed consists of 68% forest, 30%, pasture/cropland, and the remaining 2% split between residential and water/wetland land uses. The Rappahannock River (VAN-E08R-04) watershed area of 396,310 acres is comprised of forest (63%), pasture/cropland (36%), residential (1%), and water/wetland (<1%). The approximately 409,920 acres of Rappahannock River (60081) watershed are mostly forested (about 62%) with 36%, 1%, and <1% of the remaining acreage consisting of pasture/ cropland, residential, and water/wetland land uses, respectively. The Craig Run (VAN-E08R-03) watershed is approximately 5,360 acres in size. Craig Run (VAN-E08R-03) is mainly comprised of pasture/cropland (70%) with forest (24%), residential (6%) and water/wetland (<1%) land uses contributing the difference. The approximately 7,070 acres of Browns Run (VAN-E08R-03) watershed are mostly pasture/cropland (about 50%) with 47%, 2%, and 1% of the remaining acreage consisting of forest, residential, and water/wetland land uses, respectively. The Marsh Run (VAN-E08R-01) watershed area of approximately 29,400 acres is comprised of forest (41%), pasture/cropland (55%), residential (3%), and water/wetland (1%).

VADEQ personnel monitored pollutant concentrations throughout the Hughes River (3-HUE000.20), Hazel River (3-HAZ018.29 and 3-HAZ005.98), Rush River (3-RUS005.66), Rappahannock River (3-RPP175.51, 3-RPP147.10, and 3-RPP142.36), Craig Run (3-CRA000.82), Browns Run (3-BOS000.72), and Marsh Run (3-MAH000.19) watersheds. Of the 19 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 3-HUE000.20, 15.8% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Consequently, this segment of Hughes River (VAN-E03R-01) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in three of 20 (15.0%) samples collected during the 2006 Section 303(d) assessment period at station 3-

HAZ018.29. This segment of Hazel River (VAN-E04R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (18 samples) at station 3-RUS005.66 yielded sufficient exceedance (22.2%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rush River (VAN-E05R-01) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Hazel River (60076) does not support the Recreation Use goal due to five of 14 (35.7%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-HAZ005.98. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in four of 14 (28.6%) samples collected during the 2006 Section 303(d) assessment period at station 3-RPP175.51. This segment of Rappahannock River (VAN-E01R-03) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (13 samples) at station 3-RPP147.10 yielded sufficient exceedance (38.5%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rappahannock River (VAN-E08R-04) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Rappahannock River (60081) does not support the Recreation Use goal due to two of seven (28.6%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-RPP142.36. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in three of three (100.0%) samples collected during the 2006 Section 303(d) assessment period at station 3-CRA000.82. This segment of Craig Run (VAN-E08R-03) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (3 samples) at station 3-BOS000.72 yielded sufficient exceedance (100.0%) of the fecal coliform bacteria instantaneous standard to assess this segment of Browns Run (VAN-E08R-02) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Marsh Run (VAN-E08R-01) does not support the Recreation Use goal due to two of seven (28.6%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-MAH000.19. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

In order to remedy the water quality impairment pertaining to fecal coliform, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of E. coli shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. The glossary lists terms used in the development of this TMDL.

Sources of Fecal Coliform

Currently, there are one, two, two, seven, eight, two, five, and eight active point discharges with a VPDES permit within the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-

E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds, respectively. However, the majority of the fecal coliform load originates from nonpoint sources. Nonpoint sources of fecal coliform are primarily agricultural (i.e., land-applied animal waste, manure deposited directly on pastures by livestock, and a significant fecal coliform load due to cattle directly depositing manure in streams) with a significant load applied to residential and forest land use categories. Non-agricultural anthropogenic nonpoint sources of fecal coliform loadings include straight pipes, leaking sanitary sewer, failing septic systems, and pet waste. Wildlife contributes to fecal coliform loadings on all land uses, according to the acceptable habitat range for each species. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife habitat and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement or in streams, the amount of manure storage, and spreading schedules, were considered on a monthly basis.

Modeling

The Hydrologic Simulation Program – Fortran (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds. To identify localized sources of fecal coliform, the watersheds were divided into subwatersheds. These subdivisions were based primarily on homogeneity of land use. The Hazel River model was calibrated using observed flow values from USGS station #01663500 on Hazel River near Rixeyville, VA for the period October 1, 1987 to September 30, 1992. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions, as well as seasonal variations. The calibrated HSPF data set was validated on a separate period from October 1, 1982 to September 30, 1987. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable. The Rappahannock River model was calibrated using observed flow values from USGS station #01664000 on Rappahannock River near Remington, Virginia for the period October 1, 1990 to September 30, 1995. The model was validated for the period October 1, 1995 to September 30, 2000. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable.

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 3-HUE000.20, 3-HAZ018.29, 3-RUS005.66, 3-HAZ005.98, 3-RPP175.51, 3-RPP147.10, 3-RPP142.36, 3-CRA000.82, 3-BOS000.72, and3-MAH000.19 within the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments, respectively, were used to calibrate the water quality component of HSPF between January 1993 and December 1997 (if data was available). The model was validated for period January 1998 to December 2002 (if data was available). For stations with limited data, water quality calibration was performed for January 1998 to

December 2002 only. Inputs to the model included fecal coliform loadings on land and in the stream along with simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate and transport of fecal coliform in the watershed.

Margin of Safety

A margin of safety (MOS) was included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) TMDLs, the MOS was implicitly incorporated into the TMDL by conservatively estimating several factors affecting bacteria loadings, such as animal numbers, production rates, and contributions to streams.

Existing Conditions

Based on amounts of fecal coliform produced in different locations, daily fecal coliform loadings to different land use categories were calculated for each sub-watershed for input into the model. Fecal coliform content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, fecal coliform die-off on land was taken into account, as was the reduction in fecal coliform available for surface wash-off due to incorporation following waste application on cropland. Straight pipes produced a direct fecal coliform load to the stream. Direct seasonal fecal coliform loadings to streams by cattle were calculated for pastures adjacent to streams. Fecal coliform loadings to streams and land by wildlife were estimated for several species. Fecal coliform loadings to land from failing septic systems were estimated based on number and age of houses. Fecal coliform contribution from pet waste was also considered. Contributions from these various sources were represented in HSPF to establish existing conditions for a representative hydrologic period (January 1993 through December 1997).

TMDL Allocation Scenarios

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero exceedances. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Required reductions in fecal coliform loading from existing conditions for the selected TMDL allocation for the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments needed to meet both the calendar-month geometric mean and single sample water quality goals are listed in Table E.1. (Further discussion of wildlife reductions can be found in Section 6.5.4.).

Table E.1. Reduction in fecal coliform loading from existing conditions for TMDL allocation scenario.

Impairment	Percent Reduction in Fecal Coliform Loading from Existing Conditions						
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest
Hughes River (VAN-E03R-01)	100	90	90	90	90	0	0
Hazel River (VAN-E04R-01)	100	97	97	97	97	0	0
Rush River (VAN-E05R-01)	100	100	99	99	99	0	0
Hazel River (60076)	100	94	94	94	94	0	0
Rappahannock River (VAN-E01R-03)	100	99	99	99	99	11	0
Rappahannock River (VAN-E08R-04)	100	97	97	97	97	0	0
Rappahannock River (60081)	100	99	99	99	99	0	0
Craig Run (VAN-E08R-03)	100	97	97	97	97	0	0
Browns Run (VAN-E08R-02)	100	96	96	96	96	0	0
Marsh Run (VAN-E08R-01)	100	97	97	97	97	0	0

DD – direct deposition

Using equation [E.1], summaries of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) bacteria TMDLs for the selected allocation scenario are shown in Tables E.2 through E.21.

$$TMDL = WLA + LA + MOS \qquad [E.1]$$

where: WLA = wasteload allocation (point source contributions);
LA = load allocation (nonpoint source contributions); and
MOS = margin of safety (implicit).

Table E.2. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hughes River (VAN-E03R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	8.44E+09	2.28E+13	N/A	2.28E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.3. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hughes River (VAN-E03R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.31E+07	3.70E+12	N/A	3.70E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.4. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hazel River (VAN-E04R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	3.92E+12	3.38E+13	N/A	3.77E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.5. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hazel River (VAN-E04R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	1.07E+10	7.95E+12	N/A	7.96E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.6. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rush River (VAN-E05R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	5.22E+11	1.49E+12	N/A	2.01E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.7. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rush River (VAN-E05R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	1.43E+09	1.25E+12	N/A	1.25E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.8. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hazel River (60076) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	7.48E+11	9.15E+13	N/A	9.22E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.9. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hazel River (60076) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.05E+09	2.06E+13	N/A	2.06E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.10. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (VAN-E01R-03) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.79E+11	1.77E+13	N/A	1.79E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.11. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (VAN-E01R-03) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	4.35E+10	4.31E+12	N/A	4.35E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.12. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (VAN-E08R-04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.85E+13	3.20E+14	N/A	3.38E+14

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.13. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (VAN-E08R-04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.07E+10	3.74E+13	N/A	3.74E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.14. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (60081) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.18E+13	3.34E+14	N/A	3.56E+14

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.15. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (60081) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.97E+10	3.96E+13	N/A	3.97E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.16. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Craig Run (VAN-E08R-03) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.72E+10	2.69E+12	N/A	2.72E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.17. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Craig Run (VAN-E08R-03) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	8.93E+09	8.84E+11	N/A	8.93E+11

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.18. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Browns Run (VAN-E08R-02) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	3.38E+10	2.26E+12	N/A	2.29E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.19. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Browns Run (VAN-E08R-02) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	9.25E+07	9.23E+11	N/A	9.23E+11

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Table E.20. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Marsh Run (VAN-E08R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	8.76E+11	2.77E+13	N/A	2.86E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table E.21. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Marsh Run (VAN-E08R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.40E+09	3.07E+12	N/A	3.07E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

Stage 1 Implementation

Staged implementation is a key component to restoring water quality in Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01). An alternative scenario was evaluated to establish goals for the first stage of the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through continued data collection. The Stage 1 implementation goal was to provide an instantaneous standard exceedance rate below 10% and 0% reduction in loads from wildlife. The goal was met in all impairments. Stage 1 reduction scenarios are listed in Table E.22.

Table E.22. Stage 1 reduction scenarios.

Impairment	Percent Reduction in Fecal Coliform Loading from Existing Conditions						
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest
Hughes River (VAN-E03R-01)	100	20	75	20	20	0	0
Hazel River (VAN-E04R-01)	100	71	75	71	71	0	0
Rush River (VAN-E05R-01)	100	60	80	60	60	0	0
Hazel River (60076)	100	59	80	59	59	0	0
Rappahannock River (VAN-E01R-03)	100	66	75	66	66	0	0
Rappahannock River (VAN-E08R-04)	100	48	75	48	48	0	0
Rappahannock River (60081)	100	90	90	90	90	0	0
Craig Run (VAN-E08R-03)	100	81	81	81	81	0	0
Browns Run (VAN-E08R-02)	100	67	75	67	67	0	0
Marsh Run (VAN-E08R-01)	100	90	90	90	90	0	0

DD – direct deposition

Public Participation

During development of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-

03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) TMDLs, public participation was encouraged through two sets of public meetings.

The first public meetings were held at the Rappahannock County Library in Washington, Virginia and St. Luke’s Church in Remington, Virginia on October 11, 2006 and October 17, 2006, respectively, to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. The second and final public meetings were held at the Culpeper Train Depot in Culpeper, Virginia and Rappahannock County Library in Washington, Virginia on March 19, 2007 and March 22, 2007, respectively, to discuss the source allocations and reductions required to meet the TMDL. Copies of the draft TMDL report were available for public review and comment.

In addition to keeping the public apprised of progress in the development of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) TMDLs, a TMDL Technical Advisory Committee (TAC) was also established to help advise the TMDL developers. TAC meetings were held prior to public meetings. TAC meetings were held for this project on July 27, 2006, December 15, 2006, and February 27, 2007 at the Culpeper Train Depot in Culpeper. The TAC membership included representatives from the following agencies and organizations: Virginia Department of Environmental Quality; Virginia Department of Conservation and Recreation; Virginia Department of Health; Virginia Department of Forestry; Virginia Cooperative Extension; Rappahannock-Rapidan Regional Commission; Thomas Jefferson, Culpeper, John Marshall, and Tri-County/City SWCDs; Rappahannock and Fauquier County Governments; RappFLOW; Piedmont Environmental Council; Friends of the Rush River; U.S. Department of Agriculture – Natural Resources Conservation Service; Centex Homes; Rappahannock County Farm Bureau; and Walsh, Colucci, Lubeley, Emrich and Walsh.

The meetings were used as a forum to facilitate understanding of, and involvement in, the TMDL process. Data and assumptions used in the TMDL development were reviewed along with stakeholder concerns about the implications of the TMDL. Feedback from these meetings was used in the TMDL development and improved confidence in the allocation.

Project Personnel

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Acknowledgements

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Virginia Cooperative Extension

Culpeper, John Marshall, Thomas Jefferson, and Tri-County/City SWCDs

Fauquier County Government

Land owners and producers who provided data and access through their property.

Engineering Concepts, Inc. of Fincastle, Virginia supported this study as a contractor to Rappahannock-Rappahannock Regional Commission through funding provided by the Virginia Department of Environmental Quality

Chapter 1. Introduction

1.1 Background

1.1.1 TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that exceed state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL represents the total load of a pollutant that a water body can receive without exceeding state water quality standards. The TMDL process establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the allowable load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2 Impairments Listing

Marsh Run (VAN-E08R-01) was first listed as impaired streams in 1996 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003a) indicating that the recreational use goal was not being met. The stream segment was further listed in 1998, 2002, 2004, and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002, 2004, 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Browns Run (VAN-E08R-02), and Rappahannock River (VAN-E01R-03) were initially listed as impaired stream on Virginia's 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b) and remained on the 2004 Section 303(d) (VADEQ, 2004) and 2006 Section 303(d) (VADEQ, 2006) list due to water quality exceedances of the bacteria standard. Hughes River (VAN-E03R-01), Rappahannock River (VAN-E08R-04), and Craig Run (VAN-E08R-03), were initially listed as impaired stream on Virginia's 2004 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2004) due to water quality exceedances of the bacteria standard. These segments remained on the 2006 Section 303(d) (VADEQ, 2006) list due to water quality exceedances of the bacteria standard. Hazel River (60076) and Rappahannock River (60081) were initially listed as impaired stream on Virginia's 2006 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006) due to water quality exceedances of the bacteria standard.

The impaired portion of Hughes River (VAN-E03R-01) delineated by VADEQ, beginning at the confluence with Kilbys Run and continuing downstream approximately 3.68 miles to the confluence with Hazel River, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HUE000.20 at Route 644.

The impaired portion of Hazel River (VAN-E04R-01) delineated by VADEQ, beginning at Route 707 bridge and continuing downstream approximately 16.67 miles to the confluence of an Unnamed Tributary to Hazel River at rivermile 16.03, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HAZ018.29 at Route 729, station 3-HAZ026.16 at Route 522, and station 3-HAZ032.54 at Route 644. A portion of the impaired section of Hazel River was listed in Attachment C (Plaintiff's list of waters that were added to the 303(d) list in 2002) of the 1999 Consent Decree for fecal coliform.

The impaired portion of Rush River (VAN-E05R-01) delineated by VADEQ, beginning at the confluence of an Unnamed Tributary to Rush River, at rivermile 8.78, and continuing downstream approximately 4.55 miles to the confluence of Big Branch, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RUS005.66 at Route 683 bridge, upstream of Route 211/522.

The impaired portion of Hazel River (60076) delineated by VADEQ, beginning at the confluence with Indian Run and continuing downstream approximately 3.32 miles to the confluence with Muddy Run, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-HAZ005.98 at Route 625.

The impaired portion of Rappahannock River (VAN-E01R-03) delineated by VADEQ, beginning at the confluence with the Jordan River at rivermile 175.58 and continuing downstream approximately 2.17 miles to the confluence with Unnamed Tributary to Rappahannock River at rivermile 173.41, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP175.51 at Route 647. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected.

The impaired portion of the Rappahannock River (VAN-E08R-04) delineated by VADEQ, beginning at the confluence with Ruffans Run and continuing downstream approximately 2.02 miles to the confluence with Tinpot Run, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP147.10 at Route 15/29 Business bridge. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected. This segment of the Rappahannock River is included in Attachment C (Plaintiff's list of waters that were added to the 303(d) list in 2002) of the 1999 Consent Decree for fecal coliform.

The impaired portion of the Rappahannock River (60081) delineated by VADEQ, beginning at the confluence with Unnamed Tributary to the Rappahannock River at approximately rivermile 142.5 and continuing downstream approximately 2.85 miles to the confluence with Marsh Run, is listed as impaired by *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-RPP142.36 at Route 620. This segment was formerly identified with a bacterial impairment due to exceedances of the fecal coliform criterion, however, this is no longer applicable to this reach because at least twelve *E.coli* samples have been collected.

The impaired portion of Craig Run (VAN-E08R-03) delineated by VADEQ, beginning at the headwaters of Craig Run and continuing downstream approximately 3.61 miles to the confluence with Marsh Run, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-CRA000.82 at Route 656.

The impaired portion of Browns Run (VAN-E08R-02) delineated by VADEQ, beginning at the confluence with an Unnamed Tributary to Browns Run, near the Route 17 bridge and continuing downstream approximately 2.39 miles to the confluence with Marsh Run, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 3-BOS000.72 at Route 653.

The impaired portion of Marsh Run (VAN-E08R-01) delineated by VADEQ, beginning at the confluence with Craig Run and continuing downstream approximately 8.16 miles to the confluence with the Rappahannock River, is listed as impaired by fecal coliform bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at stations 3-MAH000.19 at Route 651 and station 3-MAH004.18 at Route 668. This impaired segment of Marsh Run was included in Attachment A (waters listed on Part 1 of Virginia's 1998 303(d) Report) of the 1999 Consent Decree for fecal coliform.

1.1.3 Watershed Location and Description

The Rush River (VAN-E05R-01) impairment watershed is located in Rappahannock County, Virginia. Hazel River (VAN-E04R-01) impairment watersheds are located in Rappahannock County, Virginia and Culpeper County, Virginia. Hughes River (VAN-E03R-01) and Hazel River (60076) impairment watersheds are located in Madison County, Virginia, Rappahannock County, Virginia and Culpeper County, Virginia. Rappahannock River (VAN-E01R-03) impairment watersheds are located in Rappahannock County, Virginia and Fauquier County, Virginia. Rappahannock River (VAN-E08R-04) and Rappahannock River (60081) impairment watersheds are located in Culpeper County, Virginia, Rappahannock County, Virginia, and Fauquier County, Virginia. Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-03), and Marsh Run (VAN-E08R-01) impairment watersheds are located in Fauquier County, Virginia (Figure 1.1). A summary of the land use distribution for each impairment is listed in Table 1.1.

Table 1.1. Land use distribution summary.

Impairment	Landuse Total (acres)	Percent of Total (%)			
		Forest	Pasture/ Cropland	Residential	Water/ Wetland
Hughes River (VAN-E03R-01)	45,790	74	25	0.5	0.5
Hazel River (VAN-E04R-01)	79,980	71	28	1	<1
Rush River (VAN-E05R-01)	9,840	79	20	1	<1
Hazel River (60076)	202,410	67	32	1	<1
Rappahannock River (VAN-E01R-03)	48,300	68	30	1	1
Rappahannock River (VAN-E08R-04)	396,310	63	36	1	<1
Rappahannock River (60081)	409,920	62	36	1	<1
Craig Run (VAN-E08R-03)	5,360	24	70	6	<1
Browns Run (VAN-E08R-01)	7,070	47	50	2	1
Marsh Run (VAN-E08R-01)	29,400	41	55	3	1

The Hazel River begins in Rappahannock County, Virginia slightly south of Panorama, Virginia and continues downstream to confluence with Rappahannock River northwest of Remington, Virginia. Hughes River drains directly into Hazel River near Slate Mills, Virginia. Rush River flows into Covington River, which flows into Thornton River, a tributary to Hazel River. The Rappahannock River forms in Fauquier County, Virginia southeast of Front Royal, Virginia and continues downstream until emptying into the Chesapeake Bay. Craig Run enters Marsh Run near Bealeton, Virginia and Browns Run enters Marsh Run south of Bealeton, Virginia. Marsh Run enters the Rappahannock River at Kelly's Ford, Virginia.

1.1.4 Pollutant of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, some forms can be harmful to human health and their presence in water indicates recent contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform counts may also contain pathogenic organisms. For recreational activities involving contact with water, such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for an exceedance of the state fecal coliform standard for contact recreational uses. As discussed in Section 1.2.2, Virginia has adopted an Escherichia coli (*E. coli*) standard for water quality. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

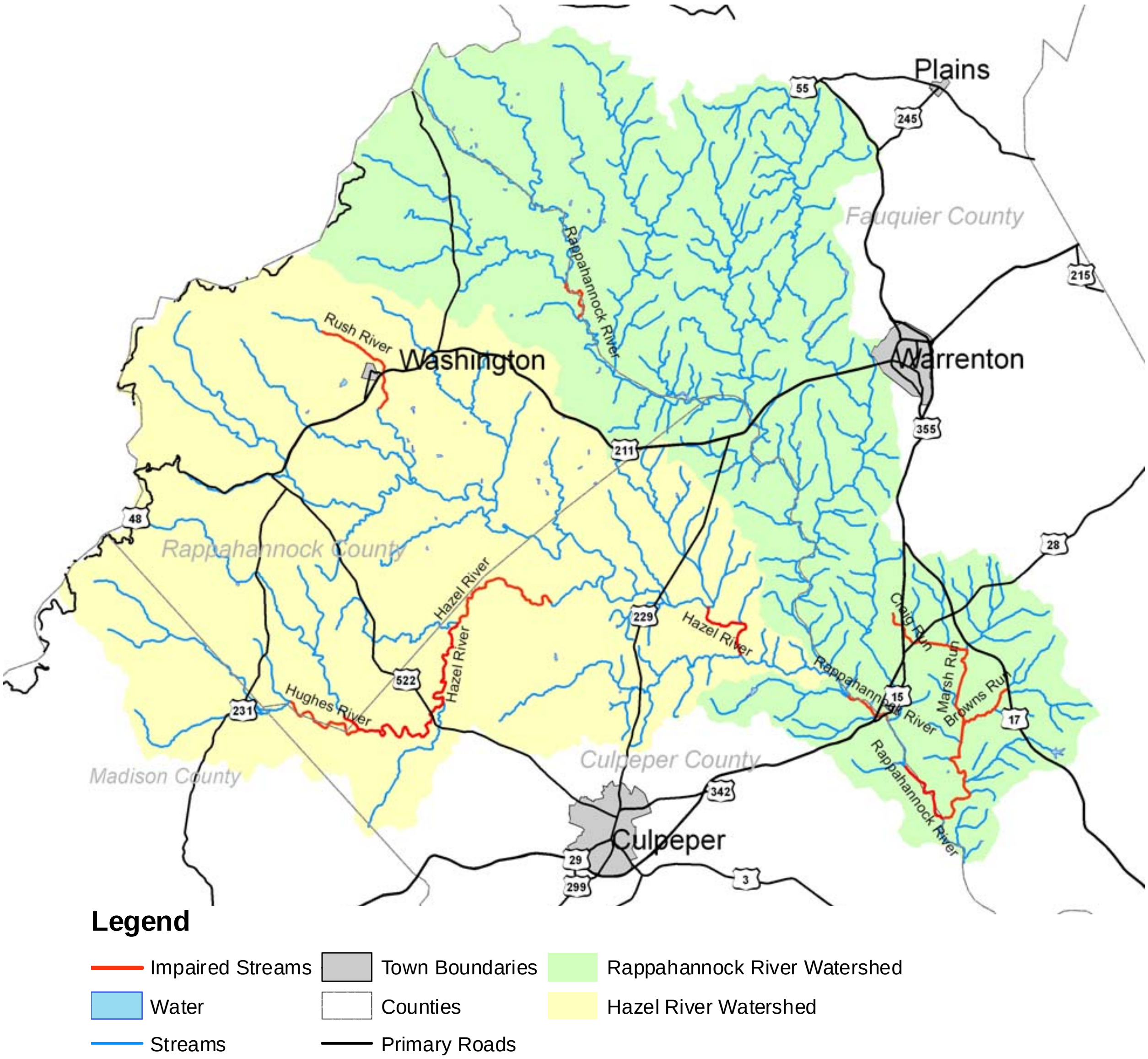

Figure 1.1. Location of Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-03), and Marsh Run (VAN-E08R-01) watersheds.

1.2 Designated Uses and Applicable Water Quality Standards

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

"A. All state waters 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)."

The goal of the Clean Water Act is that all streams should be suitable for recreational uses, including swimming and fishing. **Fecal coliform and *E. coli* bacteria** are used to indicate the presence of pathogens in streams supporting the **recreational use goal**. Bacteria in Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-03), and Marsh Run (VAN-E08R-01) exceed the fecal coliform criterion.

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

USEPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (VADEQ, 2000):

- **Interim Fecal Coliform Standard:** 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.
- **Escherichia coli Standard:** *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed an instantaneous single sample maximum of 235 cfu/100mL.

During an assessment period, conventional parameters such as bacteria require at least two exceedences of the standard, and an exceedance of greater than 10.5% of the total samples before a water is listed as impaired (VADEQ Assessment Guidance, 2006). If these conditions are met, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the segment into compliance with the water quality standard. The original impairment designation to Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-03), and Marsh Run (VAN-E08R-01) was based on exceedances of an earlier fecal coliform standard that included a numeric single sample maximum limit of 1,000 cfu/100 mL. The bacteria TMDL for these impaired segments was developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling was conducted with fecal coliform inputs, and then a translator equation developed by the VADEQ was used to convert the output of the model to *E. coli*.

Chapter 2. Watershed Characterization

2.1 Water Resources

The Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds were subdivided into sub-watersheds for fecal coliform modeling purposes, as discussed in Section 4.2.

Hazel River runs for approximately 38.7 miles from the headwaters to the confluence with Thornton River and continues flowing for approximately 12.6 miles to the confluence with Rappahannock River. Hughes River flows for approximately 13.4 miles from the headwaters to the confluence with Hazel River. Rush River flows for approximately 11.0 miles from the headwaters to the confluence with Covington River then Thornton River. Rappahannock River runs for approximately 15.7 miles from the headwaters to the Rappahannock River (VAN-E01R-03) impairment outlet, continues downstream approximately 28.4 miles to the Rappahannock River (VAN-E08R-04) impairment outlet, and runs another 4.7 miles to the Rappahannock River (60081) impairment outlet. Marsh Run flows for approximately 11.9 miles from the headwaters to the confluence with Rappahannock River. Craig Run flows for approximately 3.7 miles from the headwaters to the confluence with Marsh Run. Browns Run flows for approximately 5.2 miles from the headwaters to the confluence with Marsh Run. The Hughes River, Hazel River, Rush River, Rappahannock River, Craig Run, Browns Run, and Marsh Run are all perennial streams with a trapezoidal channel cross-section.

2.2 Ecoregion

Portions of subwatersheds HAR-01, HAR-03, HAR-11, HAR-13, HAR-14, and RAR-01 (See Figures 4.1 and 4.2 for subwatershed delineation) lie in the Blue Ridge Ecoregion and the remaining subwatersheds draining to the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments lie in the Northern Piedmont Ecoregion.

The Blue Ridge Ecoregion varies from narrow ridges to hilly plateaus to more massive mountainous areas. The mostly forested slopes, high-gradient, cool, clear streams, and rugged terrain occur primarily on metamorphic rocks, with minor areas of igneous and sedimentary geology. Appalachian Oak Forests and northern hardwoods coupled with shrub, grass, heath balds, hemlock, cove hardwoods, and oak-pine communities illustrate the floristic diversity of this ecoregion.

The Northern Piedmont Ecoregion consists primarily of low rounded hills, irregular plains, and open valleys and is underlain by metamorphic, igneous, and sedimentary rocks. The natural vegetation was mostly Appalachian Oak Forest (dominated by white and red oaks) (Woods et al., 1999). This ecoregion is a transitional area between the mostly mountainous ecoregions of the Appalachians to the west and the lower and more level ecoregions of the coastal plain to the east (Woods et al., 1999). It is a complex mosaic of Precambrian and Paleozoic metamorphic and igneous rocks, with moderately dissected irregular plains and some hills.

2.3 Climate

The climate of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds is characterized based on the meteorological observations from 02/24/1951 to 08/31/2005 assembled by the Southeast Regional Climate Center for the Warrenton S 3E, Virginia (448888) station. Average annual precipitation is 41.25 inches with 54.0% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2006). Average annual snowfall is 20.3 inches with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 54.5°F. The highest average daily temperature of 85.9°F occurs in July while the lowest average daily temperature of 22.7°F occurs in January (SERCC, 2006).

2.4 Land Use

General depiction of land use draining to impairments is listed in Table 1.1. Details of landuse used in this study are described in Section 4.3 with landuse per subwatershed listed in Tables 4.2 and 4.3.

For purposes of this study, it was assumed that residential development in the Hughes River (VAN-E03R-01) watershed will continue at the overall average rate of 11.6% annually. Residential development in the Hazel River (VAN-E04R-01) watershed was assumed to continue at a rate of 12.6% per year. It was assumed that residential development in the Rush River (VAN-E05R-01) watershed would continue at an average rate of 1.7% annually. Residential development in the Hazel River (60076) watersheds was assumed to continue at an average rate of 15.8% per year. It was assumed that residential development in the Rappahannock River (VAN-E01R-03) and Rappahannock River (VAN-E08R-04) watersheds would continue at an average rate of 14.4% annually. Residential development in the Rappahannock River (60081) watershed was assumed to continue at a rate of 7.7% per year. It was assumed that residential development in the Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds would continue at an average annual rate of 13.4%, 10.7%, and 10.3%, respectively.

2.5 Water Quality Data

2.5.1 Historic Data for Fecal Coliform

Of the 19 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 3-HUE000.20, 15.8% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard (Table 2.1). Consequently, this segment of Hughes River (VAN-E03R-01) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in three of 20 (15.0%), two of six (33%), and three of 14 (21%) samples collected during the 2006 Section 303(d) assessment period at stations 3-HAZ018.29, 3-HAZ026.16, and 3-HAZ032.54, respectively. This segment of Hazel River (VAN-E04R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (18 samples) at station 3-RUS005.66 yielded sufficient exceedance (22.2%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rush River (VAN-E05R-01) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Hazel River (60076) does not support the Recreation Use goal due to five of 14 (35.7%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-HAZ005.98. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in four of 14 (28.6%) samples collected during the 2006 Section 303(d) assessment period at station 3-RPP175.51. This segment of Rappahannock River (VAN-E01R-03) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (13 samples) at station 3-RPP147.10 yielded sufficient exceedance (38.5%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rappahannock River (VAN-E08R-04) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Rappahannock River (60081) does not support the Recreation Use goal due to two of seven (28.6%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-RPP142.36. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). The instantaneous fecal coliform bacteria standard was exceeded in three of three (100.0%) samples collected during the 2006 Section 303(d) assessment period at station 3-CRA000.82. This segment of Craig Run (VAN-E08R-03) was assessed as not supporting of the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (3 samples) at station 3-BOS000.72 yielded sufficient exceedance (100.0%) of the fecal coliform bacteria instantaneous standard to assess this segment of Browns Run (VAN-E08R-02) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Marsh Run (VAN-E08R-01) does not support the Recreation Use goal due to two of seven (28.6%) and three of four (75%) samples exceeding the instantaneous fecal coliform bacteria standard at stations 3-MAH000.19 and 3-MAH004.18, respectively. This segment was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

Table 2.1. Impairment name, monitoring station with location, and fecal coliform and E. coli water quality standard exceedance rates.

TMDL ID	Stream Name	Monitoring Station	Station Location	2006 Exceedance Rate	
				Fecal Coliform Standard	*E. Coli Standard*
VAN-E03R-01	Hughes River	3-HUE000.20	Route 644	16% (3 of 19)	36% (4 of 11)
VAN-E04R-01	Hazel River	3-HAZ018.29	Route 729	15% (3 of 20)	33% (3 of 9)
		3-HAZ026.16	Route 522	33% (2 of 6)	33% (2 of 6)
		3-HAZ032.54	Route 644	21% (3 of 14)	N/A
VAN-E05R-01	Rush River	3-RUS005.66	Route 683, upstream of Route 211/522	22% (4 of 18)	44% (4 of 9)
60076	Hazel River	3-HAZ005.98	Route 625	36% (5 of 14)	50% (5 of 10)
VAN-E01R-03	Rappahannock River	3-RPP175.51	Route 647	N/A	29% (4 of 14)
VAN-E08R-04	Rappahannock River	3-RPP147.10	Route 15/29	N/A	39% (5 of 13)
60081	Rappahannock River	3-RPP142.36	Route 620	N/A	29% (2 of 7)
VAN-E08R-03	Craig Run	3-CRA000.82	Route 656	100% (3 of 3)	N/A
VAN-E08R-02	Browns Run	3-BOS000.72	Route 653	100% (3 of 3)	N/A
VAN-E08R-01	Marsh Run	3-MAH000.19	Route 651	N/A	29% (2 of 7)
		3-MAH004.18	Route 668	75% (3 of 4)	N/A

VADEQ personnel monitored pollutant concentrations throughout the Hughes River, Hazel River, Rush River, Rappahannock River, Craig Run, Browns Run, and Marsh Run watersheds. Monitoring data with corresponding 6-day antecedent precipitation used in assessment of the impairments, as well as in this study, are included in Appendix A. Time series data of fecal coliform concentration from 1991 through the most recent data collected at the time this report was written are plotted in Figures 2.1 – 2.10.

Data from bacteria monitoring station (3-HUE000.20) in the Hughes River watershed are shown in Figure 2.1. Figure 2.2 lists fecal coliform concentration at bacteria monitoring station 3-HAZ018.29 in the Hazel River (VAN-E04R-01) watershed. Data at bacteria monitoring station 3-RUS005.66 in the Rush River watershed are listed in Figure 2.3. Figure 2.4 lists fecal coliform bacteria concentrations at station 3-HAZ005.98 in the Hazel River (60076) watershed. Fecal coliform data at station 3-RPP175.51 in the Rappahannock River (VAN-E01R-03) watershed are listed in Figure 2.5. Figure 2.6 lists fecal coliform bacteria concentrations at station 3-RPP147.10 in the Rappahannock River (VAN-E08R-04) watershed. Data from bacteria monitoring station (3-RPP142.36) in the Rappahannock River (60081) watershed are shown in Figure 2.7. Figure 2.8 lists fecal coliform concentration at bacteria monitoring station 3-CRA000.82 in the Craig Run watershed. Data at bacteria monitoring station 3-BOS000.72 in the Browns Run watershed are listed in Figure 2.9. Figure 2.10 lists fecal coliform bacteria concentrations at station 3-MAH000.19 in the Marsh Run watershed. The Most Probable Number (MPN) and membrane filtration methods were used for analyzing water samples for fecal coliform concentration.

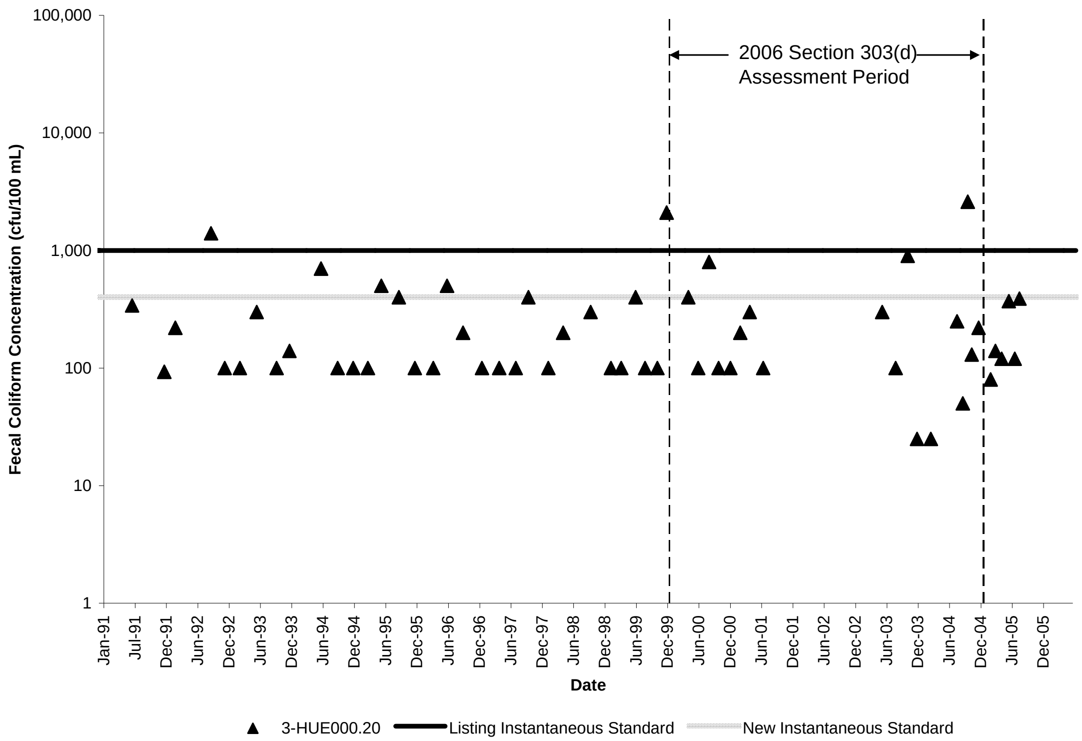

Figure 2.1. Fecal coliform concentrations (VADEQ station 3-HUE000.20) in the Hughes River (VAN-E03R-01) impairment.

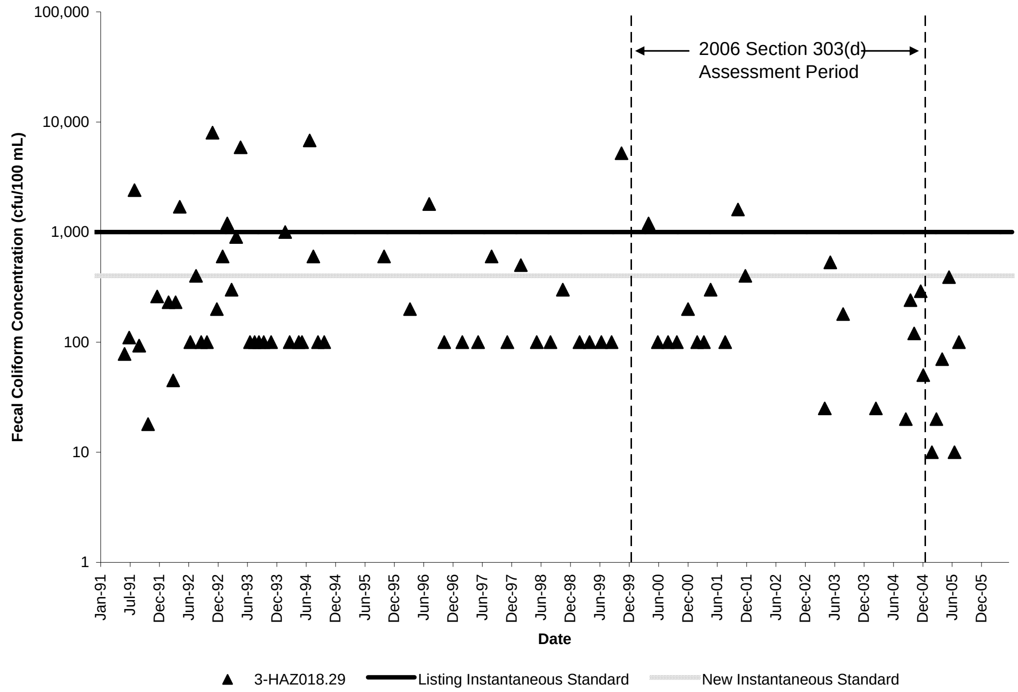

Figure 2.2. Fecal coliform concentrations (VADEQ station 3-HAZ018.29) in the Hazel River (VAN-E04R-01) impairment.

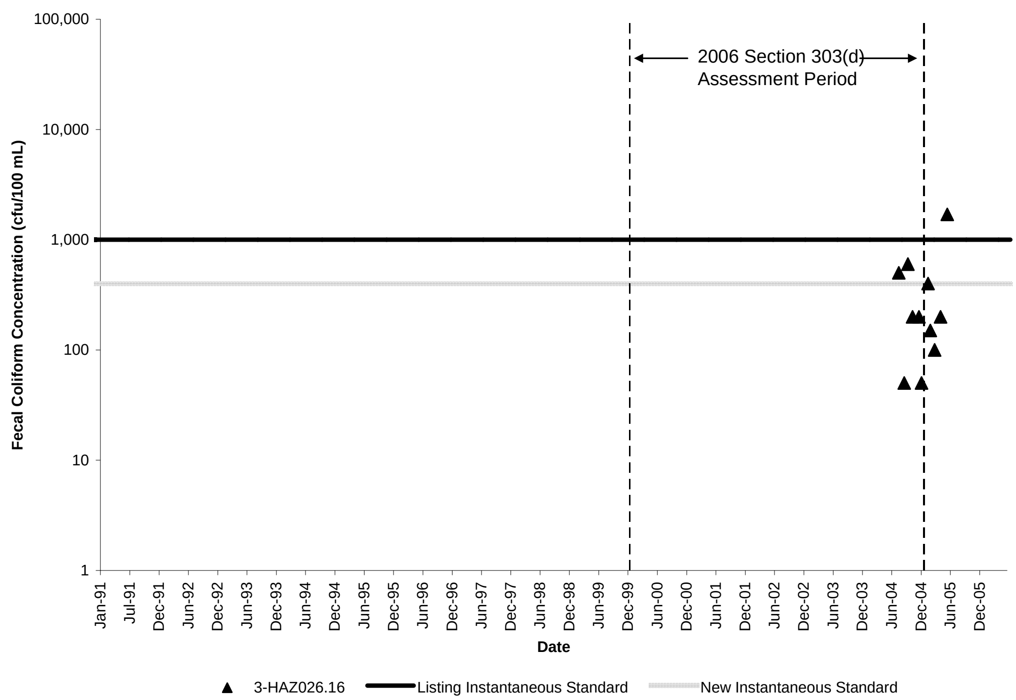

Figure 2.3. Fecal coliform concentrations (VADEQ station 3-HAZ026.16) in the Hazel River (VAN-E04R-01) impairment.

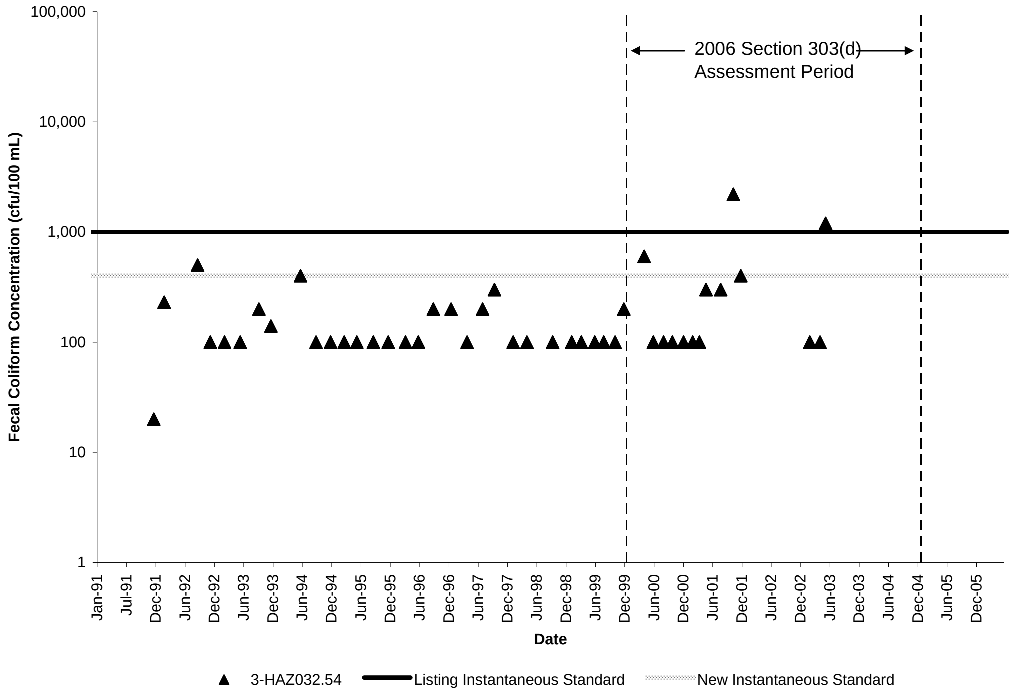

Figure 2.4. Fecal coliform concentrations (VADEQ station 3-HAZ032.54) in the Hazel River (VAN-E04R-01) impairment.

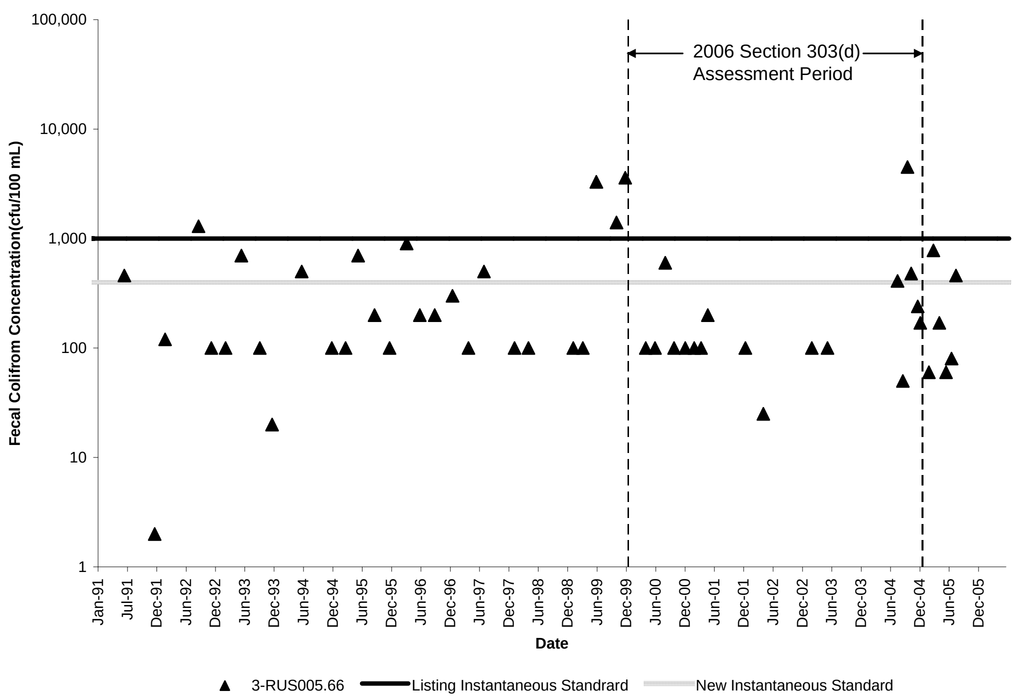

Figure 2.5. Fecal coliform concentrations (VADEQ station 3-RUS005.66) in the Rush River (VAN-E05R-01) impairment.

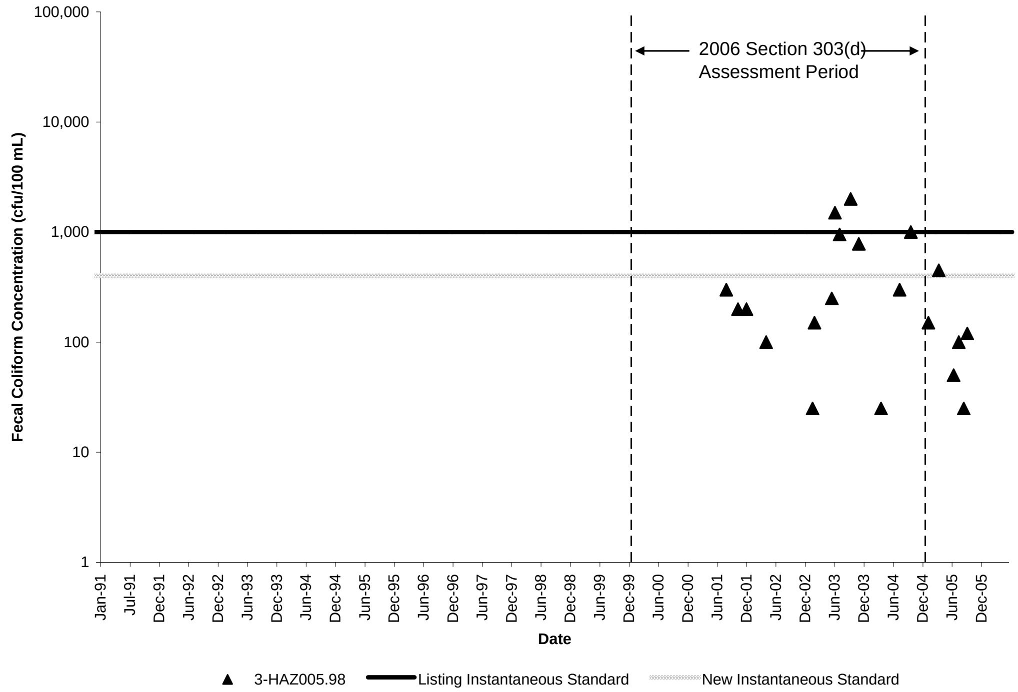

Figure 2.6. Fecal coliform concentrations (VADEQ station 3-HAZ005.98) in the Hazel River (60076) impairment.

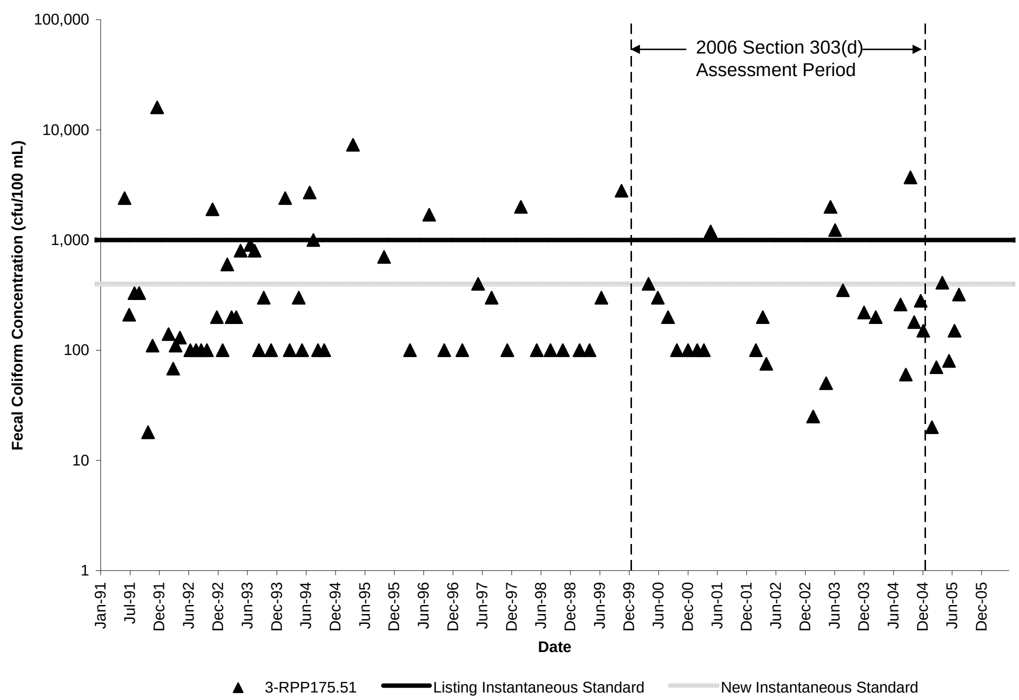

Figure 2.7. Fecal coliform concentrations (VADEQ station 3-RPP175.51) in the Rappahannock River (VAN-E01R-03) impairment.

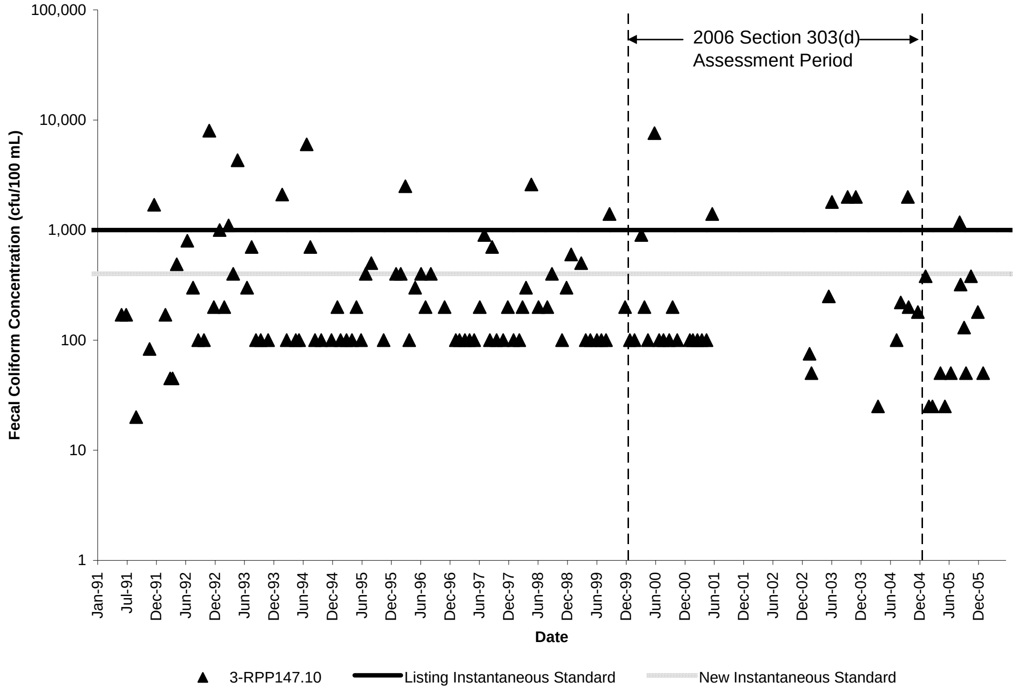

Figure 2.8. Fecal coliform concentrations (VADEQ station 3-RPP147.10) in the Rappahannock River (VAN-E08R-04) impairment.

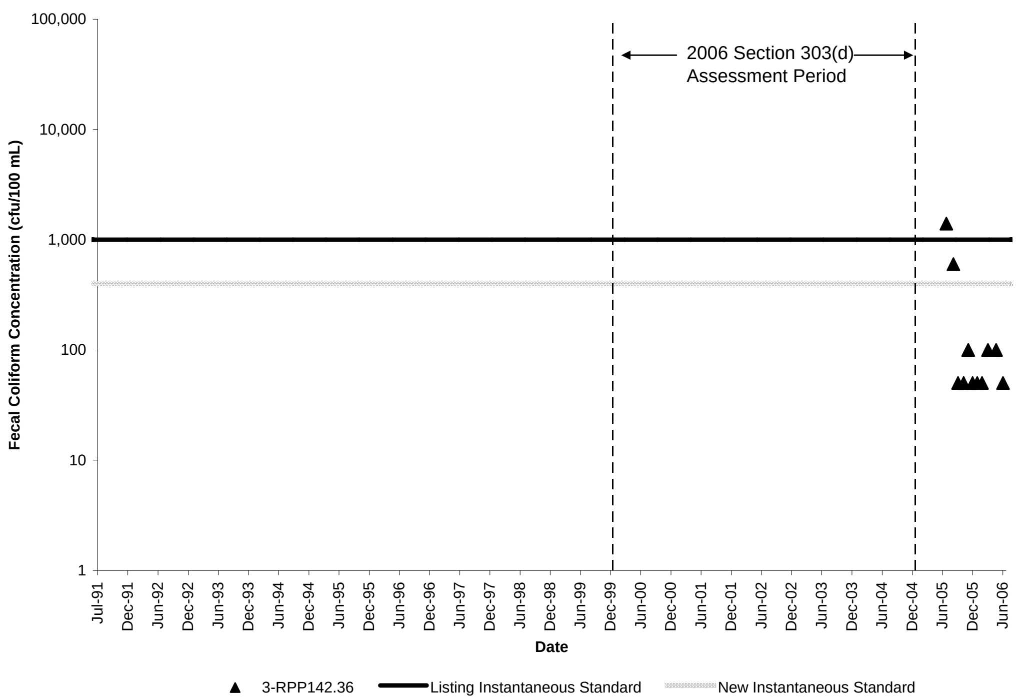

Figure 2.9. Fecal coliform concentrations (VADEQ station 3-RPP142.36) in the Rappahannock River (60081) impairment.

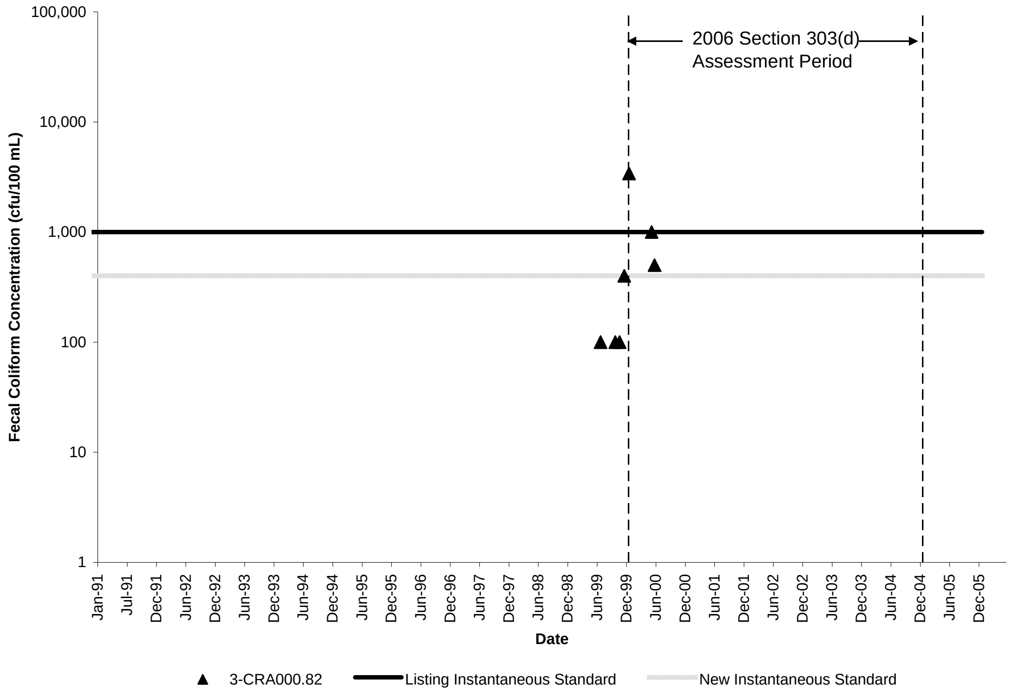

Figure 2.10. Fecal coliform concentrations (VADEQ station 3-CRA000.82) in the Craig Run (VAN-E08R-03) impairment.

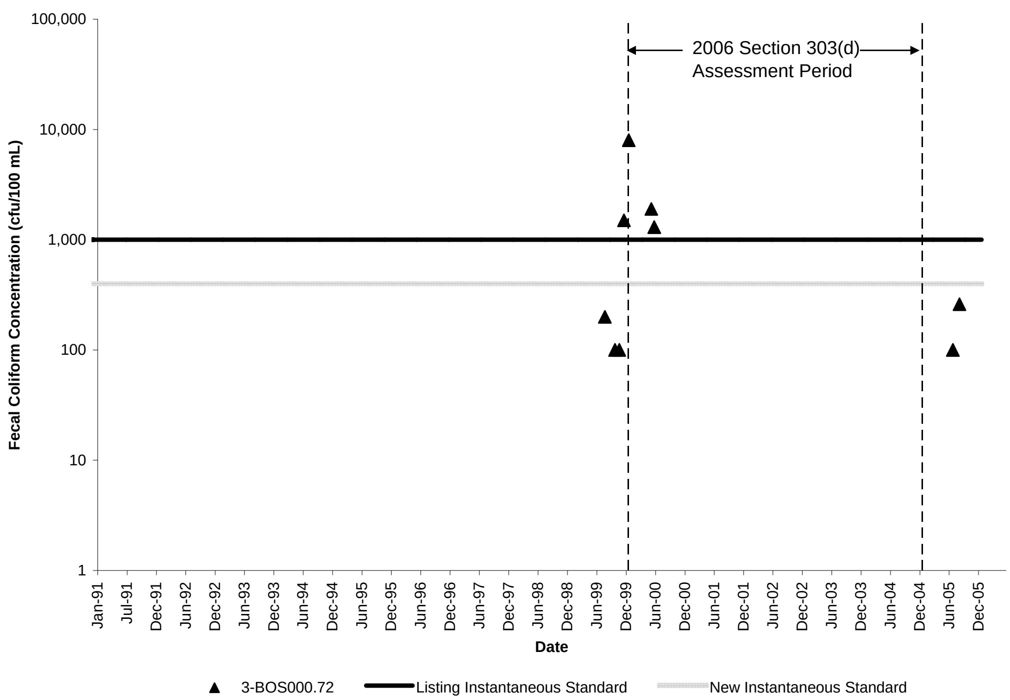

Figure 2.11. Fecal coliform concentrations (VADEQ station 3-BOS000.72) in the Browns Run (VAN-E08R-02) impairment.

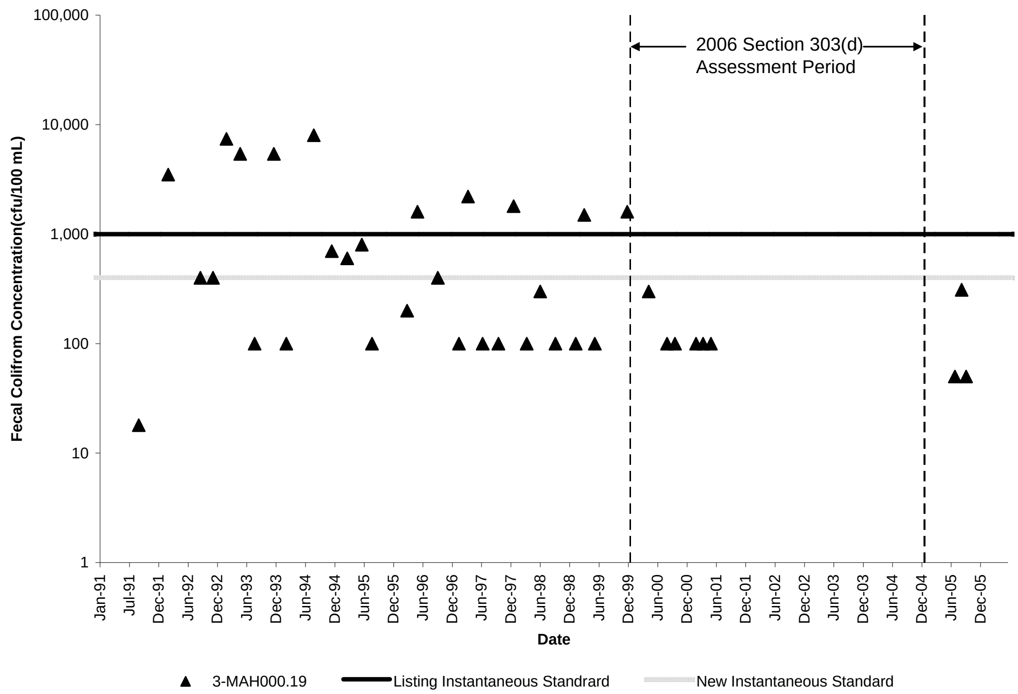

Figure 2.12. Fecal coliform concentrations (VADEQ station 3-MAH000.19) in the Marsh Run (VAN-E08R-01) impairment.

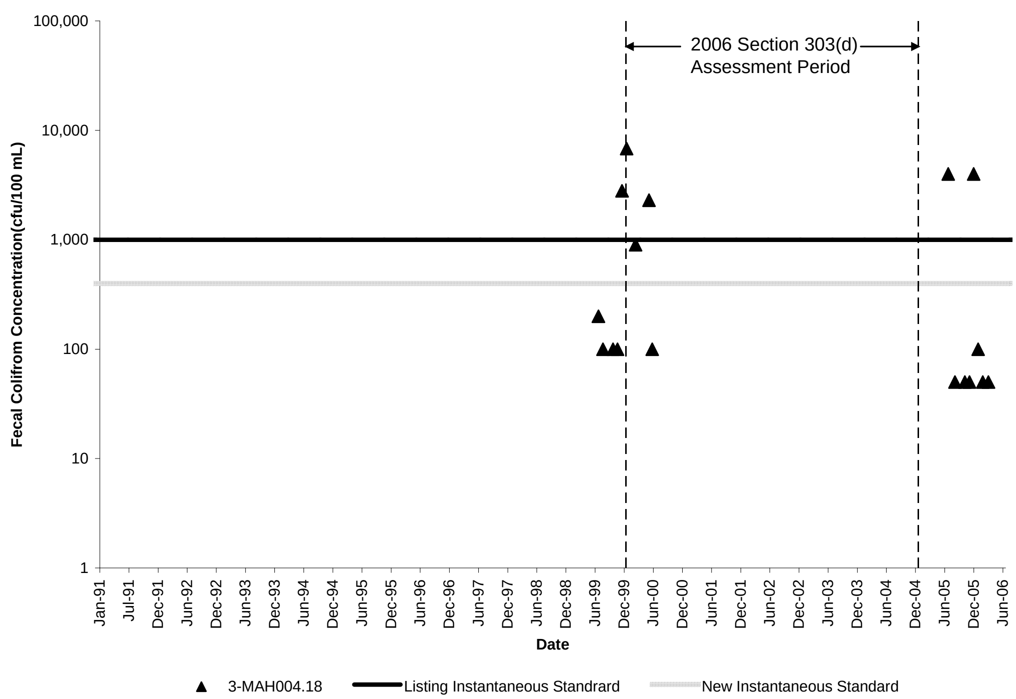

Figure 2.13. Fecal coliform concentrations (VADEQ station 3-MAH004.18) in the Marsh Run (VAN-E08R-01) impairment.

Seasonal variability of fecal coliform concentrations in the stream network was evaluated by plotting the mean monthly fecal coliform concentration values. Mean monthly fecal coliform concentration values were determined as the average of zero to 13 values for each month; the number of values varied according to the available number of samples for each month in the 1990 to 2006 period of record (Tables 2.2 through 2.4). Mean monthly fecal coliform bacteria concentrations were plotted for stations 3-HUE000.20, 3-HAZ018.29, 3-RUS005.66, 3-HAZ005.98, 3-RPP175.51, 3-RPP147.10, 3-RPP142.36, 3-CRA000.82, 3-BOS000.72, and 3-MAH000.19 (Figures 2.14 - 2.23).

The highest mean concentration occurred in September with the remaining months having an uniform distribution at station 3-HUE000.20 (Figure 2.14). Figure 2.15 shows a month with a higher mean fecal coliform concentration in the fall, summer, spring and winter seasons, particularly in November, July, May, and January, therefore seasonality was not distinguishable at station 3-HAZ018.29. At station 3-RUS005.66, the highest in-stream fecal coliform concentrations occur in September, June, and October (Figure 2.16). At station 3-HAZ005.98, the data indicate that higher in-stream fecal coliform concentrations occur during the summer and fall months, particularly in September, November, and June (Figure 2.17). The highest mean concentration occurred in December with the remaining months having a uniform distribution at station 3-RPP175.51 (Figure 2.18). Figure 2.19 shows a month with a higher mean fecal coliform concentration in the fall, summer, and spring seasons, particularly in November, June, and May, therefore seasonality was not distinguishable at station 3-RPP147.10. The summer months at station 3-RPP142.36 had the highest mean fecal coliform concentrations with July the highest (Figure 2.20). No samples were collected during several months at station 3-CRA000.82 not enabling seasonality observance (Figure 2.21). Of the months data was collected, the highest averages were recorded in January and May. No samples were collected during several months at station 3-BOS000.72 not enabling seasonality observance (Figure 2.22). Of the months data was collected, the highest averages were recorded in January and May. Figure 2.23 illustrates that each season contained a month that the mean fecal coliform concentration was elevated, therefore a seasonal difference could not be determined at station 3-MAH000.19. It should be noted that due to the upper cap (8,000 cfu/100 mL or 16,000 cfu/100 mL) and lower cap (100 cfu/100ml or 18 cfu/100ml) imposed on the fecal coliform count, the actual counts could be higher or lower in cases where fecal coliform levels are equal to these level limits, therefore changing the averages shown in Figure 2.14 – 2.23.

Table 2.2.2. Number of samples collected per month from 1/1/90 to 12/31/06 in the Hughes River, Hazel River, and Rush River impairments.

Month	Samples Collected at			
	3-HUE000.20 (#)	3-HAZ018.29 (#)	3-RUS005.66 (#)	3-HAZ005.98 (#)
January	3	1	3	2
February	5	8	4	1
March	5	5	6	2
April	5	7	5	1
May	2	9	3	1
June	9	4	8	2
July	3	7	3	3
August	4	10	2	2
September	7	5	5	3
October	5	9	3	1
November	1	6	1	1
December	8	6	9	1
TOTAL	**57**	**77**	**52**	**20**

Table 2.2.3. Number of samples collected per month from 1/1/90 to 12/31/06 in the Rappahannock River impairments.

Month	Samples Collected at		
	3-RPP175.51 (#)	3-RPP147.10 (#)	3-RPP142.36 (#)
January	1	11	1
February	11	11	1
March	6	12	1
April	9	10	0
May	9	13	1
June	5	11	1
July	8	9	1
August	9	13	1
September	4	11	1
October	8	7	1
November	7	9	1
December	5	8	1
TOTAL	**82**	**125**	**11**

Table 2.4. Number of samples collected per month from 1/1/90 to 12/31/06 in the Craig Run, Browns Run, and Marsh Run impairments.

Month	Samples Collected at		
	3-CRA000.82 (#)	3-BOS000.72 (#)	3-MAH000.19 (#)
January	1	1	2
February	0	0	5
March	0	0	6
April	0	0	1
May	1	1	4
June	1	1	3
July	1	1	1
August	0	2	6
September	0	0	4
October	1	1	2
November	1	1	0
December	1	1	4
TOTAL	**7**	**9**	**38**

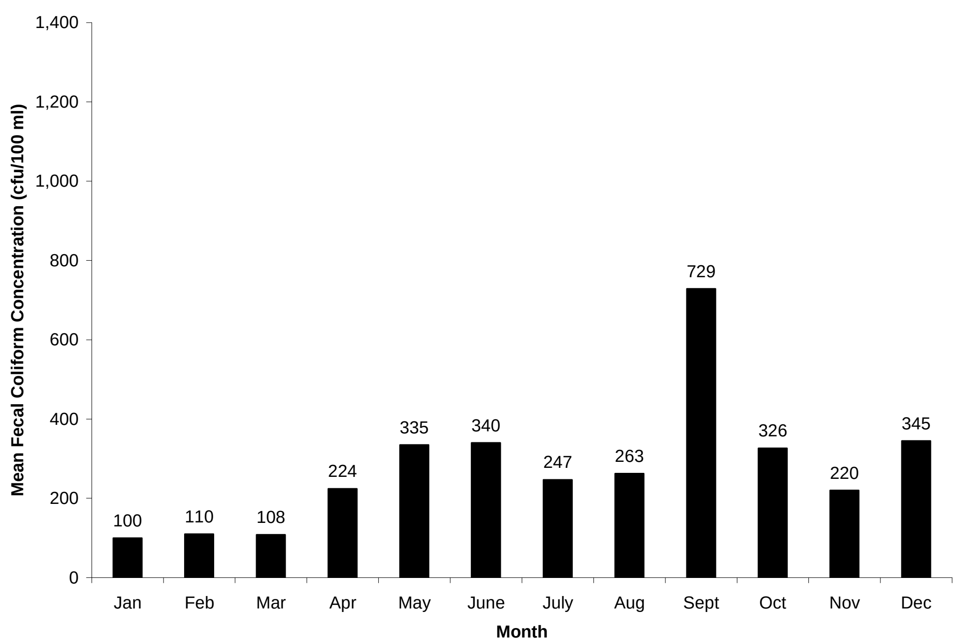

Figure 2.14. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-HUE000.20) in the Hughes River (VAN-E03R-01) impairment from January 1990 through December 2006.

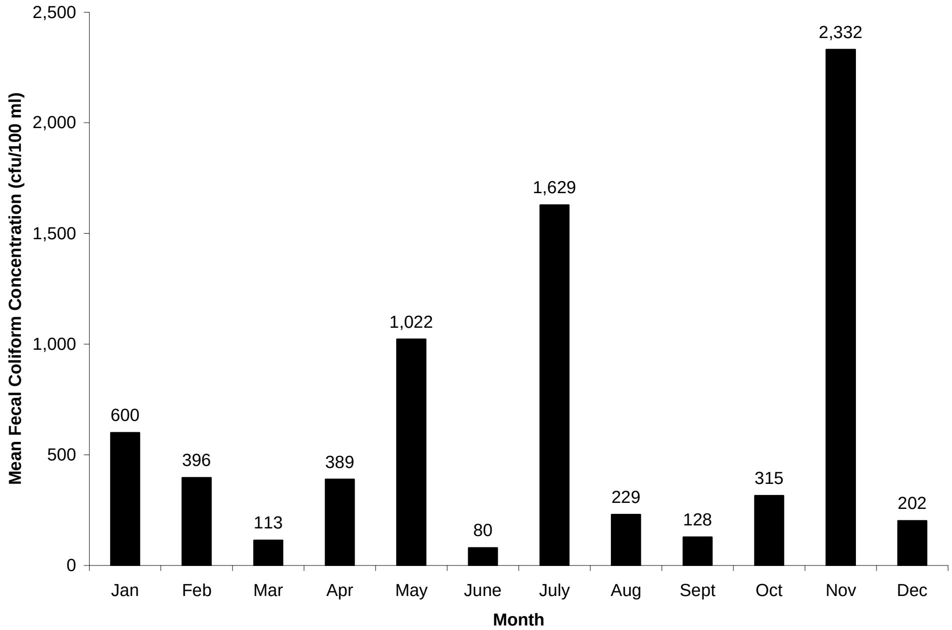

Figure 2.15. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-HAZ018.29) in the Hazel River (VAN-E04R-01) impairment from January 1990 through December 2006.

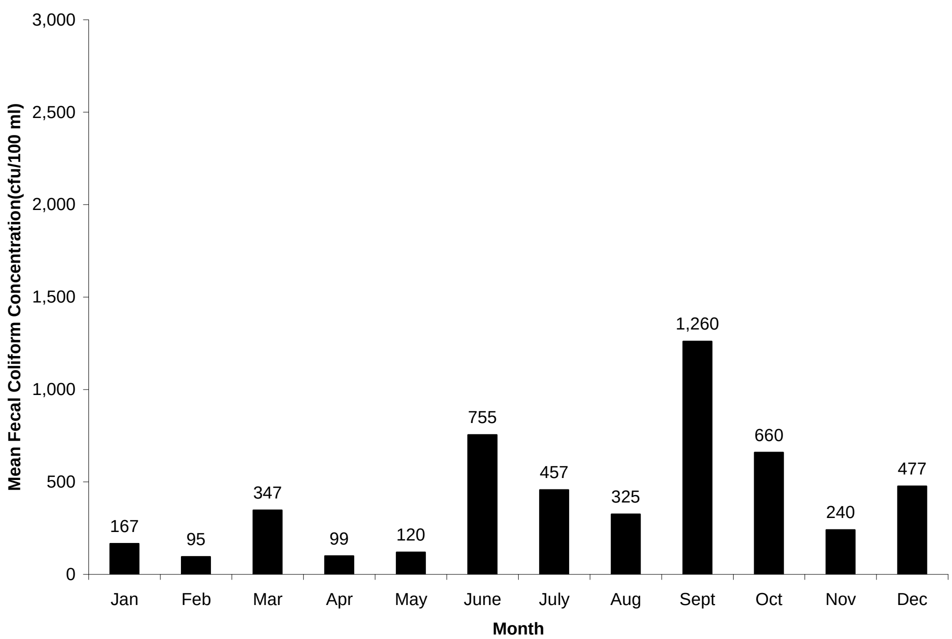

Figure 2.16. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-RUS005.66) in the Rush River (VAN-E05R-01) impairment from January 1990 through December 2006.

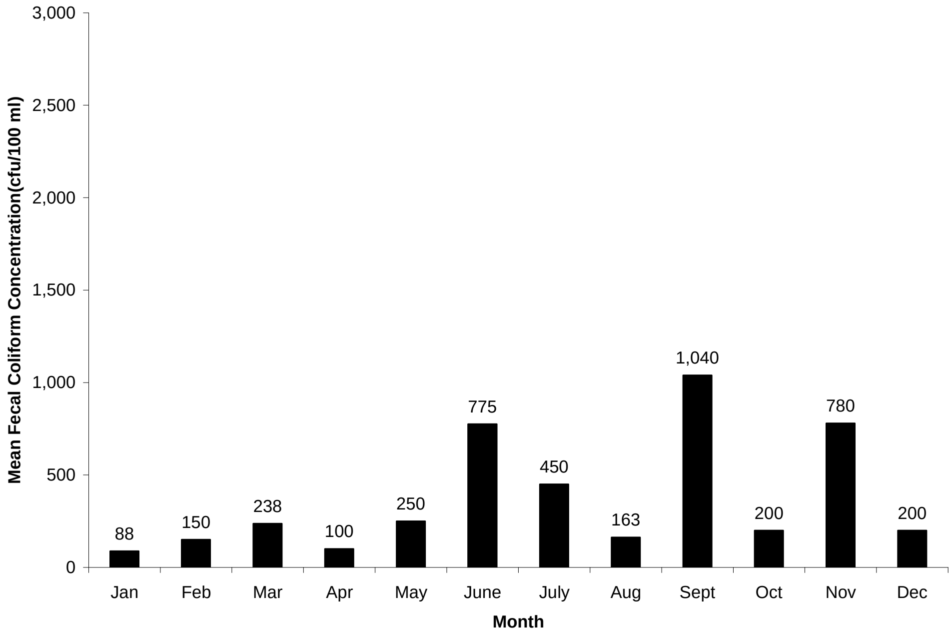

Figure 2.17. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-HAZ005.98) in the Hazel River (60076) impairment from January 1990 through December 2006.

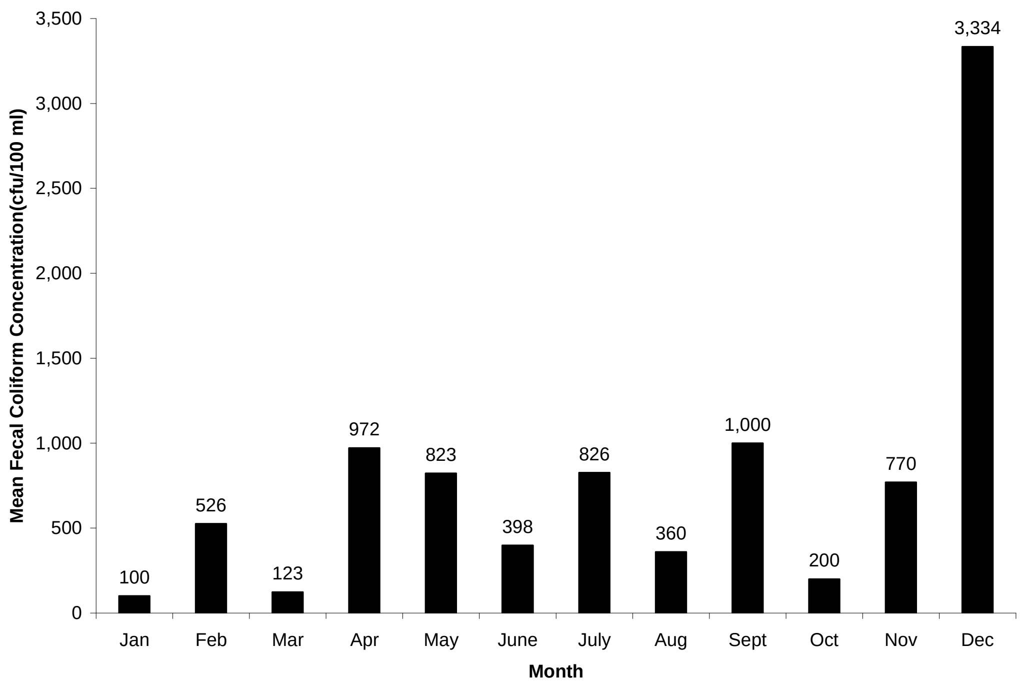

Figure 2.18. Impact of seasonality on fecal coliform (VADEQ station 3-RPP175.51) in the Rappahannock River (VAN-E08R-04) impairment from January 1990 through December 2006.

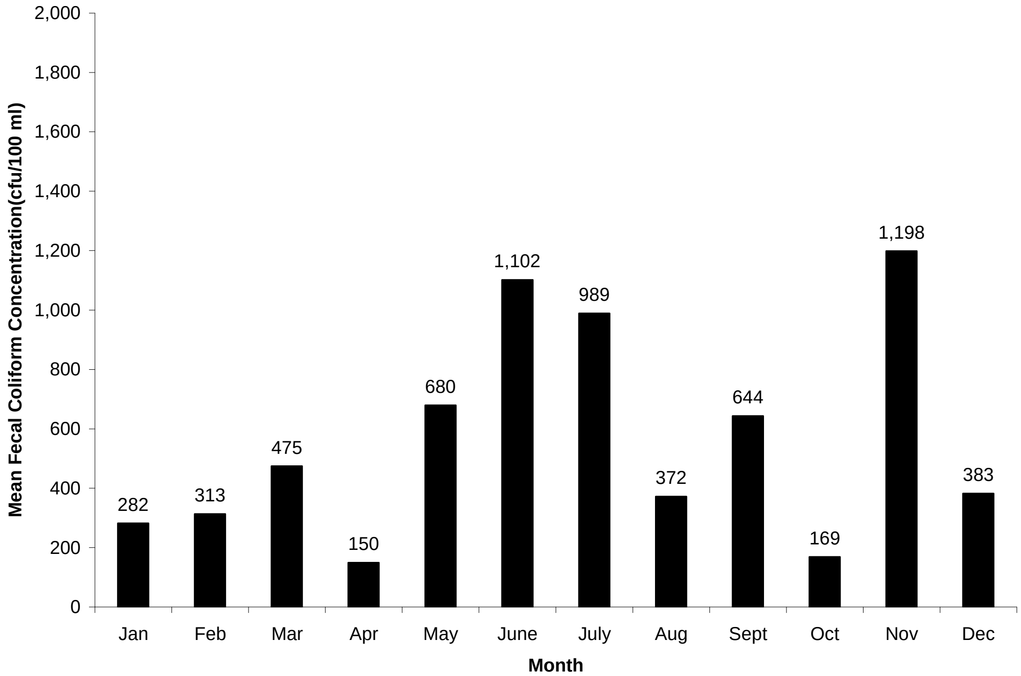

Figure 2.19. Impact of seasonality on fecal coliform (VADEQ station 3-RPP147.10) in the Rappahannock River (VAN-E08R-04) impairment from January 1990 through December 2006.

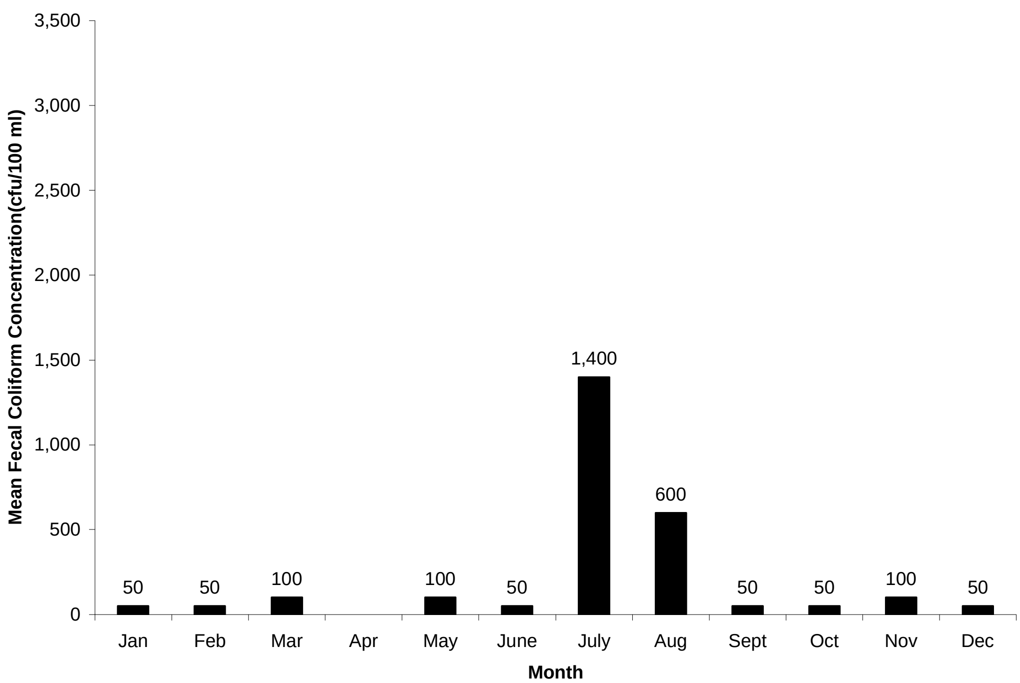

Figure 2.20. Impact of seasonality on fecal coliform (VADEQ station 3-RPP142.36) in the Rappahannock River (60081) impairment from January 1990 through December 2006.

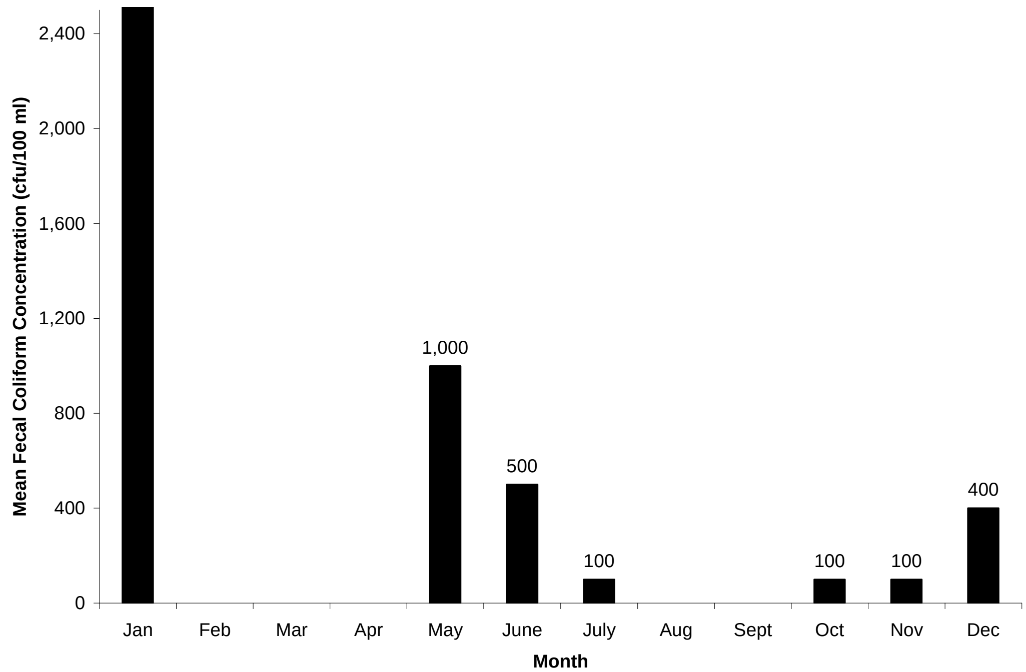

Figure 2.21. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-CRA000.82) in the Craig Run (VAN-E08R-03) impairment from January 1990 through December 2006.

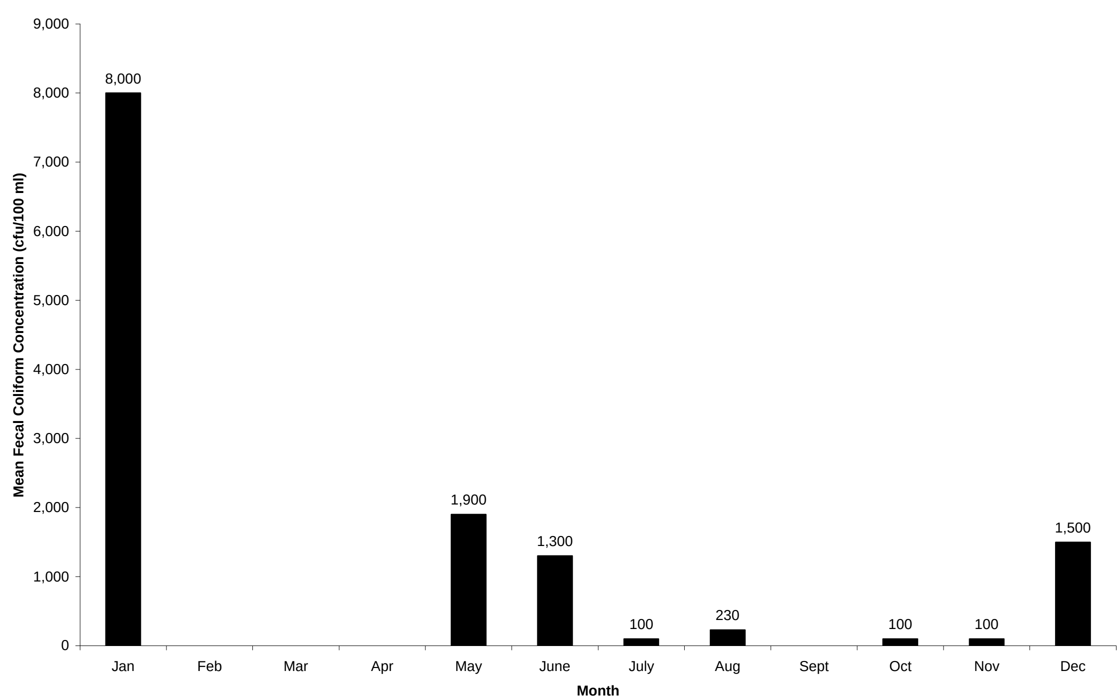

Figure 2.22. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-BOS000.72) in the Browns Run (VAN-E08R-02) impairment from January 1990 through December 2006.

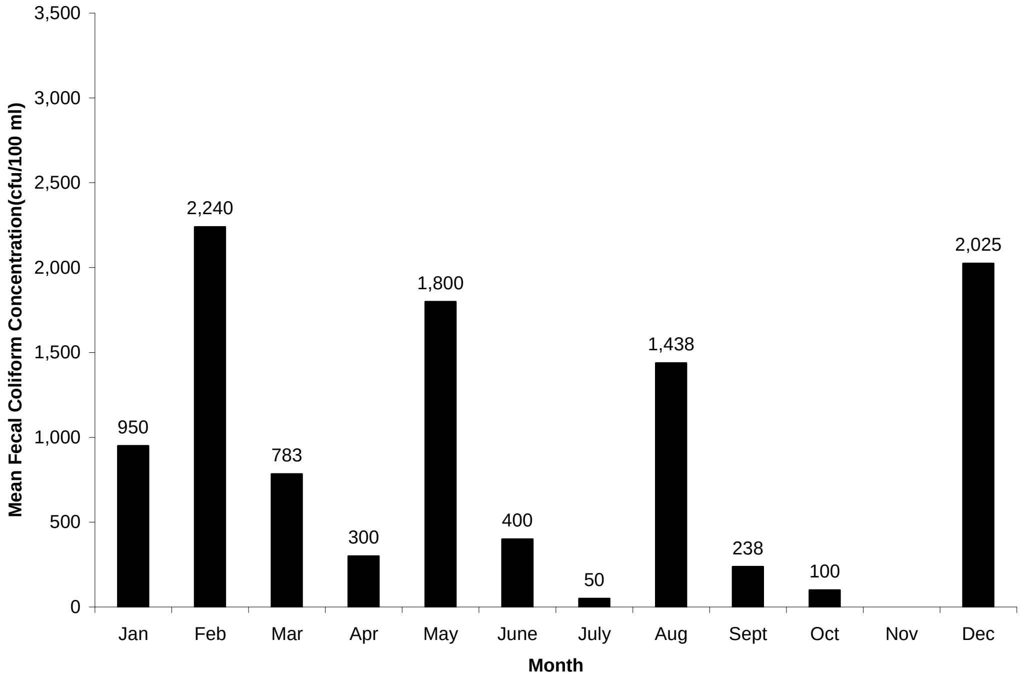

Figure 2.23. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-MAH000.19) in the Marsh Run (VAN-E08R-01) impairment from January 1990 through December 2006.

2.5.2 Historic Data for E. coli

VADEQ staff examined water samples collected at stations 3-HUE000.20, 3-HAZ018.29, 3-RUS005.66, 3-HAZ005.98, 3-RPP175.51, 3-RPP147.10, 3-RPP142.36, 3-BOS000.72, and 3-MAH000.19, for their concentration of *E. coli* (Figures 2.24 through 2.32). This analysis was conducted concurrently with other monthly testing at the stations from April 2002 through June 2006. Seven of the 19 (36.8%) samples analyzed from station 3-HUE000.20 exceeded the instantaneous *E. coli* bacteria standard of 235 cfu/100 mL. Of the 18 water quality samples collected at station 3-HAZ018.29, five (27.8%) of the samples exceeded the instantaneous *E. coli* bacteria standard. At station 3-RUS005.66, five of 14 (35.7%) samples violated the instantaneous *E. coli* bacteria standard. Of the 14 water quality samples collected at station 3-HAZ005.98, four (28.6%) of the samples exceeded the instantaneous *E. coli* bacteria standard. Seven of the 23 (30.4%) samples analyzed from station 3-RPP175.51 exceeded the instantaneous *E. coli* bacteria standard. The instantaneous *E. coli* bacteria standard was exceeded in six of 29 (20.7%) samples collected at station 3-RPP147.10. At station 3-RPP142.36, four of 22 (18.2%) samples violated the instantaneous *E. coli* bacteria standard. Of the five water quality samples collected at station 3-BOS00.72, two (40.0%) of the samples exceeded the instantaneous *E. coli* bacteria standard. At station 3-MAH000.19, three of 16 (18.75%) samples violated the instantaneous *E. coli* bacteria standard.

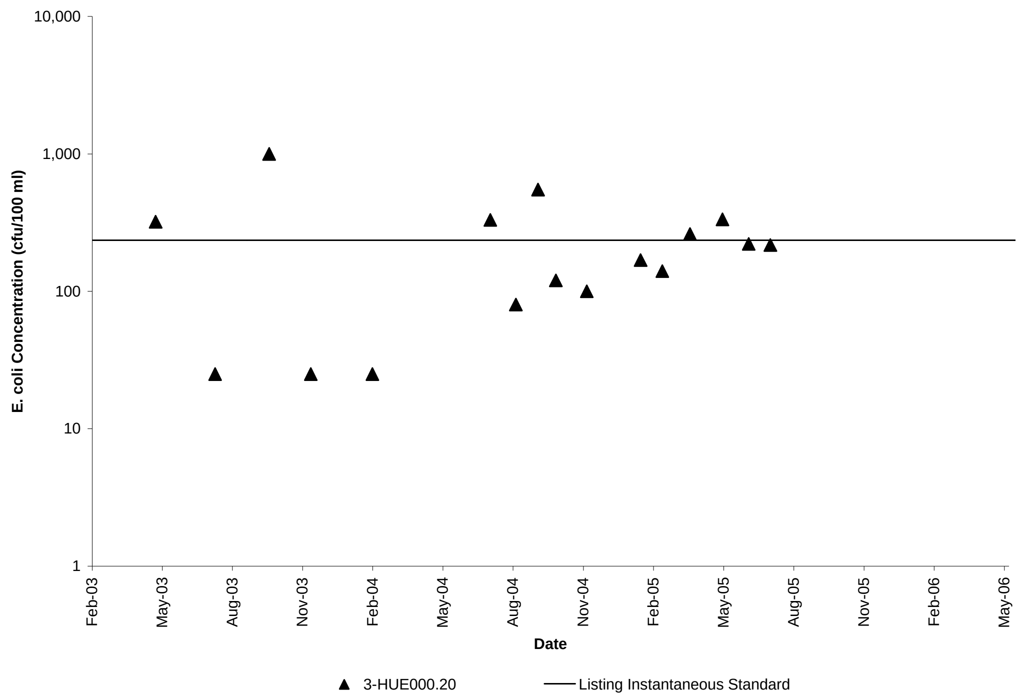

Figure 2.24. E. coli concentrations (VADEQ station 3-HUE000.20) in the Hughes River (VAN-E03R-01) impairment.

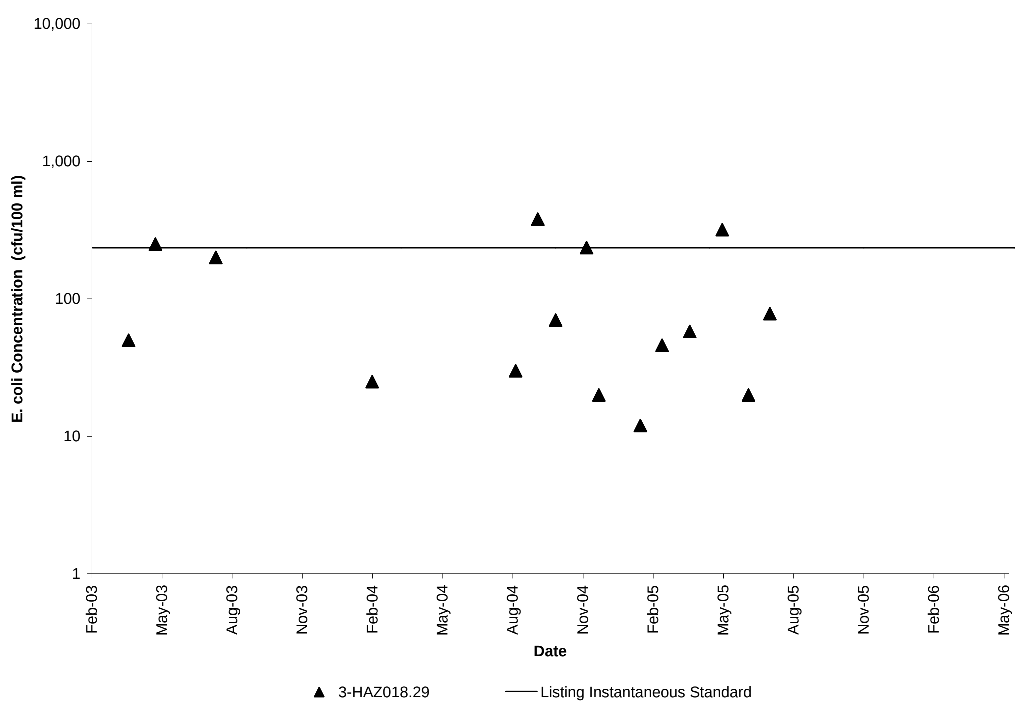

Figure 2.25. E. coli concentrations (VADEQ station 3-HAZ018.29) in the Hazel River (VAN-E04R-01) impairment.

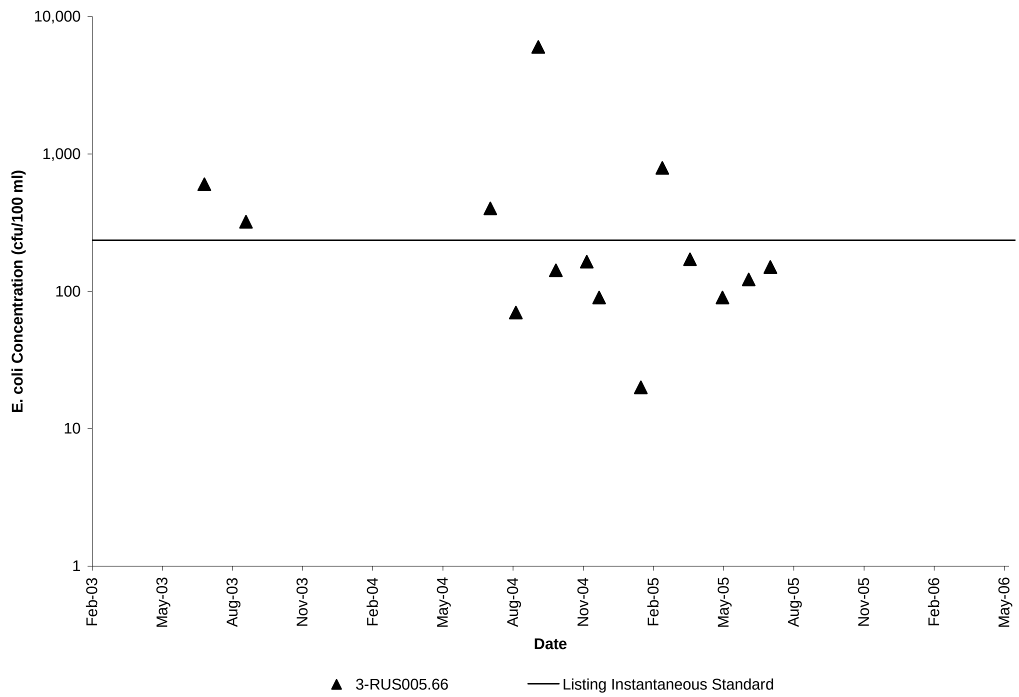

Figure 2.26. *E. coli* concentrations (VADEQ station 3-RUS005.66) in the Rush River (VAN-E05R-01) impairment.

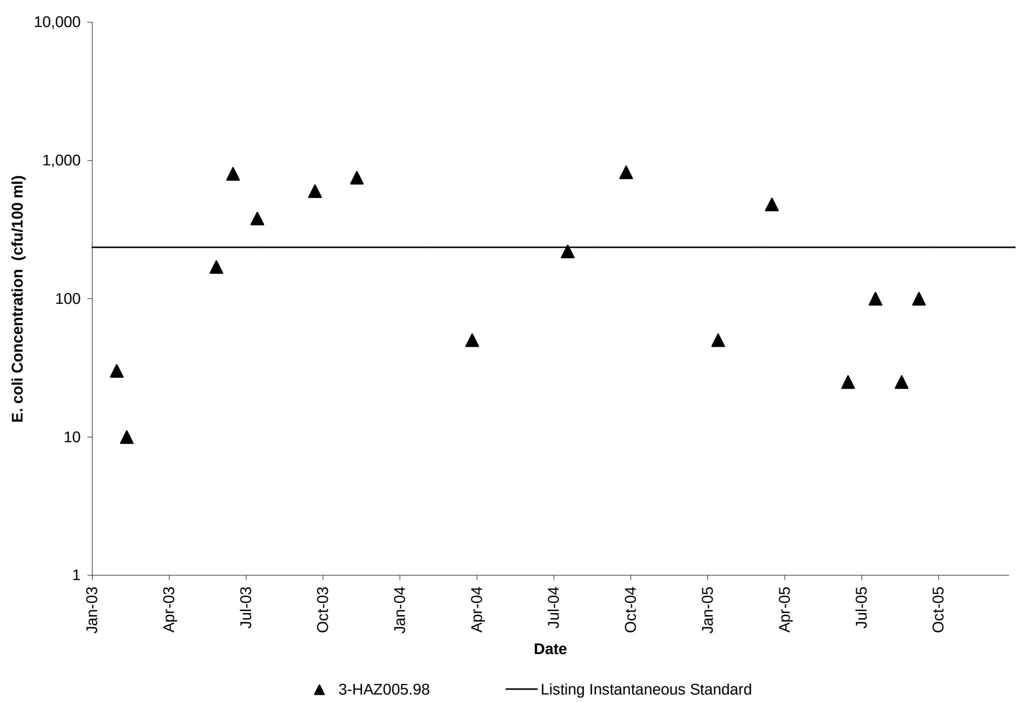

Figure 2.27. E. coli concentrations (VADEQ station 3-HAZ005.98) in the Hazel River (60076) impairment.

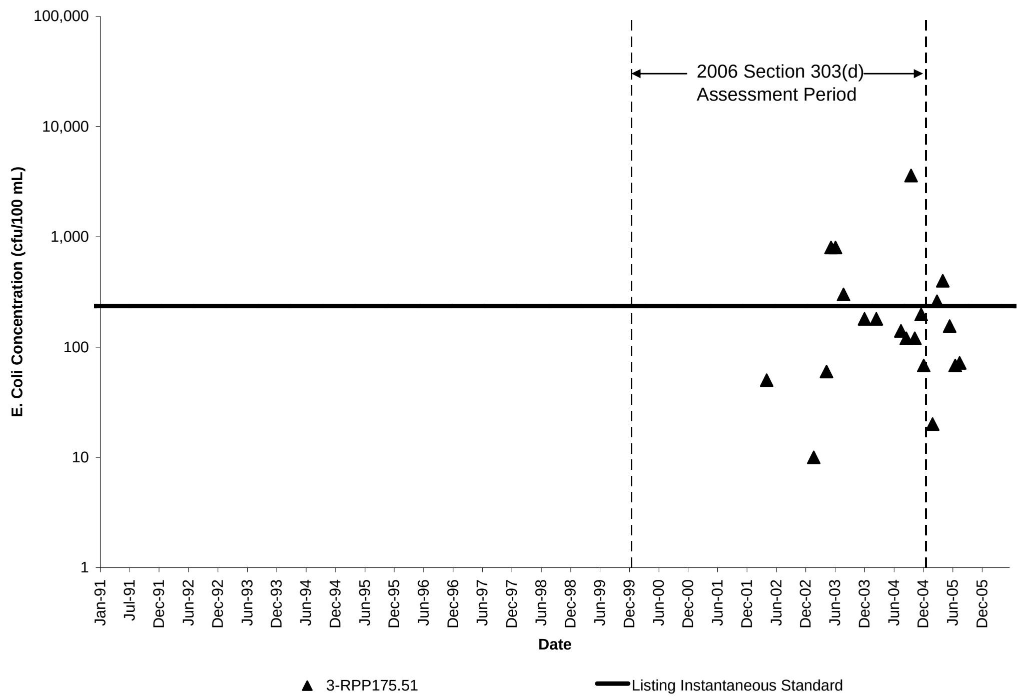

Figure 2.28. E. Coli concentrations (VADEQ station 3-RPP175.51) in the Rappahannock River (VAN-E01R-03) impairment.

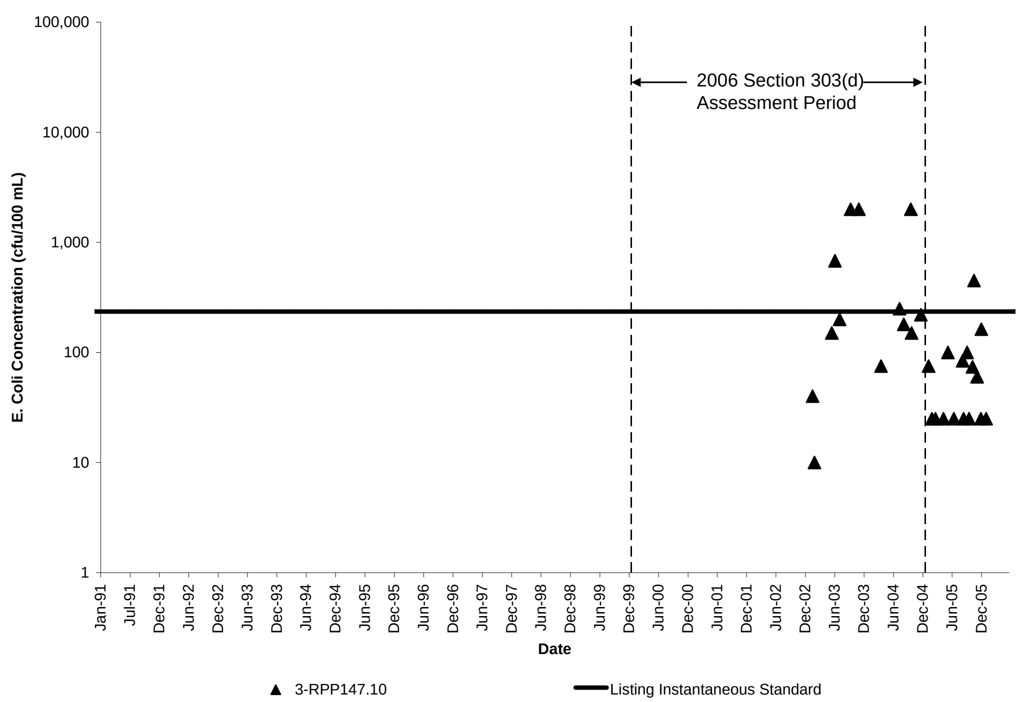

Figure 2.29. E. Coli concentrations (VADEQ station 3-RPP147.10) in the Rappahannock River (VAN-E08R-04) impairment.

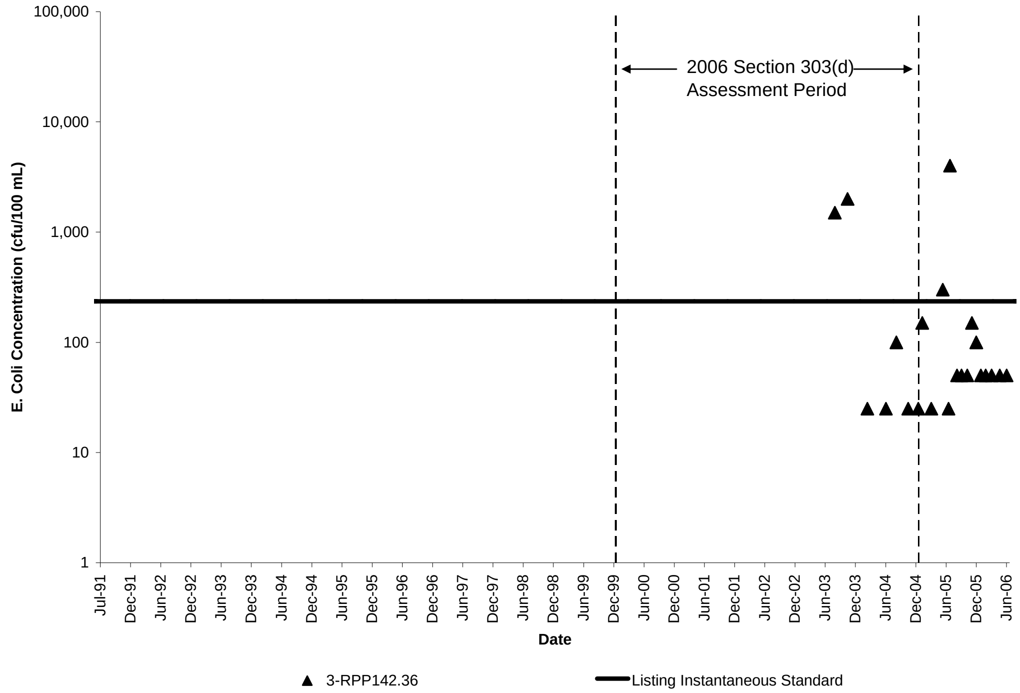

Figure 2.30. E. Coli concentrations (VADEQ station 3-RPP142.36) in the Rappahannock River (60081) impairment.

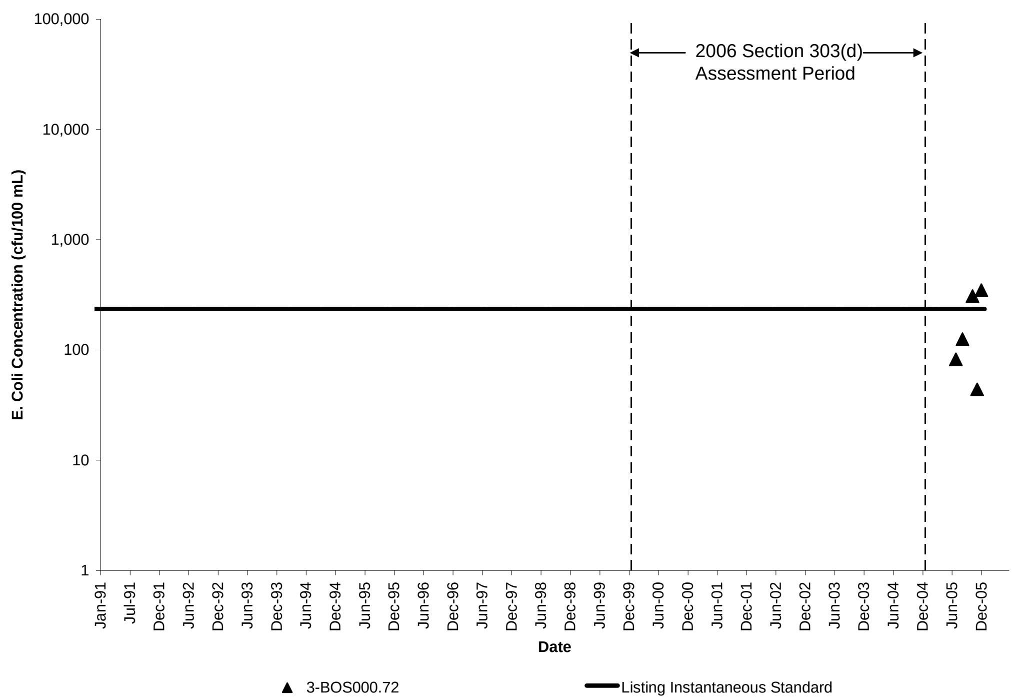

Figure 2.31. *E. Coli* concentrations (VADEQ station 3-BOS000.72) in the Browns Run (VAN-E08R-02) impairment.

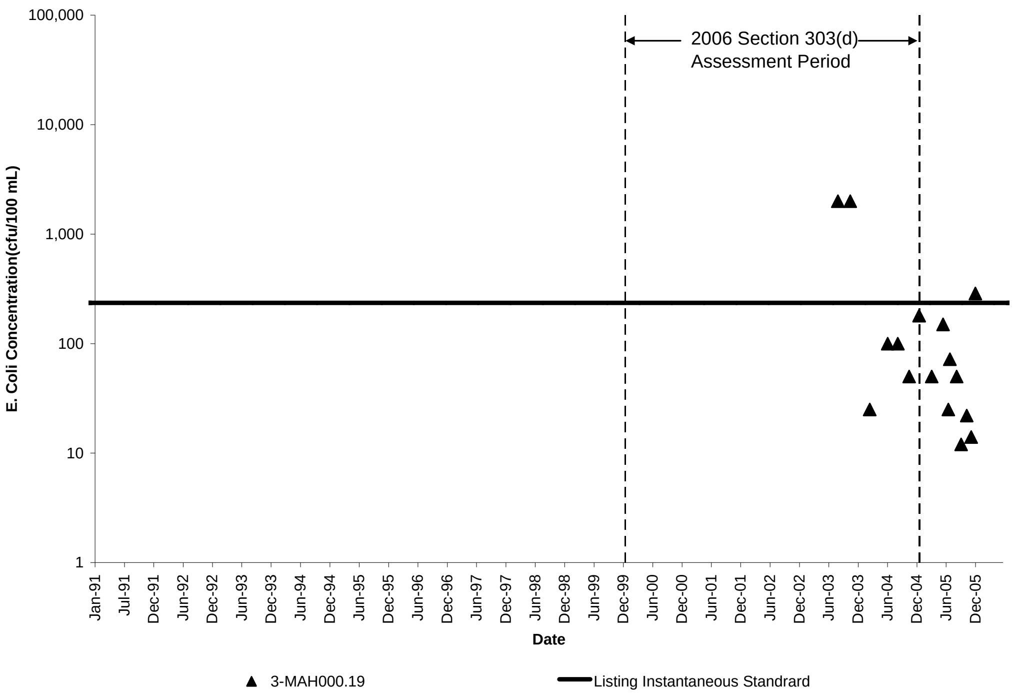

Figure 2.32. E. Coli concentrations (VADEQ station 3-MAH000.19) in the Marsh Run (VAN-E08R-01) impairment.

2.5.3 Historic Data for Bacterial Source Tracking

The results from 12 monthly bacteria source tracking (BST) samples collected at stations 3-HUE000.20, 3-HAZ018.29, 3-RUS005.66, 3-RPP175.51, 3-RPP147.10, 3-CRA000.46, 3-BOS000.72, and 3-MAH000.19 were received at the time this report was prepared. The BST analysis was performed by MapTech, Inc. and New River Highlands RC&D as a separate study. The results of the BST analysis provide a measure of the relative contribution of bacteria sources to the bacteria concentration found in the water samples. The bacteria sources were lumped into four categories: wildlife, human, livestock, and pet. Data resulting from the BST study are referenced in Appendix B. A discussion of the BST results provided by VADEQ indicates there is 90% confidence that the indicated proportions for each sample are within 15% of the sampled population (Appendix B). These data represent a brief glimpse of bacteria concentration in Hughes River, Hazel River, Rush River, Rappahannock River, Craig Run, Browns Run, and Marsh Run and may not be representative of long-term conditions in the stream.

The analysis in the BST report also included a test of statistical significance, providing an indication of presence or absence of contribution from a particular source. The presence/absence use of these data is most appropriate for use in this study due to statistical confidence, with presence defined as any proportional contribution greater than 15%. Tables 2.5

through 2.12 summarize the results of the presence/absence analysis of the BST data. The BST data were used to verify modeling methods and assumptions.

Fecal coliform and *E. coli* enumerations were also performed on the BST samples. These data are referenced in Appendix B. At station 3-HUE000.20, 33.3% (four of 12) of the samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard. The exceedances occurred in July, September of 2004 and April, May of 2005. Three of 12 (25.0%) samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard at station 3-HAZ018.29. The exceedances occurred in September, November of 2004 and May of 2005. The five exceedances (41.7%) of either the fecal coliform or E. coli bacteria instantaneous standard occurred in July, September, October of 2004 and March, July of 2005 at station 3-RUS005.66. At station 3-RPP175.51, 16.7% (2 of 12) of the samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard. The exceedances occurred in September of 2004 and March of 2005. One of 12 (8.3%) samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard at station 3-RPP147.10. The exceedance occurred in August of 2005. The four exceedances (33.3%) of either the fecal coliform or E. coli bacteria instantaneous standard occurred in July, December of 2005 and June, July of 2006 at station 3-CRA000.46. At station 3-BOS000.72, 33.3% (four of 12) of the samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard. The exceedances occurred in October, December of 2005 and May, June of 2006. One of 12 (8.3%) samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard at station 3-MAH000.19. The exceedance occurred in January of 2006.

Table 2.5. Presence/absence analysis of bacteria sources at station 3-HUE000.20 in Hughes River (VAN-E03R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	75	100
Human	25	50
Livestock	75	75
Pet	67	75

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., four) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.6. Presence/absence analysis of bacteria sources at station 3-HAZ018.29 in Hazel River (VAN-E04R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	75	100
Human	25	0
Livestock	58	67
Pet	67	67

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., three) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.7. Presence/absence analysis of bacteria sources at station 3-RUS005.66 in Rush River (VAN-E05R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	67	60
Human	42	20
Livestock	83	100
Pet	67	60

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., five) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.8. Presence/absence analysis of bacteria sources at station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	67	0
Human	42	50
Livestock	58	100
Pet	58	50

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., two) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.9. Presence/absence analysis of bacteria sources at station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	33	100
Human	25	0
Livestock	67	0
Pet	92	100

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., one) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.10. Presence/absence analysis of bacteria sources at station 3-CRA000.46 in Craig Run (VAN-E08R-03) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	58	75
Human	8	25
Livestock	58	75
Pet	83	75

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., four) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.11. Presence/absence analysis of bacteria sources at station 3-BOS000.72 in Browns Run (VAN-E08R-02) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	67	75
Human	17	25
Livestock	75	75
Pet	100	100

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., four) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Table 2.12. Presence/absence analysis of bacteria sources at station 3-MAH000.19 in Marsh Run (VAN-E08R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	58	0
Human	25	0
Livestock	50	100
Pet	92	100

1 – This is a measure of the number of times the source is present in all 12 samples.

2 – This is a measure of the number of times (i.e., one) the source was present in samples that exceeded either the fecal coliform or *E. coli* instantaneous standard.

Chapter 3. Bacteria Source Assessment

Potential bacteria sources in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds were assessed using multiple approaches, including information from VADEQ; Virginia Department of Conservation (VADCR); Virginia Department of Game and Inland Fisheries (VADGIF); Virginia Cooperative Extension (VCE); Virginia Department of Health (VDH); Rappahannock, Fauquier, Culpeper, Orange, Stafford, and Spotsylvania County Planning Departments; Natural Resources Conservation Service (NRCS); Virginia Department of Agricultural and Consumer Services (VDACS); Culpeper, John Marshall, and Tri-County/City SWCDs; public participation; watershed reconnaissance and monitoring; published information; and professional judgment. The gathered information was used to estimate source populations and their associated bacteria loads throughout the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds, forming the basis for model development and analysis of allocation scenarios (Table 3.1). The following sections discuss available information and methods used to estimate bacteria loads for each modeling segment.

Table 3.1. Sources of bacteria in the impaired watersheds.

Source Category	Source / Animal Type	Applied To
Human and Pets	Permitted Discharges	Stream Reach
	Sanitary Sewer	Land
	Straight Pipes	Stream Reach
	Failing Septic Systems	Land
	Biosolids Applications	Land
	Dogs / Cats	Land
Agricultural	Dairy Cattle	Land, Stream Reach
	Beef Cattle	Land, Stream Reach
	Horses	Land
	Turkey	Land
	Chicken	Land
	Other Livestock	Land
Wildlife	Deer	Land, Stream Reach
	Bear	Land, Stream Reach
	Raccoon	Land, Stream Reach
	Muskrats	Land, Stream Reach
	Beavers	Land, Stream Reach
	Turkeys	Land, Stream Reach
	Geese	Land, Stream Reach
	Ducks	Land, Stream Reach

3.1 Permitted Discharges

Permitted point sources in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds include all individual Virginia Pollutant Discharge Elimination System municipal and industrial permitted facilities, as well as general permits issued for domestic sewage discharges of less than or equal to 1,000 gallons per day. The 2007 VPDES Permit Manual defines an individual municipal facility as:

"A treatment works, other than an industrial facility, whose primary function is to receive and treat wastewater from domestic sources or from indirect industrial sources (analogous to a Treatment Works Treating Domestic Sewage (TWTDS), which is a publicly owned treatment works or any other sewage sludge or waste water treatment devices or systems, regardless of ownership (including federal facilities), used in the storage, treatment, recycling, and reclamation of municipal or domestic sewage, including land dedicated for the disposal of sewage sludge. This definition does not include septic tanks or similar devices. For purposes of this definition, domestic sewage includes waste and waste water from humans or household operations that are discharged to or otherwise enter a treatment works." (VPDES Permit Manual – 2007)

The permit manual defines an industrial facility is defined as:

"Establishments with activity in which they are engaged as an economic unit, generally at a single location where business is conducted, services or industrial operations performed, or in which raw materials are changed into useful products." (VPDES Permit Manual 2007)

For this reason, permitted point sources of fecal coliform include only the individual municipal or general domestic sewage permits (permits classified as industrial do not discharge bacteria). The individual municipal and general domestic sewage permits are required to maintain a fecal coliform concentration of 200 cfu/100 mL or less (the 'interim standard'), and are required to meet the new *E. coli* standard of 126 cfu/100 mL or less in their effluent on permit renewal. Table 3.2 shows the point sources in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds. There are no active permitted facilities discharging bacteria in the Rappahannock River (VAN-E01R-03) and Craig Run (VAN-E08R-03) watersheds.

In allocation scenarios, the entire allowable point source discharge concentration of 200 cfu/100 mL of fecal coliform (the 'interim standard') was used. The ultimate waste load allocation (WLA) was calculated using the *E. coli* limit of 126 cfu/100mL, and *E. coli* loads based on the facility design flow are presented in Table 3.2.

Phase II Municipal Separate Storm Sewer System (MS4) permits were also reviewed and found no facilities with MS4 permits discharge within the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds.

Table 3.2. Active VPDES permitted point sources in the Rappahannock River watershed.

Impairment	Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	*E. coli* Load (cfu/yr)
Hughes River (VAN-E03R-01)	VAG406417	Residence	HAR-01	0.001	2.68E+09	1.69E+09
Hazel River (VAN-E04R-01)	VA0065358	Boston Water and Sewer STP - Old Facility[1]	HAR-04	0.015	4.14E+10	2.61E+10
Hazel River (VAN-E04R-01)	VA0088749	Boston Water and Sewer STP - New Facility[1]	HAR-04	0.450	1.24E+12	7.85E+11
Rush River (VAN-F05R-01)	VA0087581	Washington Town Water Treatment Plant	HAR-11	0.006	0.00E+00	0.00E+00
Rush River (VAN-F05R-01)	VA0091651	Rush River Wastewater Treatment Plant	HAR-11	0.060	1.66E+11	1.04E+11
Hazel River (60076)	VA0022471	Rappahannock County Elementary School	HAR-13	0.008	2.22E+10	1.39E+10
Hazel River (60076)	VA0064181	Rappahannock County High School	HAR-13	0.005	1.38E+10	8.65E+09
Hazel River (60076)	VA0024449	Panorama Sewage Treatment Plant	HAR-14	0.015	4.16E+10	2.61E+10
Hazel River (60076)	VA0062880	Sperryville Sewage Treatment Plant	HAR-14	0.055	1.52E+11	9.56E+10
Hazel River (60076)	VAG406399	Residence	HAR-18	0.001	2.68E+09	1.69E+09
Hazel River (60076)	VAG406377	Residence	HAR-19	0.001	2.68E+09	1.69E+09
Hazel River (60076)	VAG406383	Residence	HAR-19	0.001	2.68E+09	1.69E+09
Rappahannock River (VAN-E08R-04)	VA0077411	Fauquier Springs Country Club STP	RAR-07	0.020	5.51E+10	3.48E+10
Rappahannock River (VAN-E08R-04)	VA0029238	South Wales Utility Treatment Plant [2]	RAR-07	0.070	1.93E+11	1.22E+11
Rappahannock River (VAN-E08R-04)	VA0080527	Clevengers Village Utility Sewage Treatment Plant (Formerly South Wales Utility Treatment Plant) [2]	RAR-07	0.857	2.37E+12	1.49E+12
Rappahannock River (VAN-E08R-04)	VA0088731	River Ridge Utility	RAR-07	0.050	1.38E+11	8.72E+10
Rappahannock River (VAN-E08R-04)	VA0068586	Culpeper County Industrial Airpark STP	RAR-11	0.300	8.29E+11	5.22+11
Rappahannock River (VAN-E08R-04)	VA0090603	Culpeper County - Elkwood Wastewater Treatment	RAR-11	0.900	2.49E+12	1.57E+12
Rappahannock River (VAN-E08R-04)	VAG406358	Residence	RAR-11	0.001	2.68E+09	1.69E+09
Rappahannock River (VAN-E08R-04)	VAG406023	Residence	RAR-11	0.001	2.68E+09	1.69E+09
Rappahannock River (60081)	VA0076805	Remington Wastewater Treatment Plant	RAR-12	2.500	6.90E+12	4.34E+12
Rappahannock River (60081)	VA0067750	T P Developed Parcel Limited Liability Corporation	RAR-12	0.004	1.04E+10	6.53E+09
Marsh Run (VAN-E08R-01)	VAG406084	Residence	RAR-15	0.001	2.68E+09	1.69E+09
Marsh Run (VAN-E08R-01)	VAG406138	Residence	RAR-15	0.001	2.68E+09	1.69E+09

Table 3.2. Active VPDES permitted point sources in the Rappahannock River watershed (Continued).

Impairment	Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	*E. coli* Load (cfu/yr)
Marsh Run (VAN-E08R-01)	VAG406311	Residence	RAR-15	0.001	2.68E+09	1.69E+09
Marsh Run (VAN-E08R-01)	VAG406066	Residence	RAR-16	0.001	2.68E+09	1.69E+09
Marsh Run (VAN-E08R-01)	VA0091022	Dominion-Remington CT Station	RAR-16	0.000	0.00E+00	0.00E+00
Marsh Run (VAN-E08R-01)	VA0091448	Old Dominiion Electric Cooperativer – Marsh Run	RAR-16	0.000	0.00E+00	0.00E+00
Browns Run (VAN-E08R-02)	VA0051675	Colonial Pipeline - Remington	RAR-17	0.001	0.00E+00	0.00E+00
Browns Run (VAN-E08R-02)	VAG406119	Residence	RAR-17	0.001	2.68E+09	1.69E+09
Browns Run (VAN-E08R-02)	VAG406232	Residence	RAR-17	0.001	2.68E+09	1.69E+09
Browns Run (VAN-E08R-02)	VAG406145	Residence	RAR-17	0.001	2.68E+09	1.69E+09
Browns Run (VAN-E08R-02)	VAG406312	Residence	RAR-17	0.001	2.68E+09	1.69E+09
Marsh Run (VAN-E08R-01)	VAG406365	Residence	RAR-20	0.001	2.68E+09	1.69E+09
Marsh Run (VAN-E08R-01)	VA0064726	Mary Walter Elementary School	RAR-20	0.007	1.86E+10	1.17E+10

[1] Currently, there are two permitted treatment facilities associated with Boston Sewer and Water (VA0065358 and VA0088749). The first, VA0065358 is currently in operation, and has a design flow of 0.0150 MGD. The second, VA0088749, has not been built yet, but has a design flow of 0.4500 MGD. Once the second facility has been built, and begins operation, the first facility will go offline. Thus, it is not practical to assign a load for both facilities, since both facilities will not be operating at the same time. Rather, a load was assigned to the new facility, VA0088749, because that facility has the larger design flow. A load for the new facility will be sufficient to cover the current facility while it is in operation, and provide for the operation of the new facility, once it is built.

[2] Currently, there are two permitted treatment facilities associated with Clevengers Village (VA0029238 and VA0080527). The first, VA0029238 is currently in operation, and has a design flow of 0.0700 MGD. The second, VA0080527, has not been built yet, but has a design flow of 0.8568 MGD. Once the second facility has been built, and begins operation, the first facility will go offline. Thus, it was not practical to assign a load for both facilities, since both facilities will not be operating at the same time. Rather, a load was assigned to the new facility, VA0080527, because that facility has the larger design flow. A load for the new facility will be sufficient to cover the current facility while it is in operation, and provide for the operation of the new facility, once it is built.

3.2 Hughes River (VAN-E03R-01) Sources

3.2.1 Humans and Pets

There are 91 homes served by municipal sanitary sewer in the Hughes River (VAN-E03R-01) watershed. Wastewater from 425 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Hughes River (VAN-E03R-01) watershed has an estimated population of 1,190 people (494 households at an average of 2.41 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce 1.95×10^9 cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of 2.32×10^{12} cfu/day (8.47×10^{14} cfu/year) in Hughes River (VAN-E03R-01) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.2.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Hughes River (VAN-E03R-01) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.41 persons/household was 4.70×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.4.

3.2.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 38 houses that potentially could be classified as straight pipes in the Hughes River (VAN-E03R-01) watershed (Table 3.4).

3.2.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Culpeper County. In Madison County; 8,161; 21,425; 8,704; and 379 dry tons of Class B biosolids were applied in 2002, 2003, 2004 and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Hughes River (VAN-E03R-01) watershed were not available. To estimate biosolid applications within each Hughes River (VAN-E03R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.3 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.3. Estimated average annual biosolids application amount for each subwatershed in the Hughes River (VAN-E03R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
HAR-01	669
HAR-02	186
Total	**855**

3.2.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 262 dogs and 296 cats were projected to reside in the Hughes River (VAN-E03R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 494 for Hughes River (VAN-E03R-01) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Hughes River (VAN-E03R-01) watershed is 2.2×10^{11} cfu/day

($8.1 x 10^{13}$ cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.4. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.4. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Hughes River (VAN-E03R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
HAR-01	853	30	177	77	66	88	34	384
HAR-02	338	61	69	24	12	33	4	110
Total	**1,191**	**91**	**246**	**101**	**78**	**121**	**38**	**494**

[a]Calculated from average of 1.0 pet per household.

3.2.3 Livestock Sources

In the Hughes River (VAN-E03R-01) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Hughes River (VAN-E03R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.2.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are no dairy farms presently operating in the Hughes River (VAN-E03R-01) watershed. Based on information provided, it was determined that there were 0 milk cows, 0 dry cows, and 0 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.5). Beef cattle in the Hughes River (VAN-E03R-01) watershed (1,253 pairs) included cow/calf and feeder operations (Table 3.5).

Table 3.5. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Hughes River (VAN-E03R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
HAR-01	0	0	1019
HAR-02	0	0	234
Total	**0**	**0**	**1253**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.6.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.6). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.6. Time spent by cattle in confinement and in the stream in Hughes River (VAN-E03R-01) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.7 for dairy cattle and in Tables 3.8 for beef cattle.

Table 3.7. Distribution of the dairy cattle[a] population in the Hughes River (VAN-E03R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 3.8. Distribution of the beef cattle population (pairs) in the Hughes River (VAN-E03R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	1097.07	274.75	68.69	0.45	0.00
February	0.00	1287.86	322.53	80.63	0.53	0.00
March	0.00	1325.81	332.03	83.01	0.82	0.00
April	0.00	1363.75	341.53	85.38	1.12	0.00
May	0.00	1401.46	350.98	87.74	1.73	0.00
June	0.00	1437.79	360.08	90.02	4.14	0.00
July	0.00	1475.88	369.62	92.40	4.25	0.00
August	0.00	1513.97	379.15	94.79	4.36	0.00
September	0.00	1554.00	389.18	97.30	1.91	0.00
October	0.00	953.67	238.84	59.71	0.78	0.00
November	0.00	1001.51	250.82	62.70	0.62	0.00
December	0.00	1049.37	262.80	65.70	0.43	0.00

*Number of beef cattle defecating in stream.

3.2.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.8) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Hughes River (VAN-E03R-01) watersheds is 38,752 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 5.48×10^{10} cfu/day (2.13×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.2.3.3 Direct Manure Deposition on Pastures

Beef (Table 3.8) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Hughes River (VAN-E03R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,786; 3,396; and 1,693 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Hughes River (VAN-E03R-01), averaged over the year, are 3.81×10^{12}, 1.92×10^{12}, and 9.42×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.2.4 Horses

The estimated number of horses in the Hughes River (VAN-E03R-01) watershed is included in Table 3.9. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^{8} cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Hughes River (VAN-E03R-01) watershed is 1.22×10^{11} cfu/day (4.46×10^{13} cfu/year).

Table 3.9. Horse population by subwatershed in the Hughes River (VAN-E03R-01) watershed.

Subwatershed	Horses
HAR-01	231
HAR-02	60
Total	**291**

3.2.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Hughes River (VAN-E03R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.2.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.12. The total wildlife fecal coliform production each year in the Hughes River (VAN-E03R-01) watershed, is 2.13×10^{14}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, bear, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.10).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.10). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.10, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.11.

Table 3.10. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Hughes River (VAN-E03R-01) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.046	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.005[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.11. Distribution of wildlife among sub-watersheds in Hughes River (VAN-E03R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
HAR-01	479	738	1,840	84	137	70	29
HAR-02	194	174	440	20	22	12	12
Total	**673**	**912**	**2,280**	**164**	**159**	**82**	**41**

3.2.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Hughes River (VAN-E03R-01) watershed along with average fecal coliform production rates are shown in Table 3.12. The total fecal coliform production by all sources in the Hughes River (VAN-E03R-01) watershed is 2.14×10^{16} cfu/yr.

Table 3.12. Potential fecal coliform sources and daily fecal coliform production by source in Hughes River (VAN-E03R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times 10^7$ cfu/ day)[b]
Beef Cattle (pairs)	1253	33,000	5,590,470
Horses	291	420	12,230
Humans	1191	1,950	76,937
Pets	494	450	22,245
Deer	673	350	23,571
Raccoon	912	50	4,563
Muskrat	2280	25	5,704
Beaver	164	0.2	2
Wild Turkey	41	93	382
Duck	82	2,400	14,733
Goose	159	800	9,543

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.13. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.13.

From Table 3.13, it is clear in the Hughes River (VAN-E03R-01) watershed that nonpoint source loadings to the land surface are more than 185 times as large as direct loadings to the streams, with pastures receiving about 97% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.13. Annual fecal coliform loadings to the stream and the various land use categories in the Hughes River (VAN-E03R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	6,412	0.30
Cattle in Stream	2,131	0.10
Wildlife in Stream	2,990	0.14
Loading to Land Surfaces		
Cropland	212	0.01
Pasture 1	1,588,678	74.08
Pasture 2	401,681	18.73
Pasture 3	98,378	4.59
Forest	14,344	0.67
Residential*	29,790	1.39
Total	**2,144,615**	**100.00**

*Includes loads received from failed septic systems and pets.

3.3 Hazel River (VAN-E04R-01) Sources

3.3.1 Humans and Pets

There are 103 homes served by municipal sanitary sewer in the Hazel River (VAN-E04R-01) watershed. Wastewater from 1,369 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Hazel River (VAN-E04R-01) watershed has an estimated population of 4,534 people (1,556 households at an average of 2.91 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $8.84x10^{12}$ cfu/day ($3.23x10^{15}$ cfu/year) in Hazel River (VAN-E04R-01) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.3.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Hazel River (VAN-E04R-01) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.91 persons/household was 5.68×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.15.

3.3.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 85 houses that potentially could be classified as straight pipes in the Hazel River (VAN-E04R-01) watershed (Table 3.15).

3.3.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Culpeper County. In Madison County; 8,161; 21,425; 8,704; and 379 dry tons of Class B biosolids were applied in 2002, 2003, 2004 and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Hazel River (VAN-E04R-01) watershed were not available. To estimate biosolid applications within each Hazel River (VAN-E04R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed.

Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.14 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.14. Estimated average annual biosolids application amount for each subwatershed in the Hazel River (VAN-E04R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
HAR-03	2
HAR-04	214
HAR-05	452
HAR-06	187
HAR-07	60
HAR-08	217
HAR-09	125
Total	**1,257**

3.3.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 825 dogs and 934 cats were projected to reside in the Hazel River (VAN-E04R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,557 for Hazel River (VAN-E04R-01) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Hazel River (VAN-E04R-01) watershed is 7.0×10^{11} cfu/day (2.6×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.15. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.15. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Hazel River (VAN-E04R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
HAR-03	555	33	153	37	28	69	12	263
HAR-04	457	5	72	30	18	35	13	138
HAR-05	776	10	121	56	32	61	18	237
HAR-06	917	23	203	66	40	96	32	364
HAR-07	413	8	92	33	19	44	1	153
HAR-08	753	14	115	59	37	59	3	228
HAR-09	663	10	73	51	34	40	6	174
Total	**4,534**	**103**	**829**	**332**	**208**	**404**	**85**	**1,557**

[a]Calculated from average of 1.0 pet per household.

3.3.3 Livestock Sources

In the Hazel River (VAN-E04R-01) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Hazel River (VAN-E04R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.3.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Hazel River (VAN-E03R-01) watershed. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.16). Beef cattle in the Hazel River (VAN-E04R-01) watershed (2,019 pairs) included cow/calf and feeder operations (Table 3.16).

Table 3.16. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Hazel River (VAN-E04R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
HAR-03	0	0	678
HAR-04	0	0	162
HAR-05	0	0	306
HAR-06	0	0	547
HAR-07	0	0	86
HAR-08	0	0	153
HAR-09	0	0	87
Total	**0**	**0**	**2,019**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.17.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.17). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.17. Time spent by cattle in confinement and in the stream in Hazel River (VAN-E04R-01) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.18 for dairy cattle and in Table 3.19 for beef cattle.

Table 3.18. Distribution of the dairy cattle[a] population in the Hazel River (VAN-E04R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 3.19. Distribution of the beef cattle population (pairs) in the Hazel River (VAN-E04R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	1767.74	442.71	110.68	0.73	0.00
February	0.00	2075.17	519.70	129.93	0.85	0.00
March	0.00	2136.32	535.02	133.75	1.32	0.00
April	0.00	2197.46	550.33	137.58	1.80	0.00
May	0.00	2258.22	565.54	141.39	2.78	0.00
June	0.00	2316.76	580.21	145.05	6.67	0.00
July	0.00	2378.14	595.58	148.89	6.85	0.00
August	0.00	2439.51	610.94	152.74	7.02	0.00
September	0.00	2504.01	627.10	156.77	3.09	0.00
October	0.00	1536.68	384.84	96.21	1.26	0.00
November	0.00	1613.77	404.15	101.04	0.99	0.00
December	0.00	1690.88	423.46	105.87	0.69	0.00

*Number of beef cattle defecating in stream.

3.3.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.19) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend

more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Hazel River (VAN-E04R-01) watersheds is 62,442 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 9.41×10^{10} cfu/day (3.43×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.3.3.3 Direct Manure Deposition on Pastures

Beef (Table 3.19) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Hazel River (VAN-E04R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 5,513; 2,759; and 1,375 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Hazel River (VAN-E04R-01), averaged over the year, are 3.10×10^{12}, 1.57×10^{12}, and 7.70×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.3.4 Horses

The estimated number of horses in the Hazel River (VAN-E04R-01) watershed is included in Table 3.20. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^{8} cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Hazel River (VAN-E04R-01) watershed is 2.19×10^{11} cfu/day (8.01×10^{13} cfu/year).

Table 3.20. Horse population by subwatershed in the Hazel River (VAN-E04R-01) watershed.

Subwatershed	Horses (#)
HAR-03	151
HAR-04	48
HAR-05	93
HAR-06	133
HAR-07	23
HAR-08	47
HAR-09	27
Total	**522**

3.3.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Hazel River (VAN-E04R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.3.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.23 The total wildlife fecal coliform production each year in the Hazel River (VAN-E04R-01) watershed, is 5.09×10^{14}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.21).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.21). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.21, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.22.

Table 3.21. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Hazel River (VAN-E04R-01) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.046	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.005[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.22. Distribution of wildlife among sub-watersheds in Hazel River (VAN-E04R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
HAR-03	695	544	1,260	61	79	40	52
HAR-04	201	189	384	22	23	12	13
HAR-05	272	225	734	25	32	16	13
HAR-06	591	546	941	62	68	35	43
HAR-07	190	158	169	19	22	11	16
HAR-08	177	169	377	19	21	11	11
HAR-09	121	98	151	11	14	7	9
Total	**2,247**	**1,929**	**4,016**	**219**	**259**	**132**	**157**

3.3.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Hazel River (VAN-E04R-01) watershed along with average fecal coliform production rates are shown in Table 3.23. The total fecal coliform production by all sources in the Hazel River (VAN-E04R-01) watershed is 3.54×10^{16} cfu/yr.

Table 3.23. Potential fecal coliform sources and daily fecal coliform production by source in Hazel River (VAN-E04R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times 10^7$ cfu/ day)[b]
Beef Cattle (pairs)	2,019	33,000	9,008,107
Horses	522	420	21,939
Humans	4,534	1,950	282,948
Pets	1,557	450	70,113
Deer	2,247	350	78,699
Raccoon	1,929	50	9,652
Muskrat	4,016	25	10,047
Beaver	219	0.2	4
Wild Turkey	157	93	1,461
Duck	132	2,400	23,959
Goose	259	800	15,572

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.24. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.24.

From Table 3.24 it is clear in the Hazel River (VAN-E04R-01) watershed that nonpoint source loadings to the land surface are more than 133 times as large as direct loadings to the streams, with pastures receiving about 95% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.24. Annual fecal coliform loadings to the stream and the various land use categories in the Hazel River (VAN-E04R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	17,787	0.50
Cattle in Stream	3,434	0.10
Wildlife in Stream	5,170	0.15
Loading to Land Surfaces		
Cropland	438	0.01
Pasture 1	2,564,487	72.34
Pasture 2	649,363	18.32
Pasture 3	159,399	4.50
Forest	33,805	0.95
Residential*	111,080	3.13
Total	**3,544,964**	**100.00**

*Includes loads received from failed septic systems and pets.

3.4 Rush River (VAN-E05R-01) Sources

3.4.1 Humans and Pets

There are 2 homes served by municipal sanitary sewer in the Rush River (VAN-E05R-01) watershed. Wastewater from 187 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rush River (VAN-E05R-01) watershed has an estimated population of 16,466 people (180 households at an average of 2.09 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $7.35x10^{11}$ cfu/day ($2.68x10^{14}$ cfu/year) in Rush River (VAN-E05R-01) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolids applications to pasture and cropland, or deposition of pet waste on residential land.

3.4.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Rush River (VAN-E05R-01) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.09 persons/household was 4.08×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.25.

3.4.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 15 houses that potentially could be classified as straight pipes in the Rush River (VAN-E05R-01) watershed (Table 3.25).

3.4.1.3 Biosolids

According to VDH records, no Class B biosolids were applied between 2000 and 2005 in Rappahannock County.

3.4.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 95 dogs and 108 cats were projected to reside in the Rush River (VAN-E05R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 204 for Rush River (VAN-E05R-01) watershed. The maximum typical fecal coliform production for both dogs and cats is $5.0x10^9$ cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Rush River (VAN-E05R-01) watershed is $8.1x10^{12}$ cfu/day ($3.0x10^{15}$ cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.25. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.25. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rush River (VAN-E05R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
HAR-10	154	2	64	7	0	27	4	77
HAR-11	203	0	104	2	0	40	9	115
HAR-12	20	0	10	0	0	3	2	12
Total	**377**	**2**	**178**	**9**	**0**	**70**	**15**	**204**

[a]Calculated from average of 1.0 pet per household.

3.4.3 Livestock Sources

In the Rush River (VAN-E05R-01) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Rush River (VAN-E05R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.4.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Rush River (VAN-E05R-01) watershed. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.26). Beef cattle in the Rush River (VAN-E05R-01) watershed (351 pairs) included cow/calf and feeder operations (Table 3.26).

Table 3.26. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Rush River (VAN-E05R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
HAR-10	0	0	64
HAR-11	0	0	227
HAR-12	0	0	60
Total	**0**	**0**	**351**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.27.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.27). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.27. Time spent by cattle in confinement and in the stream in Rush River (VAN-E05R-01) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.28 for dairy cattle and in Table 3.29 for beef cattle.

Table 3.28. Distribution of the dairy cattle[a] population in the Rush River (VAN-E05R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 3.29. Distribution of the beef cattle population (pairs) in the Rush River (VAN-E05R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	307.32	76.96	19.24	0.13	0.00
February	0.00	360.77	90.35	22.59	0.15	0.00
March	0.00	371.40	93.01	23.25	0.23	0.00
April	0.00	382.02	95.67	23.92	0.31	0.00
May	0.00	392.59	98.32	24.58	0.48	0.00
June	0.00	402.77	100.87	25.22	1.16	0.00
July	0.00	413.44	103.54	25.88	1.19	0.00
August	0.00	424.10	106.21	26.55	1.22	0.00
September	0.00	435.32	109.02	27.26	0.54	0.00
October	0.00	267.15	66.90	16.73	0.22	0.00
November	0.00	280.55	70.26	17.57	0.17	0.00
December	0.00	293.96	73.62	18.40	0.12	0.00

*Number of beef cattle defecating in stream.

3.4.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.29) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Rush River (VAN-E05R-01) watersheds is 10,856 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.64×10^{11} cfu/day (5.97×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.4.3.3 Direct Manure Deposition on Pastures

Beef (Table 3.29) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Rush River (VAN-E05R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 7,072; 3,536; and 1,768 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Rush River (VAN-E05R-01), averaged over the year, are 3.90×10^{12}, 1.96×10^{12}, and 9.87×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.4.4 Horses

The estimated number of horses in the Rush River (VAN-E05R-01) watershed is included in Table 3.30. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^{8} cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Rush River (VAN-E05R-01) watershed is 3.24×10^{10} cfu/day (1.18×10^{13} cfu/year).

Table 3.30. Horse population by subwatershed in the Rush River (VAN-E05R-01) watershed.

Subwatershed	Horses
HAR-10	14
HAR-11	50
HAR-12	13
Total	**77**

3.4.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Rush River (VAN-E05R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.4.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.33. The total wildlife fecal coliform production each year in the Rush River (VAN-E05R-01) watershed, is 1.00×10^{14}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.31).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.31). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.31, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.32.

Table 3.31. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rush River (VAN-E05R-01) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.046	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.005[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

[a] Muskrats per mile of stream through agricultural land.

[b] Animals per acres of all land uses.

[c] Animals per acres of forest.

Table 3.32. Distribution of wildlife among sub-watersheds in Rush River (VAN-E05R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
HAR-10	175	101	129	12	20	10	16
HAR-11	250	200	481	24	29	15	19
HAR-12	24	27	86	3	3	2	1
Total	**449**	**328**	**696**	**39**	**52**	**27**	**36**

3.4.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rush River (VAN-E05R-01) watershed along with average fecal coliform production rates are shown in Table 3.33. The total fecal coliform production by all sources in the Rush River (VAN-E05R-01) watershed is 6.00×10^{15} cfu/yr.

Table 3.33. Potential fecal coliform sources and daily fecal coliform production by source in Rush River (VAN-E05R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times10^7$ cfu/ day)[b]
Beef Cattle (pairs)	351	33,000	1,566,045
Horses	77	420	3,236
Humans	377	1,950	36,824
Pets	204	450	9,166
Deer	449	350	15,726
Raccoon	328	50	1,641
Muskrat	696	25	1,741
Beaver	39	0.2	1
Wild Turkey	36	93	335
Duck	27	2,400	4,912
Goose	52	800	3,155

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.34. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.34.

From Table 3.34, it is clear in the Rush River (VAN-E05R-01) watershed that nonpoint source loadings to the land surface are more than 153 times as large as direct loadings to the streams, with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.34. Annual fecal coliform loadings to the stream and the various land use categories in the Rush River (VAN-E05R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	2,285	0.38
Cattle in Stream	597	0.10
Wildlife in Stream	1,014	0.17
Loading to Land Surfaces		
Cropland	8	0.00
Pasture 1	436,490	72.80
Pasture 2	109,718	18.30
Pasture 3	27,632	4.61
Forest	7,370	1.23
Residential*	14,501	2.42
Total	**6,809,926**	**100.00**

*Includes loads received from failed septic systems and pets.

3.5 Hazel River (60076) Sources

3.5.1 Humans and Pets

There are 304 homes served by municipal sanitary sewer in the Hazel River (60076) watershed. Wastewater from 2,689 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Hazel River (60076) watershed has an estimated population of 9,184 people (3,097 households at an average of 2.97 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $1.79x10^{13}$ cfu/day ($6.54x10^{15}$ cfu/year) in Hazel River (60076) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.5.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Hazel River (60076) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.97 persons/household was 5.78×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.36.

3.5.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 123 houses that potentially could be classified as straight pipes in the Hazel River (60076) watershed (Table 3.36).

3.5.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Culpeper County. No biosolids applications occurred in Rappahannock County between 2000 and 2005 according to VDH records. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Hazel River (60076) watershed were not available. To estimate biosolid applications within each Hazel River (60076) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.35 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.35. Estimated average annual biosolids application amount for each subwatershed in the Hazel River (60076) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
HAR-13	0
HAR-14	0
HAR-15	310
HAR-16	142
HAR-17	405
HAR-18	569
HAR-19	270
Total	**1,696**

3.5.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 1,641dogs and 1,858 cats were projected to reside in the Hazel River (60076) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 3,116 for Hazel River (60076) watershed. The maximum typical fecal coliform production for both dogs and cats is $5.0\text{x}10^9$ cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Hazel River (60076) watershed is $1.4\text{x}10^{12}$ cfu/day ($5.1\text{x}10^{14}$ cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.36. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.36. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Hazel River (60076) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
HAR-13	588	16	246	16	0	98	28	306
HAR-14	1,159	235	208	45	37	93	39	564
HAR-15	2974	16	677	233	126	321	34	1,086
HAR-16	,562	7	63	45	30	35	3	148
HAR-17	1,303	13	151	108	62	84	5	339
HAR-18	2,200	14	243	185	120	138	13	575
HAR-19	397	3	50	36	8	27	1	98
Total	**9,183**	**304**	**1,638**	**668**	**383**	**796**	**123**	**3,116**

[a]Calculated from average of 1.0 pet per household.

3.5.3 Livestock Sources

In the Hazel River (60076) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Hazel River (60076) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.5.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Hazel River (60076) watershed. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.37). Beef cattle in the Hazel River (60076) watershed (6,206 pairs) included cow/calf and feeder operations (Table 3.37).

Table 3.37. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Hazel River (60076) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
HAR-13	0	0	904
HAR-14	0	0	1,370
HAR-15	0	0	2,934
HAR-16	0	0	98
HAR-17	0	0	287
HAR-18	0	0	422
HAR-19	0	0	191
Total	**0**	**0**	**6,206**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.38.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.38). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.38. Time spent by cattle in confinement and in the stream in Hazel River (60076) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.39 for dairy cattle and in Table 3.40 for beef cattle.

Table 3.39. Distribution of the dairy cattle[a] population in the Hazel River (60076) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	0.00	0.00	0.00	0.00	0.00	0.00
February	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00	0.00	0.00
October	0.00	0.00	0.00	0.00	0.00	0.00
November	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00	0.00	0.00

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 3.40. Distribution of the beef cattle population (pairs) in the Hazel River (60076) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	5433.67	1360.80	340.20	2.23	0.00
February	0.00	6378.66	1597.46	399.36	2.62	0.00
March	0.00	6566.63	1644.53	411.13	4.04	0.00
April	0.00	6754.54	1691.59	422.90	5.55	0.00
May	0.00	6941.31	1738.37	434.59	8.55	0.00
June	0.00	7121.27	1783.43	445.86	20.50	0.00
July	0.00	7309.91	1830.68	457.67	21.04	0.00
August	0.00	7498.55	1877.92	469.48	21.59	0.00
September	0.00	7696.83	1927.58	481.89	9.48	0.00
October	0.00	4723.46	1182.93	295.73	3.88	0.00
November	0.00	4960.40	1242.27	310.57	3.05	0.00
December	0.00	5197.43	1301.63	325.41	2.13	0.00

*Number of beef cattle defecating in stream.

3.5.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.40) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend

more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Hazel River (60076) watersheds is 191,936 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 2.89×10^{11} cfu/day (1.06×10^{14} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.5.3.3 Direct Manure Deposition on Pastures

Beef (Table 3.40) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Hazel River (60076) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,262; 3.132; and 1,564 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Hazel River (60076), averaged over the year, are 3.49×10^{12}, 1.76×10^{12}, and 8.74×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.5.4 Horses

The estimated number of horses in the Hazel River (60076) watershed is included in Table 3.41. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^8 cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Hazel River (60076) watershed is 6.22×10^{10} cfu/day (2.27×10^{13} cfu/year).

Table 3.41. Horse population by subwatershed in the Hazel River (60076) watershed.

Subwatershed	Horses (#)
HAR-13	201
HAR-14	304
HAR-15	671
HAR-16	30
HAR-17	88
HAR-18	128
HAR-19	59
Total	**1,481**

3.5.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Hazel River (60076) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.5.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.44. The total wildlife fecal coliform production each year in the Hazel River (60076) watershed, is 1.17×10^{15}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.42).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.42). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.42, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.43.

Table 3.42. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Hazel River (60076) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.046	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.005[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.43. Distribution of wildlife among sub-watersheds in Hazel River (60076) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
HAR-13	761	656	1,690	75	87	22	53
HAR-14	1,505	1,109	2,272	124	171	44	145
HAR-15	1,847	1,624	4,405	182	211	54	104
HAR-16	103	94	240	11	12	3	6
HAR-17	278	233	656	26	33	9	16
HAR-18	492	427	983	48	57	15	32
HAR-19	134	117	413	14	16	4	6
Total	**5,120**	**4,260**	**10,659**	**480**	**587**	**151**	**362**

3.5.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Hazel River (60076) watershed along with average fecal coliform production rates are shown in Table 3.44.

The total fecal coliform production by all sources in the Hazel River (60076) watershed is 1.06×10^{17} cfu/yr.

Table 3.44. Potential fecal coliform sources and daily fecal coliform production by source in Hazel River (60076) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times 10^7$ cfu/ day)[b]
Beef Cattle (pairs)	6,206	33,000	27,689,110
Horses	1,481	420	62,245
Humans	9,183	1,950	538,141
Pets	3,116	450	140,316
Deer	5,120	350	179,323
Raccoon	4,260	50	21,315
Muskrat	10,659	25	26,666
Beaver	480	0.2	10
Wild Turkey	362	93	3,369
Duck	151	2,400	53,784
Goose	587	800	35,256

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.45. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.45.

From Table 3.45, it is clear in the Hazel River (60076) watershed that nonpoint source loadings to the land surface are more than 231 times as large as direct loadings to the streams, with pastures receiving about 97% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.45. Annual fecal coliform loadings to the stream and the various land use categories in the Hazel River (60076) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	22,998	0.22
Cattle in Stream	10,556	0.10
Wildlife in Stream	12,005	0.11
Loading to Land Surfaces		
Cropland	508	0.00
Pasture 1	7,791,856	73.58
Pasture 2	1,965,075	18.56
Pasture 3	489,067	4.62
Forest	73,302	0.69
Residential*	224,639	2.12
Total	10,590,006	100.00

*Includes loads received from failed septic systems and pets.

3.6 Rappahannock River (VAN-E01R-03) Sources

3.6.1 Humans and Pets

There are 97 homes served by municipal sanitary sewer in the Rappahannock River (VAN-E01R-03) watershed. Wastewater from 894 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rappahannock River (VAN-E01R-03) watershed has an estimated population of 2,683 people (1,023 households at an average of 2.62 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $5.23x10^{12}$ cfu/day ($1.91x10^{15}$ cfu/year) in Rappahannock River (VAN-E01R-03) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolids applications to pasture and cropland, or deposition of pet waste on residential land.

3.6.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Rappahannock River (VAN-E01R-03) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.62 persons/household was 5.11×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.47.

3.6.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 31 houses that potentially could be classified as straight pipes in the Rappahannock River (VAN-E01R-03) watershed (Table 3.47).

3.6.1.3 Biosolids

According to VDH records; 18,861; 16,414; 3,322; 7,296; 11,001; and 13,888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Fauquier County. No Class B biosolids were applied between 2000 and 2005 in Rappahannock County according to VDH records. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Rappahannock River (VAN-E01R-03) watershed were not available. To estimate biosolids applications within each Rappahannock River (VAN-E01R-03) subwatershed, records of biosolids applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed.

Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.46 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.46. Estimated average annual biosolids application amount for each subwatershed in the Rappahannock River (VAN-E01R-03) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-01	360
RAR-02	8
Total	**368**

3.6.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 542 dogs and 614 cats were projected to reside in the Rappahannock River (VAN-E01R-03) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,022 for Rappahannock River (VAN-E01R-03) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Rappahannock River (VAN-E01R-03) watershed is 4.6×10^{11} cfu/day (1.7×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.47. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.47. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rappahannock River (VAN-E01R-03) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-01	2,624	97	680	163	32	306	31	1,003
RAR-02	59	0	13	4	2	6	0	19
Total	**2,683**	**97**	**693**	**167**	**34**	**312**	**31**	**1,022**

[a]Calculated from average of 1.0 pet per household.

3.6.3 Livestock Sources

In the Rappahannock River (VAN-E01R-03) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Rappahannock River (VAN-E01R-03) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.6.3.1 Cattle

Based on information provided, it was determined that there were no dairy farms currently operating in the watershed. Beef cattle in the Rappahannock River (VAN-E01R-03) watershed (2,107 pairs) included cow/calf and feeder operations (Table 3.48).

Table 3.48. Distribution of beef cattle among subwatersheds in Rappahannock River (VAN-E01R-03) watersheds.

Subwatershed	Beef Cattle (pairs)
RAR-01	2085
RAR-02	22
Total	**2107**

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.

- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.49). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.49. Time spent by cattle in the stream in Rappahannock River (VAN-E01R-03) watershed.

Month	Time Spent in Stream (hours/day)*
January	0.50
February	0.50
March	0.75
April	1.00
May	1.50
June	3.50
July	3.50
August	3.50
September	1.50
October	1.00
November	0.75
December	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.50 for beef cattle.

Table 3.50. Distribution of the beef cattle population (pairs) in the Rappahannock River (VAN-E01R-03) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	1844.79	462.00	115.50	0.76	0.00
February	0.00	2165.62	542.35	135.59	0.89	0.00
March	0.00	2229.44	558.34	139.58	1.37	0.00
April	0.00	2293.24	574.31	143.58	1.88	0.00
May	0.00	2356.65	590.19	147.55	2.90	0.00
June	0.00	2417.74	605.49	151.37	6.96	0.00
July	0.00	2481.79	621.53	155.38	7.14	0.00
August	0.00	2545.83	637.57	159.39	7.33	0.00
September	0.00	2613.15	654.43	163.61	3.22	0.00
October	0.00	1603.66	401.62	100.40	1.32	0.00
November	0.00	1684.11	421.76	105.44	1.04	0.00
December	0.00	1764.58	441.92	110.48	0.72	0.00

*Number of beef cattle defecating in stream.

3.6.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.50) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Rappahannock River (VAN-E01R-03) watersheds is 65,164 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 9.82×10^{10} cfu/day (3.58×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.6.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.50). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Rappahannock River (VAN-E01R-03) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 5,801; 2,901; and 1,449 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Rappahannock River (VAN-E01R-03), averaged over the year, are 3.23×10^{12}, 1.62×10^{12}, and 8.12×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.6.4 Horses

The estimated number of horses in the Rappahannock River (VAN-E01R-03) watershed is included in Table 3.51. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^{8} cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Rappahannock River (VAN-E01R-03) watershed is 3.27×10^{11} cfu/day (1.19×10^{14} cfu/year).

Table 3.51. Horse population by subwatershed in the Rappahannock River (VAN-E01R-03) watershed.

Subwatershed	Horses (#)
RAR-01	765
RAR-02	12
Total	**777**

3.6.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Rappahannock River (VAN-E01R-03) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.6.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.54. The total wildlife fecal coliform production each year in the Rappahannock River (VAN-E01R-03) watershed, 4.13×10^{14}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.52).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.52). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.52, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.53.

Table 3.52. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rappahannock River (VAN-E01R-03) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.046	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.006[c]	0.00

[a] Muskrats per mile of stream through agricultural land.

[b] Animals per acres of all land uses.

[c] Animals per acres of forest.

Table 3.53. Distribution of wildlife among sub-watersheds in Rappahannock River (VAN-E01R-03) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-01	1,553	1,715	3,804	194	246	125	149
RAR-02	31	38	33	5	5	2	4
Total	**1,584**	**1,753**	**3,837**	**199**	**251**	**127**	**153**

3.6.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rappahannock River (VAN-E01R-03) watershed along with average fecal coliform production rates are shown in Table 3.54. The total fecal coliform production by all sources in the Rappahannock River (VAN-E01R-03) watershed is $3.59x10^{16}$ cfu/yr.

Table 3.54. Potential fecal coliform sources and daily fecal coliform production by source in Rappahannock River (VAN-E01R-03) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Beef Cattle (pairs)	2,107	33,000	9,400,734
Horses	777	420	32,656
Humans	2,683	1,950	179,985
Pets	1,022	450	46,076
Deer	1,584	350	55,478
Raccoon	1,753	50	8,771
Muskrat	3,837	25	9,599
Beaver	199	0.2	4
Wild Turkey	153	93	1,424
Duck	127	2,400	22,879
Goose	251	800	15,053

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.55. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.55.

From Table 3.55, it is clear in the Rappahannock River (VAN-E01R-03) watershed that nonpoint source loadings to the land surface are more than 249 times as large as direct loadings to the streams, with pastures receiving about 97% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.55. Annual fecal coliform loadings to the stream and the various land use categories in the Rappahannock River (VAN-E01R-03) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	5,920	0.16
Cattle in Stream	3,584	0.10
Wildlife in Stream	4,866	0.14
Loading to Land Surfaces		
Cropland	193	0.01
Pasture 1	2,641,393	73.53
Pasture 2	666,065	18.54
Pasture 3	166,410	4.63
Forest	27,419	0.76
Residential*	76,593	2.13
Total	**3,592,442**	**100.00**

*Includes loads received from failed septic systems and pets.

3.7 Rappananack River (VAN-E08R-04) Sources

3.7.1 Humans and Pets

There are 1,544 homes served by municipal sanitary sewer in the Rappahannock River (VAN-E08R-04) watershed. Wastewater from 3,237 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rappahannock River (VAN-E08R-04) watershed has an estimated population of 15,142 people (4,796 households at an average of 3.16 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $2.95x10^{13}$ cfu/day ($1.08x10^{16}$ cfu/year) in Rappahannock River (VAN-E08R-04) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolids applications to pasture and cropland, or deposition of pet waste on residential land.

3.7.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Rappahannock River (VAN-E08R-04) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.16 persons/household was 6.16×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.57.

3.7.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 51 houses that potentially could be classified as straight pipes in the Rappahannock River (VAN-E08R-04) watershed (Table 3.57).

3.7.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Culpeper County. In Fauquier County; 18,861; 16,414; 3,322; 7,296; 11,001; and 13,888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004 and 2005, respectively. No Class B biosolids were applied between 2000 and 2005 in Rappahannock County according to VDH records. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Rappahannock River (VAN-E08R-04) watershed were not available. To estimate biosolid applications within each Rappahannock River (VAN-E08R-04) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.56 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.56. Estimated average annual biosolids application amount for each subwatershed in the Rappahannock River (VAN-E08R-04) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-03	10
RAR-04	675
RAR-05	147
RAR-06	781
RAR-07	603
RAR-08	523
RAR-09	467
RAR-10	478
RAR-11	320
Total	**4,004**

3.7.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 2,542 dogs and 2,878 cats were projected to reside in the Rappahannock River (VAN-E08R-04) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 4,832 for Rappahannock River (VAN-E08R-04) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Rappahannock River (VAN-E08R-04) watershed is 2.2×10^{12} cfu/day (7.9×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.57. Pet waste is generated in the residential land use type.

Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.57. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rappahannock River (VAN-E08R-04) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-03	485	2	127	40	17	59	4	190
RAR-04	1,545	76	322	86	17	147	1	502
RAR-05	944	2	175	76	44	87	2	299
RAR-06	3,413	341	460	268	105	241	11	1,185
RAR-07	2,052	217	184	115	49	98	13	578
RAR-08	4,520	637	461	230	84	233	14	1,425
RAR-09	1,437	194	135	80	0	69	3	412
RAR-10	266	6	63	15	2	28	2	89
RAR-11	481	69	56	26	0	27	1	152
Total	**15,143**	**1,544**	**1,983**	**936**	**318**	**989**	**51**	**4,832**

[a]Calculated from average of 1.0 pet per household.

3.7.3 Livestock Sources

In the Rappahannock River (VAN-E08R-04) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Rappahannock River (VAN-E08R-04) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.7.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are two dairy farms presently operating in the Rappahannock River (VAN-E08R-04) watershed. Based on information provided, it was determined that there were 345 milk cows, 173 dry cows, and 173 heifers distributed between the farms. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.58). Beef cattle in the Rappahannock River (VAN-E08R-04) watershed (5,289 pairs) included cow/calf and feeder operations (Table 3.58).

Table 3.58. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Rappahannock River (VAN-E08R-04) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
RAR-03	0	0	346
RAR-04	0	0	1,037
RAR-05	0	0	400
RAR-06	0	0	1,191
RAR-07	0	0	501
RAR-08	0	0	811
RAR-09	500	2	426
RAR-10	0	0	320
RAR-11	190	2	257
Total	**690**	**4**	**5,289**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.59.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.59). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.59. Time spent by cattle in confinement and in the stream in Rappahannock River (VAN-E08R-04) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.60 for dairy cattle and in Table 3.61 for beef cattle.

Table 3.60. Distribution of the dairy cattle[a] population in the Rappahannock River (VAN-E08R-04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	397.15	223.72	56.03	14.01	0.09	0.00
February	397.15	223.72	56.03	14.01	0.09	0.00
March	138.00	420.96	105.42	26.36	0.26	0.00
April	103.50	447.15	111.98	28.00	0.37	0.00
May	103.50	447.01	111.95	27.99	0.55	0.00
June	103.50	446.45	111.81	27.95	1.29	0.00
July	103.50	446.45	111.81	27.95	1.29	0.00
August	103.50	446.45	111.81	27.95	1.29	0.00
September	103.50	447.01	111.95	27.99	0.55	0.00
October	103.50	447.15	111.98	28.00	0.37	0.00
November	138.00	420.96	105.42	26.36	0.26	0.00
December	397.15	223.72	56.03	14.01	0.09	0.00

[a]Includes milk cows, dry cows, and heifers.
[b]Number of dairy cattle defecating in stream.
[c]Milk cows in loafing lot.

Table 3.61. Distribution of the beef cattle population (pairs) in the Rappahannock River (VAN-E08R-04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	4630.79	1159.73	289.93	1.90	0.00
February	0.00	5436.15	1361.42	340.35	2.23	0.00
March	0.00	5596.34	1401.54	350.38	3.45	0.00
April	0.00	5756.49	1441.64	360.41	4.73	0.00
May	0.00	5915.66	1481.51	370.38	7.29	0.00
June	0.00	6069.03	1519.91	379.98	17.47	0.00
July	0.00	6229.80	1560.18	390.04	17.93	0.00
August	0.00	6390.56	1600.44	400.11	18.40	0.00
September	0.00	6559.54	1642.76	410.69	8.08	0.00
October	0.00	4025.52	1008.14	252.04	3.31	0.00
November	0.00	4227.45	1058.71	264.68	2.60	0.00
December	0.00	4429.45	1109.30	277.33	1.82	0.00

*Number of beef cattle defecating in stream.

3.7.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 3.60) and beef cattle (Table 3.61) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Rappahannock River (VAN-E08R-04) watersheds is 181,986 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is $2.60\text{x}10^{10}$ cfu/day ($9.48\text{x}10^{12}$ cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.7.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.60) and beef (Table 3.61) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Rappahannock River (VAN-E08R-04) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 4,629; 2,317; and 1,154 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Rappahannock River (VAN-E08R-04), averaged over the year, are 2.47×10^{12}, 1.26×10^{12}, and 6.15×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.7.3.4 Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 pounds and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule and the number of milk cows, annual liquid dairy manure production in the Rappahannock River (VAN-E08R-04) watershed is 9,207,213 gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 3.88×10^7 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories (BSE, 2003), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 138.9 acres of cropland and 0.0 acres of pasture 1 in the Rappahannock River (VAN-E08R-04) watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.62. Dry cows and heifers were assumed to produce only solid manure.

Table 3.62. Schedule of cattle waste application in Rappahannock River (VAN-E08R-04) watershed.

Month	Liquid Manure Applied (%)*	Solid Manure and Poultry Litter Applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

* As percent of annual production.

3.7.3.5 Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.63.

Solid manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle exhibits different fecal coliform concentrations (cfu/lb) (Table 3.63). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 3.63). Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May and the months of October and November.

Solid manure can be applied to pasture during the whole year except during December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 3.62. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 40.5 acres of the cropland and 0.0 acres of the pasture 1 in Rappahannock River (VAN-E08R-04) received solid manure application.

Table 3.63. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure in Rappahannock River (VAN-E08R-04) watershed.

Type of Cattle	Population	Typical Weight (lb) [a]	Solid Manure Produced (lb/animal-day) [a]	Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) [a]	Weighted Average Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb)
Dry Cow	173	1,400	115.0	2.17	5.24
Heifer	173	640	40.7	2.17	
Beef (pairs)	5289	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.7.4 Horses

The estimated number of horses in the Rappahannock River (VAN-E08R-04) watershed is included in Table 3.64. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Rappahannock River (VAN-E08R-04) watershed is $1.36x10^{12}$ cfu/day ($4.98x10^{14}$ cfu/year).

Table 3.64. Horse population by subwatershed in the Rappahannock River (VAN-E08R-04) watershed.

Subwatershed	Horses (#)
RAR-03	88
RAR-04	789
RAR-05	159
RAR-06	906
RAR-07	244
RAR-08	617
RAR-09	288
RAR-10	101
RAR-11	115
Total	**3307**

3.7.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Rappahannock River (VAN-E08R-04) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.7.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.67. The total wildlife fecal coliform production each year in the Rappahannock River (VAN-E08R-04) watershed, is 1.21×10^{15}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.65).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.65). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.65, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.66.

Table 3.65. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rappahannock River (VAN-E08R-04) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.041	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.006[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.66. Distribution of wildlife among sub-watersheds in Rappahannock River (VAN-E08R-04) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-03	366	293	388	33	38	23	21
RAR-04	1,020	864	2,589	97	139	49	79
RAR-05	435	392	491	44	56	26	35
RAR-06	1,554	1,378	2,742	154	213	75	146
RAR-07	485	503	1,091	54	81	28	48
RAR-08	784	624	1,737	69	109	38	60
RAR-09	296	287	986	32	47	17	20
RAR-10	146	151	581	17	28	10	8
RAR-11	141	147	571	17	24	9	8
Total	**5,227**	**4,639**	**11,176**	**517**	**735**	**275**	**425**

3.7.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rappahannock River (VAN-E08R-04) watershed along with average fecal coliform production rates are shown in Table 3.67. The total fecal coliform production by all sources in the Rappahannock River (VAN-E08R-04) watershed is $9.90x10^{16}$ cfu/yr.

Table 3.67. Potential fecal coliform sources and daily fecal coliform production by source in Rappahannock River (VAN-E08R-04) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	518	25,000	1,295,887
Heifers	173	8,800	197,850
Beef Cattle (pairs)	5,289	33,000	23,597,761
Horses	3,307	420	136,467
Humans	15,143	1,950	651,656
Pets	4,832	450	217,635
Deer	5,227	350	183,070
Raccoon	4,639	50	23,211
Muskrat	11,176	25	27,959
Beaver	517	0.2	10
Wild Turkey	425	93	3,955
Duck	275	2,400	49,712
Goose	735	800	44,120

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.68. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.68.

From Table 3.68, it is clear in the Rappahannock River (VAN-E08R-04) watershed that nonpoint source loadings to the land surface are more than 286 times as large as direct loadings to the streams, with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.68. Annual fecal coliform loadings to the stream and the various land use categories in the Rappahannock River (VAN-E08R-04) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	11,857	0.12
Cattle in Stream	9,412	0.10
Wildlife in Stream	12,645	0.13
Loading to Land Surfaces		
Cropland	6,329	0.06
Pasture 1	7,084,446	72.70
Pasture 2	1,802,108	18.49
Pasture 3	440,940	4.52
Forest	71,408	0.73
Residential*	305,434	3.13
Total	**9,744,580**	**100.00**

*Includes loads received from failed septic systems and pets.

3.8 Rappahannock River (60081) Sources

3.8.1 Humans and Pets

There are 469 homes served by municipal sanitary sewer in the Rappahannock River (60081) watershed. Wastewater from 508 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rappahannock River (60081) watershed has an estimated population of 3,291 people (982 households at an average of 3.35 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $6.42x10^{12}$ cfu/day ($2.34x10^{15}$ cfu/year) in Rappahannock River (60081) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.8.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1995, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Rappahannock River (60081) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.35 persons/household was 6.54×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.70.

3.8.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded four houses that potentially could be classified as straight pipes in the Rappahannock River (60081) watershed (Table 3.70).

3.8.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Culpeper County. In Fauquier County; 18,861; 16,414; 3,322; 7,296; 11,001; and 13,888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004 and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Rappahannock River (60081) watershed were not available. To estimate biosolid applications within each Rappahannock River (60081) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.69 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.69. Estimated average annual biosolids application amount for each subwatershed in the Rappahannock River (60081) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-12	590
RAR-13	112
Total	**702**

3.8.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 520 dogs and 589 cats were projected to reside in the Rappahannock River (60081) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 981 for Rappahannock River (60081) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Rappahannock River (60081) watershed is 4.4×10^{11} cfu/day (1.61×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.70. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.70. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rappahannock River (60081) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-12	3,139	462	231	179	50	130	4	926
RAR-13	151	7	34	11	3	16	0	55
Total	**3,290**	**469**	**265**	**190**	**53**	**146**	**4**	**981**

[a]Calculated from average of 1.0 pet per household.

3.8.3 Livestock Sources

In the Rappahannock River (60081) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Rappahannock River (60081) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.8.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Rappahannock River (60081) watershed. Beef cattle in the Rappahannock River (60081) watershed (751 pairs) included cow/calf and feeder operations (Table 3.71).

Table 3.71. Distribution of beef cattle among subwatersheds in Rappahannock River (60081) watersheds.

Subwatershed	Beef Cattle (pairs)
RAR-11	667
RAR-12	84
Total	**751**

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.72). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.72. Time spent by cattle in the stream in Rappahannock River (60081) watershed.

Month	Time Spent in Stream (hours/day)*
January	0.50
February	0.50
March	0.75
April	1.00
May	1.50
June	3.50
July	3.50
August	3.50
September	1.50
October	1.00
November	0.75
December	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.73 for beef cattle.

Table 3.73. Distribution of the beef cattle population (pairs) in the Rappahannock River (60081) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	657.54	164.67	41.17	0.27	0.00
February	0.00	771.89	193.31	48.33	0.32	0.00
March	0.00	794.64	199.01	49.75	0.49	0.00
April	0.00	817.38	204.70	51.18	0.67	0.00
May	0.00	839.98	210.36	52.59	1.03	0.00
June	0.00	861.76	215.82	53.95	2.48	0.00
July	0.00	884.59	221.53	55.38	2.55	0.00
August	0.00	907.41	227.25	56.81	2.61	0.00
September	0.00	931.41	233.26	58.31	1.15	0.00
October	0.00	571.59	143.15	35.79	0.47	0.00
November	0.00	600.27	150.33	37.58	0.37	0.00
December	0.00	628.95	157.51	39.38	0.26	0.00

*Number of beef cattle defecating in stream.

3.8.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.73) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend

more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Rappahannock River (60081) watersheds is 23,226 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 3.50×10^{10} cfu/day (1.28×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.8.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.73). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Rappahannock River (60081) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 3,276; 1,640; and 816 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Rappahannock River (60081), averaged over the year, are 1.87×10^{12}, 9.52×10^{11}, and 4.62×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.8.4 Horses

The estimated number of horses in the Rappahannock River (60081) watershed is included in Table 3.74. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2×10^8 cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Rappahannock River (60081) watershed is 1.97×10^{11} cfu/day (7.19×10^{13} cfu/year).

Table 3.74. Horse population by subwatershed in the Rappahannock River (60081) watershed.

Subwatershed	Horses (#)
RAR-12	433
RAR-13	36
Total	**469**

3.8.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Rappahannock River (60081) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.8.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.77. The total wildlife fecal coliform production each year in the Rappahannock River (60081) watershed, is 1.27×10^{14} cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.75).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.75). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.75, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.76.

Table 3.75. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rappahannock River (60081) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.039	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.006[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.76. Distribution of wildlife among sub-watersheds in Rappahannock River (60081) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-12	466	342	1,192	38	70	25	25
RAR-13	73	53	99	6	13	5	7
Total	**539**	**395**	**1,291**	**44**	**83**	**30**	**32**

3.8.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rappahannock River (60081) watershed along with average fecal coliform production rates are shown in Table 3.77. The total fecal coliform production by all sources in the Rappahannock River (60081) watershed is 1.34×10^{16} cfu/yr.

Table 3.77. Potential fecal coliform sources and daily fecal coliform production by source in Rappahannock River (60081) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Beef Cattle (pairs)	751	33,000	3,350,713
Horses	469	420	19,711
Humans	3,290	1,950	98,998
Pets	981	450	44,198
Deer	539	350	18,878
Raccoon	395	50	1,976
Muskrat	1,291	25	3,230
Beaver	44	0.2	1
Wild Turkey	32	93	298
Duck	30	2,400	5,511
Goose	83	800	4,991

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.78. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.78.

From Table 3.78, it is clear in the Rappahannock River (60081) watershed that nonpoint source loadings to the land surface are more than 364 times as large as direct loadings to the streams, with pastures receiving about 95% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.78. Annual fecal coliform loadings to the stream and the various land use categories in the Rappahannock River (60081) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	990	0.07
Cattle in Stream	1,277	0.10
Wildlife in Stream	1,395	0.10
Loading to Land Surfaces		
Cropland	378	0.03
Pasture 1	969,109	72.47
Pasture 2	247,115	18.48
Pasture 3	60,036	4.49
Forest	5,704	0.43
Residential*	51,276	3.83
Total	**1,337,281**	**100.00**

*Includes loads received from failed septic systems and pets.

3.9 Craig Run (VAN-E08R-03) Sources

3.9.1 Humans and Pets

There are 319 homes served by municipal sanitary sewer in the Craig Run (VAN-E08R-03) watershed. Wastewater from 212 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Craig Run (VAN-E08R-03) watershed has an estimated population of 1,836 people (532 households at an average of 3.45 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $3.58x10^{12}$ cfu/day ($1.31x10^{15}$ cfu/year) in Craig Run (VAN-E08R-03) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.9.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Craig Run (VAN-E08R-03) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.45 persons/household was 6.73×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.80.

3.9.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded two houses that potentially could be classified as straight pipes in the Craig Run (VAN-E08R-03) watershed (Table 3.80).

3.9.1.3 Biosolids

According to VDH records 18861, 16414, 3322, 7296, 11001, and 13888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Fauquier County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Craig Run (VAN-E08R-03) watershed were not available. To estimate biosolid applications within each Craig Run (VAN-E08R-03) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.79 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.79. Estimated average annual biosolids application amount for each subwatershed in the Craig Run (VAN-E08R-03) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-14	234
Total	**234**

3.9.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 282 dogs and 319 cats were projected to reside in the Craig Run (VAN-E08R-03) impairment. All pets were combined for modeling purposes into a standard 'unit pet' category. This 'unit pet' was assumed equivalent to one dog or several cats, and a rate of one 'unit pet' per household was used to calculate a total pet population of 533 for Craig Run (VAN-E08R-03) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Craig Run (VAN-E08R-03) watershed is 2.4×10^{11} cfu/day (8.7×10^{13} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.80. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.80. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Craig Run (VAN-E08R-03) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-14	1836	319	106	88	18	60	2	533
Total	**1836**	**319**	**106**	**88**	**18**	**60**	**2**	**533**

[a]Calculated from average of 1.0 pet per household.

3.9.3 Livestock Sources

In the Craig Run (VAN-E08R-03) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Craig Run (VAN-E08R-03) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.9.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the Craig Run (VAN-E08R-03) watershed. Based on information provided, it was determined that there were 250 milk cows, 125 dry cows, and 125 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.81). Beef cattle in the Craig Run (VAN-E08R-03) watershed (335 pairs) included cow/calf and feeder operations (Table 3.81).

Table 3.81. Distribution of beef cattle among subwatersheds in Craig Run (VAN-E08R-03) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
RAR-14	500	1	335
Total	**500**	**1**	**335**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.82.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.82). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.

- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.82. Time spent by cattle in the stream in Craig Run (VAN-E08R-03) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.83 for dairy cattle and in Table 3.84 for beef cattle.

Table 3.83. Distribution of the dairy cattle[a] population in the Craig Run (VAN-E08R-03) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	287.50	161.79	40.52	10.13	0.07	0.00
February	287.50	161.79	40.52	10.13	0.07	0.00
March	100.00	304.49	76.26	19.06	0.19	0.00
April	75.00	323.47	81.01	20.25	0.27	0.00
May	75.00	323.37	80.98	20.25	0.40	0.00
June	75.00	322.97	80.88	20.22	0.93	0.00
July	75.00	322.97	80.88	20.22	0.93	0.00
August	75.00	322.97	80.88	20.22	0.93	0.00
September	75.00	323.37	80.98	20.25	0.40	0.00
October	75.00	323.47	81.01	20.25	0.27	0.00
November	100.00	304.49	76.26	19.06	0.19	0.00
December	287.50	161.79	40.52	10.13	0.07	0.00

[a]Includes milk cows, dry cows, and heifers.

[b]Number of dairy cattle defecating in stream.

[c]Milk cows in loafing lot

Table 3.84. Distribution of the beef cattle population (pairs) in the Craig Run (VAN-E08R-03) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	293.31	73.46	18.36	0.12	0.00
February	0.00	344.32	86.23	21.56	0.14	0.00
March	0.00	354.47	88.77	22.19	0.22	0.00
April	0.00	364.61	91.31	22.83	0.30	0.00
May	0.00	374.69	93.84	23.46	0.46	0.00
June	0.00	384.41	96.27	24.07	1.11	0.00
July	0.00	394.59	98.82	24.71	1.14	0.00
August	0.00	404.77	101.37	25.34	1.17	0.00
September	0.00	415.47	104.05	26.01	0.51	0.00
October	0.00	254.97	63.85	15.96	0.21	0.00
November	0.00	267.76	67.06	16.76	0.16	0.00
December	0.00	280.56	70.26	17.57	0.12	0.00

*Number of beef cattle defecating in stream.

3.9.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy cattle (Table 3.83) and beef cattle (Table 3.84) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Craig Run (VAN-E08R-03) watersheds is 23,683 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 2.38×10^{10} cfu/day (8.70×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.9.3.3 Direct Manure Deposition on Pastures

Dairy cattle (Table 3.83) and beef cattle (Table 3.84) that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Craig Run (VAN-E08R-03) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 37,271; 18,644; and 9,305 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Craig Run (VAN-E08R-03), averaged over the year, are 1.41×10^{13}, 7.12×10^{12}, and 3.51×10^{12} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.9.3.4 Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 pounds and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule and the number of milk cows, annual liquid dairy manure production in the Craig Run (VAN-E08R-03) watershed is 6,671,894 gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 3.88×10^7 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories (BSE, 2003), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 82.5 acres of cropland and 30.7 acres of pasture 1 in the Craig Run (VAN-E08R-03) watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.85. Dry cows and heifers were assumed to produce only solid manure.

Table 3.85. Schedule of cattle waste application in Craig Run (VAN-E08R-03) watershed.

Month	Liquid Manure Applied (%)*	Solid Manure and Poultry Litter Applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

* As percent of annual production.

3.9.3.5 Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.86.

Solid manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle exhibits different fecal coliform concentrations (cfu/lb) (Table 3.86). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 3.86). Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May and the months of October and November.

Solid manure can be applied to pasture during the whole year except during December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 3.85. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 0.0 acres of the cropland and 29.3 acres of the pasture 1 in Craig Run (VAN-E08R-03) received solid manure application.

Table 3.86. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure in Craig Run (VAN-E08R-03) watershed.

Type of Cattle	Population	Typical Weight (lb) [a]	Solid Manure Produced (lb/animal-day) [a]	Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) [a]	Weighted Average Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb)
Dry Cow	125	1,400	115	2.17	3.86
Heifer	125	640	40.7	2.17	
Beef (pairs)	335	1,000	60	5.5	

[a]Source: BSE (2003)

3.9.4 Horses

The estimated number of horses in the Craig Run (VAN-E08R-03) watershed is included in Table 3.87. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Craig Run (VAN-E08R-03) watershed is $1.07x10^{11}$ cfu/day ($3.91x10^{13}$ cfu/year).

Table 3.87. Horse population by subwatershed in the Craig Run (VAN-E08R-03) watershed.

Subwatershed	Horses (#)
RAR-14	255
Total	**255**

3.9.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Craig Run (VAN-E08R-03) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.9.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.90. The total wildlife fecal coliform production each year in the Craig Run (VAN-E08R-03) watershed, is $5.42x10^{13}$cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.88).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.88). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.88, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.89.

Table 3.88. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Craig Run (VAN-E08R-03) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.045	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.007[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.89. Distribution of wildlife among sub-watersheds in Craig Run (VAN-E08R-03) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-14	225	171	754	19	33	12	8
Total	**225**	**171**	**754**	**19**	**33**	**12**	**8**

3.9.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Craig Run (VAN-E08R-03) watershed along with average fecal coliform production rates are shown in Table 3.90. The total fecal coliform production by all sources in the Craig Run (VAN-E08R-03) watershed is 9.89×10^{15} cfu/yr.

Table 3.90. Potential fecal coliform sources and daily fecal coliform production by source in Craig Run (VAN-E08R-03) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^6$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	375	25,000	9,381,421
Heifers	125	8,800	1,429,550
Beef Cattle (pairs)	335	33,000	14,946,587
Horses	255	420	107,173
Humans	1,836	1,950	434,983
Pets	533	450	239,658
Deer	225	350	78,804
Raccoon	171	50	8,556
Muskrat	754	25	18,863
Beaver	19	0.2	4
Wild Turkey	8	93	745
Duck	12	2,400	21,561
Goose	33	800	19,965

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.91. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.91.

From Table 3.91, it is clear in the Craig Run (VAN-E08R-03) watershed that nonpoint source loadings to the land surface are more than 441 times as large as direct loadings to the streams, with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.91. Annual fecal coliform loadings to the stream and the various land use categories in the Craig Run (VAN-E08R-03) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	504	0.06
Cattle in Stream	870	0.10
Wildlife in Stream	611	0.07
Loading to Land Surfaces		
Cropland	2,284	0.26
Pasture 1	644,503	73.34
Pasture 2	162,703	18.52
Pasture 3	40,140	4.57
Forest	2,996	0.34
Residential*	24,120	2.74
Total	**878,732**	**100.00**

*Includes loads received from failed septic systems and pets.

3.10 Browns Run (VAN-E08R-02) Sources

3.10.1 Humans and Pets

There are 24 homes served by municipal sanitary sewer in the Browns Run (VAN-E08R-02) watershed. Wastewater from 343 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Browns Run (VAN-E08R-02) watershed has an estimated population of 1,148 people (369 households at an average of 3.11 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $2.24x10^{12}$ cfu/day ($8.17x10^{14}$ cfu/year) in Browns Run (VAN-E08R-02) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.10.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994was used in the development of the Browns Run (VAN-E08R-02) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.11 persons/household was 6.07×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.93.

3.10.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded two houses that potentially could be classified as straight pipes in the Browns Run (VAN-E08R-02) watershed (Table 3.93).

3.10.1.3 Biosolids

According to VDH records; 18,861; 16,414; 3,322; 7,296; 11,001; and 13,888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Fauquier County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Browns Run (VAN-E08R-02) watershed were not available. To estimate biosolids applications within each Browns Run (VAN-E08R-02) subwatershed, records of biosolids applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.92 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.92. Estimated average annual biosolids application amount for each subwatershed in the Browns Run (VAN-E08R-02) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-17	137
RAR-18	85
Total	**222**

3.10.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 196 dogs and 221 cats were projected to reside in the Browns Run (VAN-E08R-02) impairment. All pets were combined for modeling purposes into a standard 'unit pet' category. This 'unit pet' was assumed equivalent to one dog or several cats, and a rate of one 'unit pet' per household was used to calculate a total pet population of 370 for Browns Run (VAN-E08R-02) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^{9} cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^{8} cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Browns Run (VAN-E08R-02) watershed is 1.7×10^{11} cfu/day (6.1×10^{13} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.90. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.93. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Browns Run (VAN-E08R-02) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-17	714	1	133	58	39	66	2	233
RAR-18	434	23	54	35	24	30	0	137
Total	**1,148**	**24**	**187**	**93**	**63**	**96**	**2**	**370**

[a]Calculated from average of 1.0 pet per household.

3.10.3 Livestock Sources

In the Browns Run (VAN-E08R-02) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Browns Run (VAN-E08R-02) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.10.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are two dairy farms presently operating in the Rappahannock River (VAN-E03R-01) watershed. Based on information provided, it was determined that there were 285 milk cows, 143 dry cows, and 143 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.94). Beef cattle in the Browns Run (VAN-E08R-02) watershed (318 pairs) included cow/calf and feeder operations (Table 3.94).

Table 3.94. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Browns Run (VAN-E08R-02) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
RAR-17	0	0	195
RAR-18	571	2	123
Total	**571**	**2**	**318**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.95.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.95). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.

- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.95. Time spent by cattle in confinement and in the stream in Browns Run (VAN-E08R-02) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.96 for dairy cattle and in Table 3.97 for beef cattle.

Table 3.96. Distribution of the dairy cattle[a] population in the Browns Run (VAN-E08R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	328.15	184.89	46.30	11.58	0.08	0.00
February	328.15	184.89	46.30	11.58	0.08	0.00
March	114.00	347.88	87.12	21.78	0.21	0.00
April	85.50	369.52	92.54	23.14	0.30	0.00
May	85.50	369.40	92.51	23.13	0.46	0.00
June	85.50	368.94	92.40	23.10	1.06	0.00
July	85.50	368.94	92.40	23.10	1.06	0.00
August	85.50	368.94	92.40	23.10	1.06	0.00
September	85.50	369.40	92.51	23.13	0.46	0.00
October	85.50	369.52	92.54	23.14	0.30	0.00
November	114.00	347.88	87.12	21.78	0.21	0.00
December	328.15	184.89	46.30	11.58	0.08	0.00

[a]Includes milk cows, dry cows, and heifers.

[b]Number of dairy cattle defecating in stream.

[c]Milk cows in loafing lot.

Table 3.97. Distribution of the beef cattle population (pairs) in the Browns Run (VAN-E08R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	278.43	69.73	17.43	0.11	0.00
February	0.00	326.85	81.85	20.46	0.13	0.00
March	0.00	336.48	84.27	21.07	0.21	0.00
April	0.00	346.11	86.68	21.67	0.28	0.00
May	0.00	355.68	89.08	22.27	0.44	0.00
June	0.00	364.90	91.38	22.85	1.05	0.00
July	0.00	374.57	93.81	23.45	1.08	0.00
August	0.00	384.23	96.23	24.06	1.11	0.00
September	0.00	394.39	98.77	24.69	0.49	0.00
October	0.00	242.03	60.61	15.15	0.20	0.00
November	0.00	254.17	63.65	15.91	0.16	0.00
December	0.00	266.32	66.70	16.67	0.11	0.00

*Number of beef cattle defecating in stream.

3.10.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 3.96) and beef cattle (Table 3.97) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Browns Run (VAN-E08R-02) watersheds is 25,049 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 2.42×10^{10} cfu/day (8.84×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.10.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.96) and beef (Table 3.97) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Browns Run (VAN-E08R-02) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 9,807; 4,906; and 2,449 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Browns Run (VAN-E08R-02), averaged over the year, are 3.56×10^{12}, 1.80×10^{12}, and 8.88×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.10.3.4 Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 pounds and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule and the number of milk cows, annual liquid dairy manure production in the Browns Run (VAN-E08R-02) watershed is 7,605,959 gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 3.88×10^{7} cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories (BSE, 2003), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 114.2 acres of cropland and 0.9 acres of pasture 1 in the Browns Run (VAN-E08R-02) watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.98. Dry cows and heifers were assumed to produce only solid manure.

Table 3.98. Schedule of cattle waste application in Browns Run (VAN-E08R-02) watershed.

Month	Liquid Manure Applied (%)*	Solid Manure and Poultry Litter Applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

* As percent of annual production.

3.10.3.5 Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.99.

Solid manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle exhibits different fecal coliform concentrations (cfu/lb) (Table 3.99). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 3.99). Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May and the months of October and November.

Solid manure can be applied to pasture during the whole year except during December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 3.98. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 0.0 acres of the cropland and 33.5 acres of the pasture 1 in Browns Run (VAN-E08R-02) received solid manure application.

Table 3.99. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure in Browns Run (VAN-E08R-02) watershed.

Type of Cattle	Population	Typical Weight (lb) [a]	Solid Manure Produced (lb/animal-day) [a]	Fecal Coliform Concentration in Fresh Manure (x10^{8} cfu/lb) [a]	Weighted Average Fecal Coliform Concentration in Fresh Manure (x10^{8} cfu/lb)
Dry Cow	143	1,400	115.0	2.17	
Heifer	143	640	40.7	2.17	3.71
Beef (pairs)	318	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.10.4 Horses

The estimated number of horses in the Browns Run (VAN-E08R-02) watershed is included in Table 3.100. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces 4.2x10^{8} cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Browns Run (VAN-E08R-02) watershed is 1.02x10^{1} cfu/day (3.71x10^{13} cfu/year).

Table 3.100. Horse population by subwatershed in the Browns Run (VAN-E08R-02) watershed.

Subwatershed	Horses (#)
RAR-17	148
RAR-18	94
Total	**242**

3.10.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Browns Run

(VAN-E08R-02) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.10.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.103. The total wildlife fecal coliform production each year in the Browns Run (VAN-E08R-02) watershed, is 7.02×10^{13}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.101).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.101). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.101, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.102.

Table 3.101. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Browns Run (VAN-E08R-02) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.045	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.007[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.102. Distribution of wildlife among sub-watersheds in Browns Run (VAN-E08R-02) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-17	214	178	372	20	30	11	17
RAR-18	95	63	192	8	13	5	5
Total	**309**	**241**	**564**	**28**	**43**	**16**	**22**

3.10.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Browns Run (VAN-E08R-02) watershed along with average fecal coliform production rates are shown in Table 3.103. The total fecal coliform production by all sources in the Browns Run (VAN-E08R-02) watershed is $1.02x10^{16}$ cfu/yr.

Table 3.103. Potential fecal coliform sources and daily fecal coliform production by source in Browns Run (VAN-E08R-02) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	428	25,000	1,070,733
Heifers	143	8,800	163,541
Beef Cattle (pairs)	318	33,000	1,418,810
Horses	242	420	10,171
Humans	1,148	1,950	60,829
Pets	370	450	16,634
Deer	309	350	10,822
Raccoon	241	50	1,206
Muskrat	564	25	1,411
Beaver	28	0.2	1
Wild Turkey	22	93	205
Duck	16	2,400	2,996
Goose	43	800	2,595

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.104. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.104.

From Table 3.104, it is clear in the Browns Run (VAN-E08R-02) watershed that nonpoint source loadings to the land surface are more than 435 times as large as direct loadings to the streams, with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.104. Annual fecal coliform loadings to the stream and the various land use categories in the Browns Run (VAN-E08R-02) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	449	0.05
Cattle in Stream	884	0.10
Wildlife in Stream	723	0.08
Loading to Land Surfaces		
Cropland	3,170	0.35
Pasture 1	653,588	72.92
Pasture 2	165,148	18.42
Pasture 3	40,783	4.55
Forest	3,779	0.42
Residential*	27,825	3.10
Total	**896,349**	**100.00**

*Includes loads received from failed septic systems and pets.

3.11 Marsh Run (VAN-E08R-01) Sources

3.11.1 Humans and Pets

There are 626 homes served by municipal sanitary sewer in the Marsh Run (VAN-E08R-01) watershed. Wastewater from 3,563 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Marsh Run (VAN-E08R-01) watershed has an estimated population of 11,890 people (4,189 households at an average of 2.84 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^{9}$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $2.32x10^{13}$ cfu/day ($8.46x10^{15}$ cfu/year) in Marsh Run (VAN-E08R-01) watershed.

Bacteria from humans and pets can be transported to streams from failing septic systems, straight pipes discharging directly into streams, biosolid applications to pasture and cropland, or deposition of pet waste on residential land.

3.11.1.1 Failing Septic Systems

Septic systems are designed to filter septic tank effluent through the soil allowing removal of bacteria and nutrients from the wastewater. Septic system failure is manifested by the rise of effluent to the soil surface. It was assumed treatment of effluent ceased once effluent containing fecal coliform reached the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters.

Total septic systems were classified into one of three age categories (pre-1984, 1985-1994, and post-1994) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1994, and a 3% failure rate on all systems designed and installed after 1994 was used in the development of the Marsh Run (VAN-E08R-01) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2006 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.84 persons/household was 5.53×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.106.

3.11.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded one house that potentially could be classified as a straight pipe in the Marsh Run (VAN-E08R-01) watershed (Table 3.106).

3.11.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,108; 5,524; 12,362; and 14,425 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively in Culpeper County. In Fauquier County; 18,861; 16,414; 3,322; 7,296; 11,001; and 13,888 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004 and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Marsh Run (VAN-E08R-01) watershed were not available. To estimate biosolids applications within each Marsh Run (VAN-E08R-01) subwatershed, records of biosolids applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2005 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of Blue Plains biosolids from a sample collected and tested by VDH in 2006 was less than 2 cfu/g (Swanson, 2006). Therefore, an average fecal coliform density of 2 cfu/g was used for bacteria loading calculations. Table 3.105 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.105. Estimated average annual biosolids application amount for each subwatershed in the Marsh Run (VAN-E08R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
RAR-15	249
RAR-16	72
RAR-19	63
RAR-20	172
Total	**556**

3.11.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 2,220 dogs and 2,513 cats were projected to reside in the Marsh Run (VAN-E08R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 4,189 for Marsh Run (VAN-E08R-01) watershed. The maximum typical fecal coliform production for both dogs and cats is 5.0×10^9 cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce 4.5×10^8 cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Marsh Run (VAN-E08R-01) watershed is 1.9×10^{12} cfu/day (6.9×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.106. Pet waste is generated in the residential land use type. Bacteria loading to streams from pet waste can result from surface runoff transporting bacteria from residential areas.

Table 3.106. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Marsh Run (VAN-E08R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
RAR-15	8646	155	164	79	2790	165	1	3190
RAR-16	1543	296	47	68	48	34	0	458
RAR-19	875	165	28	40	28	20	0	260
RAR-20	825	10	126	107	38	73	0	281
Total	**11889**	**626**	**365**	**294**	**2904**	**4189**	**1**	**4189**

[a]Calculated from average of 1.0 pet per household.

3.11.3 Livestock Sources

In the Marsh Run (VAN-E08R-01) watershed, bacteria from livestock waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animals depositing waste on pastures or from applying collected waste on crop and hay land. Livestock populations in the Marsh Run (VAN-E08R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.11.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the Marsh Run (VAN-E08R-01) watershed. Based on information provided, it was determined that there were 280 milk cows, 140 dry cows, and 140 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.107). Beef cattle in the Marsh Run (VAN-E08R-01) watershed (816 pairs) included cow/calf and feeder operations (Table 3.107).

Table 3.107. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Marsh Run (VAN-E08R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
RAR-15	560	1	357
RAR-16	0	0	97
RAR-19	0	0	94
RAR-20	0	0	268
Total	**560**	**1**	**816**

[a]Consists of the milking herd, dry cows, and heifers.

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- Cows are confined according to the schedule given in Table 3.108.
- When cattle are not confined, they spend their time on pasture and in loafing lots, where applicable.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.108). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other things.
- Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 3.108. Time spent by cattle in confinement and in the stream in Marsh Run (VAN-E08R-01) watershed.

Month	Time Spent in Confinement (%)		Time Spent in Stream (hours/day)*
	Milking	Dry Cows, Heifers, and Beef Cattle	
January	75	40	0.50
February	75	40	0.50
March	40	0	0.75
April	30	0	1.00
May	30	0	1.50
June	30	0	3.50
July	30	0	3.50
August	30	0	3.50
September	30	0	1.50
October	30	0	1.00
November	40	0	0.75
December	75	40	0.50

* Time spent in and around the stream by cows that have stream access.

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.109 for dairy cattle and in Table 3.110 for beef cattle.

Table 3.109. Distribution of the dairy cattle[a] population in the Marsh Run (VAN-E08R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	322.00	181.20	45.38	11.34	0.07	0.00
February	322.00	181.20	45.38	11.34	0.07	0.00
March	112.00	341.03	85.41	21.35	0.21	0.00
April	84.00	362.29	90.73	22.68	0.30	0.00
May	84.00	362.18	90.70	22.68	0.45	0.00
June	84.00	361.72	90.59	22.65	1.04	0.00
July	84.00	361.72	90.59	22.65	1.04	0.00
August	84.00	361.72	90.59	22.65	1.04	0.00
September	84.00	362.18	90.70	22.68	0.45	0.00
October	84.00	362.29	90.73	22.68	0.30	0.00
November	112.00	341.03	85.41	21.35	0.21	0.00
December	322.00	181.20	45.38	11.34	0.07	0.00

[a]Includes milk cows, dry cows, and heifers.

[b]Number of dairy cattle defecating in stream.

[c]Milk cows in loafing lot

Table 3.110. Distribution of the beef cattle population (pairs) in the Marsh Run (VAN-E08R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	714.45	178.93	44.73	0.29	0.00
February	0.00	838.70	210.04	52.51	0.34	0.00
March	0.00	863.42	216.23	54.06	0.53	0.00
April	0.00	888.13	222.42	55.61	0.73	0.00
May	0.00	912.68	228.57	57.14	1.12	0.00
June	0.00	936.34	234.50	58.62	2.70	0.00
July	0.00	961.15	240.71	60.18	2.77	0.00
August	0.00	985.95	246.92	61.73	2.84	0.00
September	0.00	1012.02	253.45	63.36	1.25	0.00
October	0.00	621.07	155.54	38.88	0.51	0.00
November	0.00	652.22	163.34	40.84	0.40	0.00
December	0.00	683.39	171.15	42.79	0.28	0.00

*Number of beef cattle defecating in stream.

3.11.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy cattle (Table 3.109) and beef cattle (Table 3.110) defecating in the stream. However, only cattle on pastures contiguous to streams which have not been fenced off have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the Marsh Run (VAN-E08R-

01) watersheds is 40,157 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 4.73×10^{10} cfu/day (1.72×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.11.3.3 Direct Manure Deposition on Pastures

Dairy cattle (Table 3.109) and beef cattle (Table 3.110) that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Marsh Run (VAN-E08R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,168; 3,086; and 1,539 lb/ac-year, respectively. The loadings vary because the stocking rate varies with pasture type, with improved pasture able to stock the most cattle. Fecal coliform loadings from cattle in Marsh Run (VAN-E08R-01), averaged over the year, are 2.74×10^{12}, 1.39×10^{12}, and 6.84×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.11.3.4 Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 pounds and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule and the number of milk cows, annual liquid dairy manure production in the Marsh Run (VAN-E08R-01) watershed is 7,472,521 gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 3.88×10^7 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) in application to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories (BSE, 2003), respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 112.7 acres of cropland and 0.0 acres of pasture 1 in the Browns Run (VAN-E08R-02) watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.111. Dry cows and heifers were assumed to produce only solid manure.

Table 3.111. Schedule of cattle waste application in Marsh Run (VAN-E08R-01) watershed.

Month	Liquid Manure Applied (%)*	Solid Manure and Poultry Litter Applied (%)*
January	0	0
February	5	5
March	25	25
April	20	20
May	5	5
June	10	5
July	0	5
August	5	5
September	15	10
October	5	10
November	10	10
December	0	0

* As percent of annual production.

3.11.3.5 Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.112.

Solid manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle exhibits different fecal coliform concentrations (cfu/lb) (Table 3.112). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 3.112). Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May and the months of October and November.

Solid manure can be applied to pasture during the whole year except during December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 3.111. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 32.8 acres of the cropland and 0.0 acres of the pasture 1 in Marsh Run (VAN-E08R-01) received solid manure application.

Table 3.112. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, fecal coliform concentration in fresh solid manure in individual cattle type, and weighted average fecal coliform concentration in fresh solid manure in Marsh Run (VAN-E08R-01) watershed.

Type of Cattle	Population	Typical Weight (lb) [a]	Solid Manure Produced (lb/animal-day) [a]	Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) [a]	Weighted Average Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb)
Dry Cow	140	1,400	115	2.17	4.47
Heifer	140	640	40.7	2.17	
Beef (pairs)	816	1,000	60	5.5	

[a]Source: BSE (2003)

3.11.4 Horses

The estimated number of horses in the Marsh Run (VAN-E08R-01) watershed is included in Table 3.113. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Marsh Run (VAN-E08R-01) watershed is $2.61x10^{11}$ cfu/day ($9.54x10^{13}$ cfu/year).

Table 3.113. Horse population by subwatershed in the Marsh Run (VAN-E08R-01) watershed.

Subwatershed	Horses (#)
RAR-15	272
RAR-16	74
RAR-19	72
RAR-20	204
Total	**622**

3.11.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., sheep) were present during watershed visits; however, a significant population was not identified within the Marsh Run (VAN-E08R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.11.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.116. The total wildlife fecal coliform production each year in the Marsh Run (VAN-E08R-01) watershed, is 1.70×10^{14}cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.114).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.114). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams and pastures.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among sub-watersheds based on habitat descriptions included in Table 3.114, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.115.

Table 3.114. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Marsh Run (VAN-E08R-01) watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.045	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.070	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.019[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.015	0.50
Geese	300 feet buffer around main streams	0.006[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.007[c]	0.00

[a] Muskrats per mile of stream through agricultural land.
[b] Animals per acres of all land uses.
[c] Animals per acres of forest.

Table 3.115. Distribution of wildlife among sub-watersheds in Marsh Run (VAN-E08R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
RAR-15	265	198	679	22	37	13	13
RAR-16	110	60	123	7	16	6	9
RAR-19	69	54	228	7	10	4	2
RAR-20	296	274	641	30	41	15	25
Total	**740**	**586**	**1671**	**66**	**104**	**38**	**49**

3.11.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Marsh Run (VAN-E08R-01) watershed along with average fecal coliform production rates are shown in Table 3.116. The total fecal coliform production by all sources in the Marsh Run (VAN-E08R-01) watershed is 1.97×10^{16} cfu/yr.

Table 3.116. Potential fecal coliform sources and daily fecal coliform production by source in Marsh Run (VAN-E08R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times 10^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	420	25,000	1,050,719
Heifers	140	8,800	160,110
Beef Cattle (pairs)	816	33,000	3,640,721
Horses	622	420	26,142
Humans	11,889	1,950	169,932
Pets	4,189	450	188,630
Deer	740	350	25,918
Raccoon	586	50	2,932
Muskrat	1,671	25	4,180
Beaver	66	0.2	1
Wild Turkey	49	93	456
Duck	38	2,400	6,948
Goose	104	800	6,269

[a]Source: Keeling (2003) - Production per animal unit per species.

[b]Fecal coliform production adjusted to account for local animal weight. This may not equal the product of the other two columns.

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.117. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.117.

From Table 3.117, it is clear in the Marsh Run (VAN-E08R-01) watershed that nonpoint source loadings to the land surface are more than 495 times as large as direct loadings to the streams, with pastures receiving about 92% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.117. Annual fecal coliform loadings to the stream and the various land use categories in the Marsh Run (VAN-E08R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	198	0.01
Cattle in Stream	1,725	0.09
Wildlife in Stream	1,791	0.10
Loading to Land Surfaces		
Cropland	4,387	0.24
Pasture 1	1,286,758	69.89
Pasture 2	326,856	17.75
Pasture 3	80,559	4.38
Forest	8,169	0.44
Residential*	130,677	7.10
Total	**1,841,120**	**100.00**

*Includes loads received from failed septic systems and pets.

Chapter 4. Modeling Process for Fecal Coliform TMDL Development

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

4.1 Model Description

Conducting a TMDL study requires the use of a watershed-based model that integrates both point and non-point sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – Fortran (HSPF) (Bicknell et al., 2000) was used to model fecal coliform transport and fate in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds. The ArcView 9.2 GIS program was used to display and analyze landscape information.

The HSPF model simulates non-point source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Bicknell et al., 2000). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the models for Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds are discussed below in Sections 4.2 through 4.6. This information is translated into model parameters.

Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in BASINS Version 3.0 User's Manual 3.0 (USEPA, 2001). Water quality parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the BASINS Version 3.0 User's Manual (USEPA, 2001). Values for the hydrology and water quality parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used.

4.2 Selection of Sub-watersheds

The stream network was delineated based on the blue line stream network from USGS topographic maps with each subwatershed having at least one stream segment. Subwatershed delineation was based on potential fecal loadings, flow and water quality data availability, and HSPF model constraints. Because loadings of fecal coliform are believed to be associated with land use activities, subwatersheds were chosen based on uniformity of land use. HSPF outputs flow and fecal coliform concentration at subwatershed outlets, therefore subwatershed outlets were chosen to correspond to flow and water quality station locations. An hourly model time-step was used requiring the time of concentration in each subwatershed to be greater than one hour.

The Hazel River watershed is 224,150 acres and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into 20 subwatersheds as shown in Figure 4.1. The unimpaired segment HAR-01 drains into the impaired segment HAR-02 of Hughes River (VAN-E03R-01). Unimpaired segment HAR-03 drains to the impaired segments (HAR-04 through HAR-08) of Hazel River (VAN-E04R-01). Segment HAR-09 follows the impairment and drains to the Rappahannock River. Unimpaired segment HAR-10 drains to impaired segments HAR-11 and HAR-12 of the Rush River (VAN-E05R-01). Covington River (HAR13), Thornton River (HAR-14 and HAR-15), Indian Run (HAR-18), and unimpaired segments HAR16 and HAR-17 drains to impaired segment HAR-19 of Hazel River (60076). Muddy Run (HAR-20) drains to Hazel River.

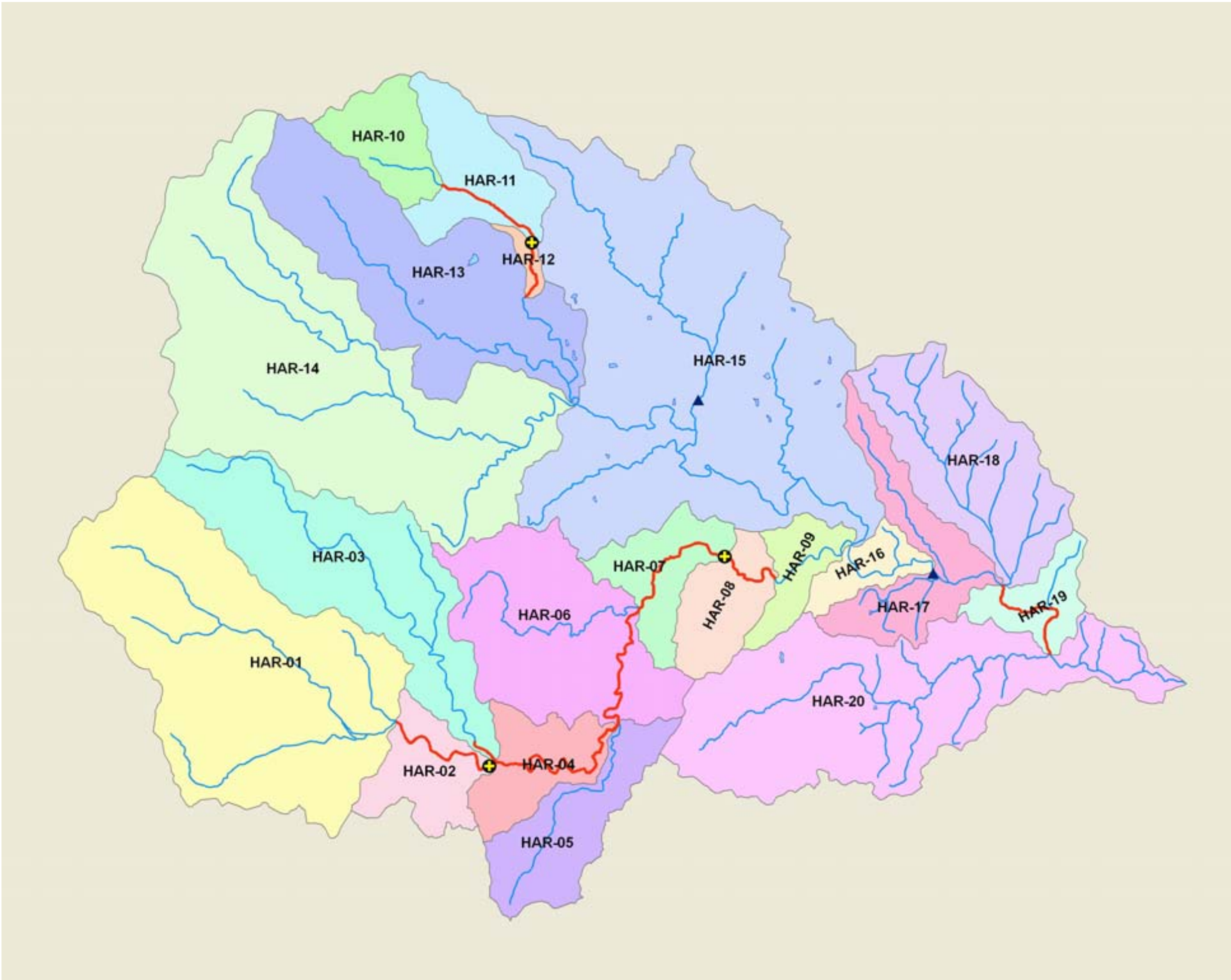

Figure 4.1. Hazel River subwatersheds.

The Rappahannock River watershed is 218,240 acres and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into 21 subwatersheds as shown in Figure 4.2. Unimpaired segment RAR-01 drains to the impaired segment (RAR-02) of Rappahannock River (VAN-E01R-03). Thumb Run (RAR-04), Carter Run (RAR-06), Great Run (RAR-08), and unimpaired segments (RAR-03, RAR-05, RAR-07, RAR-09, and RAR-10) drain to the impaired segment (RAR-11) of Rappahannock River (VAN-E08R-04). The unimpaired segment RAR-12 drains to the impaired segment RAR-13 of Rappahannock River (60081). Craig Run (VAN-E08R-03) impairment is contained in segment RAR-14. Unimpaired segment RAR-17 drains to impaired segment RAR-18 of Browns Run (VAN-E08R-02). Unimpaired segment RAR-15 drains to impaired segments RAR-16, RAR-19, and RAR-20 of Marsh Run (VAN-E08R-01). Segment RAR-21 is just upstream of Rappahannock River and Rapidan River confluence.

Figure 4.2. Rappahannock River subwatersheds.

4.3 Land Use

The National Land Cover Data (NLCD) produced by U.S. Geological Survey (USGS) in cooperation with the USEPA was used for this study. NLCD was developed from 30-meter Landsat 7 thematic mapper (TM) data between 1990 and 1994 and updated with data between 1999 and 2003 acquired by the Multi-resolution Land Characterization (MRLC) Consortium, a partnership between USGS, USEPA, U.S. Forest Service, National Oceanic and Atmospheric Administration (NOAA), Bureau of Land Management (BLM), NRCS, National Park Service (NPS), National Aeronautics and Space Administration (NASA), and United States Fish and Wildlife Service (USFWS). NLCD is classified into 21 land use types. The NLCD land use types within the watershed were consolidated into eight categories based on similarities in hydrologic and waste application/production features (Table 4.1). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

Table 4.1. Consolidation of NLCD land use categories for Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds.

TMDL Land Use Categories	Pervious / Impervious* (%)	NLCD Land Use Classification (Class No.)
Cropland	Pervious (100)	Row Crops (82) Small grains (83)
Pasture 1	Pervious (100)	Pasture/Hay (81)
Pasture 2	Pervious (100)	Pasture/Hay (81)
Pasture 3	Pervious (100)	Pasture/Hay (81)
Residential	Pervious (75), Impervious (25)	Low Density Residential (21) High Intensity Residential (22) Commercial/Industrial/Transportation (23)
Water	Impervious (100)	Open Water (11)
Wetland	Pervious (100)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)
Forest	Pervious (100)	Transitional (33) Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)

*Percent pervious / impervious information was used in modeling (described in later sections).

As discussed in Section 4.2, subwatersheds in each impairment were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figures 4.1 and 4.2). Land use distribution in the subwatersheds as well as in the entire Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds is presented in Tables 4.2 and 4.3.

Table 4.2. Land use distribution in Hazel River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
HAR-1	421.5	3,234.9	1,620.3	810.2	384.0	72.3	19,865.4	26,408.6
HAR-2	31.4	933.7	467.6	233.8	110.0	6.4	2,445.2	4,228.2
HAR-3	74.5	2162.5	1,083.2	541.6	263.0	42.4	10,990.1	15,157.2
HAR-4	86.1	827.2	414.3	207.2	138.0	12.0	2,727.7	4,412.5
HAR-5	218.9	1,602.6	802.7	401.3	237.0	51.8	2,709.7	6,023.9
HAR-6	134.1	2,022.3	1,012.9	506.5	364.0	19.8	8,963.8	13,023.5
HAR-7	10.2	365.4	183.0	91.5	153.0	16.0	3,341.4	4,160.5
HAR-8	17.5	820.0	410.7	205.4	228.0	16.5	2,220.9	3,919.0
HAR-9	18.3	468.0	234.4	117.2	173.0	13.9	1,622.2	2,647.0
HAR-10	1.7	204.5	102.4	51.2	72.0	3.4	3,361.5	3,796.7
HAR-11	2.2	722.4	361.8	180.9	99.0	9.7	4,112.1	5,488.1
HAR-12	5.7	191.3	95.8	47.9	29.1	1.2	179.5	550.5
HAR-13	94.9	2,879.5	1,442.3	721.1	289.0	78.8	11,234.4	16,740.0
HAR-14	48.1	4,365.5	2,186.6	1,093.3	564.0	67.3	24,666.4	32,991.2
HAR-15	326.7	9,817.9	4,917.6	2,458.8	1,086.0	238.8	21,803.9	40,649.7
HAR-16	28.1	526.3	263.6	131.8	147.0	2.5	1,131.3	2,230.6
HAR-17	81.0	1,523.0	762.8	381.4	338.0	7.3	3,130.5	6,224.1
HAR-18	55.7	2,212.6	1,108.2	554.1	575.0	6.3	6,325.2	10,837.1
HAR-19	10.7	1,024.5	513.1	256.6	98.0	0.0	1,019.7	2,922.6
HAR-20	500.3	4,834.2	2421.4	1,210.7	1,025.0	38.3	11,713.4	21,743.3
Total	**2,167.5**	**40,738.2**	**20,404.8**	**10,202.4**	**6,372.1**	**704.8**	**143,564.3**	**224,154.2**

Table 4.3. Land use distribution in Rappahannock River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
RAR-1	306.2	8,086.6	4,050.4	2,025.2	1,004.0	277.1	31,690.7	47,440.1
RAR-2	7.6	101.4	50.8	25.4	19.0	14.0	645.2	863.5
RAR-3	20.3	1,171.9	587.0	293.5	190.0	36.0	5,643.6	7,942.3
RAR-4	367.3	5,981.5	2,996.0	1,498.0	502.0	31.5	11,586.3	22,962.6
RAR-5	62.7	1,691.4	847.2	423.6	298.0	18.3	6,839.5	10,180.6
RAR-6	503.8	6,869.4	3,440.7	1,720.3	1,185.0	21.9	21,544.1	35,285.2
RAR-7	459.8	2,762.5	1,383.7	691.8	579.0	8.7	7,440.8	13,326.4
RAR-8	206.7	4,676.9	2,342.5	1,171.3	1,425.0	30.1	8,147.2	17,999.6
RAR-9	318.4	2,367.7	1,185.9	593.0	384.0	6.6	2,839.9	7,695.5
RAR-10	220.6	1,713.8	858.4	429.2	90.0	22.5	1,152.9	4,487.4
RAR-11	174.6	1,404.6	703.6	351.8	143.0	0.0	1,196.3	3,973.8
RAR-12	516.5	3,779.3	1,893.0	946.5	926.0	5.7	3,493.8	11,560.7
RAR-13	82.5	456.5	228.6	114.3	55.0	34.4	1,072.8	2,044.1
RAR-14	375.4	1,930.9	967.1	483.6	532.0	12.8	1,061.5	5,363.3
RAR-15	394.7	2,056.5	1,030.1	515.0	1,263.0	19.5	844.6	6,123.5
RAR-16	180.5	558.0	279.5	139.7	459.0	2.0	935.4	2,554.0
RAR-17	226.0	1,122.4	562.2	281.1	232.0	57.1	2,425.8	4,906.7
RAR-18	114.2	710.1	355.7	177.8	137.0	5.0	662.4	2,162.3
RAR-19	63.1	542.8	271.9	135.9	261.0	0.8	253.9	1,529.4
RAR-20	52.0	1,546.9	774.8	387.4	291.0	48.4	3,656.7	6,757.2
RAR-21	83.2	482.8	241.8	120.9	95.0	32.0	2,029.9	3,085.6
Total	**4,736.0**	**50,014.0**	**25,050.8**	**12,525.4**	**10,070.0**	**684.4**	**115,163.5**	**218,244.0**

4.4 Stream Channel Characteristics

For each stream reach, a function table (F-Table) is required to describe the relationship between water depth, surface area, volume, and discharge (Bicknell et al., 2000). These parameters were estimated by surveying representative channel cross-sections in each subwatershed. Trapezoidal channel geometry with pitch breaks at the beginning of the flood plain was developed for each reach. Information on stream geometry in each subwatershed is presented in Tables 4.4 and 4.5.

Table 4.4. Stream channel characteristics used to calculate F-Tables in the Hazel River watershed.

Sub-shed	Stream Length (mile)	Average Width (ft)	Average Depth (ft)	Stream Relief (ft/ft)	Channel Slope (ft/ft)	Channel Manning's n[a]	Flood Plain Manning's n[a]
HAR-1	9.8	22	6	0.0315	3	0.038	0.110
HAR-2	3.7	27	7	0.0052	3	0.038	0.110
HAR-3	14.4	30	6	0.0282	4	0.038	0.110
HAR-4	5.4	35	7	0.0007	2	0.038	0.110
HAR-5	6.2	10	4	0.0040	2	0.038	0.110
HAR-6	4.3	40	7	0.0020	3	0.038	0.110
HAR-7	3.6	45	7	0.0007	3	0.038	0.110
HAR-8	1.9	50	8	0.0007	3	0.038	0.110
HAR-9	2.9	60	8	0.0047	3	0.038	0.110
HAR-10	2.3	5	2	0.1357	2	0.038	0.110
HAR-11	2.9	15	4	0.0138	3	0.038	0.110
HAR-12	1.6	25	5	0.0107	4	0.038	0.110
HAR-13	4.3	30	5	0.0045	4	0.038	0.110
HAR-14	16.0	36	4	0.0242	4	0.038	0.110
HAR-15	12.6	60	8	0.0026	3	0.038	0.110
HAR-16	3.2	80	10	0.0008	2	0.038	0.110
HAR-17	2.1	85	11	0.0003	2	0.038	0.110
HAR-18	7.4	8	5	0.0059	2	0.038	0.110
HAR-19	3.3	90	12	0.0006	2	0.038	0.110
HAR-20	4.1	100	13	0.0001	2	0.038	0.110

[a] Dimensionless.

Table 4.5. Stream channel characteristics used to calculate F-Tables in the Rappahannock River watershed.

Sub-shed	Stream Length (mile)	Average Width (ft)	Average Depth (ft)	Stream Relief (ft/ft)	Channel Slope (ft/ft)	Channel Manning's n[a]	Flood Plain Manning's n[a]
RAR-1	13.6	18	1	0.0243	2	0.038	0.110
RAR-2	2.2	18	2	0.0049	3	0.038	0.110
RAR-3	3.6	21	2	0.0003	3	0.038	0.110
RAR-4	16.9	20	3	0.0043	3	0.038	0.110
RAR-5	6.0	34	3	0.0022	4	0.038	0.110
RAR-6	18.0	35	3	0.0031	3	0.038	0.110
RAR-7	8.9	52	4	0.0010	4	0.038	0.110
RAR-8	15.1	21	3	0.0079	3	0.038	0.110
RAR-9	7.0	62	5	0.0001	5	0.038	0.110
RAR-10	0.9	149	12	0.0004	6	0.038	0.110
RAR-11	2.0	150	12	0.0002	6	0.038	0.110
RAR-12	1.8	154	12	0.0109	6	0.038	0.110
RAR-13	2.8	155	12	0.0093	6	0.038	0.110
RAR-14	3.7	12	3	0.0054	3	0.038	0.110
RAR-15	3.9	12	4	0.0033	4	0.038	0.110
RAR-16	3.1	15	4	0.0006	4	0.038	0.110
RAR-17	2.9	15	2	0.0009	2	0.038	0.110
RAR-18	2.3	30	4	0.0008	2	0.038	0.110
RAR-19	1.1	20	5	0.0046	4	0.038	0.110
RAR-20	3.9	25	5	0.0005	4	0.038	0.110
RAR-21	2.2	167	13	0.0002	7	0.038	0.110

[a] Dimensionless.

4.5 Climatological Data

The climate data needed for model simulations conducted as a part of this study were obtained from the National Climatic Data Center (NCDC) (NCDC, 2005), part of the National Weather Service (NWS). Simulations performed for Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds used hourly weather data from the Piedmont Research Station (446712) and Culpeper (442159) weather stations. Daily precipitation data from stations Piedmont Research Station (446712), Culpeper (442159), Boston 4 SE (440860), Somerset (447904), Lake of the Woods (444692), and Gordonsville 3 S (443466) was transformed to address discrepancies (i.e., missing data) between observed runoff and hourly precipitation records.

Using hourly precipitation data, frequency of precipitation events and precipitation amounts per hour were calculated. For daily precipitation amounts equal to or less than 0.3 inches, the daily amount was assigned to the hour with the highest likelihood of rainfall. For daily rainfall amounts greater than 0.3 inches, the daily amount was distributed over the day using the calculated hourly precipitation amount frequency distribution.

4.6 Accounting for Pollutant Sources

4.6.1 Overview

There are one, one, two, seven, seven, two, five, and nine permitted point discharges located in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds, respectively, as identified in Section 3.1. This source was modeled using the permitted concentration and design discharge. Currently, MS4 permitted facilities do not exist in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds.

Fecal coliform loads that are directly deposited into the stream by straight pipes, or by cattle and wildlife in the stream, were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct non-point source loading was applied to the stream in each sub-watershed as appropriate.

Nonpoint source loading was applied as fecal coliform counts to the pervious fraction of each land use category in a sub-watershed on a daily basis. Both direct non-point and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams. Nonpoint source loading was applied as fecal coliform counts to the impervious fraction of each land use category in a subwatershed at a constant rate during the year. These constant application rates are a function of land use and are discussed in detail in Section 4.6.4. Fecal coliform die-off was simulated during periods when manure is stored, while on the land between runoff generating precipitation events, and while in streams.

4.6.2 Modeling Fecal Coliform Die-off

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

$$C_t = C_0 10^{-kt} \qquad [4.1]$$

where: C_t = concentration or load at time t;

C_0 = starting concentration or load (cfu/ 100ml);

K = decay rate (day-1); and

t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush

River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds (Table 4.6).

Table 4.6. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds.

Waste Type	Storage / Application	Decay Rate (1/day)	Reference
Dairy Manure	Pile (not covered)	0.066	Jones (1971)*
	Pile (covered)	0.028	
Beef Manure	Anaerobic Lagoon	0.375	Coles (1973)*

*Cited in Crane and Moore (1986).

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

- Liquid dairy manure: no decay rate for liquid dairy manure storage could be found in the literature, therefore the decay rate for beef manure in anaerobic lagoons (0.375 / day) was used.
- Solid cattle manure: based on the range of decay rates (0.028-0.066 / day) reported for solid dairy manure, a decay rate of 0.05 / day was used assuming that a majority of manure piles are not covered.

Based on these decay rates, die-off of fecal coliform in different storage capacities at the end of the respective storage period were calculated using Equation [4.1]. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage was calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition was considered to arrive at an effective survival fraction over the entire storage period. By multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure), the amount of fecal coliform available for application to land per year was estimated. Monthly fecal coliform application to land was estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. The decay rate for fecal coliform on the land surface was represented in HSPF by specifying a maximum surface buildup (i.e., MON-SQOLIM) based on the daily loading rate (i.e., MON-ACCUM). An in-stream decay rate for each reach segment (i.e., FSTDEC) was specified in HSPF.

4.6.3 Modeling Direct Non-point Sources

Fecal coliform loads from direct non-point sources included straight pipes, cattle in streams, and wildlife in streams. Also, contribution of fecal coliform from interflow was modeled as having a constant concentration of 4 cfu/100mL. Based on Technical Advisory Committee

(TAC) feedback, no instances of groundwater contamination were acknowledged and as a result it was assumed that the groundwater contained no bacteria. Loads from direct non-point sources in each watershed are described in detail in Chapter 3.

4.6.4 Modeling Land-based Non-point Sources

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

- Cropland: Where applicable, liquid dairy manure, solid manure, and poultry litter are applied to cropland as described in Chapter 3. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over as many acres within the subwatershed as were needed to utilize the generated manure. Thus, loading rate varied by month and sub-watershed.

- Pasture: Deposition of manure on pasture resulted from deposition from livestock and wildlife, as well as dairy manure, solid manure, and poultry litter applications as described in Chapter 3. For modeling, the monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

- Residential: Fecal coliform loading on the pervious fraction of this land use category is described in Chapter 3. Residential land use loading came from failing septic systems and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied. Loading to the impervious fraction of this land use category was assumed constant throughout the year varying per subwatershed.

- Forest: Wildlife not defecating in streams or on cropland and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife was applied uniformly over the forest areas, except for the percentage considered as direct load to forested streams.

4.6.5 Modeling Existing BMPs

Data describing existing best management practices (BMPs) were provided by staff from the VADCR. Additional data were collected during windshield surveys in the watershed. These data were applied in multiple fashions when developing the model to represent the effects of BMPs on loads and load transport. BMPs were either accounted for directly in the development of loads associated with direct deposition and/or deposition on specific land uses, accounted for during calibration of the water quality model, or incorporated into the implicit margin of safety (MOS).

BMPs incorporated directly into the model, such as collection, storage, and spreading of confined animal waste were modeled as previously described. Die-off during storage was accounted for prior to spreading, as well as after spreading. Three grades of pasture were modeled to represent pasture management practices observed in the watershed. Reductions in stream access based on exclusion fencing were accounted for directly when developing the cattle distribution schedules listed in Chapter 3.

Due to a shortage of data describing bacteria removal efficiencies, some BMPs were accounted for during calibration. Grassed buffer strips between pasture or crop and stream edges is a good example of an identified BMP that was accounted for during calibration of the water quality model.

Identified BMPs that were not directly accounted for during load development or model calibration were incorporated into the implicit MOS. The MOS accounts for uncertainty in the model and helps ensure that the final TMDL allocation will enable the stream to meet water quality standards when implemented.

4.7 Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology and water quality components are presented.

4.7.1 Hydrology

4.7.1.1 Hazel River

The Hazel River model was calibrated using observed flow values from USGS station #01663500 on Hazel River near Rixeyville, VA for the period October 1, 1987 to September 30, 1992. The model was validated for the period October 1, 1982 to September 30, 1987. The daily average flow data were used in the hydrologic calibration and validation. Output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable.

The HSPEXP decision support system developed by USGS and tools developed by Engineering Concepts, Inc. were used to calibrate and validate the hydrologic portion of HSPF. Calibration and validation criteria as well as model performance are presented in Table 4.7 and

4.8, respectively. All criteria were within the recommended ranges. As shown in Figures 4.3 and 4.4, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 4.5 and 4.6 for a representative storm. The agreement of the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 4.7 and 4.8).

Table 4.7. Summary statistics for the calibration period (10/1/87 to 9/30/92) in Hazel River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	74.1	74.7	0.8
Total of Highest 10% Flow Volume (in)	15	28.1	27.5	-2.2
Total of Lowest 50% Flow Volume (in)	10	13.3	13.7	2.9
Total Winter Flow Volume (in)	20	21.4	23.2	7.8
Total Summer Flow Volume (in)	20	9.7	9.8	1.0
Total Storm Volume (in)	20	70.3	71.1	1.1
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.73			

Table 4.8. Summary statistics for the validation period (10/1/82 to 9/30/87) in Hazel River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	20	86.5	82.0	-5.5
Total of Highest 10% Flow Volume (in)	25	40.4	37.0	-9.2
Total of Lowest 50% Flow Volume (in)	20	10.2	10.6	3.8
Total Winter Flow Volume (in)	30	29.4	27.3	-7.7
Total Summer Flow Volume (in)	30	6.1	7.0	12.9
Total Storm Volume (in)	30	83.7	78.6	-6.5
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.79			

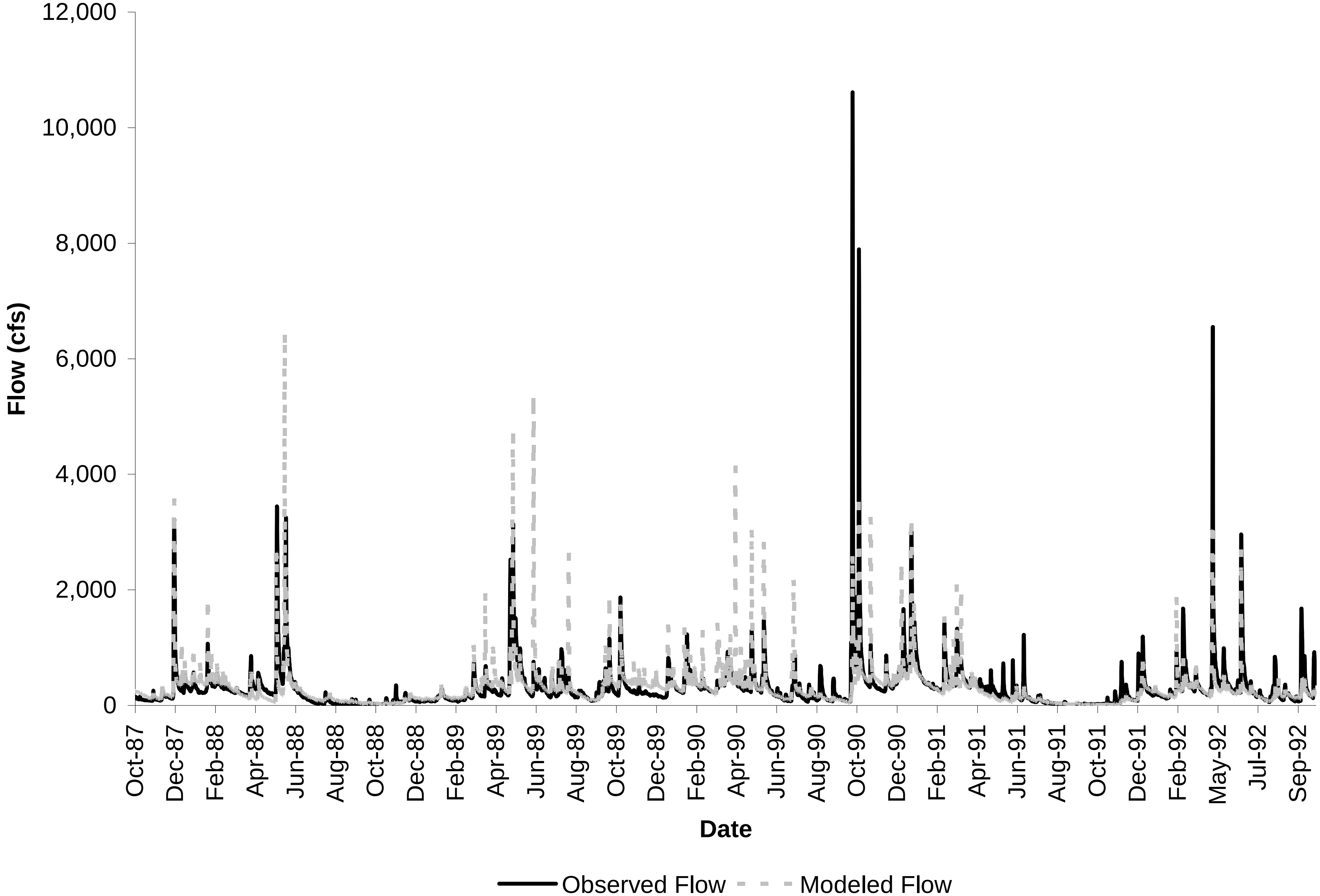

Figure 4.3. Observed and modeled flows for the calibration period 10/1/87 to 9/30/92 in Hazel River watershed.

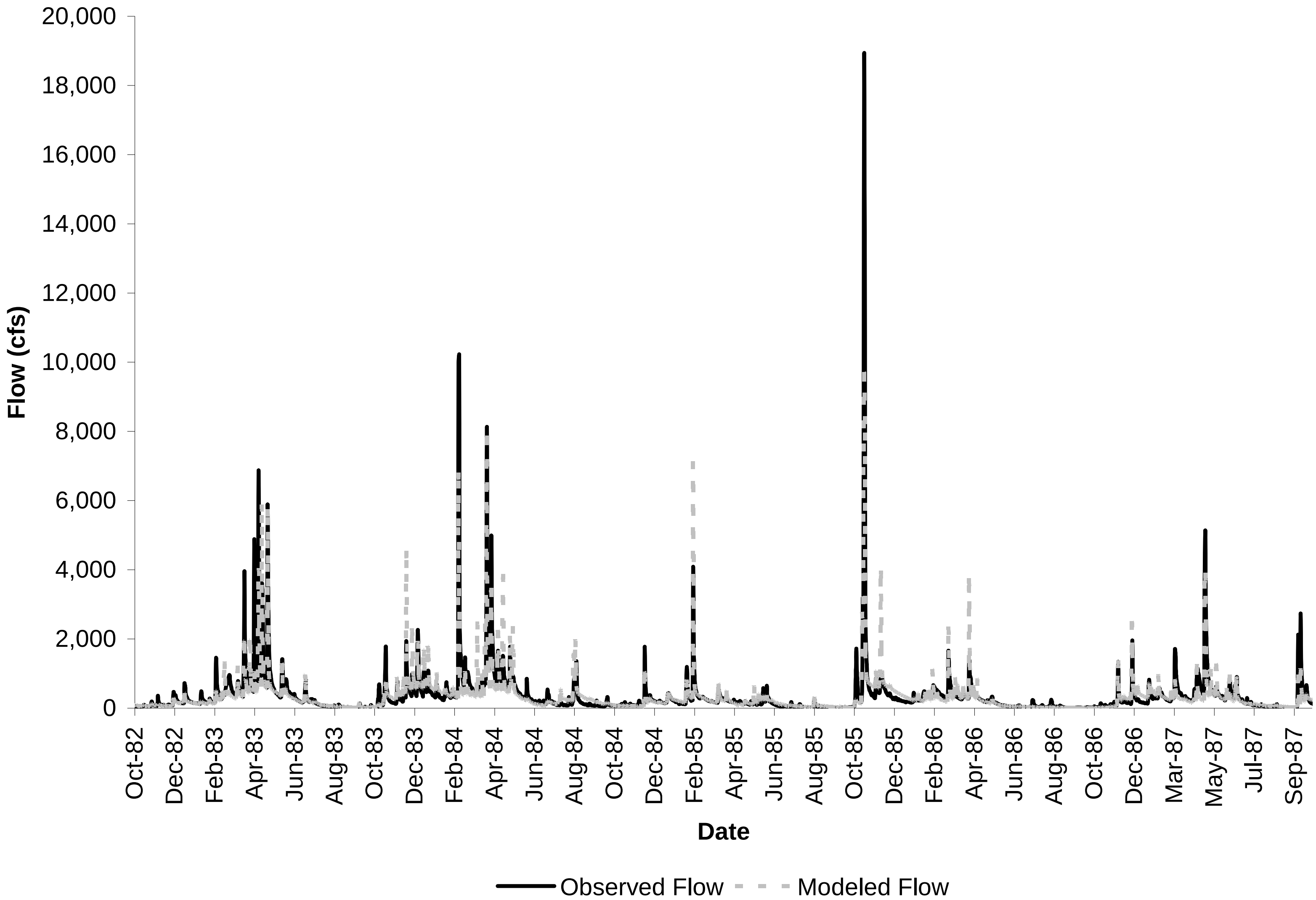

Figure 4.4. Observed and modeled flows for the validation period 10/1/82 to 9/30/87 in Hazel River watershed.

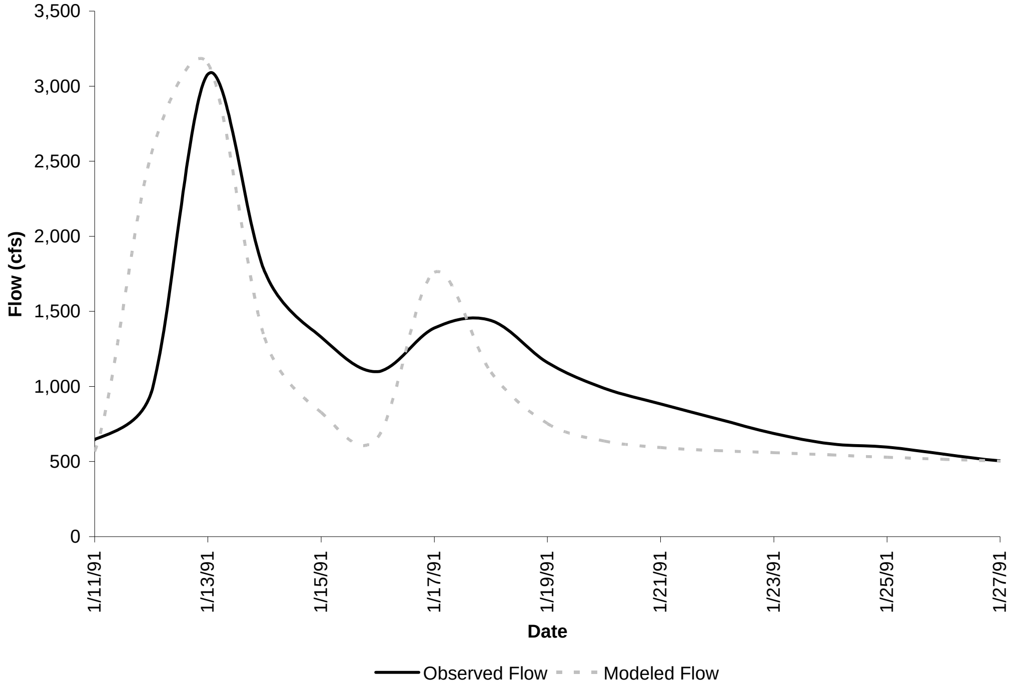

Figure 4.5. Observed and modeled flows for representative storms (1/11/91-1/27/91) during the calibration period in Hazel River watershed.

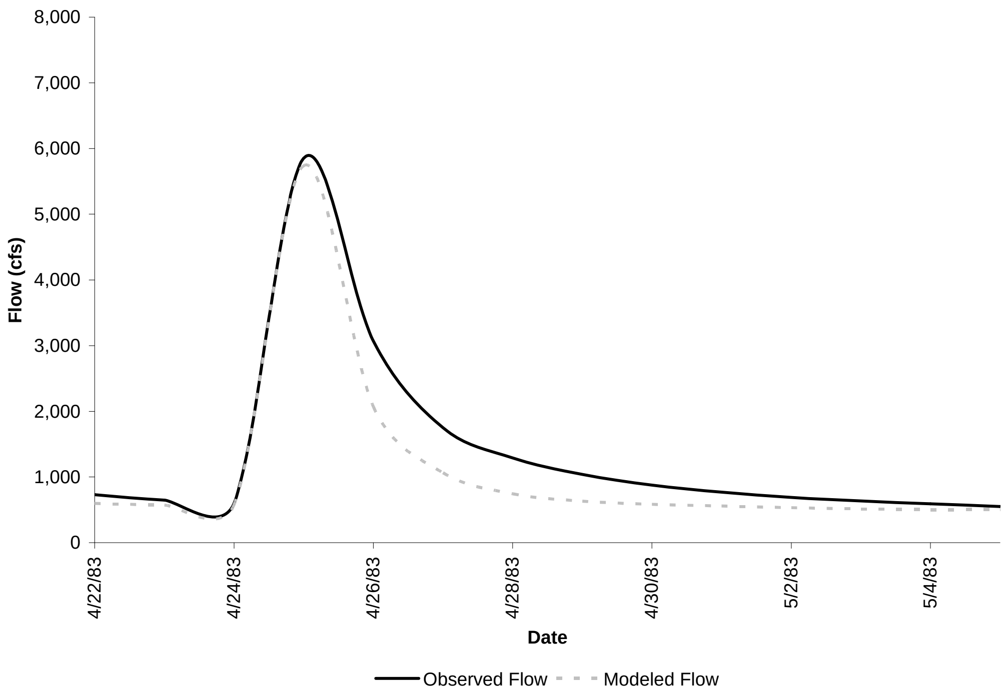

Figure 4.6. Observed and modeled flows for a representative storm (4/22/83-5/5/83) during the validation period in Hazel River watershed.

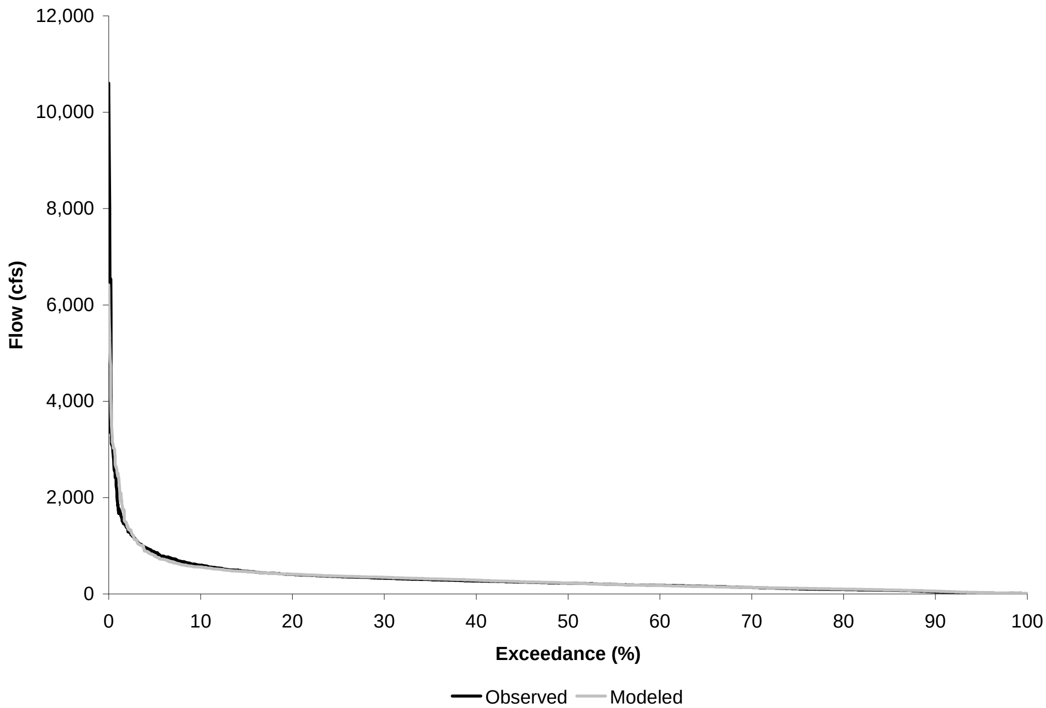

Figure 4.7. Cumulative frequency curves for the calibration period 10/1/87 to 9/30/92 in Hazel River watershed.

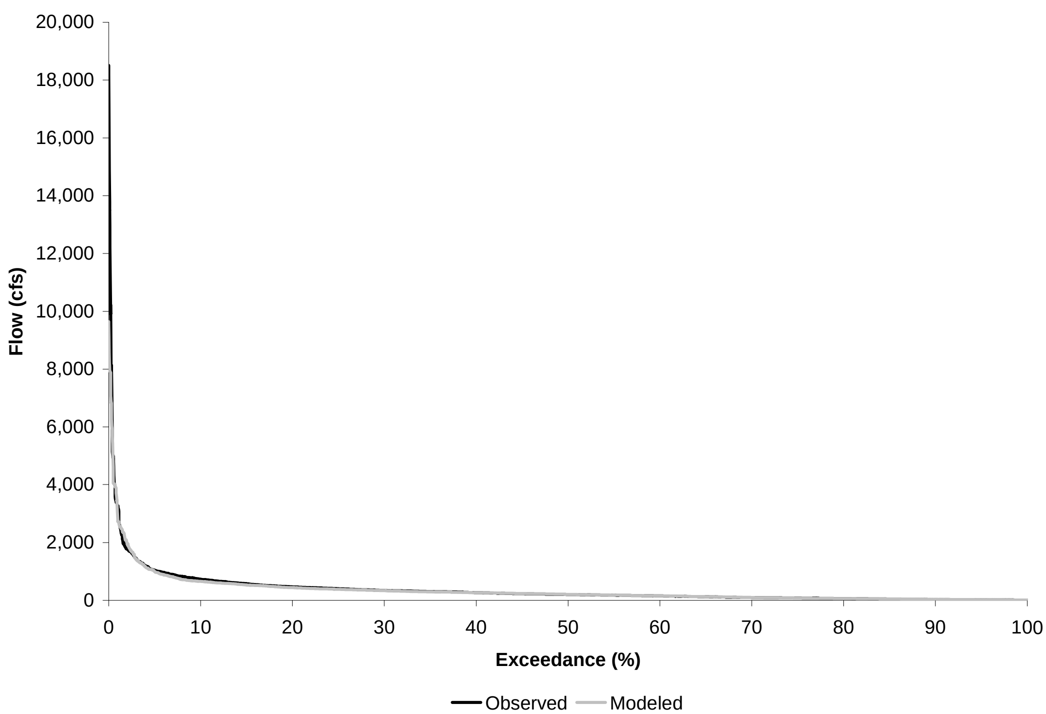

Figure 4.8. Cumulative frequency curves for the validation period 10/1/82 to 9/30/87 in Hazel River watershed.

Flow partitioning for Hazel River hydrologic model calibration and validation is shown in Table 4.9.

Table 4.9. Flow partitioning for the calibration and validation periods in Hazel River watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	63.2	72.8
Surface Runoff (in)	9.9 (15.7%)	13.4 (18.4%)
Interflow (in)	12.8 (20.3%)	15.4 (21.2%)
Baseflow (in)	40.05 (64.0%)	44.0 (60.5%)

A list of final calibration parameters for the hydrology calibration can be found in Tables 4.10 and 4.11.

Table 4.10. Calibrated hydrology HSPF parameters (PERLND) for Hazel River watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.0	0.5	0.0	0.95	0.5	0.5	Forest cover
LZSN	Lower zone nominal soil moisture storage	in	3.0	8.0	2.0	15.0	3.5	3.5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.21	0.07 - 0.25	Soil and cover condition
LSUR	Length of overland flow	ft	200	500	100	700	300	300	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.033-0.280	0.033-0.280	Determined by GIS
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.94	0.971	Calibrate
PWAT-PARM3									
PETMAX	Temp below which evapotranspiration (ET) is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of groundwater inflow to deep recharge	none	0.0	0.2	0.0	0.5	0.0	0.1	Geology
BASETP	Fraction of remain ET from active baseflow	none	0.0	0.05	0.0	0.2	0.056	0.066	Riparian vegetation
AGWETP	Fraction of remain ET from active groundwater	none	0.0	0.05	0.0	0.2	0.0	0.0 – 0.7	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	in	0.03	0.2	0.01	0.4	0.1	0.01 – 0.20	Vegetation
UZSN	Upper zone nominal soil moisture storage	in	0.10	1	0.05	2	1.0	1.25	Soil properties
NSUR	Manning’s n (roughness)	none	0.15	0.35	0.1	0.5	0.20 - 0.35	0.20 - 0.35	Land use, surface conditions
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.5	1.0	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.3	0.3	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.1-0.7	0.5 - 0.9	Vegetation

* USEPA, 2000.

Table 4.11. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for Hazel River watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	ft	200	500	100	700	100	100	Topography
SLSUR	Slope of overland flow	none	0.01	0.15	0.001	0.3	0.02 - 0.28	0.02 - 0.28	Topography
NSUR	Manning’s n (roughness)	none	0.15	0.35	0.1	0.5	0.1	0.1	Land use, surface condition
RETSC	Retention/interception storage capacity	in	0.03	0.2	0.01	0.4	0.065	0.065	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing	none	0.3	0.7	0.0	0.9	0.5	0.5	Stream channel, topography

* USEPA, 2000.

4.7.1.2 Rappahannock River

The Rappahannock River model was calibrated using observed flow values from USGS station #01664000 on Rappahannock River near Remington, Virginia for the period October 1, 1990 to September 30, 1995. The model was validated for the period October 1, 1995 to September 30, 2000. The daily average flow data were used in the hydrologic calibration and validation. Output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable.

The HSPEXP decision support system developed by USGS and tools developed by Engineering Concepts, Inc. were used to calibrate and validate the hydrologic portion of HSPF. Calibration and validation criteria as well as model performance are presented in Table 4.12 and 4.13, respectively. All criteria were within the recommended ranges. As shown in Figures 4.9 and 4.10, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 4.11 and 4.12 for a representative storm. The agreement of the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 4.13 and 4.14).

Table 4.12. Summary statistics for the calibration period (10/1/90 to 9/30/95) in Rappahannock River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	90.7	90.1	-0.7
Total of Highest 10% Flow Volume (in)	15	40.3	39.4	-2.3
Total of Lowest 50% Flow Volume (in)	10	11.9	13.0	8.5
Total Winter Flow Volume (in)	20	36.3	38.1	4.7
Total Summer Flow Volume (in)	20	11.1	11.4	2.6
Total Storm Volume (in)	20	87.7	86.1	-1.9
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.83			

Table 4.13. Summary statistics for the validation period (10/1/95 to 9/30/00) in Rappahannock River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	20	88.8	89.2	0.4
Total of Highest 10% Flow Volume (in)	25	36.6	38.4	4.7
Total of Lowest 50% Flow Volume (in)	20	12.2	12.6	3.2
Total Winter Flow Volume (in)	30	35.7	39.5	9.6
Total Summer Flow Volume (in)	30	12.9	11.0	-17.3
Total Storm Volume (in)	30	86.8	86.7	-0.1
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.80			

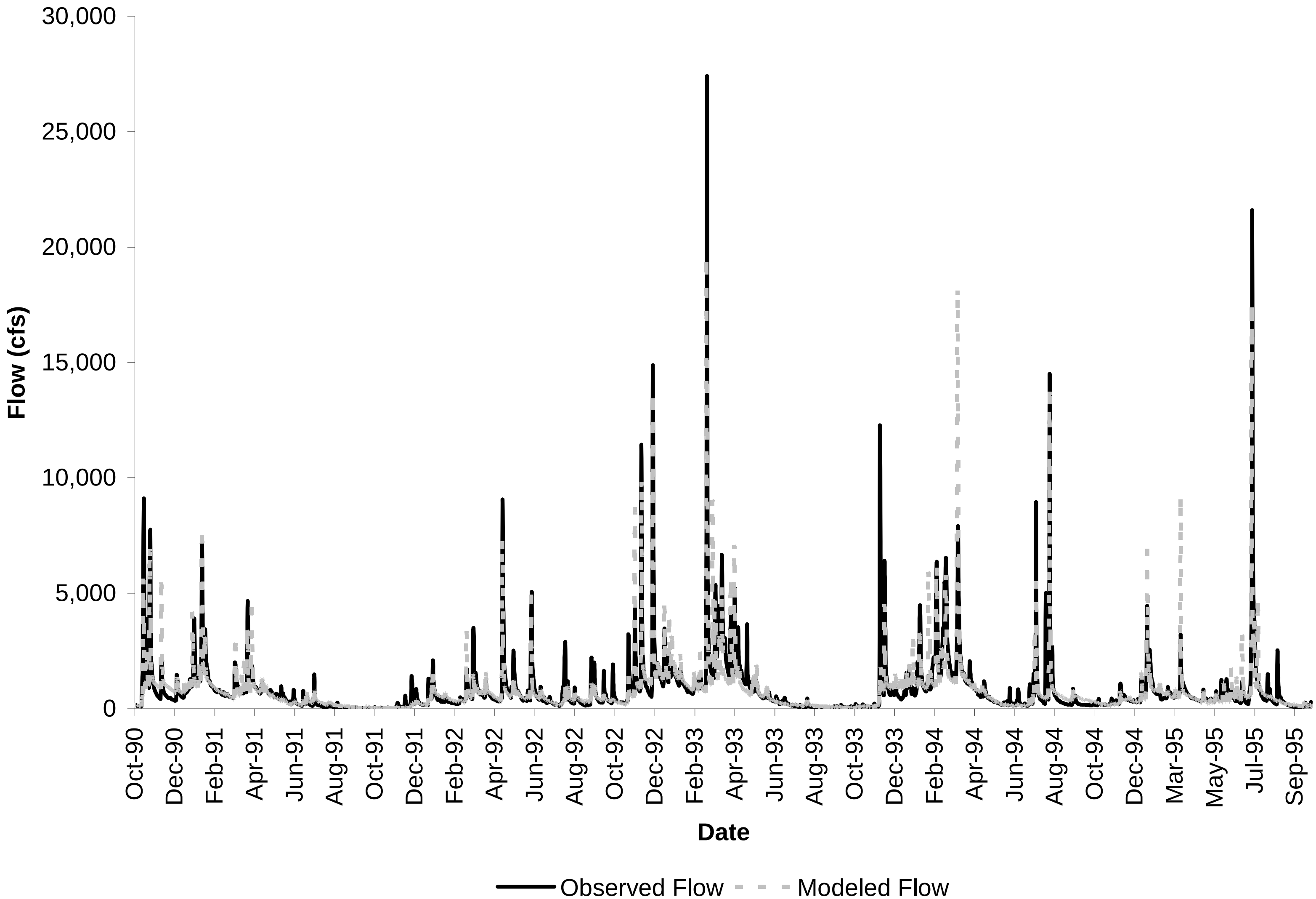

Figure 4.9. Observed and modeled flows for the calibration period 10/1/90 to 9/30/95 in Rappahannock River watershed.

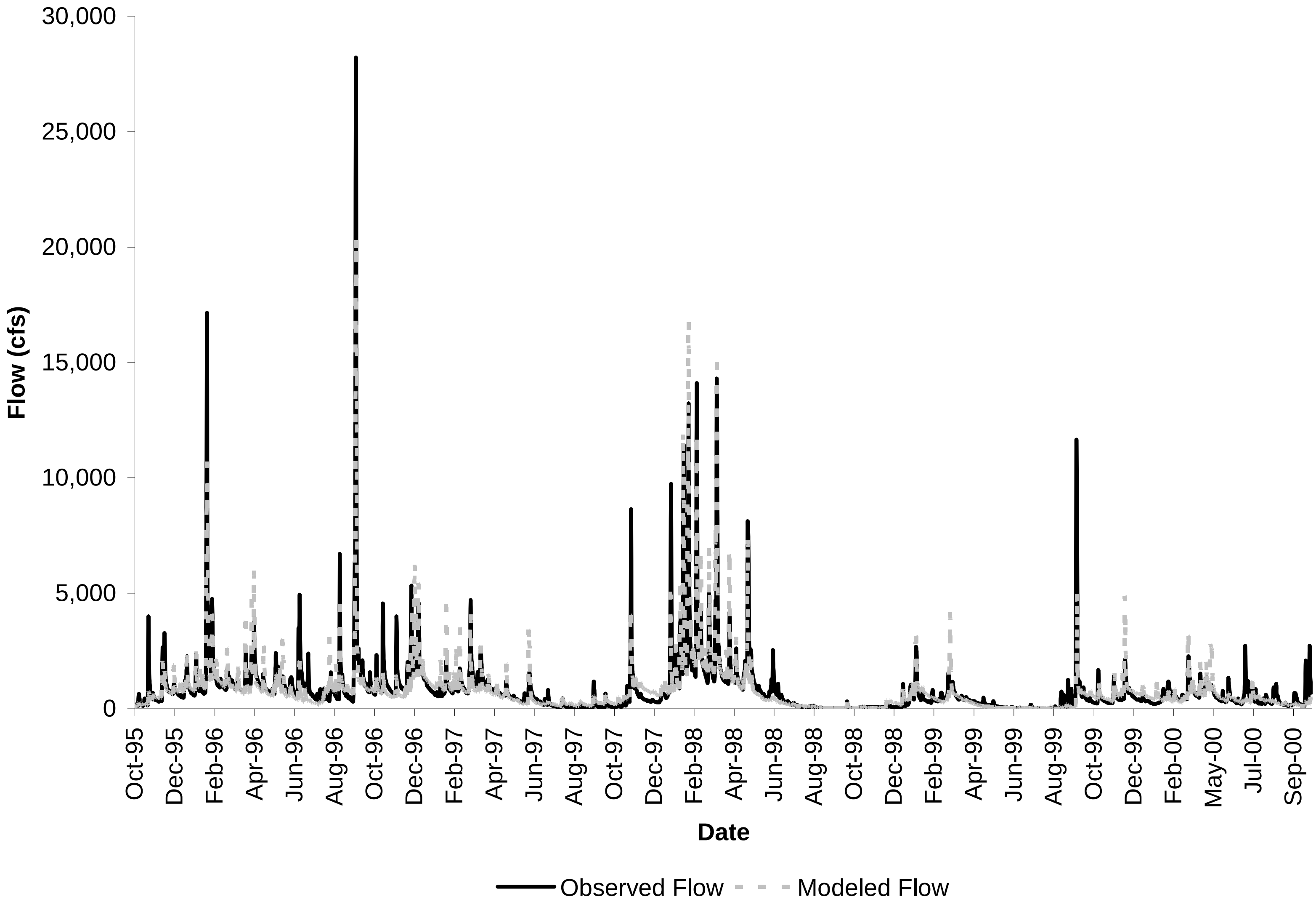

Figure 4.10. Observed and modeled flows for the validation period 10/1/95 to 9/30/00 in Rappahannock River watershed.

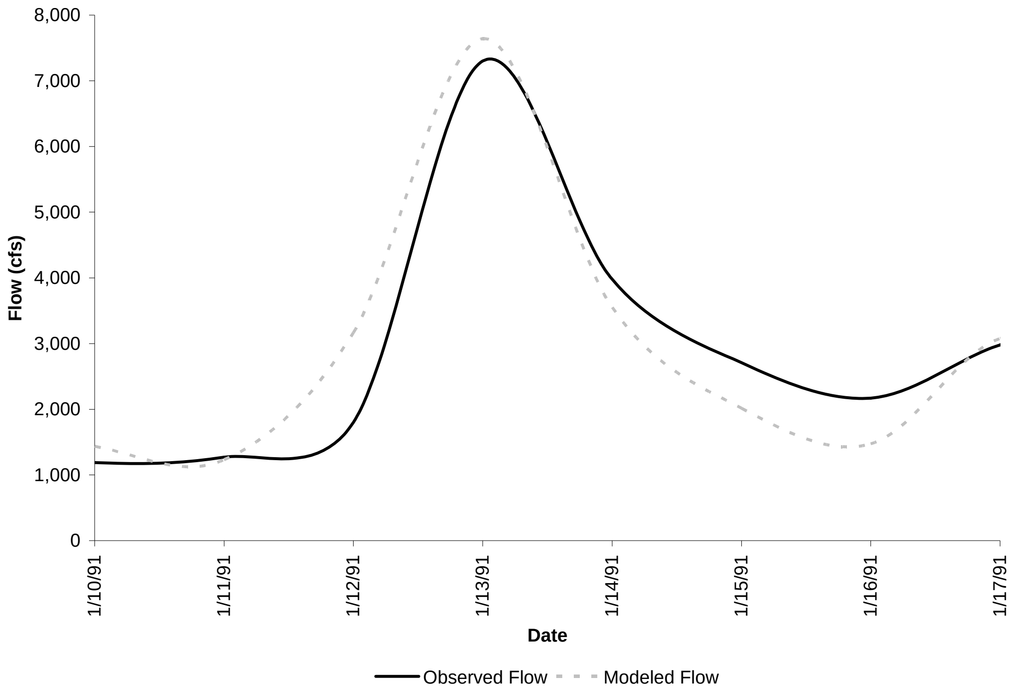

Figure 4.11. Observed and modeled flows for a representative storm (1/10/91-1/17/91) during the calibration period in Rappahannock River watershed.

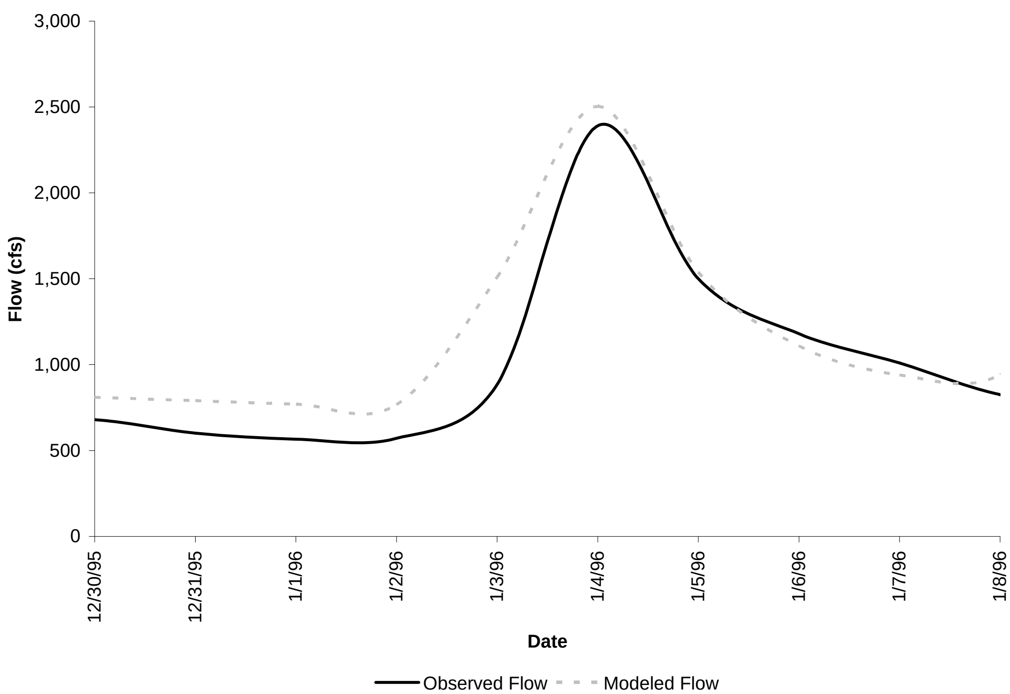

Figure 4.12. Observed and modeled flows for a representative storm (12/30/95-1/8/96) during the validation period in Rappahannock River watershed.

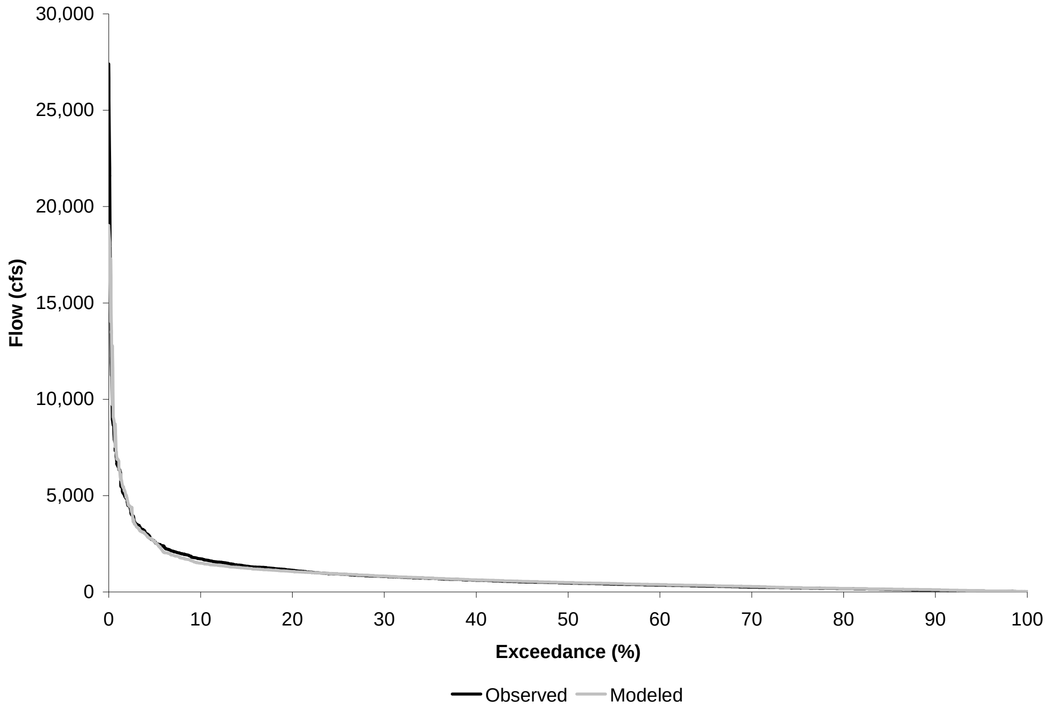

Figure 4.13. Cumulative frequency curves for the calibration period 10/1/90 to 9/30/95 in Rappahannock River watershed.

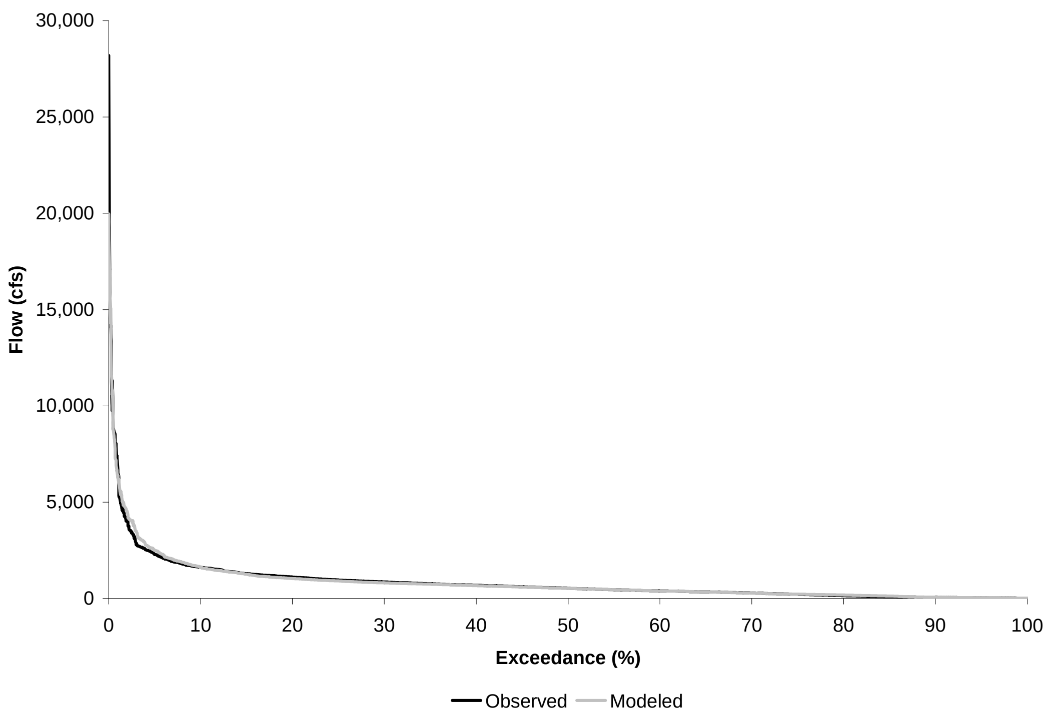

Figure 4.14. Cumulative frequency curves for the validation period 10/1/95 to 9/30/00 in Rappahannock River watershed.

Flow partitioning for Rappahannock River hydrologic model calibration and validation is shown in Table 4.14.

Table 4.14. Flow partitioning for the calibration and validation periods in Rappahannock River watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	77.7	76.6
Surface Runoff (in)	17.2 (22.2%)	14.7 (19.1%)
Interflow (in)	14.8 (19.1%)	16.6 (21.7%)
Baseflow (in)	45.6 (58.7%)	45.3 (59.1%)

A list of final calibration parameters for the hydrology calibration can be found in Tables 4.15 and 4.16.

Table 4.15. Calibrated hydrology HSPF parameters (PERLND) for Rappahannock River watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
PWAT-PARM2									
FOREST	Fraction forest cover	none	0.0	0.5	0.0	0.95	0.5	0.5	Forest cover
LZSN	Lower zone nominal soil moisture storage	in	3.0	8.0	2.0	15.0	3.5	3.5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.21	0.03 - 0.19	Soil and cover condition
LSUR	Length of overland flow	ft	200	500	100	700	300	300	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.033 - 0.283	0.033 - 0.283	Determined by GIS
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.94	0.971	Calibrate
PWAT-PARM3									
PETMAX	Temp below which evapotranspiration (ET) is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of groundwater inflow to deep recharge	none	0.0	0.2	0.0	0.5	0.0	0.1	Geology
BASETP	Fraction of remain ET from active baseflow	none	0.0	0.05	0.0	0.2	0.056	0.066	Riparian vegetation
AGWETP	Fraction of remain ET from active groundwater	none	0.0	0.05	0.0	0.2	0.0	0.0 – 0.7	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	in	0.03	0.2	0.01	0.4	0.1	0.01 – 0.20	Vegetation
UZSN	Upper zone nominal soil moisture storage	in	0.10	1	0.05	2	1.0	1.25	Soil properties
NSUR	Manning's n (roughness)	none	0.15	0.35	0.1	0.5	0.20 - 0.35	0.20 - 0.35	Land use, surface conditions
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.5	1.0	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.3	0.3	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.1-0.7	0.5 - 0.9	Vegetation

* USEPA, 2000.

Table 4.16. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for Rappahannock River watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	ft	200	500	100	700	100	100	Topography
SLSUR	Slope of overland flow	none	0.01	0.15	0.001	0.3	0.02-0.28	0.02-0.28	Topography
NSUR	Manning's n (roughness)	none	0.15	0.35	0.1	0.5	0.1	0.1	Land use, surface condition
RETSC	Retention/interception storage capacity	in	0.03	0.2	0.01	0.4	0.065	0.065	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing	none	0.3	0.7	0.0	0.9	0.5	0.5	Stream channel, topography

* USEPA, 2000.

4.7.2 Water Quality

The simulation of water quality concentrations (e.g., bacteria concentrations) is built on the hydrology simulation. The simulation runs at an hourly time step with average daily fecal coliform bacteria concentrations output at the stream reaches. Based on critical period analysis and availability of data, modeling periods were chosen for water quality calibration and validation for each impairment (Sections 4.7.2.1 through 4.7.2.10).

The PQUAL and IQUAL modules of HSPF were used to represent the build-up, die-off, and wash-off of fecal coliform bacteria from land surfaces. The modules are characterized by the following parameters: 1) Daily accumulation rate of bacteria on the soil surface (ACQOP); 2) Maximum bacteria build-up rate on the soil (SQOLIM); 3) Rate of surface runoff that removes 90% of the accumulated bacteria from the soil surface (WSQOP); and 4) Bacteria concentration in interflow, PQUAL only (IOQC). The GQUAL module in HSPF was used to represent the transport, settling, and die-off of dissolved bacteria in-stream. Settling and die-off were estimated using the first-order decay rate (FSTDEC). Additionally, F-Tables were adjusted to account for additional assimilative capacity in the watershed not represented by channel volumes derived for the reach section. Added assimilation can be achieved through three additional pathways. First, only the main channel of the impairment streams and the major tributaries are explicitly represented in HSPF. Stream channels not represented add additional water volume available to dilute fecal coliform loads during low flow conditions and increase channel residence time, which increases settling and die-off of bacteria in transit. Second, dead water that occurs during minimal streamflow can provide added storage. Third, flow in the watershed drains through a multitude of farm ponds. Using GIS, ponds were estimated by separating water in the stream layer from water in the land use layer. Surface area of the ponds was multiplied by an estimated depth of four feet to calculate the total storage volume of all ponds in a subwatershed. To account for the three sources of additional storage, an additional storage volume was added to each line of the F-table. This storage has no effect on the functional relationship between volume of water stored in the channel and flow in the channel. The listed model parameters were adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established.

A number of factors, not inclusive to description below, complicate the water quality calibration. The difficulty in measuring bacteria concentrations is attributed to variability in bacteria density in feces, variability in location and timing of fecal deposition, variability in bacteria amount delivered to the stream, and environmental impacts on re-growth and die-off. The bacteria concentrations are highly dependent on flow conditions and variability associated with modeling stream flows compounds the variability in modeling the bacteria concentrations. The usually limited number of grab samples collected at each VADEQ station and the practice of censoring both high (over 8,000 cfu/100 ml or 16,000 cfu/100 ml) and low (under 100 cfu/100 ml or 18 cfu/100 ml) concentrations hinder the water quality calibration process.

4.7.2.1 Hughes River (VAN-E03R-01)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-HUE000.20 within the Hughes River (VAN-E03R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.17. Observations from the VADEQ station, 3-HUE000.20, were graphically compared to corresponding modeled concentrations at subwatershed HAR-2 (Figures 4.15 and 4.16). It should be noted that each observed bacteria concentration datum represents a "snapshot" resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.18 and 4.19 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.18 and 4.19. A difference of one exceedance could result in a difference of exceedance rate of 6%. The highest difference (13%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard exceedance rates (142%) was recorded during the validation period. Seventeen observations were available for comparison during this period resulting in a 6% weighting when comparing the water quality standard exceedance rate. This translates into three model observations that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Hughes River (VAN-E03R-01) watershed.

Table 4.17. Calibrated water quality HSPF parameters for Hughes River (VAN-E03R-01) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	12E06-01E10	12E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E08-12E10	01E08-12E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2.0	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	20E08-33E08	20E08-33E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E10-03E10	02E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	8.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

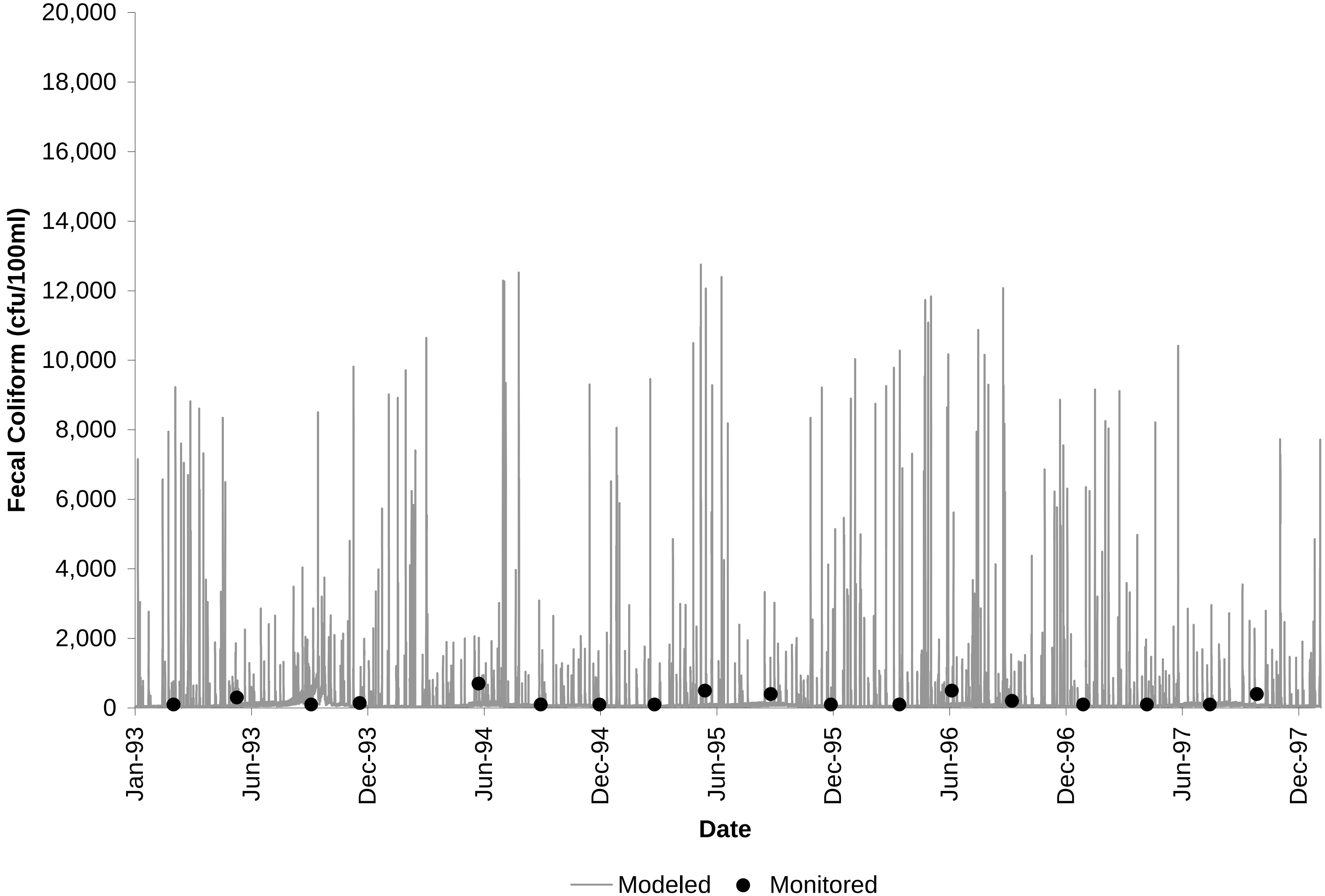

Figure 4.15. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed HAR-2 in Hughes River (VAN-E03R-01) impairment.

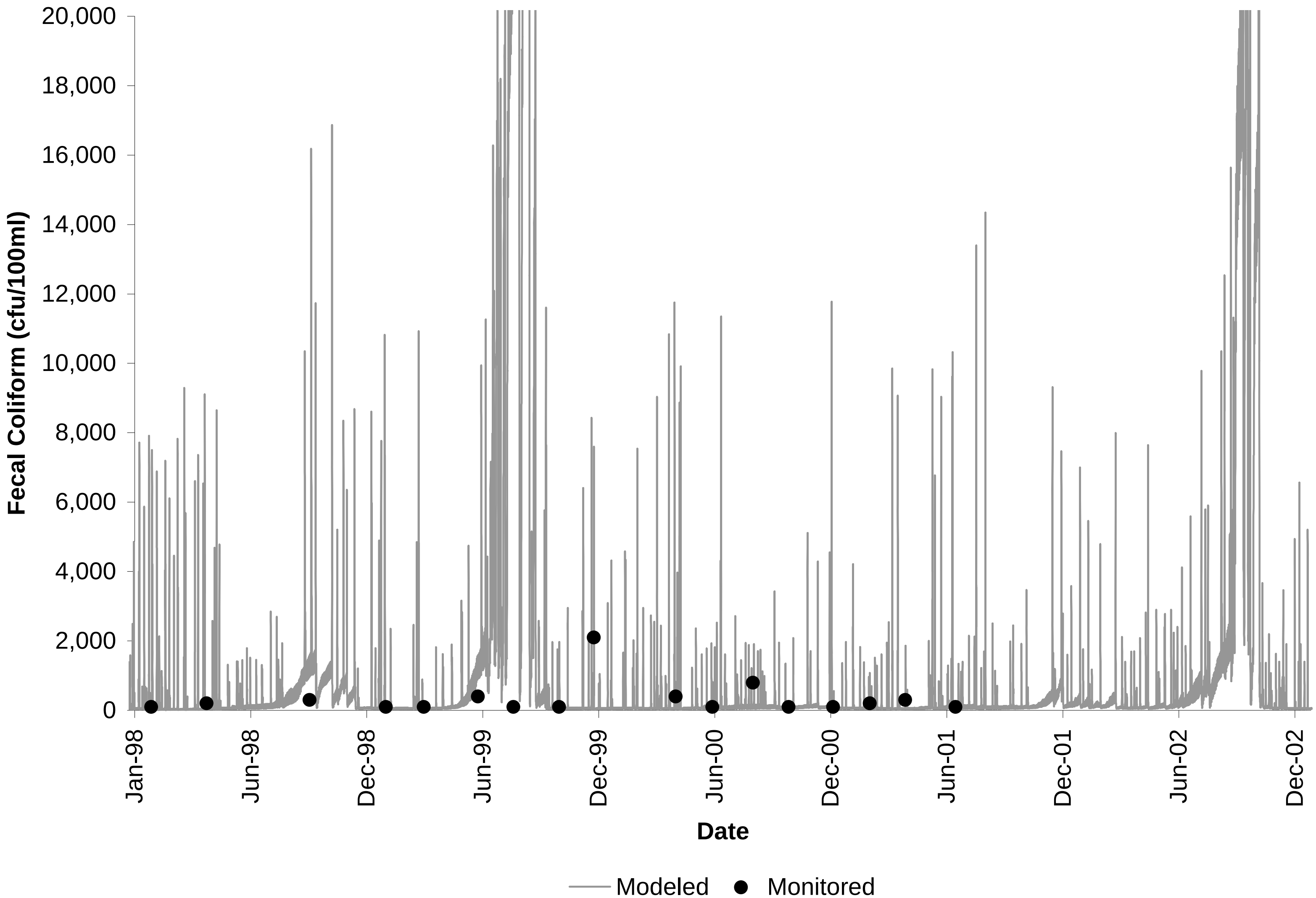

Figure 4.16. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed HAR-2 in Hughes River (VAN-E03R-01) impairment.

Table 4.18. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Hughes River (VAN-E03R-01) watershed.

Parameter	Sub HAR-02
Geometric Mean of Observed Values (cfu/100mL)	175
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	155
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	17
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	17

Table 4.19. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Hughes River (VAN-E03R-01) watershed.

Parameter	Sub HAR-02
Geometric Mean of Observed Values (cfu/100mL)	205
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	200
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	6
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	6
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	12
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	29

4.7.2.2 Hazel River (VAN-E04R-01)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-HAZ018.29 within the Hazel River (VAN-E04R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.20. Observations from the VADEQ station, 3-HAZ018.29, were graphically compared to corresponding modeled concentrations at subwatershed HAR-7 (Figures 4.17 and 4.18). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.21 and 4.22 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.21 and 4.22. A difference of one exceedance could result in a difference of exceedance rate of 4-5%. The highest difference (19%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (50%) was recorded during the validation period. Twenty observations were available for comparison during this period resulting in a 5% weighting when comparing the water quality standard exceedance rate. This translates into two model observations that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Hazel River (VAN-E04R-01) watershed.

Table 4.20. Calibrated water quality HSPF parameters for Hazel River (VAN-E04R-01) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	21E06-01E10	21E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-12E10	02E08-12E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2.0	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	21E08-31E08	21E08-31E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E10-03E10	02E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	2.1	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

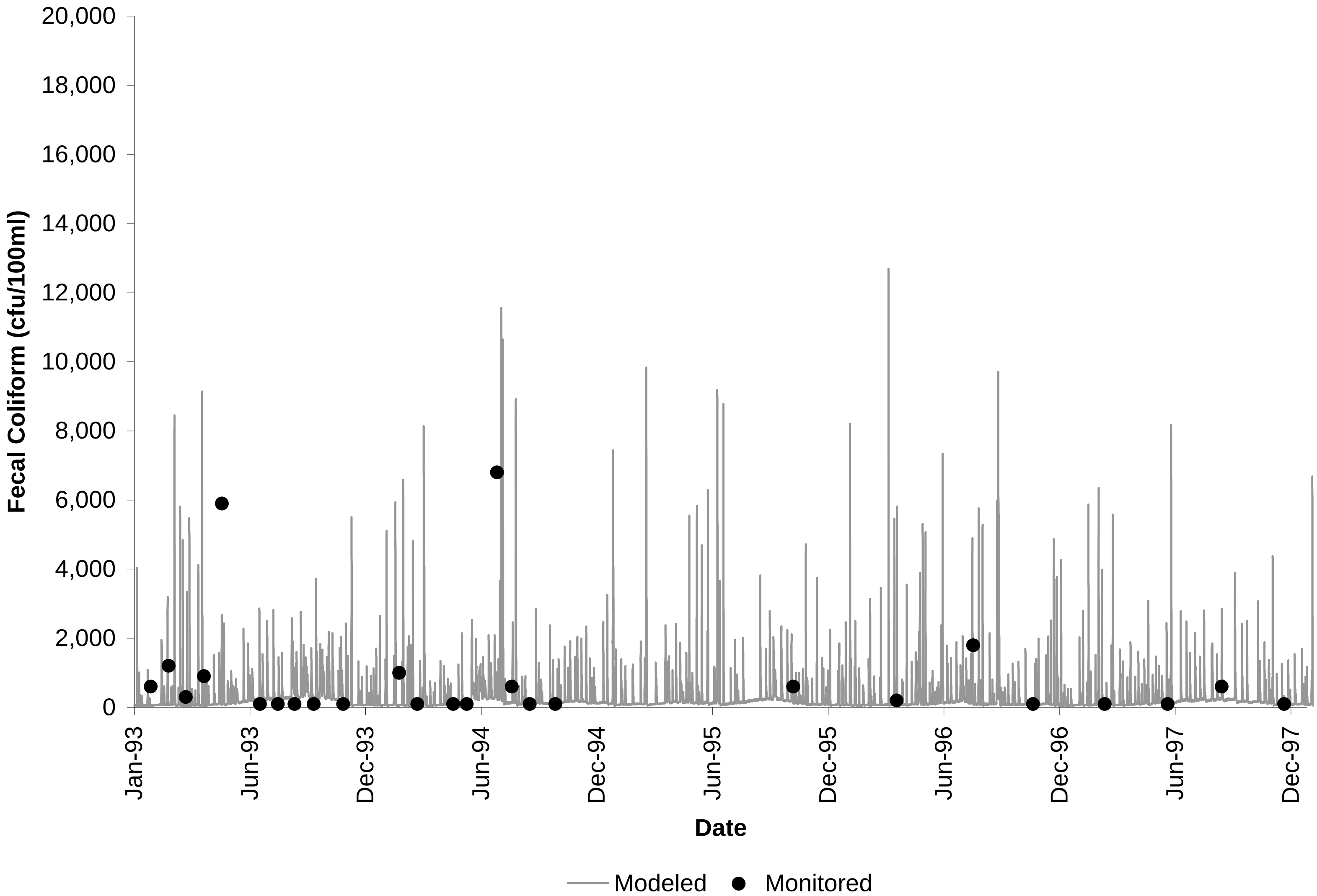

Figure 4.17. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed HAR-07 in Hazel River (VAN-E04R-01) impairment.

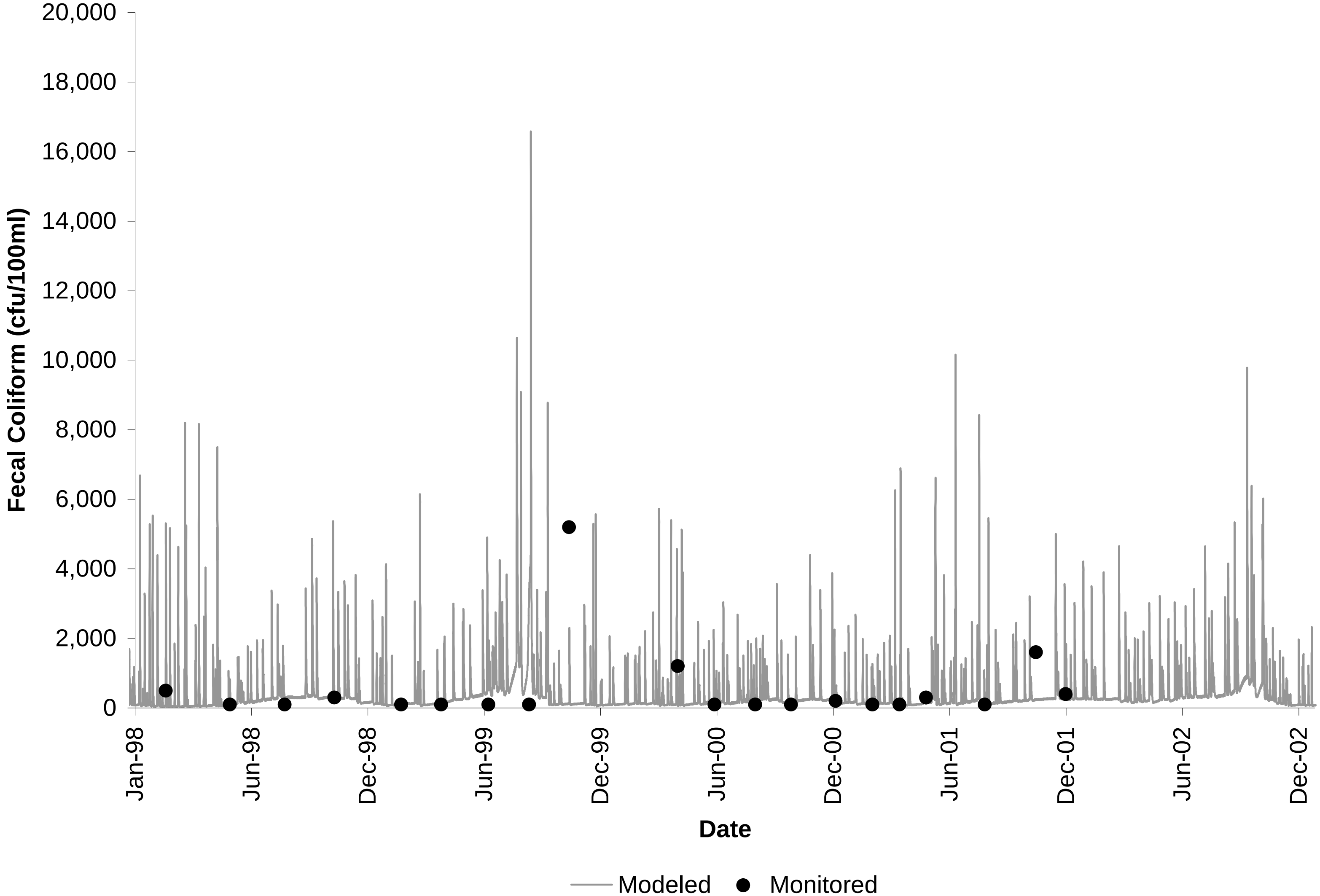

Figure 4.18. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed HAR-07 in Hazel River (VAN-E04R-01) impairment.

Table 4.21. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Hazel River (VAN-E04R-01) watershed.

Parameter	Sub HAR-07
Geometric Mean of Observed Values (cfu/100mL)	284
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	270
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	15
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	15
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	38
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	31

Table 4.22. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Hazel River (VAN-E04R-01) watershed.

Parameter	Sub HAR-07
Geometric Mean of Observed Values (cfu/100mL)	213
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	263
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	15
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	15
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	20
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	30

4.7.2.3 Rush River (VAN-E05R-01)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-RUS005.66 within the Rush River (VAN-E05R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.23. Observations from the VADEQ station, 3-RUS005.66, were graphically compared to corresponding modeled concentrations at subwatershed HAR-11 (Figures 4.19 and 4.20). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.24 and 4.25 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.24 and 4.25. A difference of one exceedance could result in a difference of exceedance rate of 6%. The highest difference (9%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (0%) was recorded during the calibration and validation period. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Rush River (VAN-E05R-01) watershed.

Table 4.23. Calibrated water quality HSPF parameters for Rush River (VAN-E05R-01) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	21E06-01E10	21E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-12E10	02E08-12E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2.0	Land use
IOQC	Constituent concentration in interflow	#/ft^3	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	#/ft^3	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	11E08-32E08	11E08-32E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	99E08-03E10	99E08-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	6.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

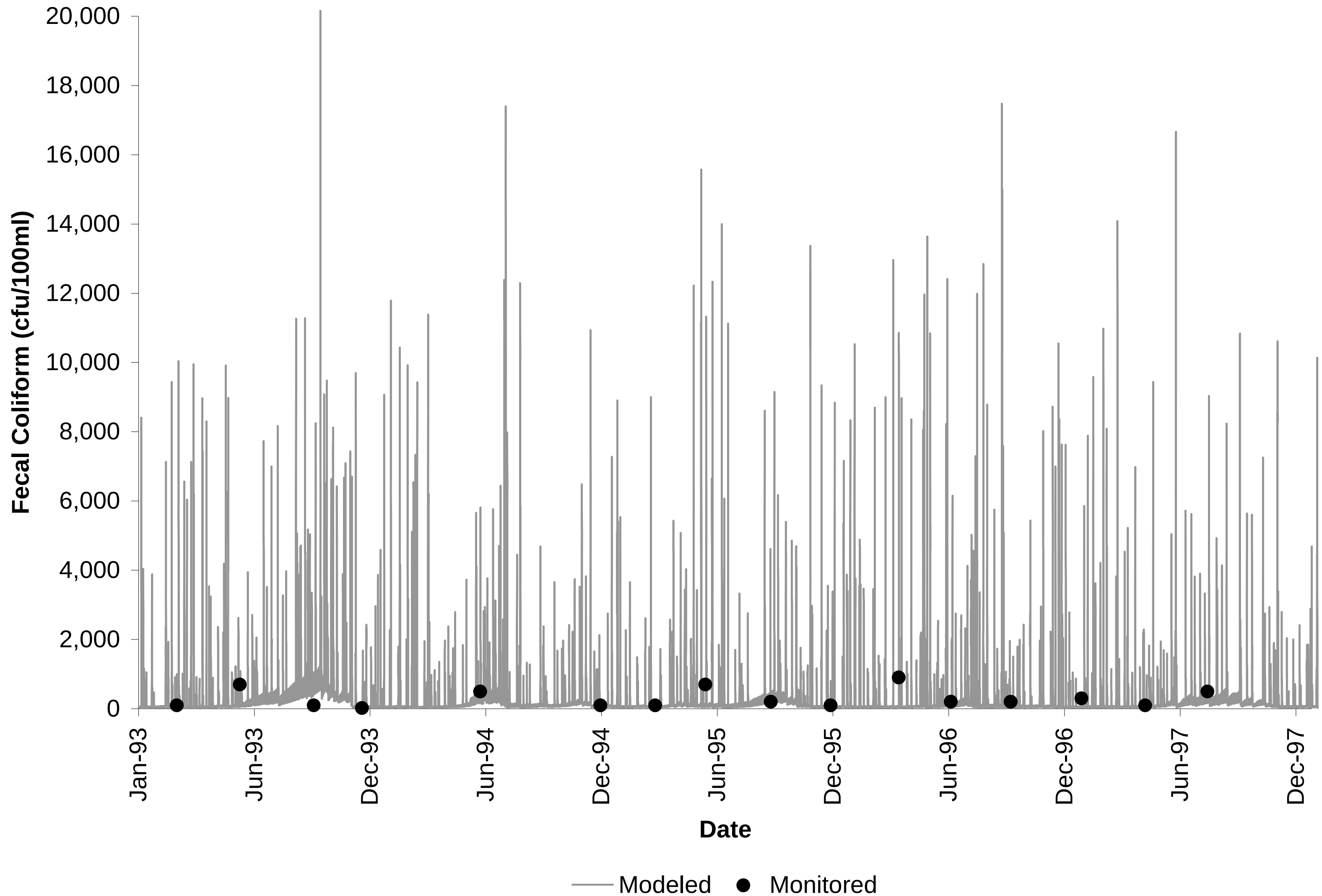

Figure 4.19. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed HAR-11 in Rush River (VAN-E05R-01) impairment.

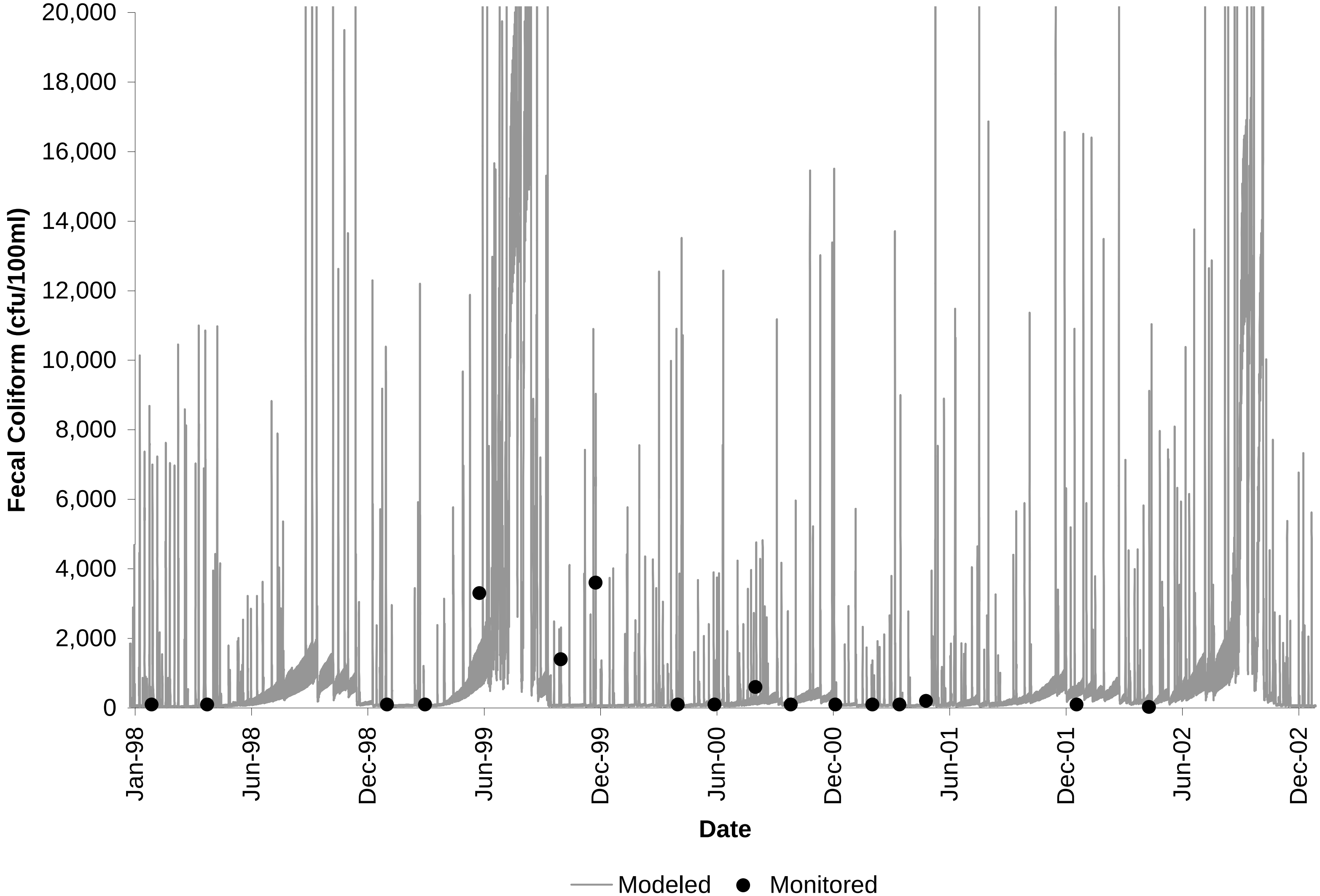

Figure 4.20. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed HAR-11 in Rush River (VAN-E05R-01) impairment.

Table 4.24. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Rush River (VAN-E05R-01) watershed.

Parameter	Sub HAR-11
Geometric Mean of Observed Values (cfu/100mL)	197
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	198
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	31
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	31

Table 4.25. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Rush River (VAN-E05R-01) watershed.

Parameter	Sub HAR-11
Geometric Mean of Observed Values (cfu/100mL)	189
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	207
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	18
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	18
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	24
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	24

4.7.2.4 Hazel River (60076)

The period January 1, 1998 through December 31, 2002 was chosen for water quality calibration. Additional water quality data coinciding with available hourly precipitation data was not available to perform separate water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-HAZ005.98 within the Hazel River (60076) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.26. Observations from the VADEQ station, 3-HAZ005.98, were graphically compared to corresponding modeled concentrations at subwatershed HAR-19 (Figure 4.21). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Table 4.27 shows the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration period. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Table 4.27. A difference of one exceedance could result in a difference of exceedance rate of 25%. The highest difference (2%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard exceedance rates (0%) was recorded during the calibration period. Four observations were available for comparison during this period resulting in a 25% weighting when comparing the water quality standard exceedance rate. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration period.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Hazel River (60076) watershed.

Table 4.26. Calibrated water quality HSPF parameters for Hazel River (60076) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	21E06-01E10	21E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-12E10	02E08-12E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2.0	Land use
IOQC	Constituent concentration in interflow	#/ft^3	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	#/ft^3	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	13E08-38E08	13E08-38E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E10-03E10	01E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	3.5-6.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

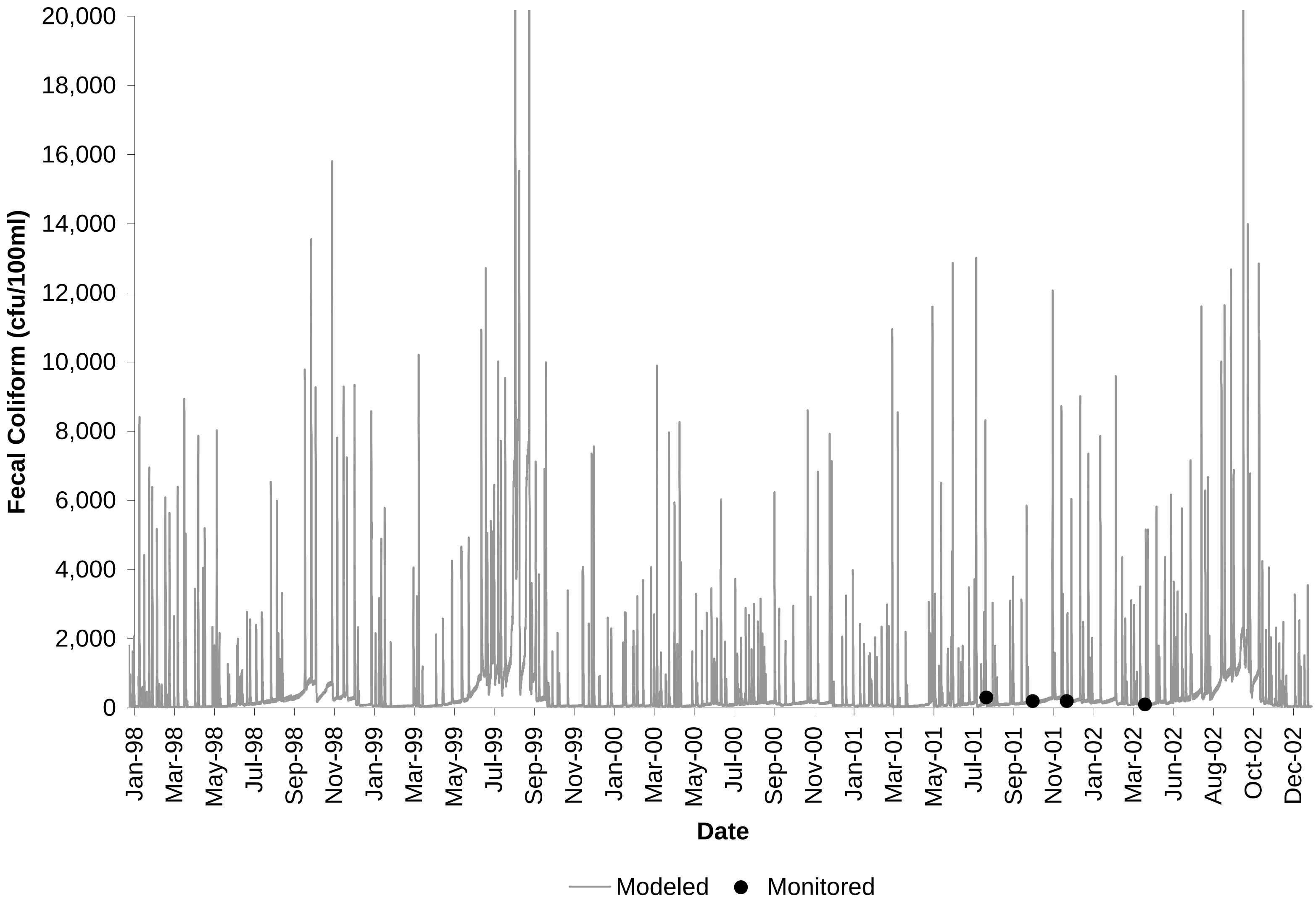

Figure 4.21. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed HAR-19 in Hazel River (60076) impairment.

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Table 4.27. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Hazel River (60076) watershed.

Parameter	Sub HAR-19
Geometric Mean of Observed Values (cfu/100mL)	186
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	189
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	0
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	0

4.7.2.5 Rappahannock River (VAN-E01R-03)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-RPP175.51 within the Rappahannock River (VAN-E01R-03) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.28. Observations from the VADEQ station, 3-RPP175.51, were graphically compared to corresponding modeled concentrations at subwatershed RAR-1 (Figures 4.22 and 4.23). It should be noted that each observed bacteria concentration datum represents a "snapshot" resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.29 and 4.30 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It

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should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.29 and 4.30. A difference of one exceedance could result in a difference of exceedance rate of 4-5%. The highest difference between observed and modeled geometric mean concentrations (6%) and the water quality standard exceedance rates (36%) was recorded during the calibration period. Twenty seven observations were available for comparison during this period resulting in a 4% weighting when comparing the water quality standard exceedance rate. This translates into one model observation that was below 1000 cfu/100ml. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Rappahannock River (VAN-E01R-03) watershed.

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Table 4.28. Calibrated water quality HSPF parameters for Rappahannock River (VAN-E01R-03) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	17E06-01E10	17E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-10E10	02E08-10E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2. 0	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	29E08-34E08	29E08-34E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	03E10	03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	1.9	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

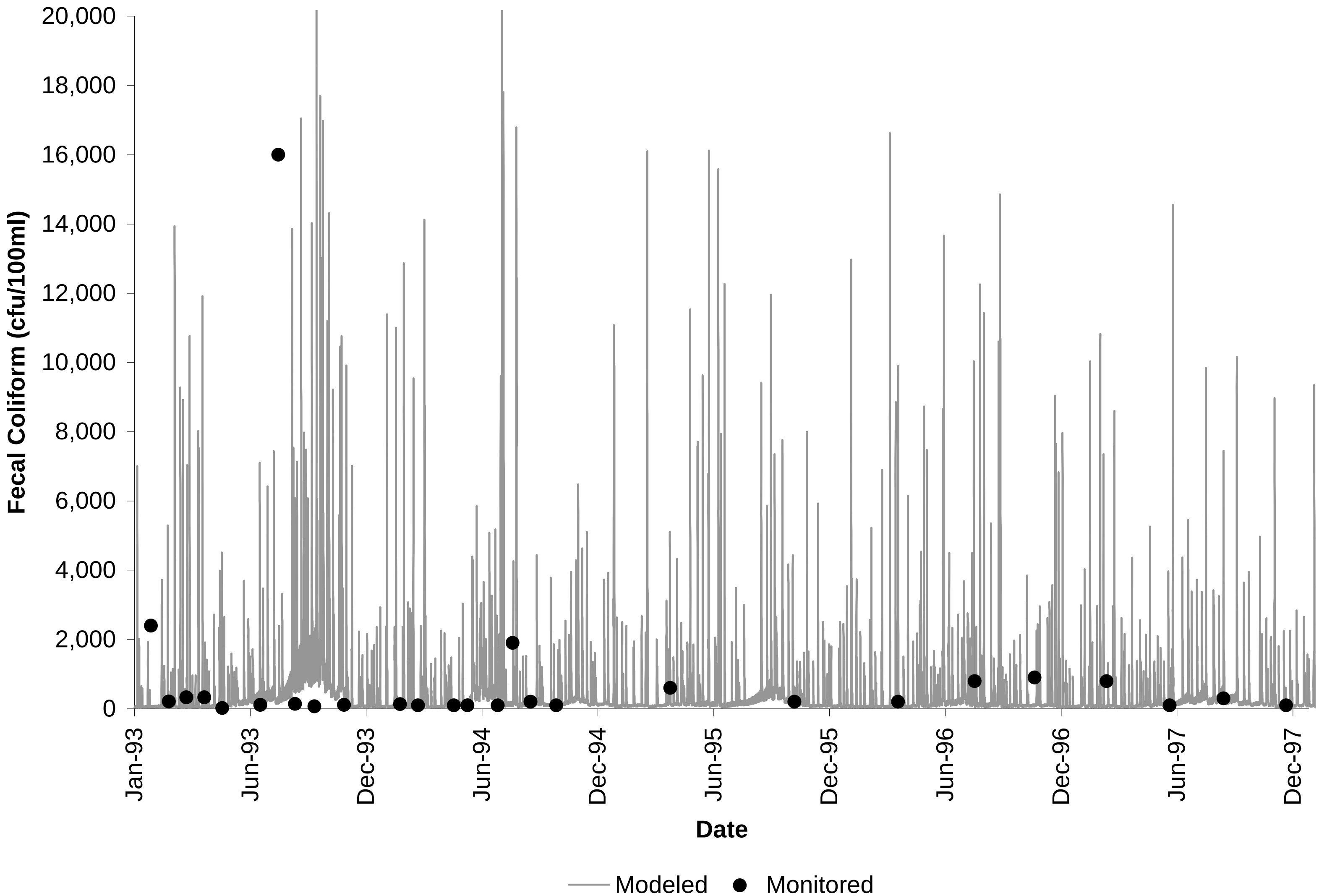

Figure 4.22. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed RAR-01 in Rappahannock River (VAN-E01R-03) impairment.

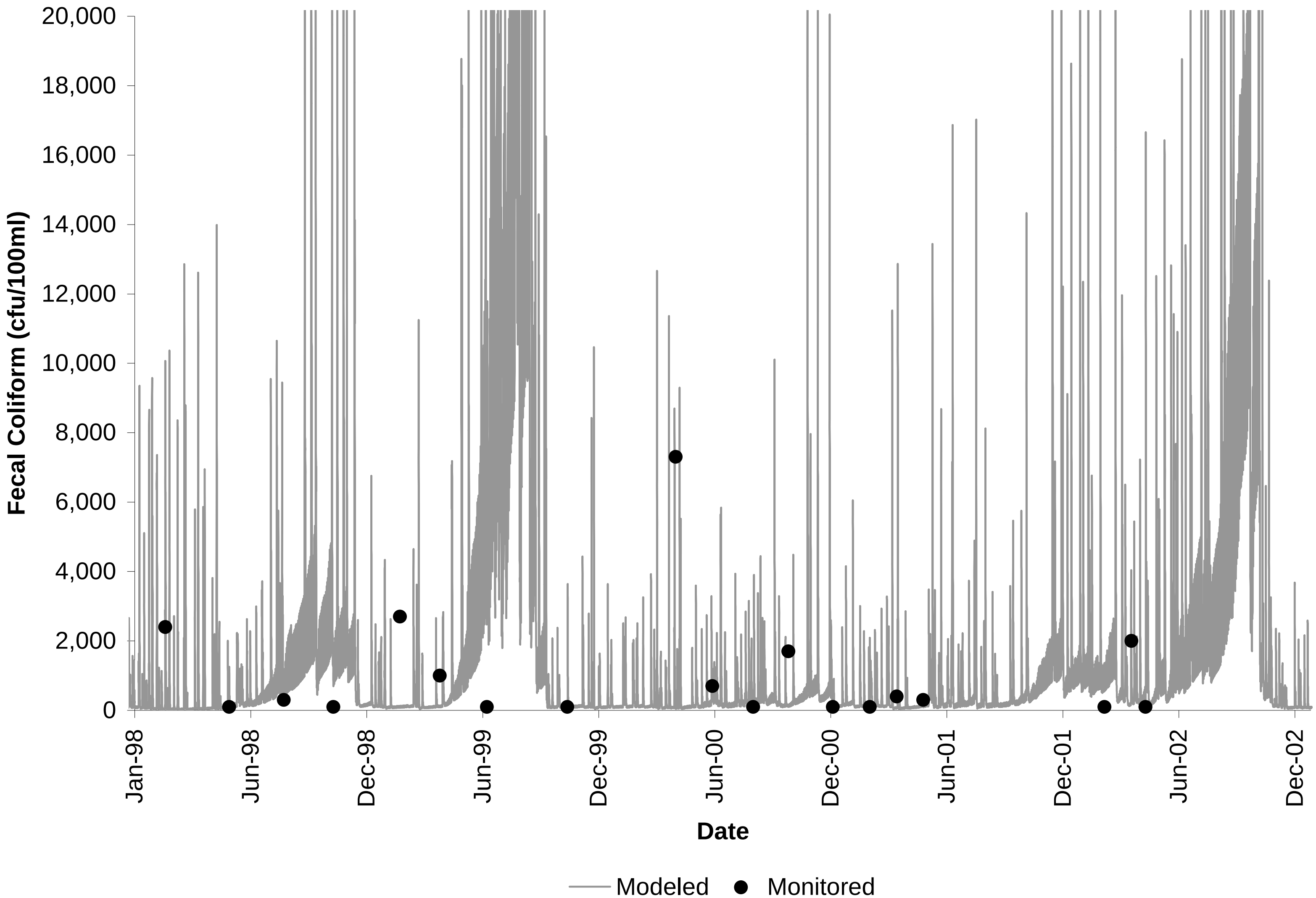

Figure 4.23. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed RAR-01 in Rappahannock River (VAN-E01R-03) impairment.

Table 4.29. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Rappahannock River (VAN-E01R-03) watershed.

Parameter	Sub RAR-01
Geometric Mean of Observed Values (cfu/100mL)	246
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	232
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	7
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	26
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	26

Table 4.30. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Rappahannock River (VAN-E01R-03) watershed.

Parameter	Sub RAR-01
Geometric Mean of Observed Values (cfu/100mL)	362
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	352
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	26
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	21
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	37
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	37

4.7.2.6 Rappahannock River (VAN-E08R-04)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-RPP147.10 within the Rappahannock River (VAN-E08R-04) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.31. Observations from the VADEQ station, 3-RPP147.10, were graphically compared to corresponding modeled concentrations at subwatershed RAR-11 (Figures 4.24 and 4.25). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.32 and 4.33 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.32 and 4.33. A difference of one exceedance could result in a difference of exceedance rate of 2-3%. The highest difference (29%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (89%) was recorded during the validation period. Thirty-six observations were available for comparison during this period resulting in a 3% weighting when comparing the water quality standard exceedance rate. This translates into six model observations that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Rappahannock River (VAN-E08R-04) watershed.

Table 4.31. Calibrated water quality HSPF parameters for Rappahannock River (VAN-E08R-04) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	15E06-01E10	15E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E08-11E10	01E08-11E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2. 0	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	18E08-32E08	18E08-32E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E10-03E10	02E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	0.62	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

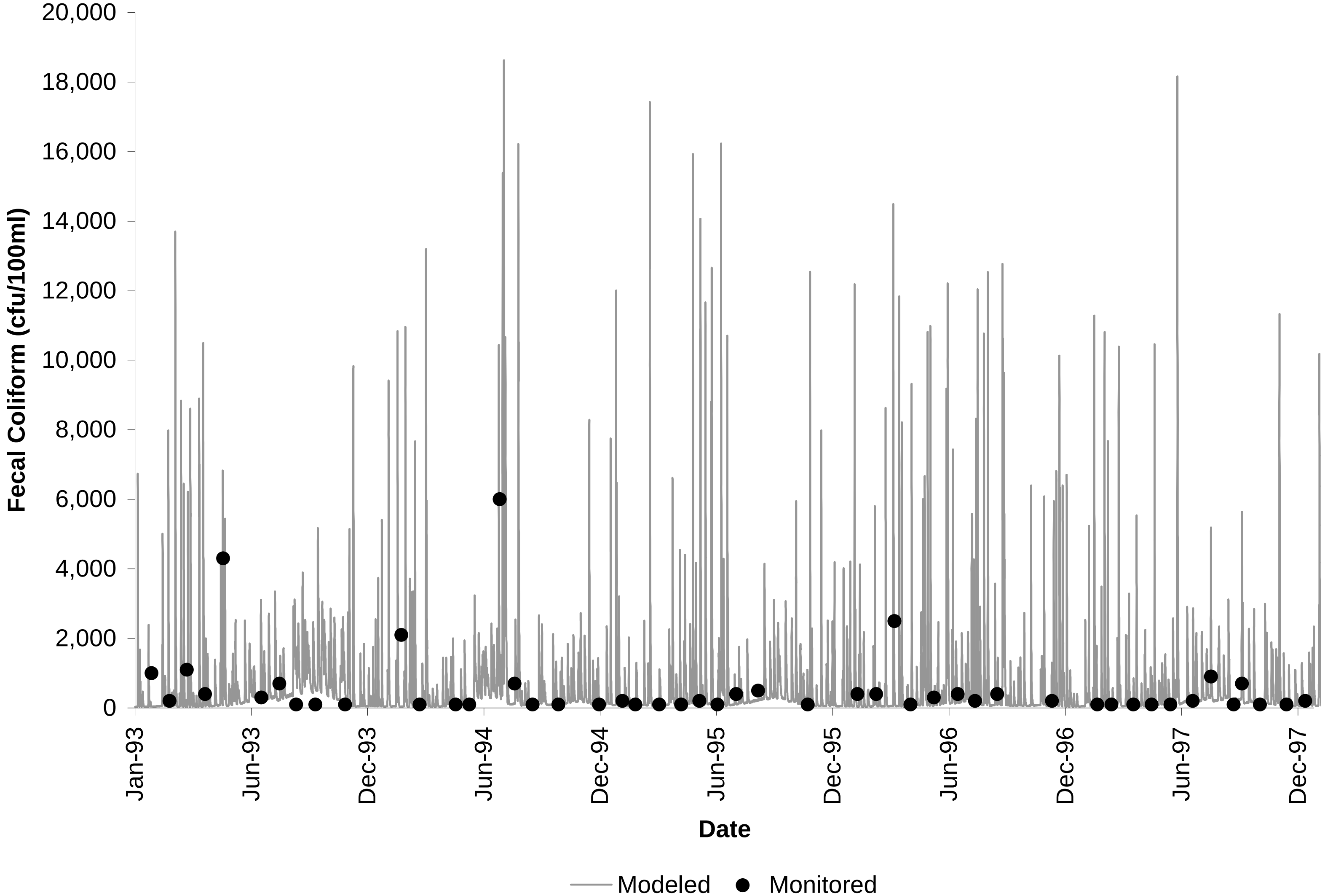

Figure 4.24. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed RAR-11 in Rappahannock River (VAN-E08R-04) impairment.

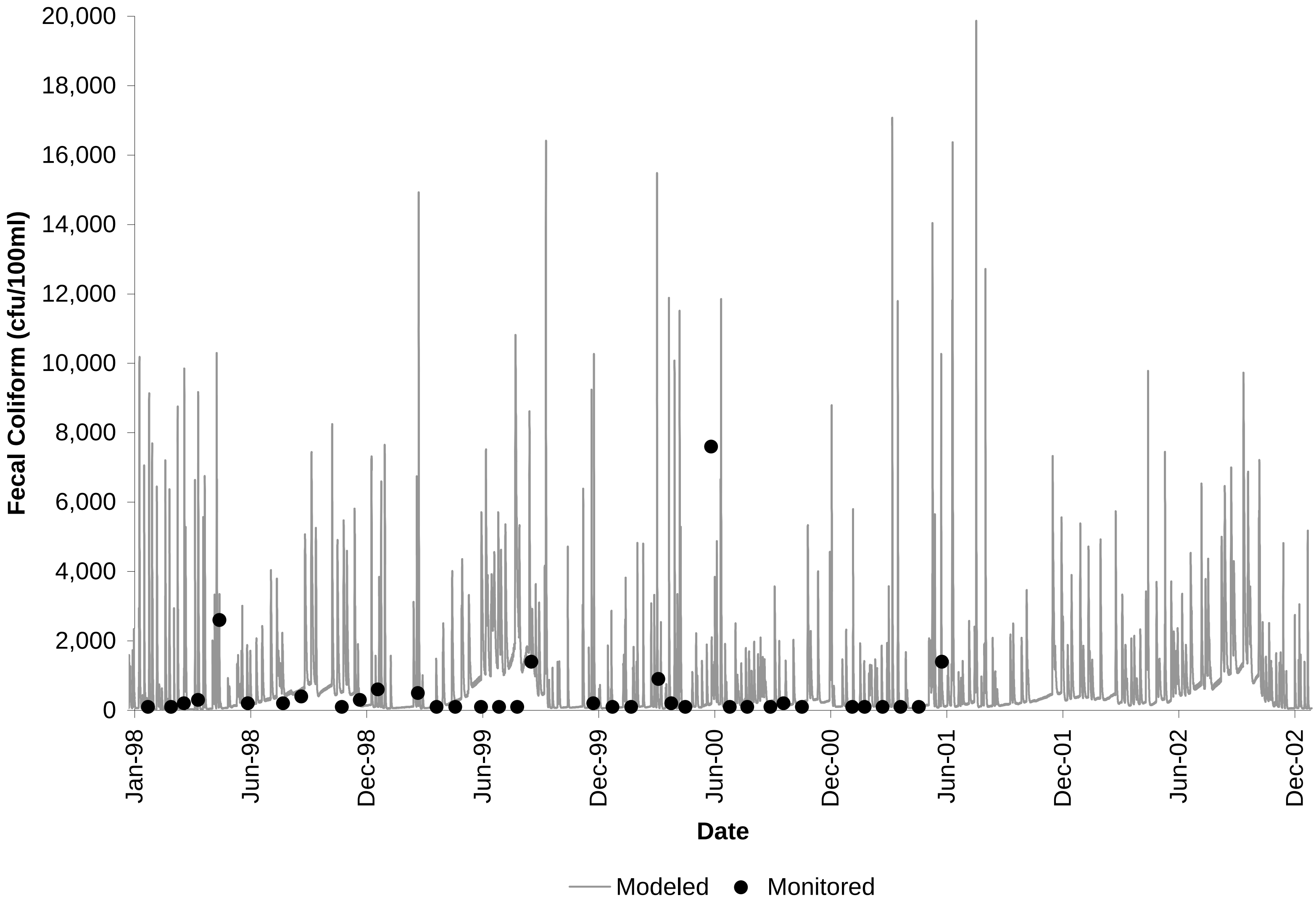

Figure 4.25. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed RAR-11 in Rappahannock River (VAN-E08R-04) impairment.

Table 4.32. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Rappahannock River (VAN-E08R-04) watershed.

Parameter	Sub RAR-11
Geometric Mean of Observed Values (cfu/100mL)	245
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	211
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	10
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	6
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	22
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	22

Table 4.33. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Rappahannock River (VAN-E08R-04) watershed.

Parameter	Sub RAR-11
Geometric Mean of Observed Values (cfu/100mL)	207
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	293
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	17
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	19
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	36

4.7.2.7 Rappahannock River (60081)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-RPP142.36 within the Rappahannock River (60081) impairment were not available; therefore a “paired watershed” approach was used for water quality calibration and validation.

The approach assumes that the paired watershed and Rappahannock River (60081) watershed have similar hydrologic and water quality responses based on physical, geologic, and hydrologic characteristics. The Rappahannock River (VAN-E08R-04) watershed was chosen as the paired watershed due to similar physiographic and hydrologic characteristics. The impairments are separated by one subwatershed. Water quality calibration and validation were performed based on the physical, hydrologic, and land use data for the Rappahannock River (VAN-E08R-04) watershed. After calibration and validation completion, the parameterization (e.g., WSQOP, IOQC, AOQC, FSTDEC) for the Rappahannock River (VAN-E08R-04) model was transferred to the Rappahannock River (60081) model. Parameters describing watershed characteristics such as daily accumulation rate of bacteria on the soil surface (ACQOP) and maximum bacteria build-up rate on the soil (SQOLIM) were updated to reflect bacteria loads in Rappahannock River (60081) watershed.

Table 4.34. Calibrated water quality HSPF parameters for Rappahannock River (60081) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	15E06-78E08	15E06-78E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E08-07E10	01E08-07E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	0.75	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	17E08-28E08	17E08-28E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E10-03E10	02E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	0.62	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

4.7.2.8 Craig Run (VAN-E08R-03)

The period January 1, 1998 through December 31, 2002 was chosen for water quality calibration. Additional water quality data coinciding with available hourly precipitation data was not available to perform separate water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-CRA000.82 within the Craig Run (VAN-E08R-03) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.35. Observations from the VADEQ station, 3-CRA000.82, were graphically compared to corresponding modeled concentrations at subwatershed RAR-14 (Figure 4.26). There were no observations during the validation period. It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Table 4.36 shows the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration period. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Table 4.36. A difference of one exceedance could result in a difference of exceedance rate of 14%. The highest difference (4%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard exceedance rates (0%) was recorded during the calibration period. Seven observations were available for comparison during this period resulting in a 14% weighting when comparing the water quality standard exceedance rate. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration period.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Craig Run (VAN-E08R-03) watershed.

Table 4.35. Calibrated water quality HSPF parameters for Craig Run (VAN-E08R-03) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	20E06-01E10	20E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-10E10	02E08-10E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2. 0	Land use
IOQC	Constituent concentration in interflow	#/ft^3	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	#/ft^3	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	14E08	14E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E10	01E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	8.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

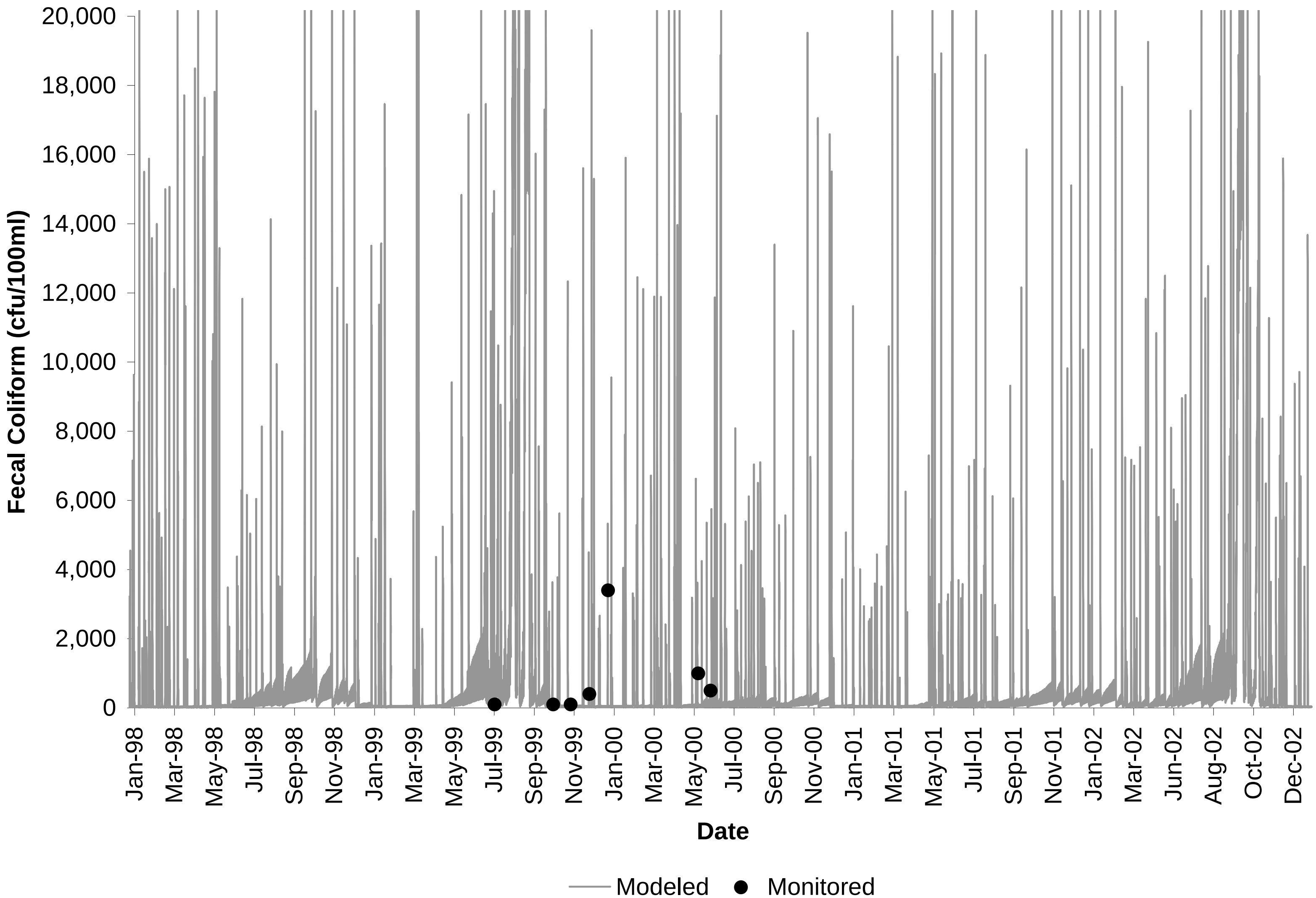

Figure 4.26. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed RAR-14 in Craig Run (VAN-E08R-03) impairment.

Table 4.36. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Craig Run (VAN-E08R-03) watershed.

Parameter	Sub RAR-14
Geometric Mean of Observed Values (cfu/100mL)	353
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	341
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	14
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	29
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	43
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	43

4.7.2.9 Browns Run (VAN-E08R-02)

The period January 1, 1998 through December 31, 2002 was chosen for water quality calibration. Additional water quality data coinciding with available hourly precipitation data was not available to perform separate water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-BOS000.72 within the Browns Run (VAN-E08R-02) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.37. Observations from the VADEQ station, 3-BOS000.72, were graphically compared to corresponding modeled concentrations at subwatershed RAR-18 (Figure 4.27). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Table 4.38 shows the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration period. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Table 4.38. A difference of one exceedance could result in a difference of exceedance rate of 14%.

The highest difference (1%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard exceedance rates (0%) was recorded during the calibration period. Seven observations were available for comparison during this period resulting in a 14% weighting when comparing the water quality standard exceedance rate. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration period.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Browns Run (VAN-E08R-02) watershed.

Table 4.37. Calibrated water quality HSPF parameters for Browns Run (VAN-E08R-02) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	19E06-02E10	19E06-02E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-16E10	02E08-16E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2. 0	Land use
IOQC	Constituent concentration in interflow	#/ft^3	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	#/ft^3	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	25E08-31E08	25E08-31E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E10-03E10	02E10-03E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	8.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

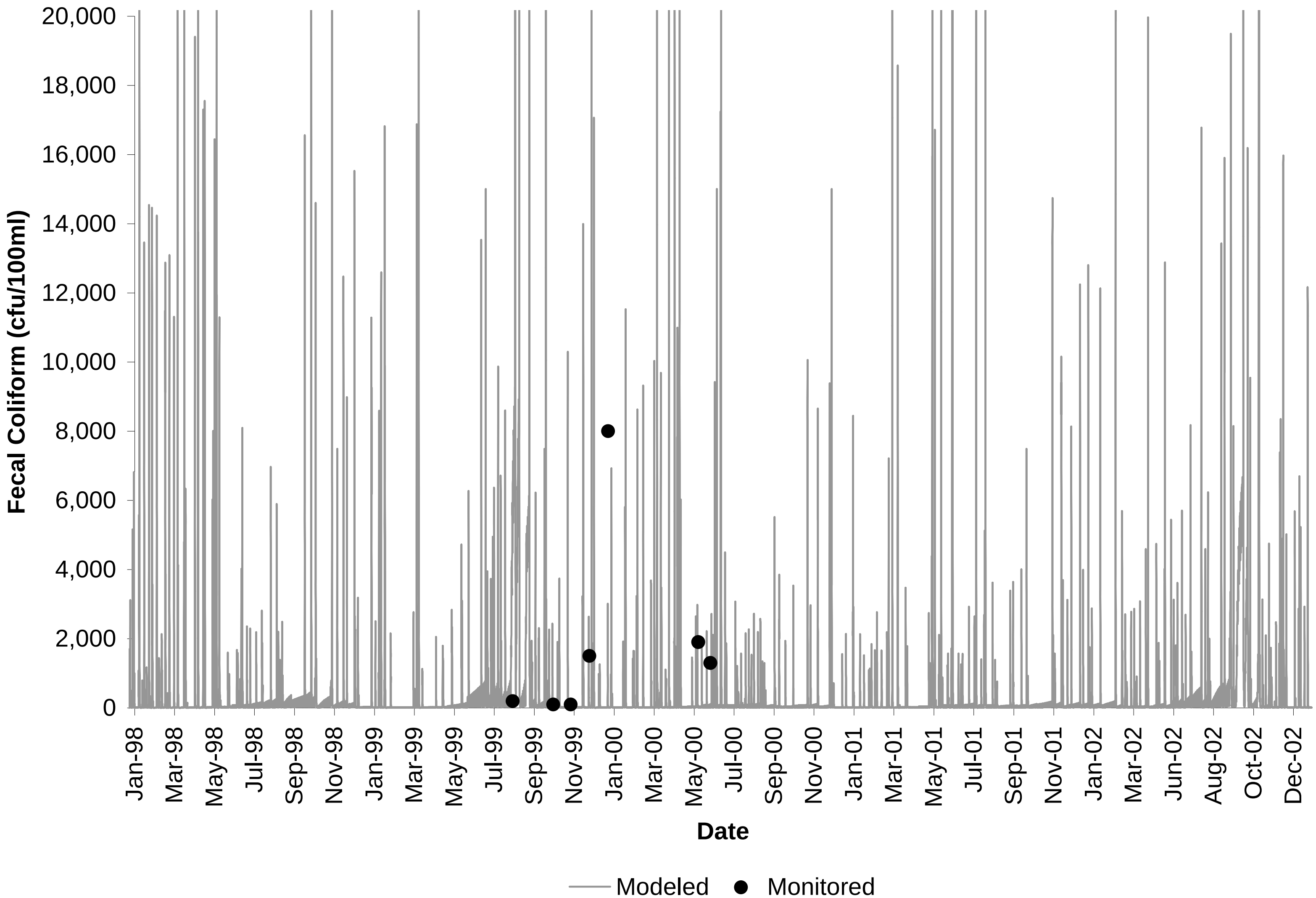

Figure 4.27. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed RAR-18 in Browns Run (VAN-E08R-02) impairment.

Table 4.38. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Browns Run (VAN-E08R-02) watershed.

Parameter	Sub RAR-18
Geometric Mean of Observed Values (cfu/100mL)	668
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	672
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	57
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	71
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	57
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	71

4.7.2.10 Marsh Run (VAN-E08R-01)

The period January 1, 1993 through December 31, 1997 was chosen for water quality calibration and January 1, 1998 through December 31, 2002 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 3-MAH000.19 within the Marsh Run (VAN-E08R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.39. Observations from the VADEQ station, 3-MAH000.19, were graphically compared to corresponding modeled concentrations at subwatershed RAR-20 (Figures 4.28 and 4.29). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.40 and 4.41 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.40 and 4.41. A difference of one exceedance could result in a difference of exceedance rate of 6-7%. The highest difference (15%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (71%) was recorded during the validation period. Fourteen observations were available for comparison during this period resulting in a 7% weighting when comparing the water quality standard exceedance rate. This translates into two model observations that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Marsh Run (VAN-E08R-01) watershed.

Table 4.39. Calibrated water quality HSPF parameters for Marsh Run (VAN-E08R-01) watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
PERLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E08	1E08	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	21E06-01E10	21E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-10E10	02E08-10E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	2. 0	Land use
IOQC	Constituent concentration in interflow	$\#/ft^3$	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	$\#/ft^3$	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	09E08-27E08	09E08-27E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	85E08-02E10	85E08-02E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	0.5-2.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

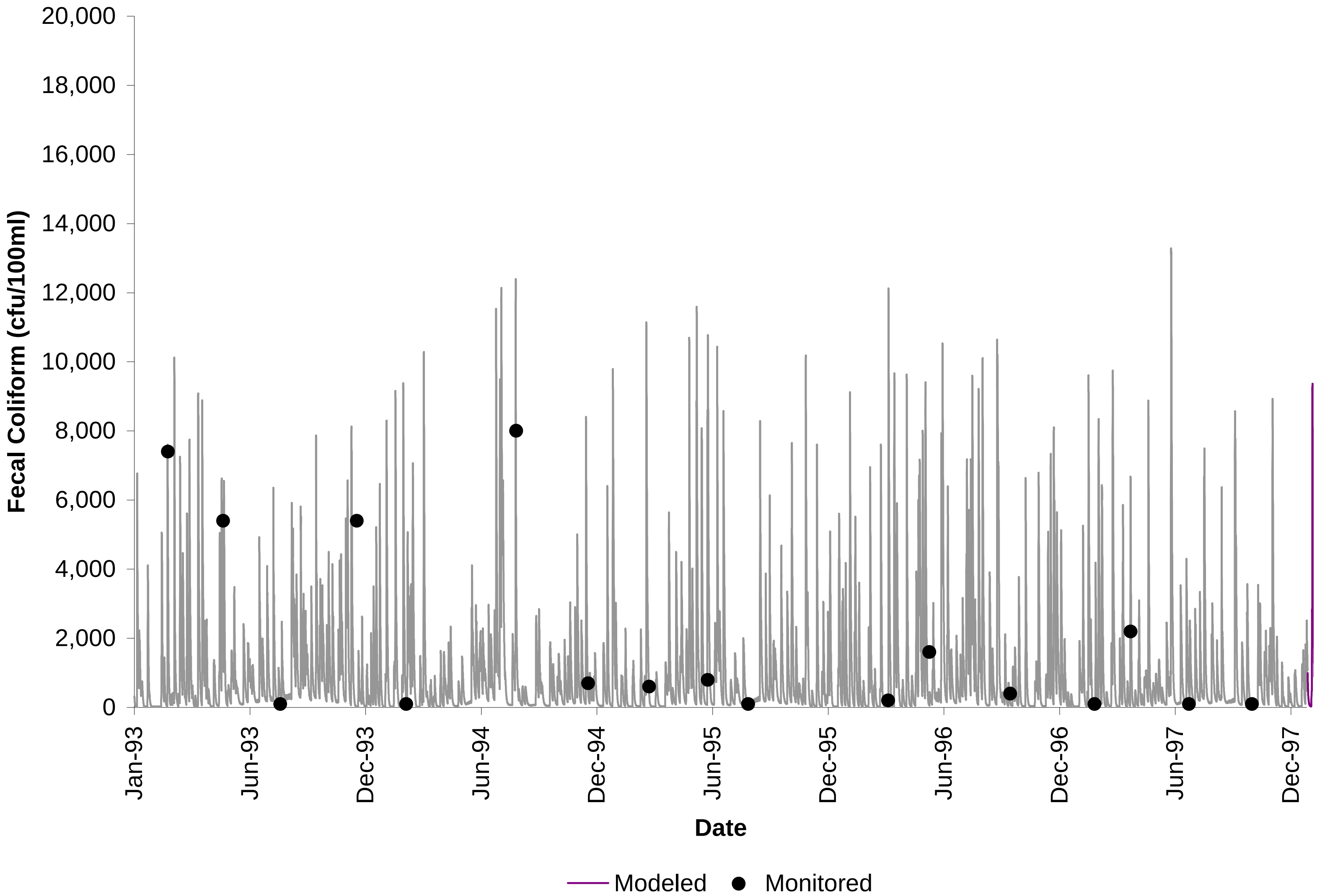

Figure 4.28. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed RAR-20 in Marsh Run (VAN-E08R-01) impairment.

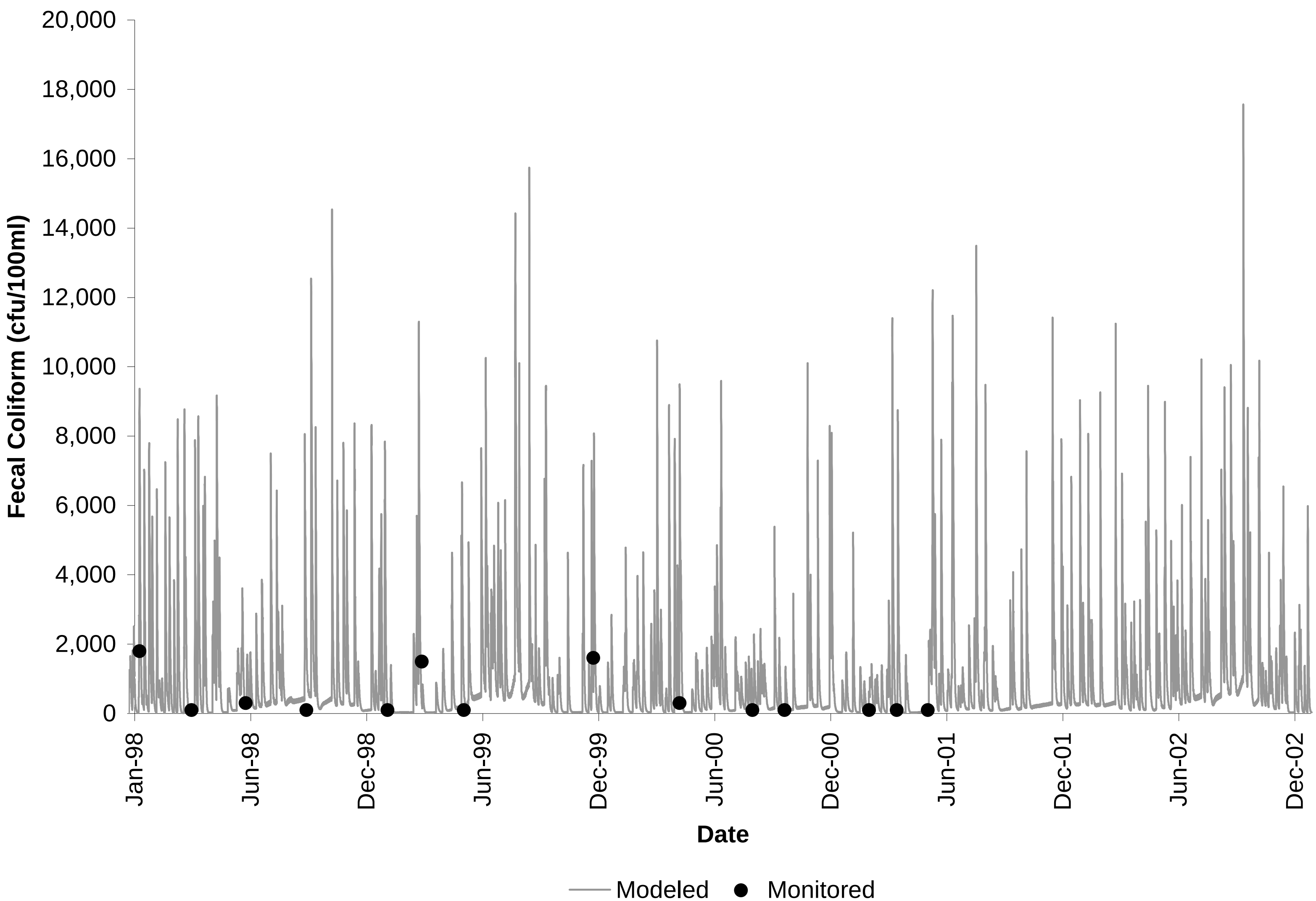

Figure 4.29. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed RAR-20 in Marsh Run (VAN-E08R-01) impairment.

Table 4.40. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Marsh Run (VAN-E08R-01) watershed.

Parameter	Sub RAR-20
Geometric Mean of Observed Values (cfu/100mL)	599
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	541
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	35
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	24
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	53
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	53

Table 4.41. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Marsh Run (VAN-E08R-01) watershed.

Parameter	Sub RAR-20
Geometric Mean of Observed Values (cfu/100mL)	213
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	251
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	21
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	21
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	21
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	36

Chapter 5. Load Allocations

5.1 Background

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The goal for the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) TMDLs was to determine what reductions in bacteria loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing *E. coli* to Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01). The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL is defined in the following equation:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \qquad [5.1]$$

where: WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit MOS was used by formulating conservative estimates of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the highest in-stream bacteria conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard exceedances will occur if the TMDL plan is followed.

Bacteria loadings were updated to reflect 2006 conditions for the existing conditions and allocation runs. The simulation period selected for the load allocation study was January 1993 to December 1997. This period incorporates average rainfall, low rainfall, and high rainfall years allowing the representation of both low and high flow conditions.

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

The guidance for developing an *E. coli* TMDL put forth by the VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, the model output of average fecal coliform concentrations is converted to daily average *E. coli* concentrations through the use of the following translator equation derived by the VADEQ:

$$\log_2(EC) = -0.0172 + 0.91905*\log_2(FC) \qquad [5.2]$$

where: EC = *E. coli* concentration (cfu/100mL); and
FC = fecal coliform concentration (cfu/100mL)

Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Average annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

5.2 Existing Conditions

Bacteria loadings for 2006 conditions were inserted into the model and simulated for the period January 1993 to December 1997. Model output was translated to average daily *E. coli* concentrations and the monthly geometric mean was calculated. Average daily *E. coli* concentrations at the impairment outlets were compared to the single sample maximum standard of 235 cfu/100 mL. Subwatershed outlets were used for comparison of modeled concentrations to water quality standards for the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments. Appendix C contains tables with monthly land-based and direct bacteria loadings for existing conditions.

5.2.1 Hughes River (VAN-E03R-01)

Figure 5.1 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.2). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Hughes River (VAN-E03R-01) impairment was subwatershed HAR-02.

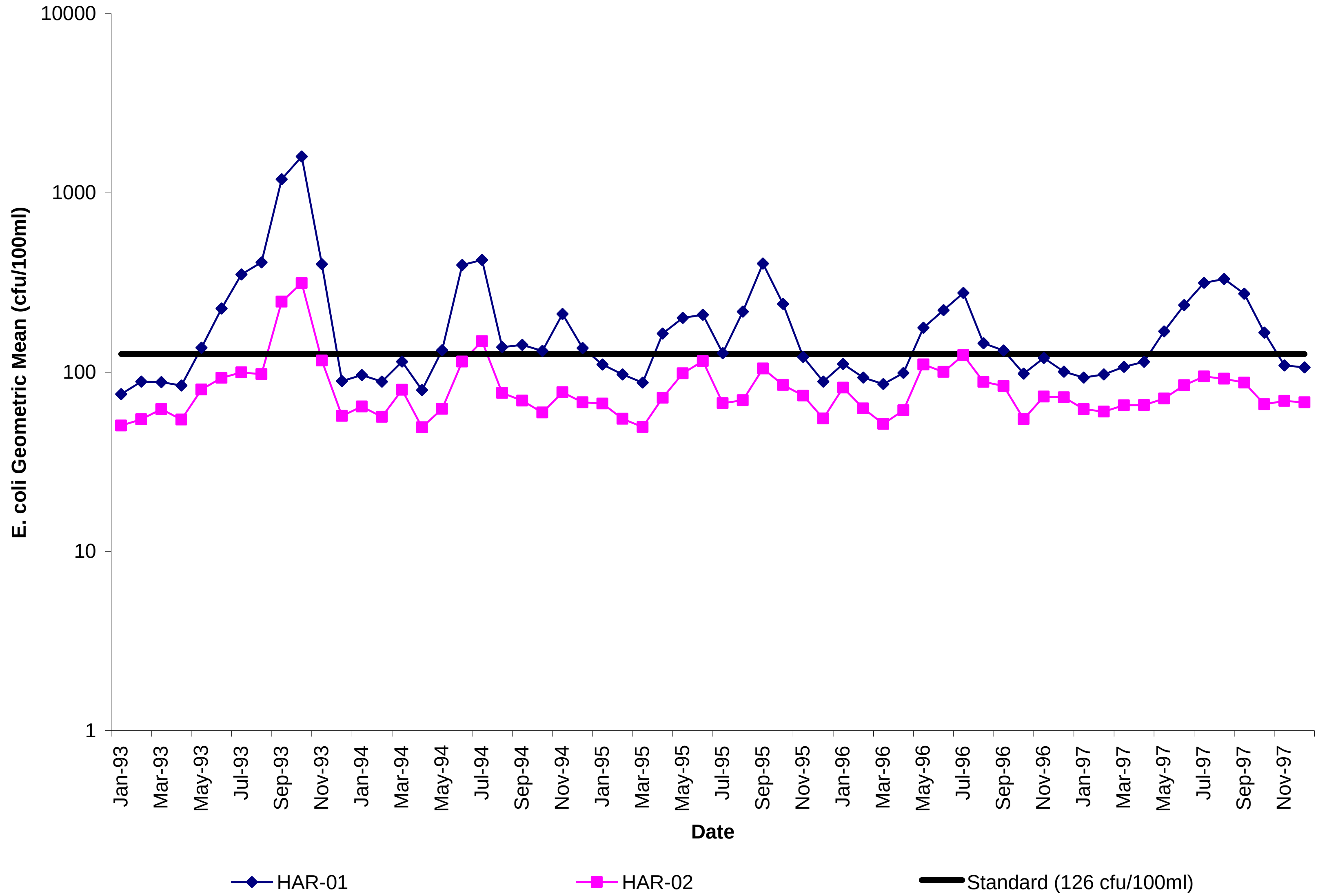

Figure 5.1. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds HAR-01 to HAR-02 in the Hughes River (VAN-E03R-01) watershed.

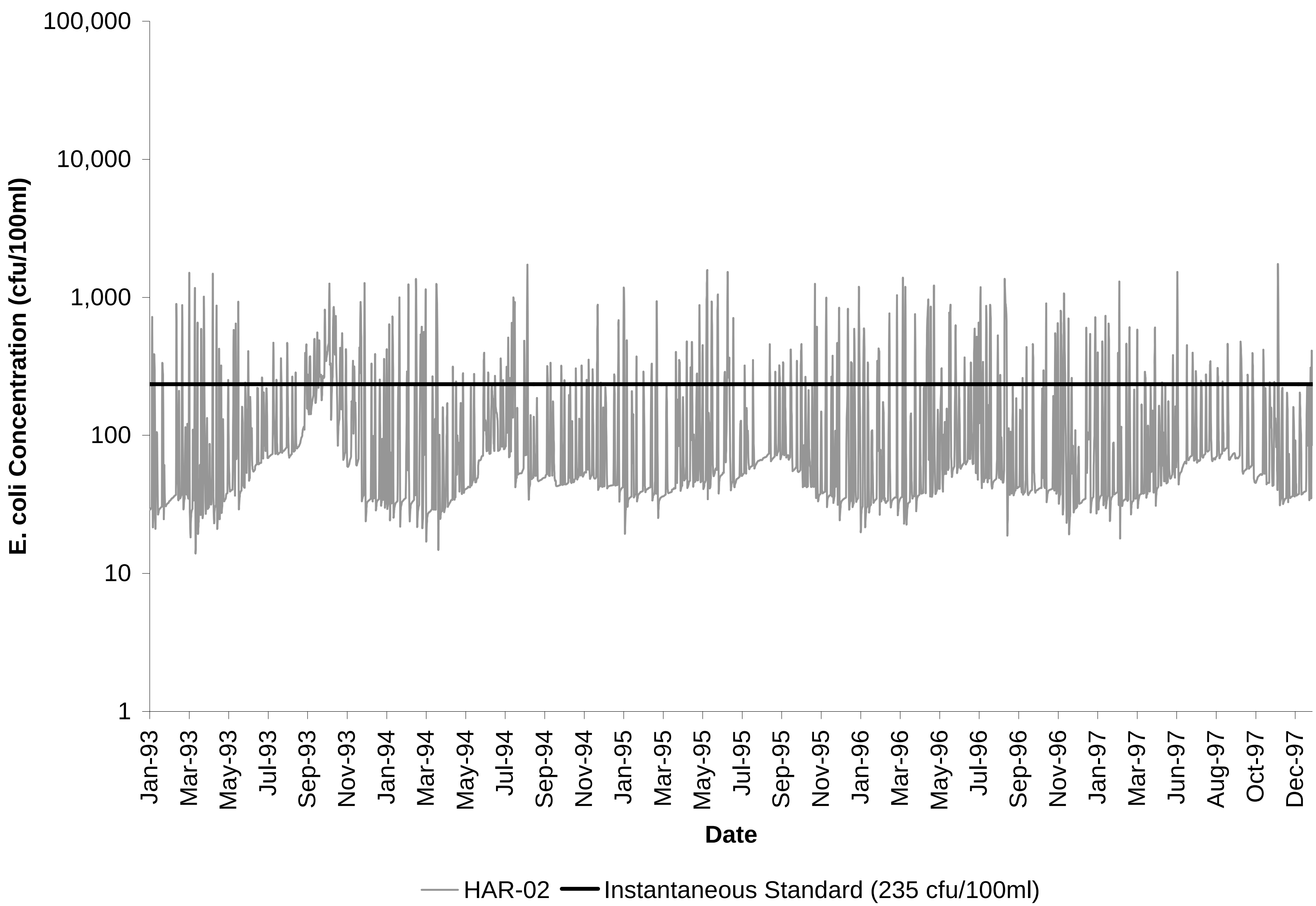

Figure 5.2. Daily average *E. coli* concentrations for subwatershed HAR-02 in Hughes River (VAN-E03R-01) watershed.

5.2.2 Hazel River (VAN-E04R-01)

Figure 5.3 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.4). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Hazel River (VAN-E04R-01) impairment was subwatershed HAR-09.

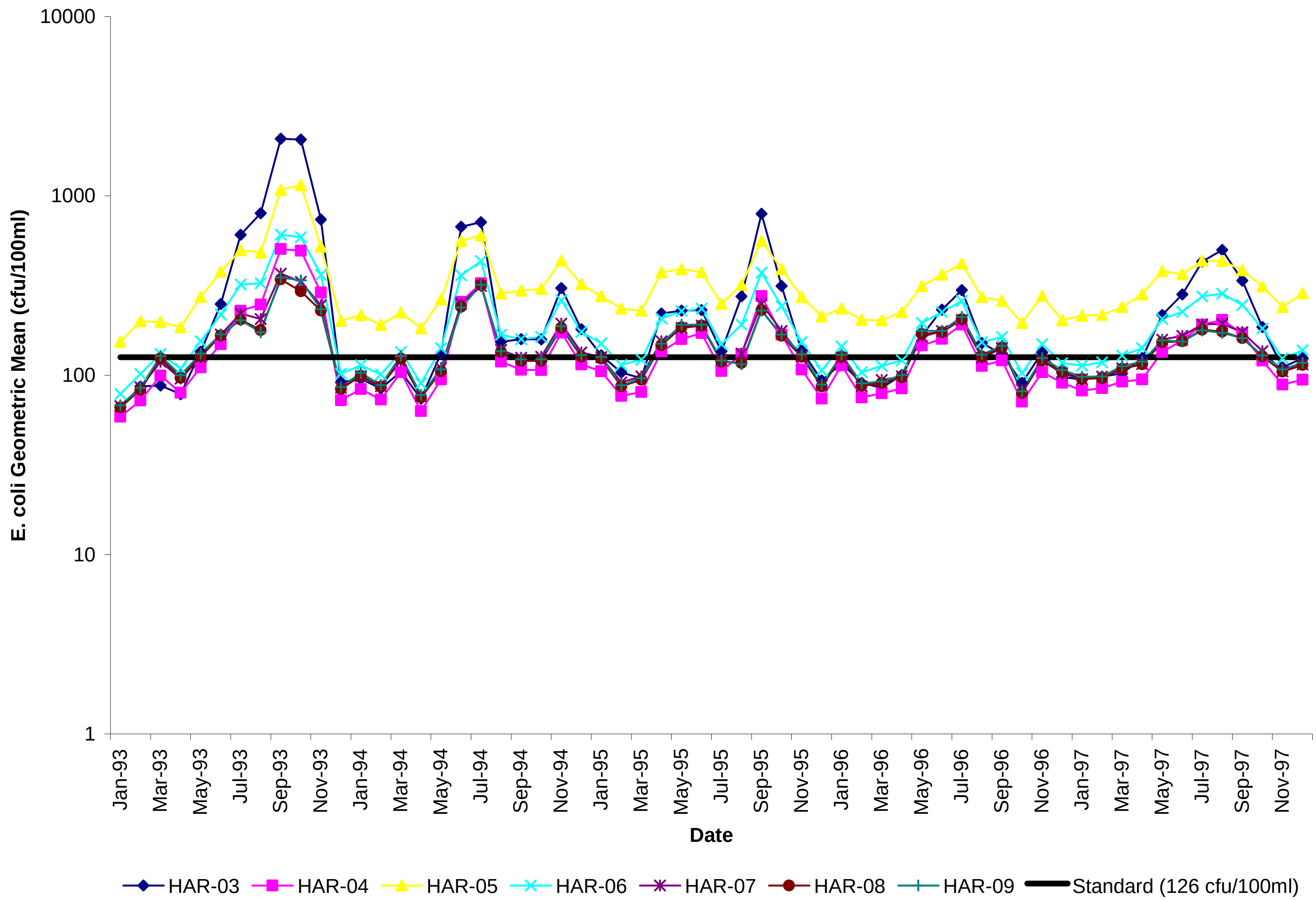

Figure 5.3. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds HAR-03 to HAR-09 in the Hazel River (VAN-E04R-01) watershed.

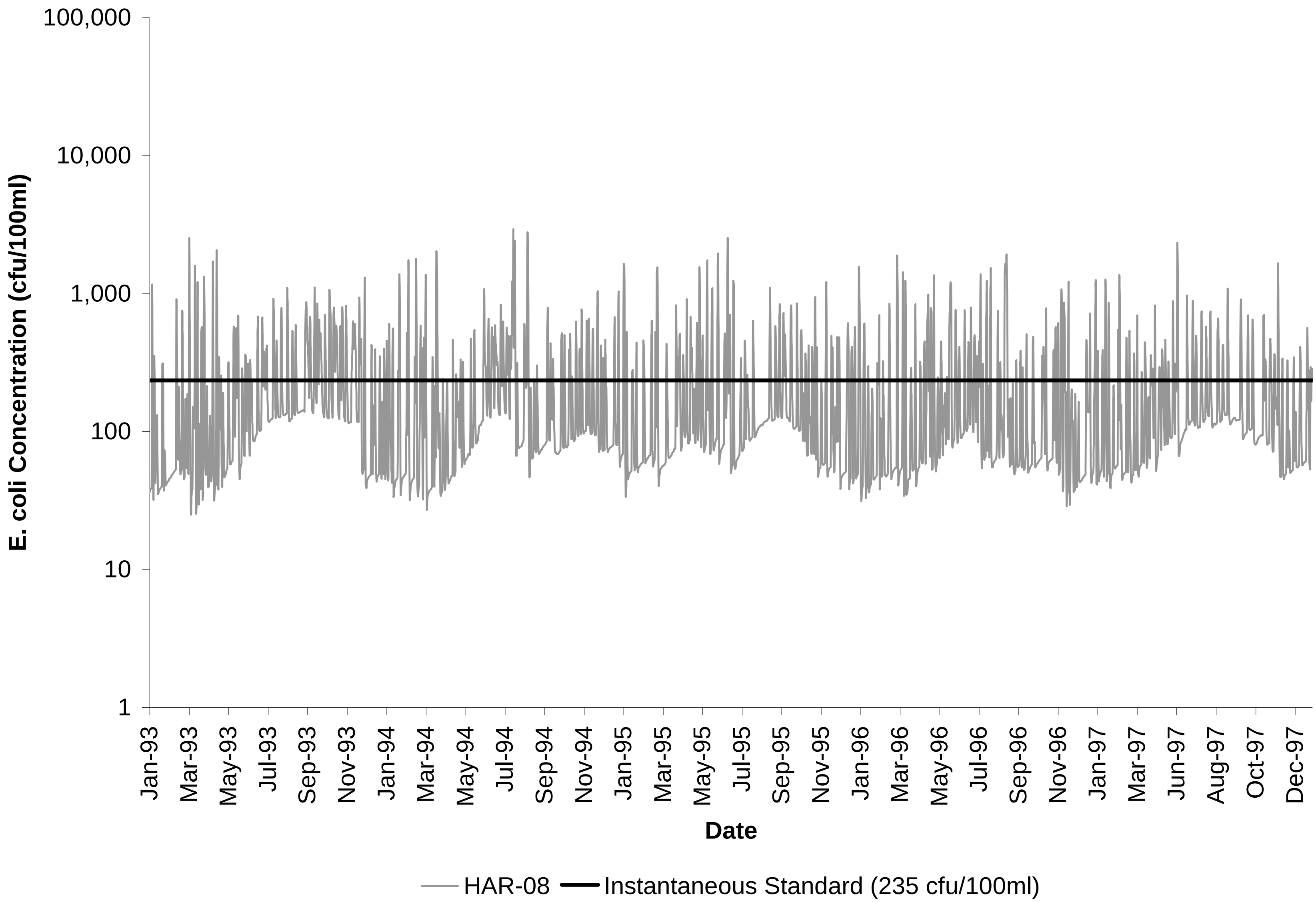

Figure 5.4. Daily average *E. coli* concentrations for subwatershed HAR-09 in Hazel River (VAN-E04R-01) watershed.

5.2.3 Rush River (VAN-E05R-01)

Figure 5.5 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.6). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rush River (VAN-E05R-01) impairment was subwatershed HAR-12.

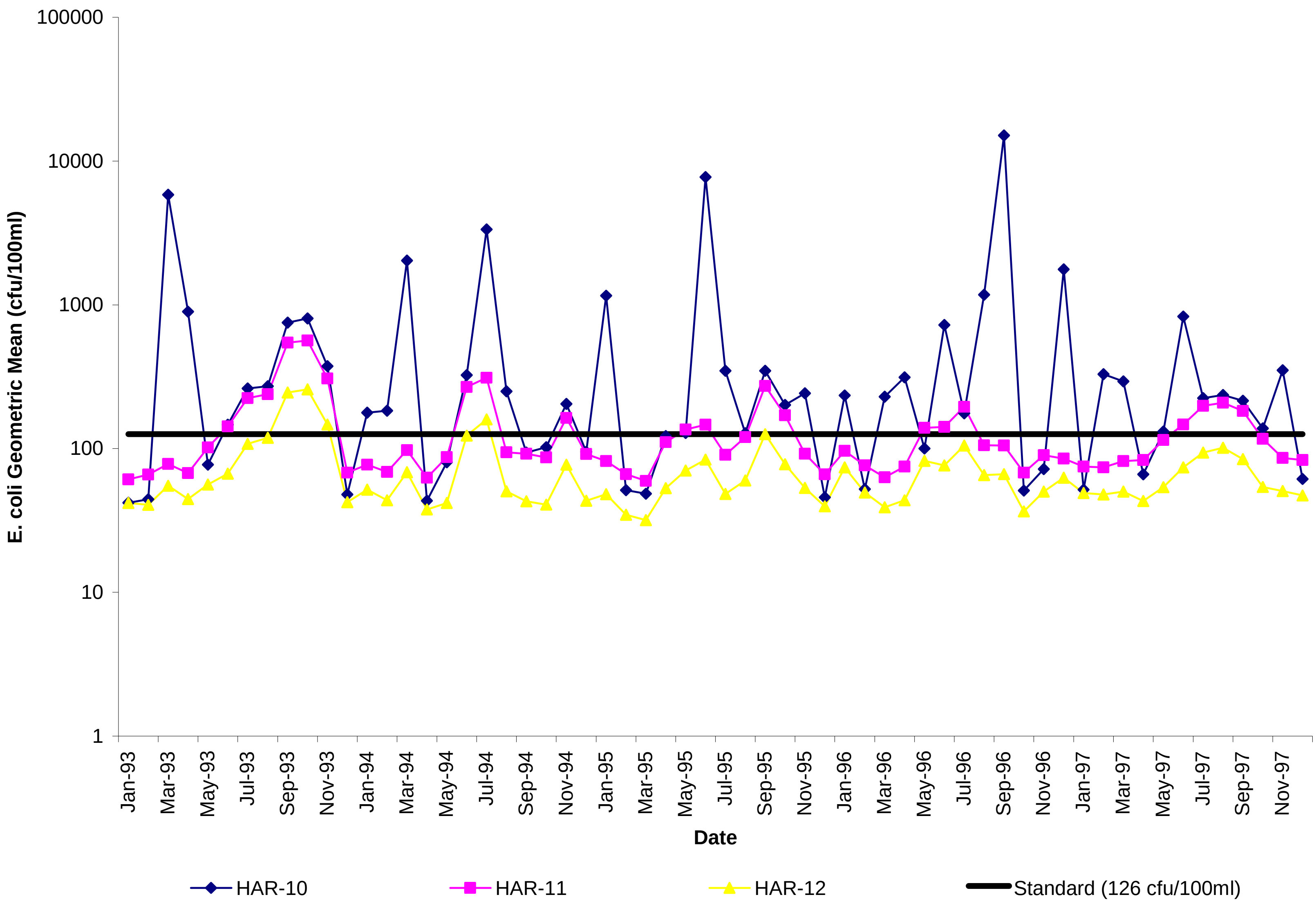

Figure 5.5. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds HAR-10 to HAR-12, in Rush River (VAN-E05R-01) watershed.

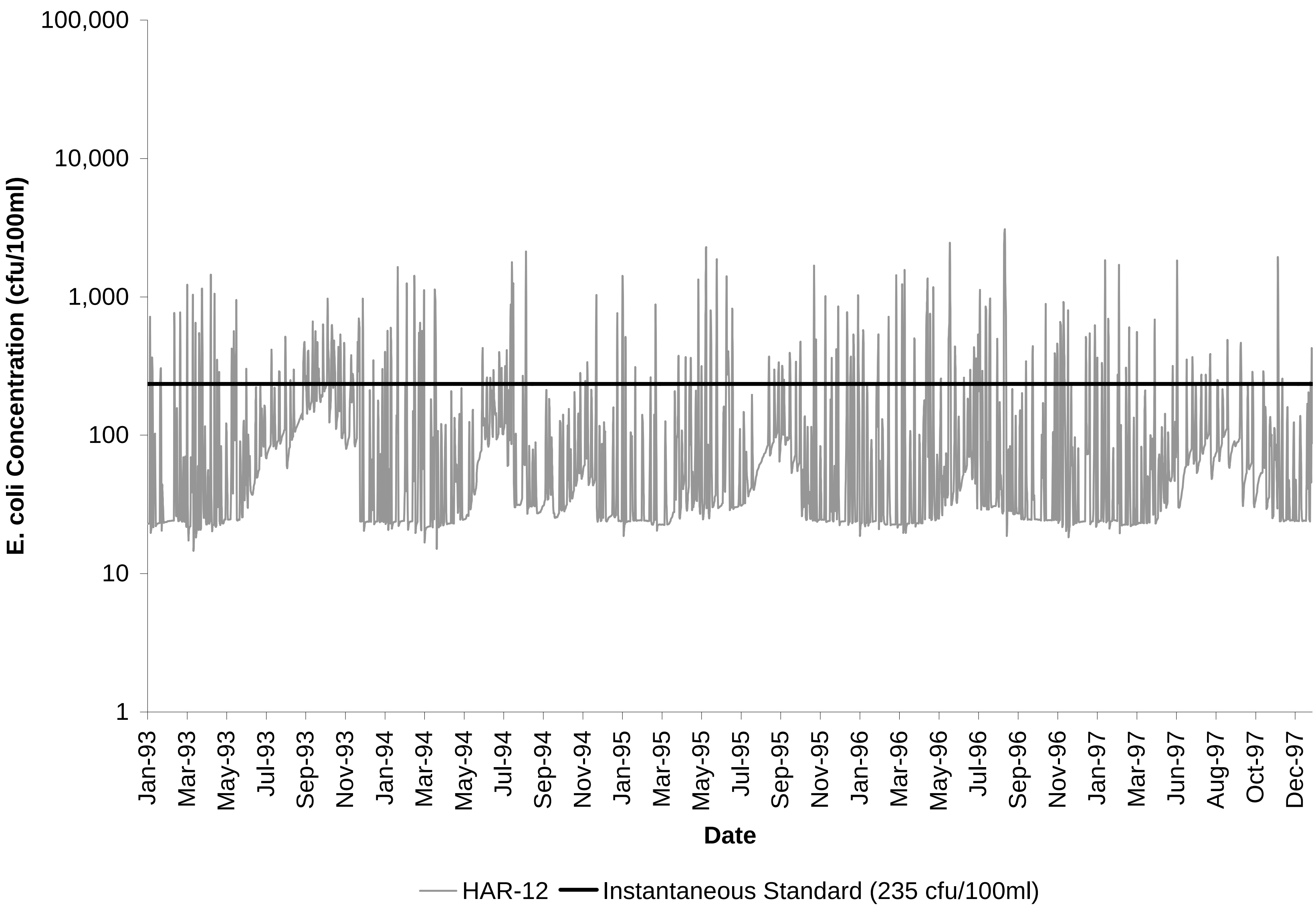

Figure 5.6. Daily average *E. coli* concentrations for subwatershed HAR-12 in Rush River (VAN-E05R-01) watershed.

5.2.4 Hazel River (60076)

Figure 5.7 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.8). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Hazel River (60076) impairment was subwatershed HAR-19.

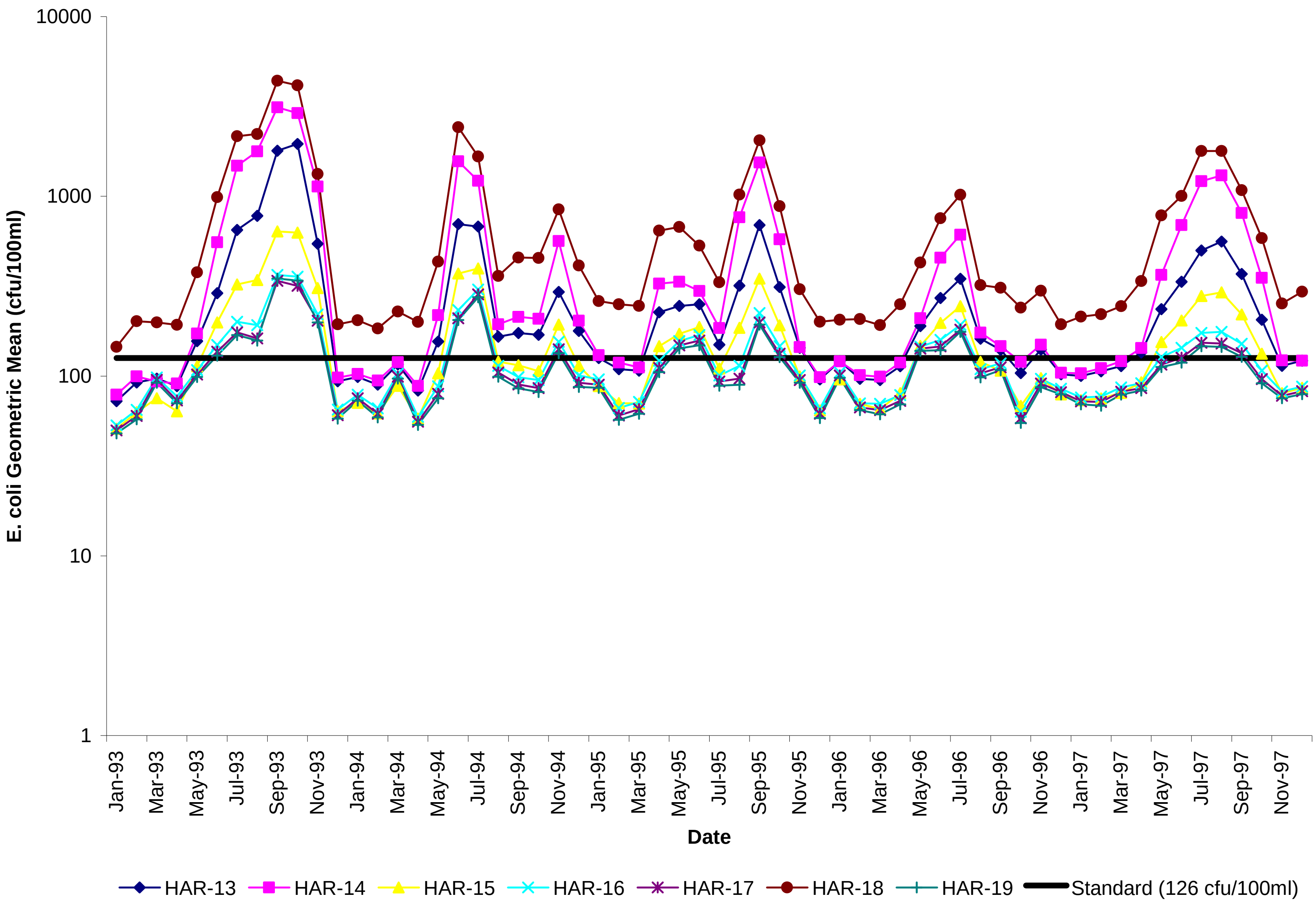

Figure 5.7. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds HAR-13 and HAR-19 in Hazel River (60076) watershed.

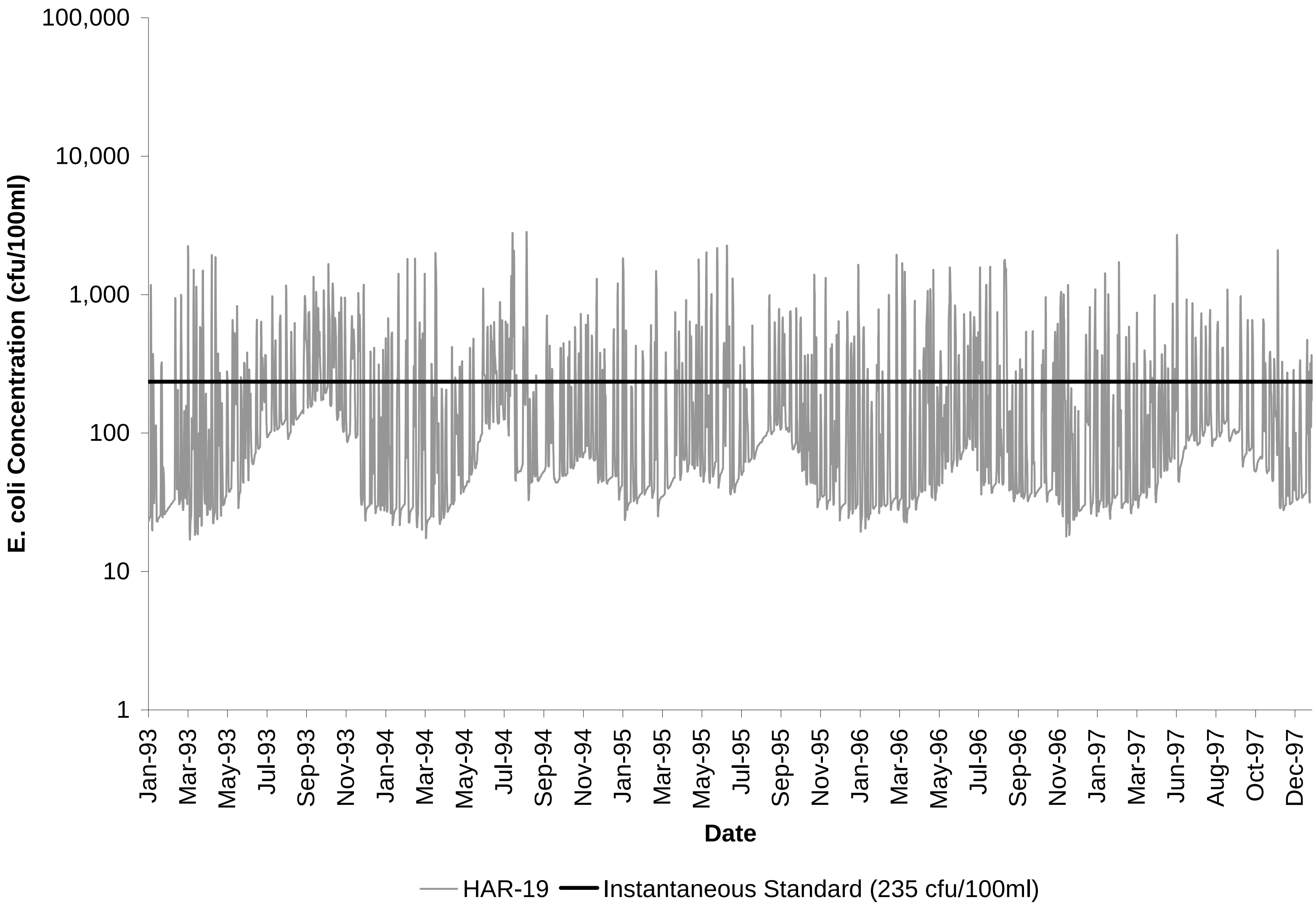

Figure 5.8. Daily average *E. coli* concentrations for subwatershed HAR-19 in Hazel River (60076) watershed.

5.2.5 Rappahannock River (VAN-E01R-03)

Figure 5.9 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.10). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rappahannock River (VAN-E01R-03) impairment was subwatershed RAR-02.

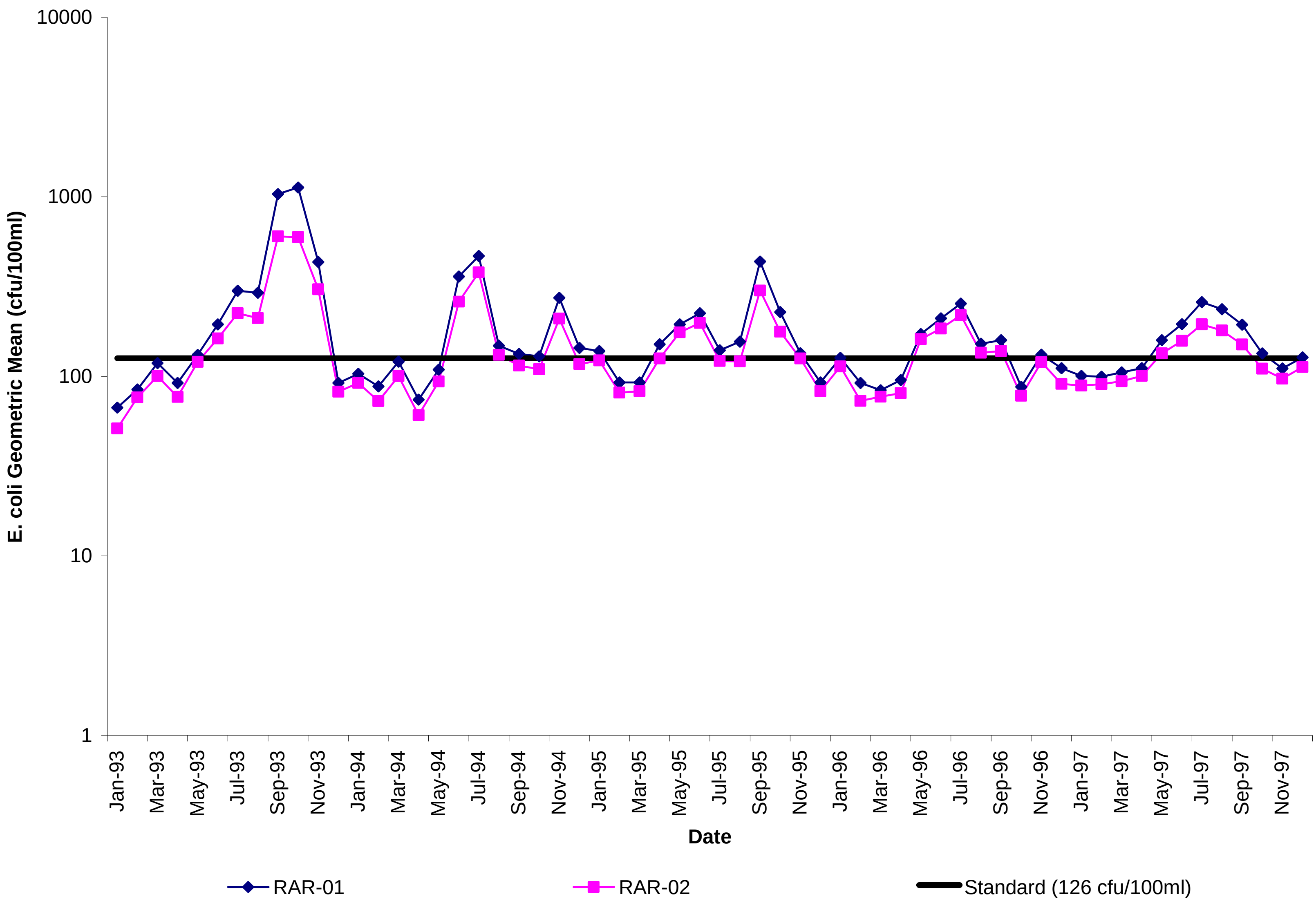

Figure 5.9. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds RAR-01 to RAR-02 in Rappahannock River (VAN-E01R-03) watershed.

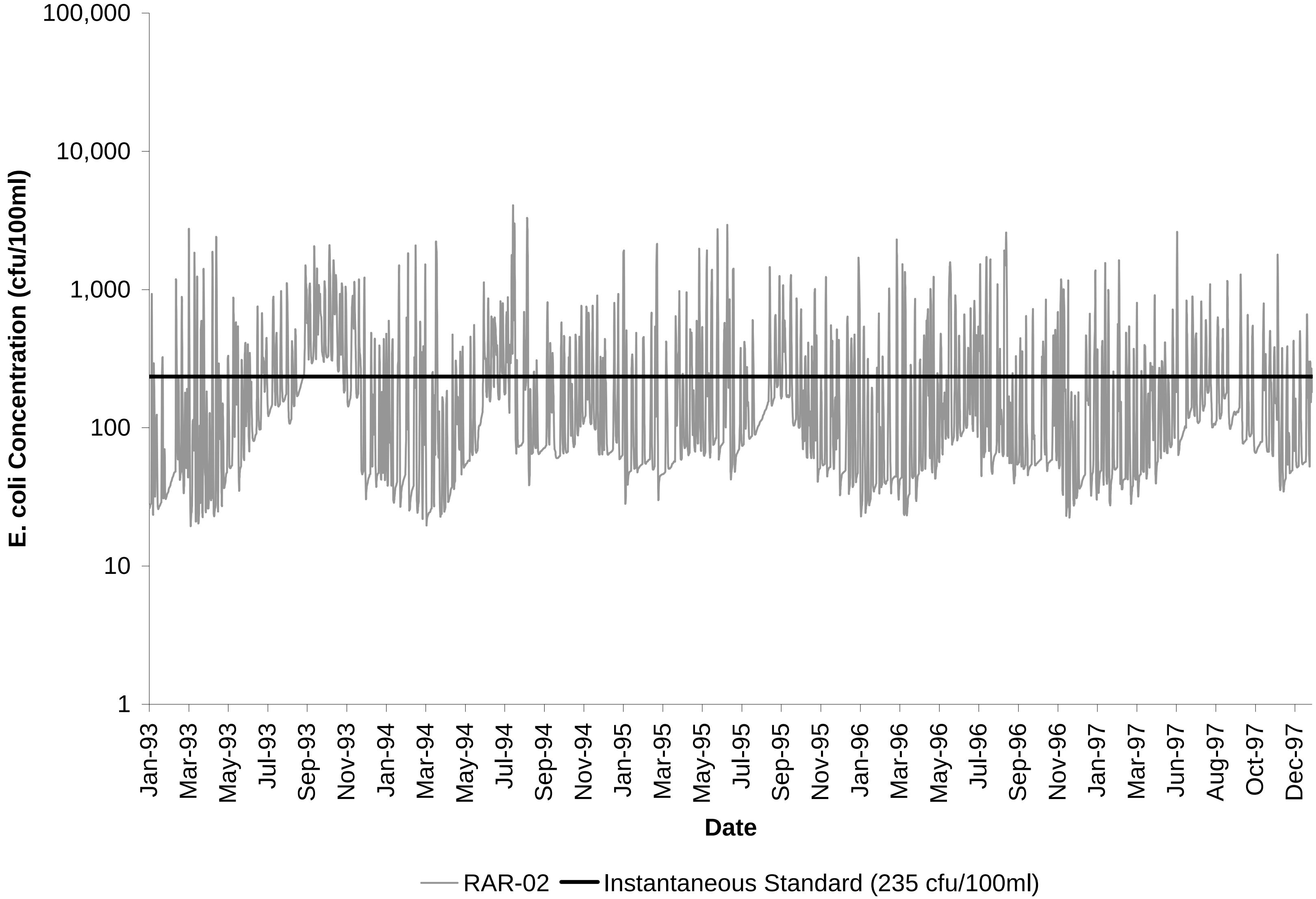

Figure 5.10. Daily average *E. coli* concentrations for subwatershed RAR-02 in Rappahannock River (VAN-E01R-03) watershed.

5.2.6 Rappahannock River (VAN-E08R-04)

Figure 5.11 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.12). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rappahannock River (VAN-E08R-04) impairment was subwatershed RAR-11.

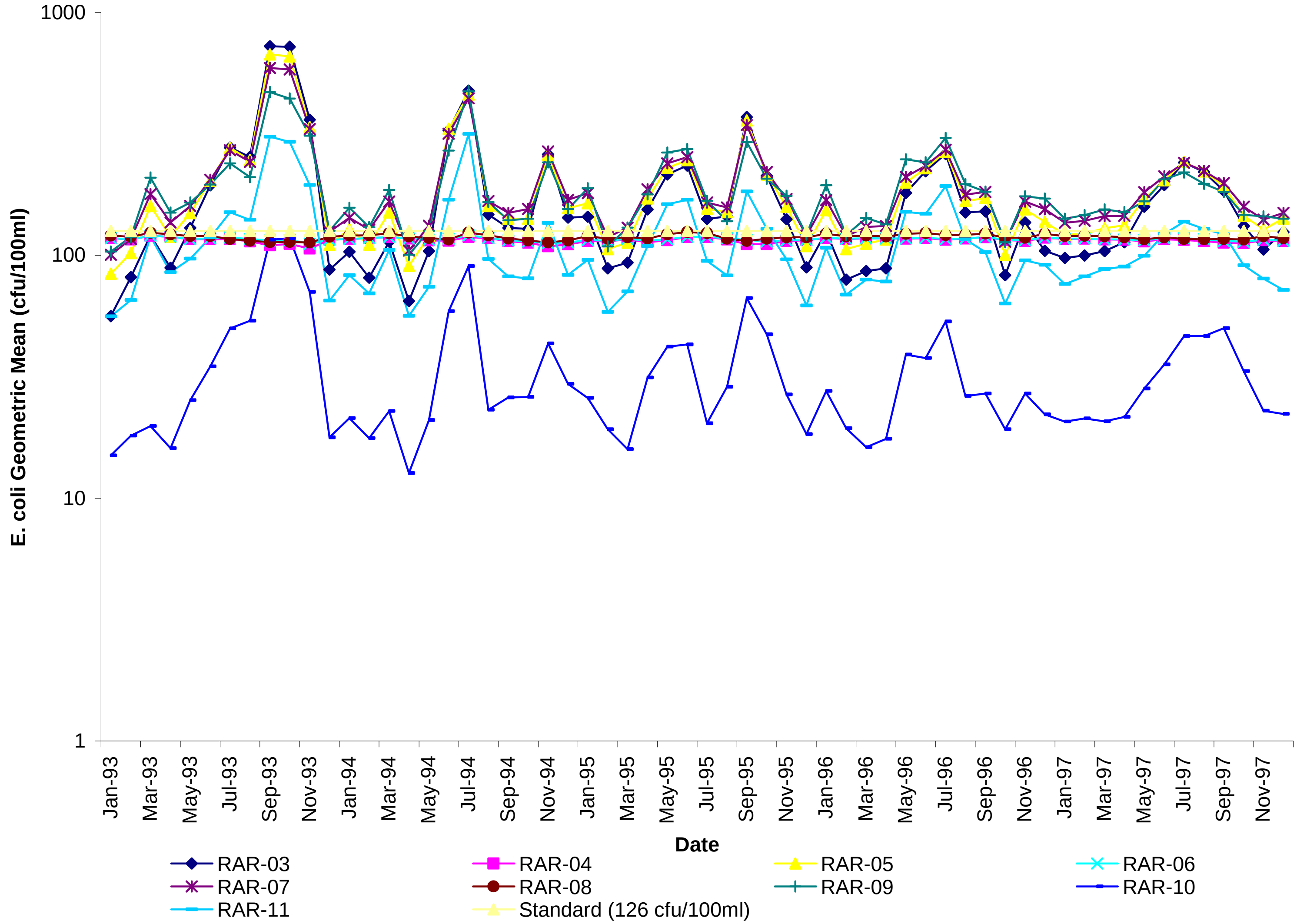

Figure 5.11. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds RAR-03 to RAR-11 in Rappahannock River (VAN-E08R-04) watershed.

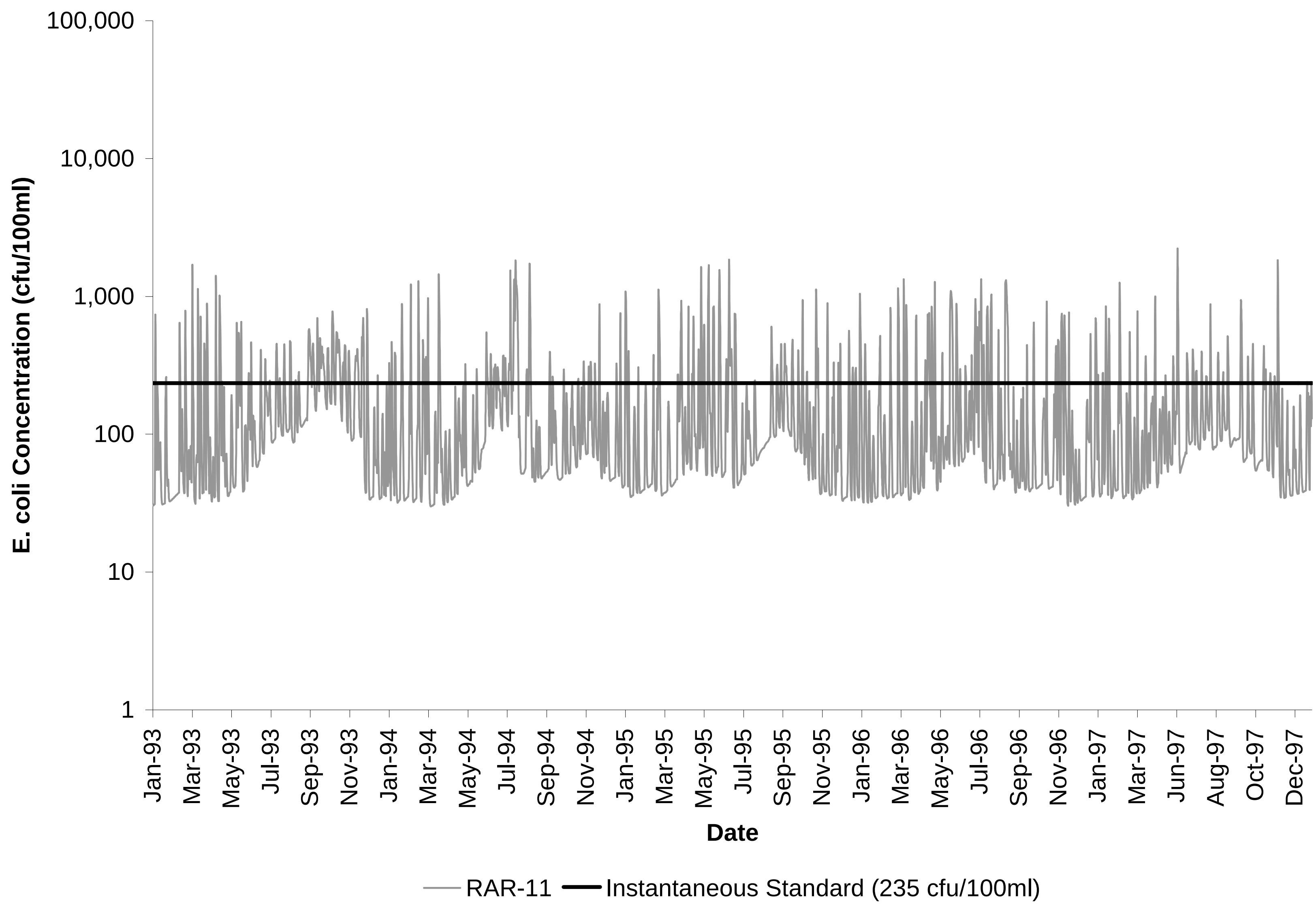

Figure 5.12. Daily average *E. coli* concentrations for subwatershed RAR-11 in Rappahannock River (VAN-E08R-04) watershed.

5.2.7 Rappahannock River (60081)

Figure 5.13 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.14). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rappahannock River (60081) impairment was subwatershed RAR-13.

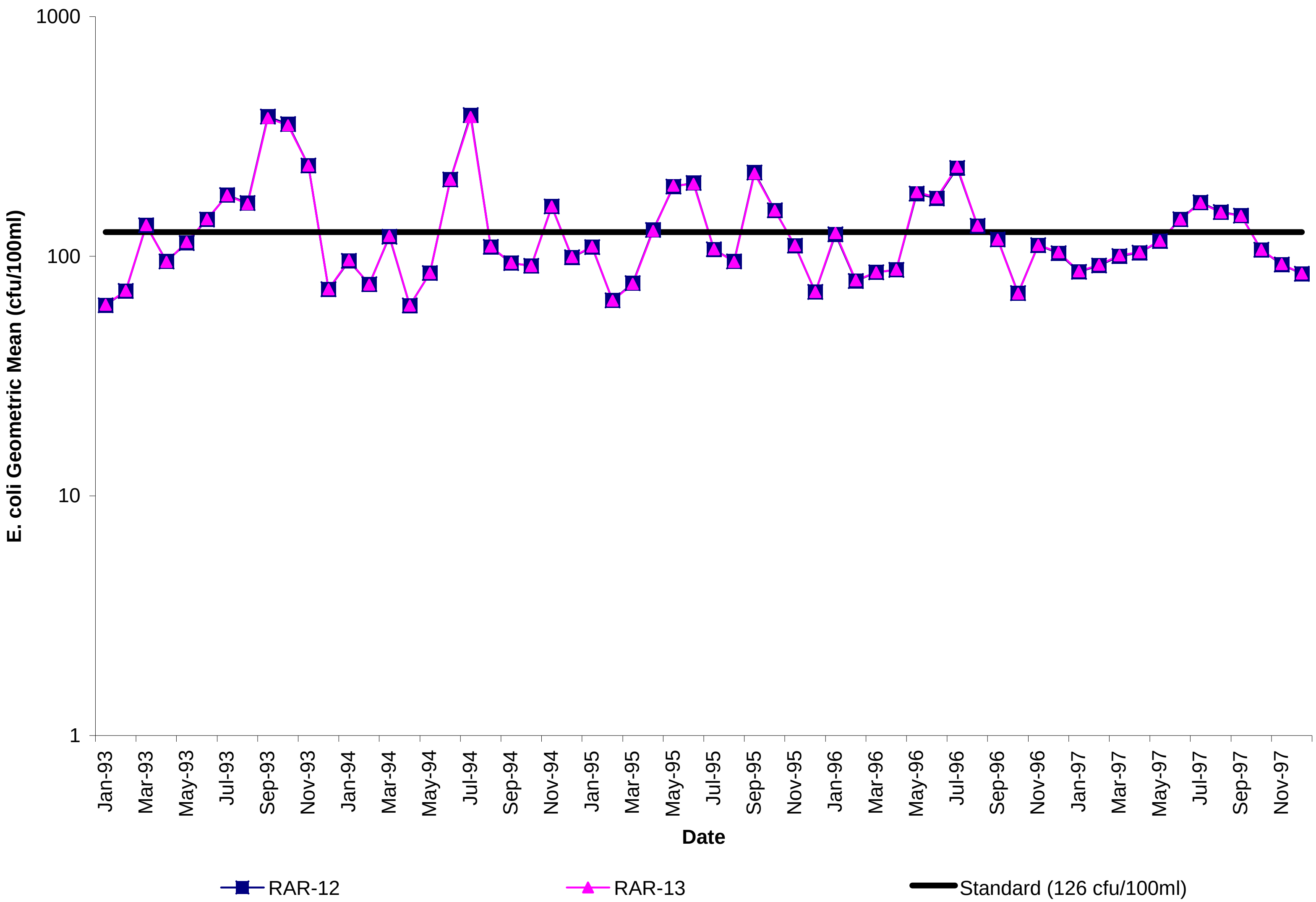

Figure 5.13. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds RAR-12 to RAR-13 in Rappahannock River (60081) watershed.

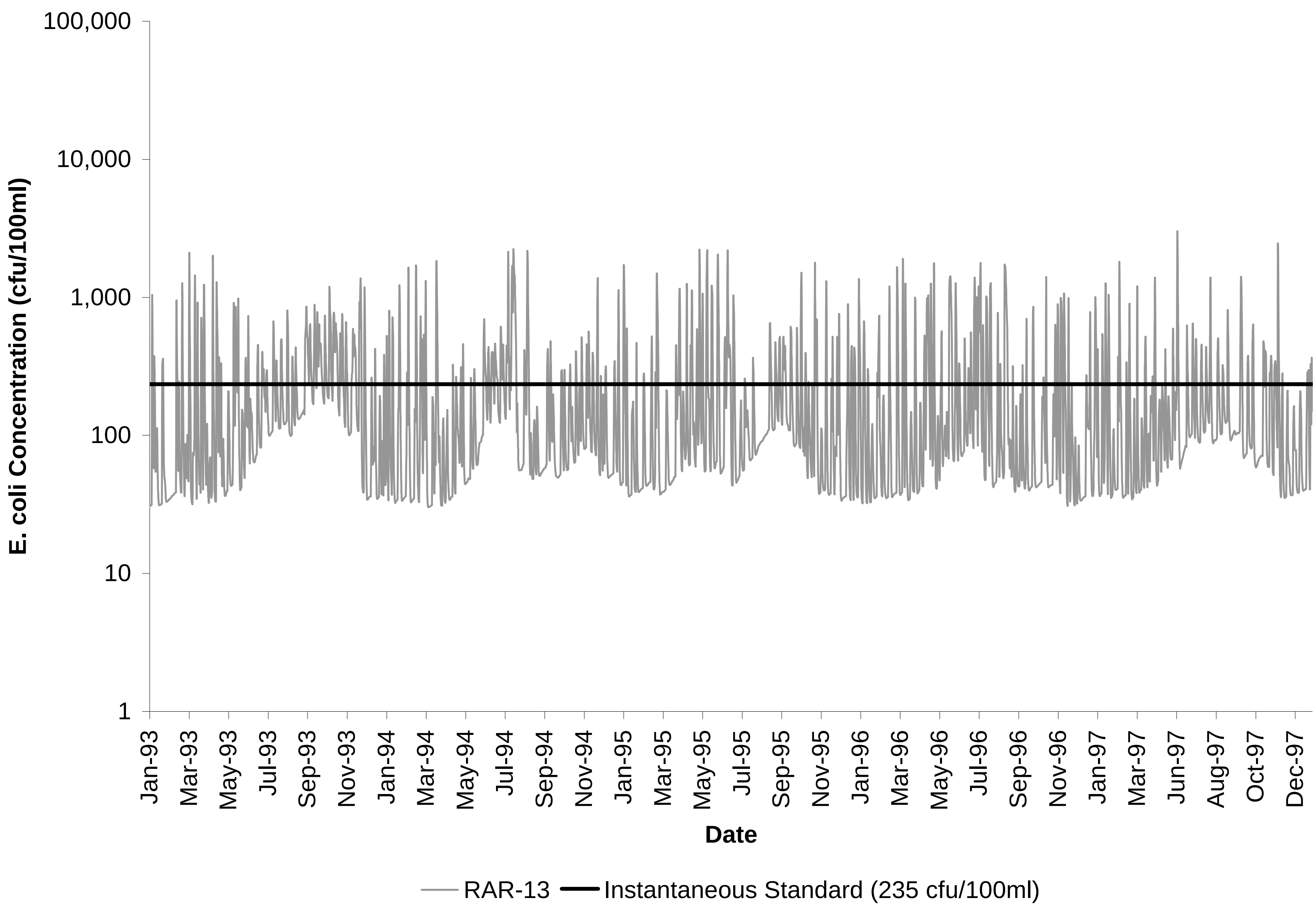

Figure 5.14. Daily average *E. coli* concentrations for subwatershed RAR-13 in Rappahannock River (60081) watershed.

5.2.8 Craig Run (VAN-E08R-03)

Figure 5.15 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.16). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Craig Run (VAN-E08R-03) impairment was subwatershed RAR-14.

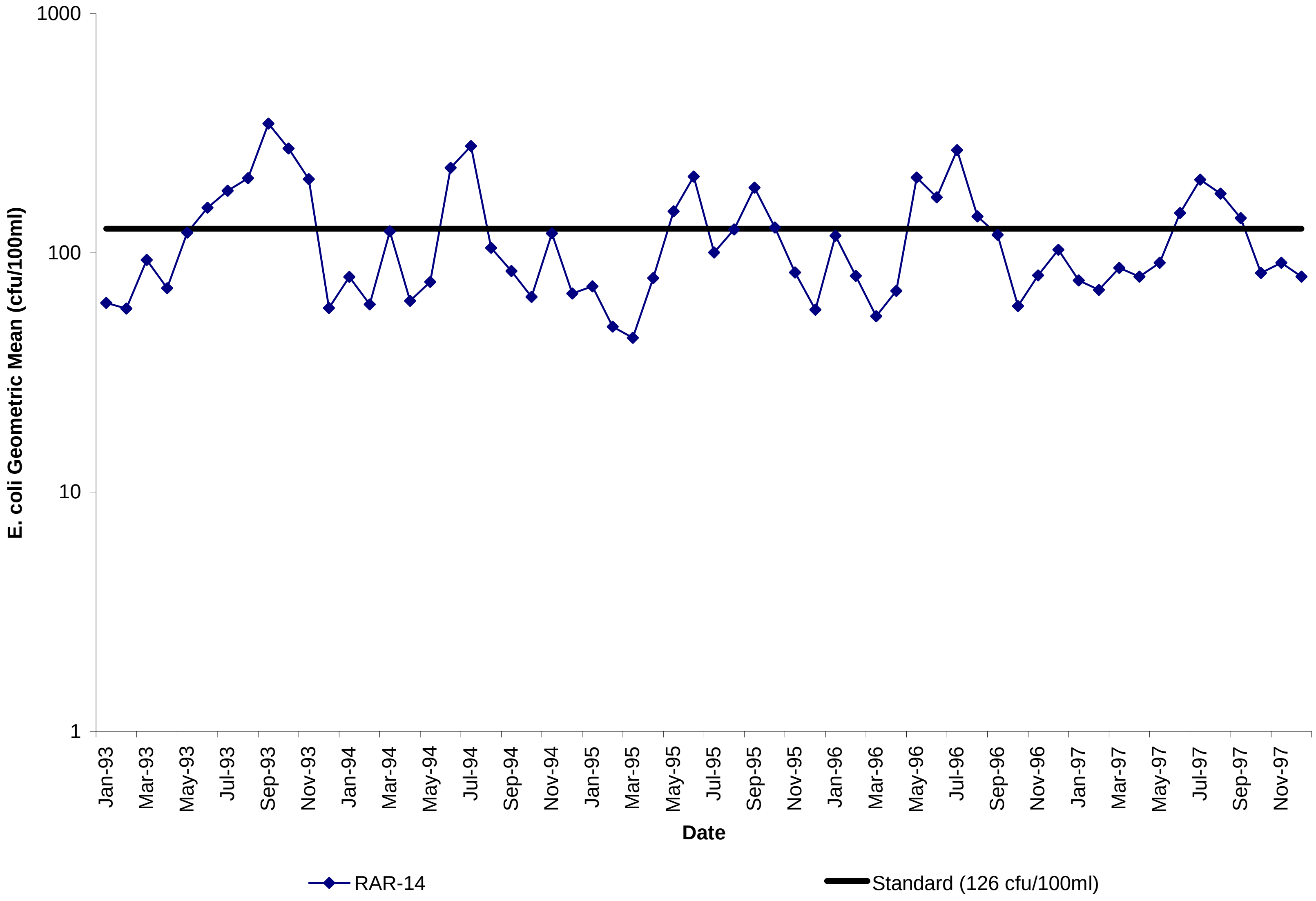

Figure 5.15. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatershed RAR-14 in Craig Run (VAN-E08R-03) watershed.

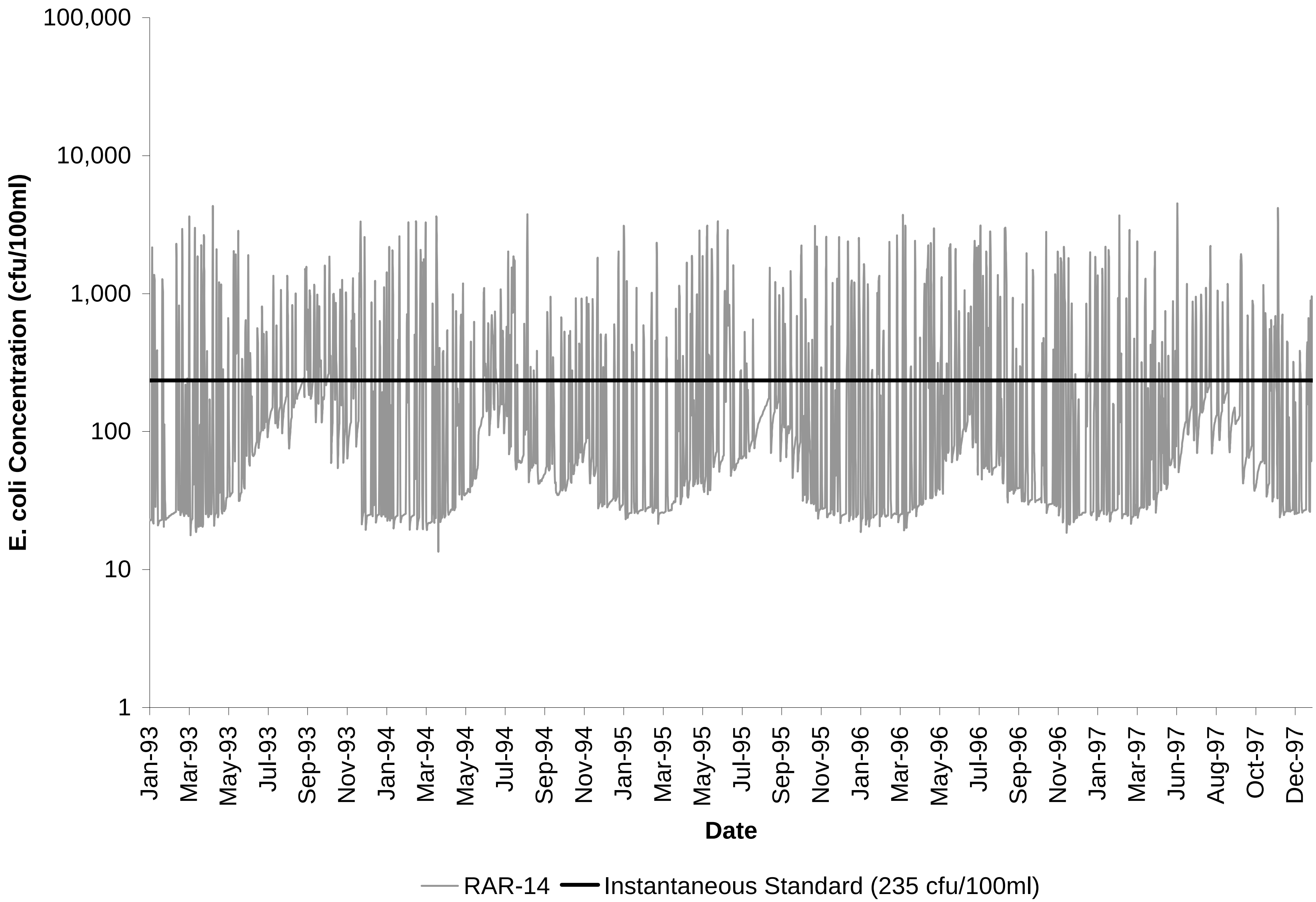

Figure 5.16. Daily average *E. coli* concentrations for subwatershed RAR-14 in Craig Run (VAN-E08R-03) watershed.

5.2.9 Browns Run (VAN-E08R-02)

Figure 5.17 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.18). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Browns Run (VAN-E08R-02) impairment was subwatershed RAR-18.

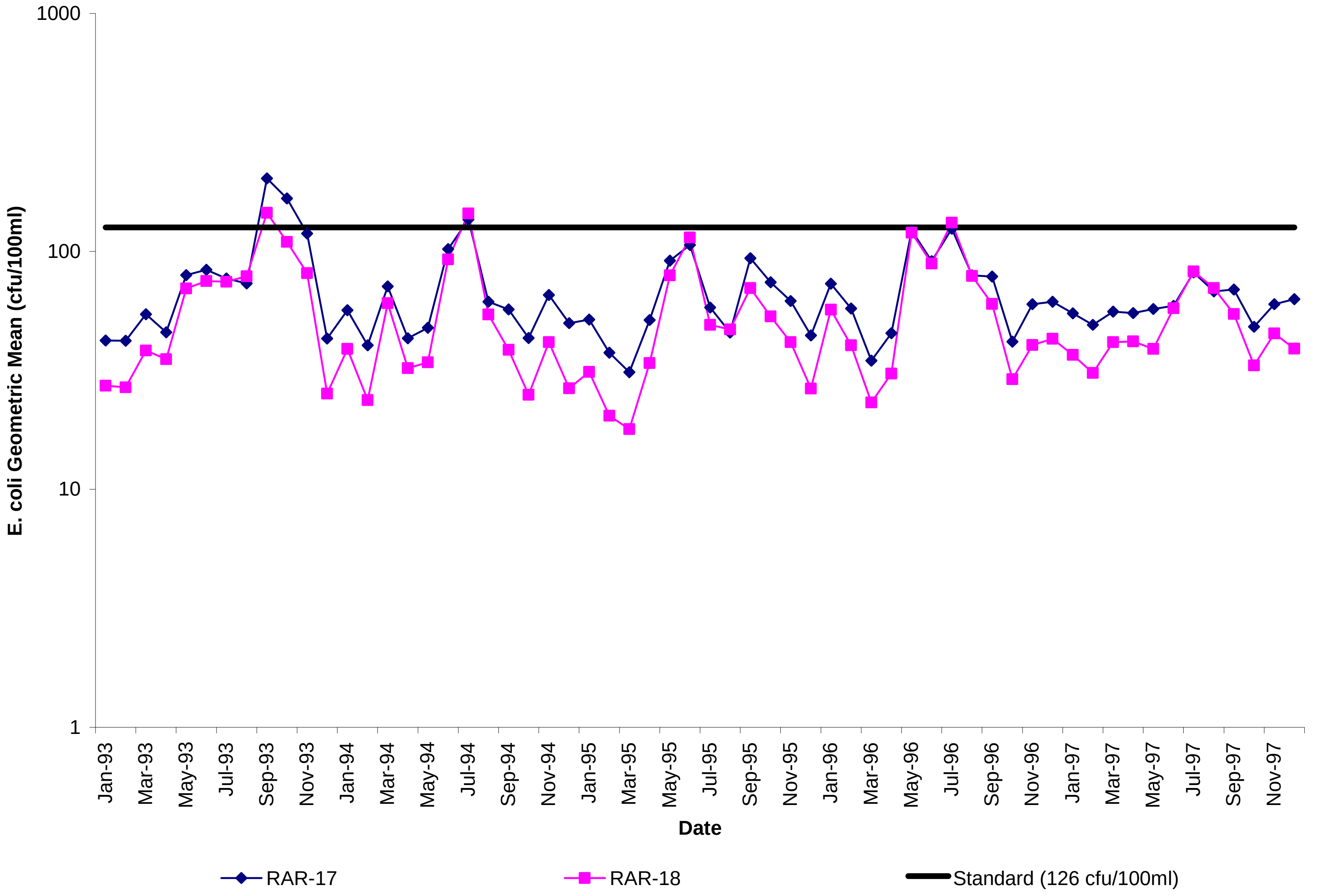

Figure 5.17. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds RAR-17 to RAR-18 in Browns Run (VAN-E08R-02) watershed.

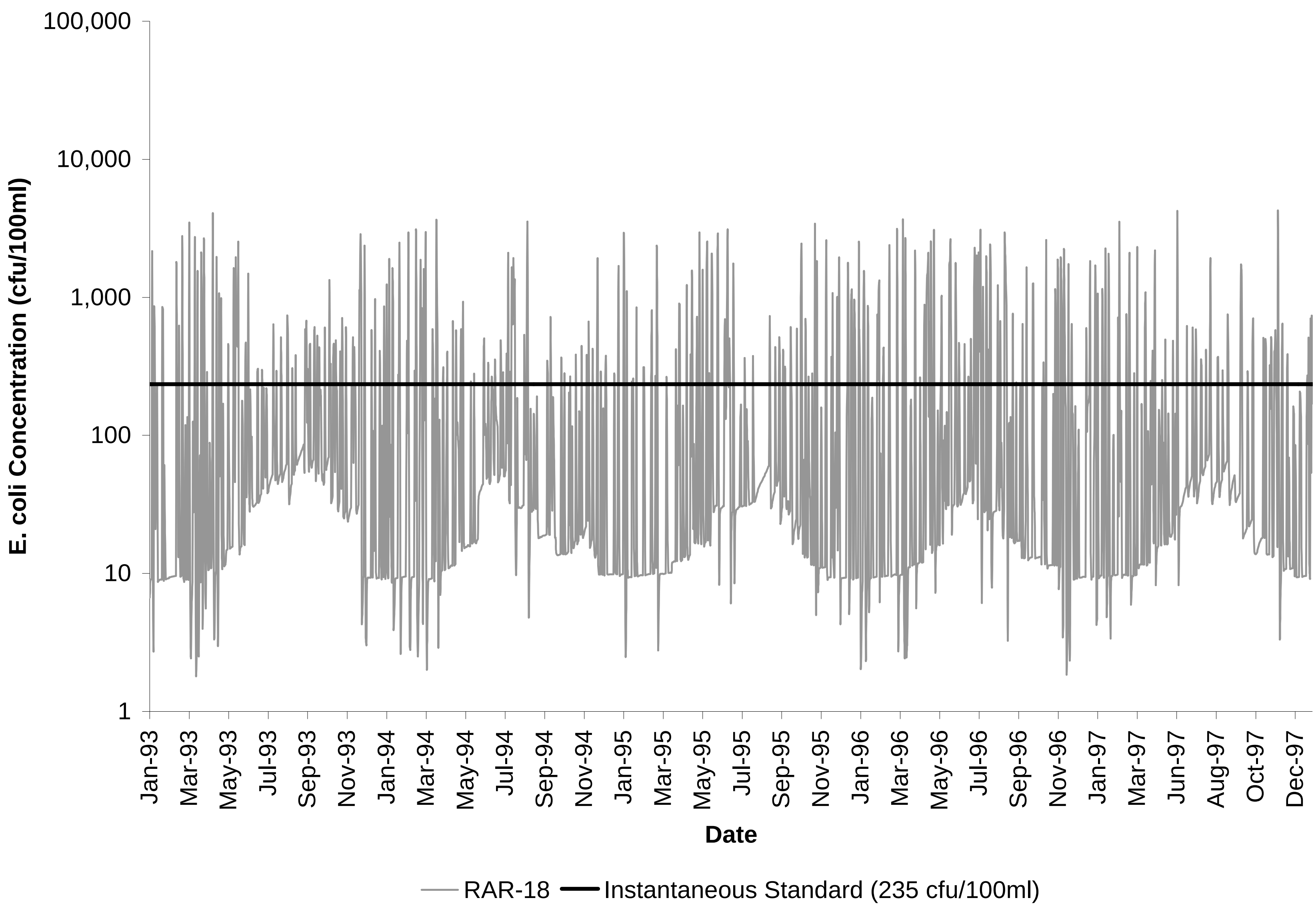

Figure 5.18. Daily average *E. coli* concentrations for subwatershed RAR-18 in Browns Run (VAN-E08R-02) watershed.

5.2.10 Marsh Run (VAN-E08R-01)

Figure 5.19 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.20). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Marsh Run (VAN-E08R-01) impairment was subwatershed RAR-20.

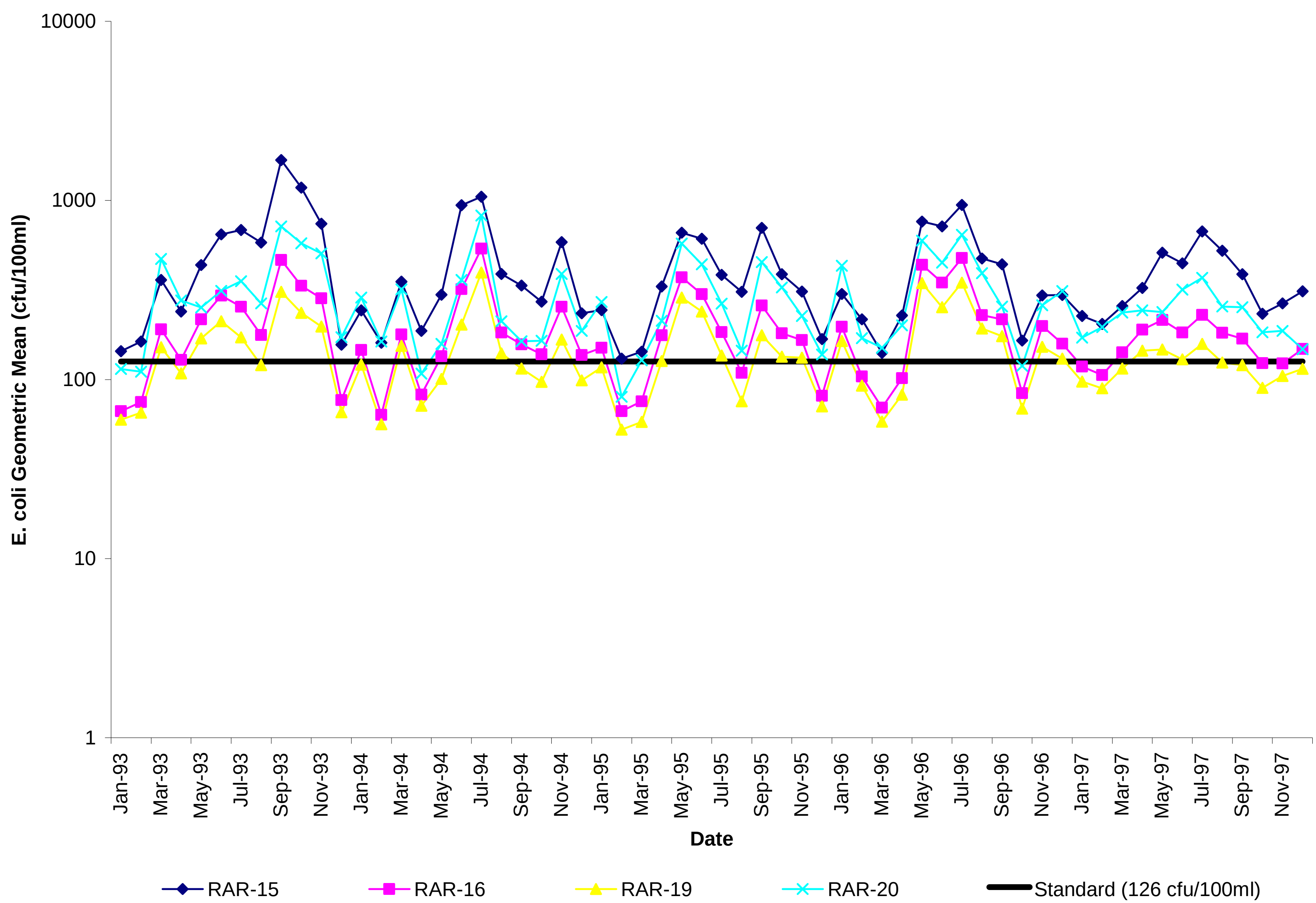

Figure 5.19. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds RAR-15 to RAR-16; RAR-19 to RAR-20 in Marsh Run (VAN-E08R-01) watershed.

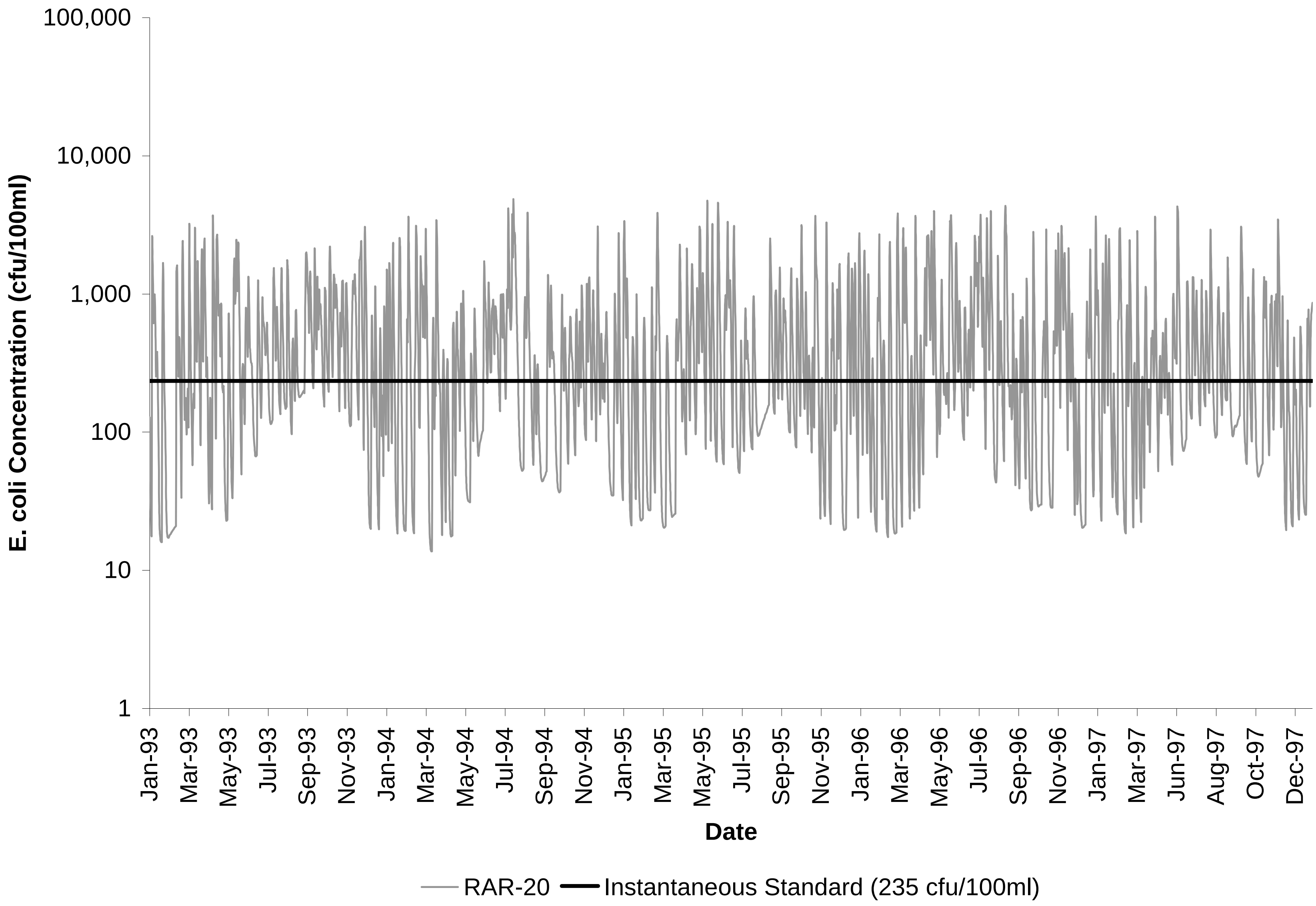

Figure 5.20. Daily average *E. coli* concentrations for subwatershed RAR-20 in Marsh Run (VAN-E08R-01) watershed.

5.3 Impact Analysis

Analyses were conducted to assess the impact of unknown variability in source allocations on changes in direct and land-based loads. Model output from existing conditions was set as the comparative base to adjustments in direct and land-based loads of +100%, +10%, -10%, and -100% of the base value. Model simulations were made for the period January 1993 to December 1997, corresponding with the period used in the allocation scenarios. Percent difference in monthly geometric mean *E. coli* concentration and maximum daily average *E. coli* concentration per month for each direct and land-based load change to base value was calculated and plotted. Analysis results were used to assess the affects of future growth on the rate of water quality standards exceedance.

5.3.1 Hughes River (VAN-E03R-01)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.21 and 5.22, respectively. Figures 5.23 and 5.24, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.21 with Figure 5.22 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.23 to Figure 5.24 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

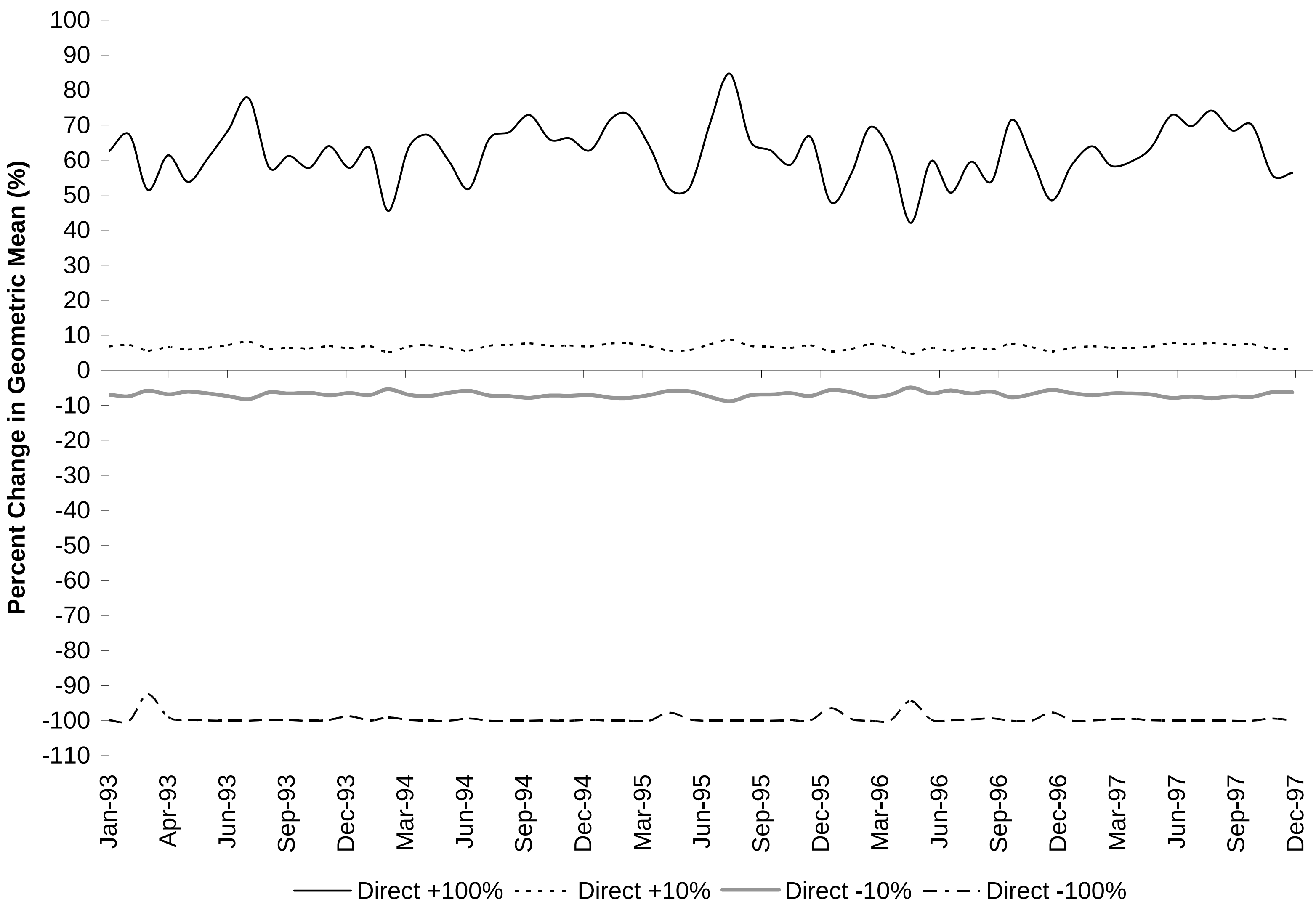

Figure 5.21. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-2) of Hughes River (VAN-E03R-01) watershed, as affected by direct load changes.

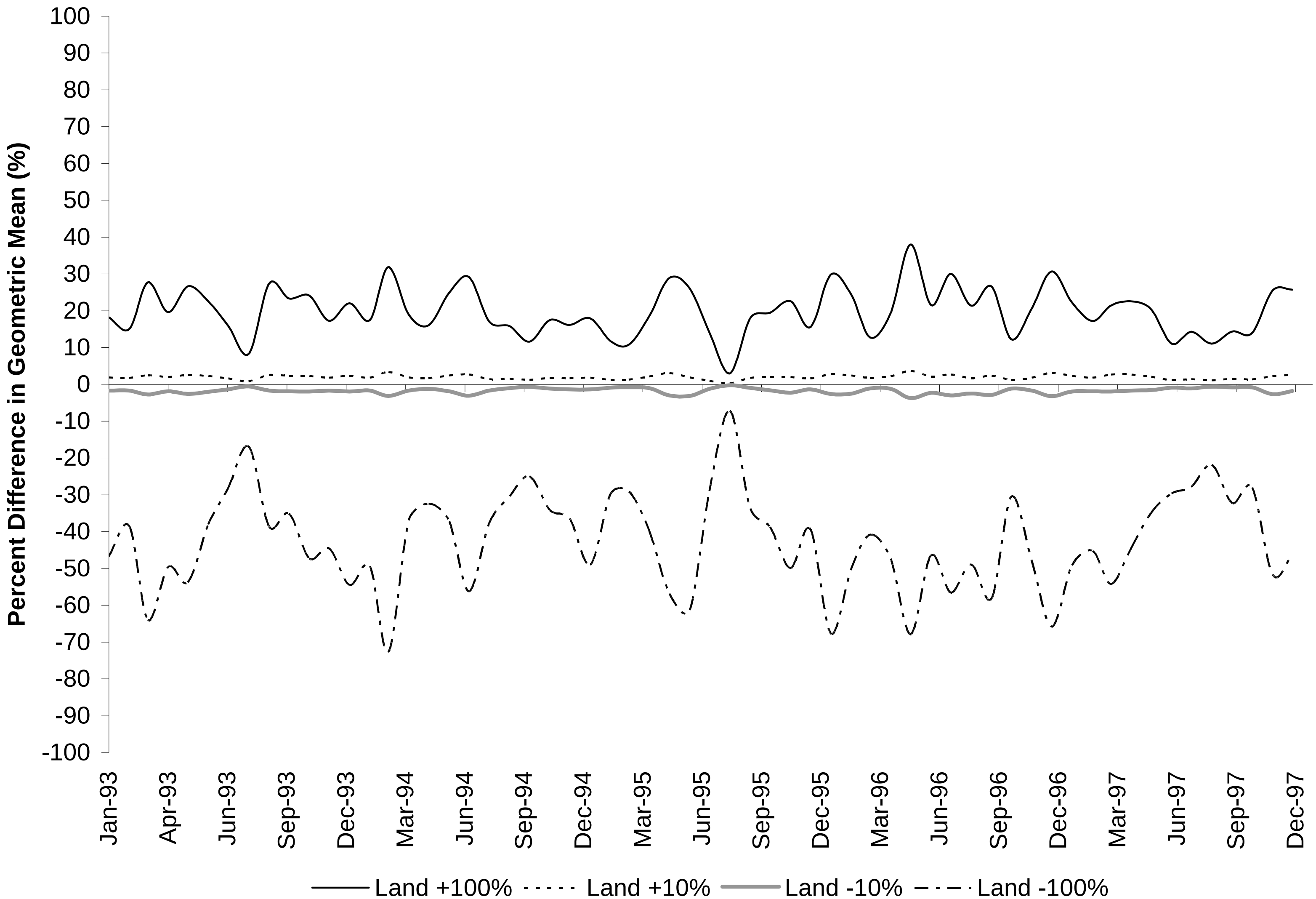

Figure 5.22. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-2) of Hughes River (VAN-E03R-01) watershed, as affected by land-based load changes.

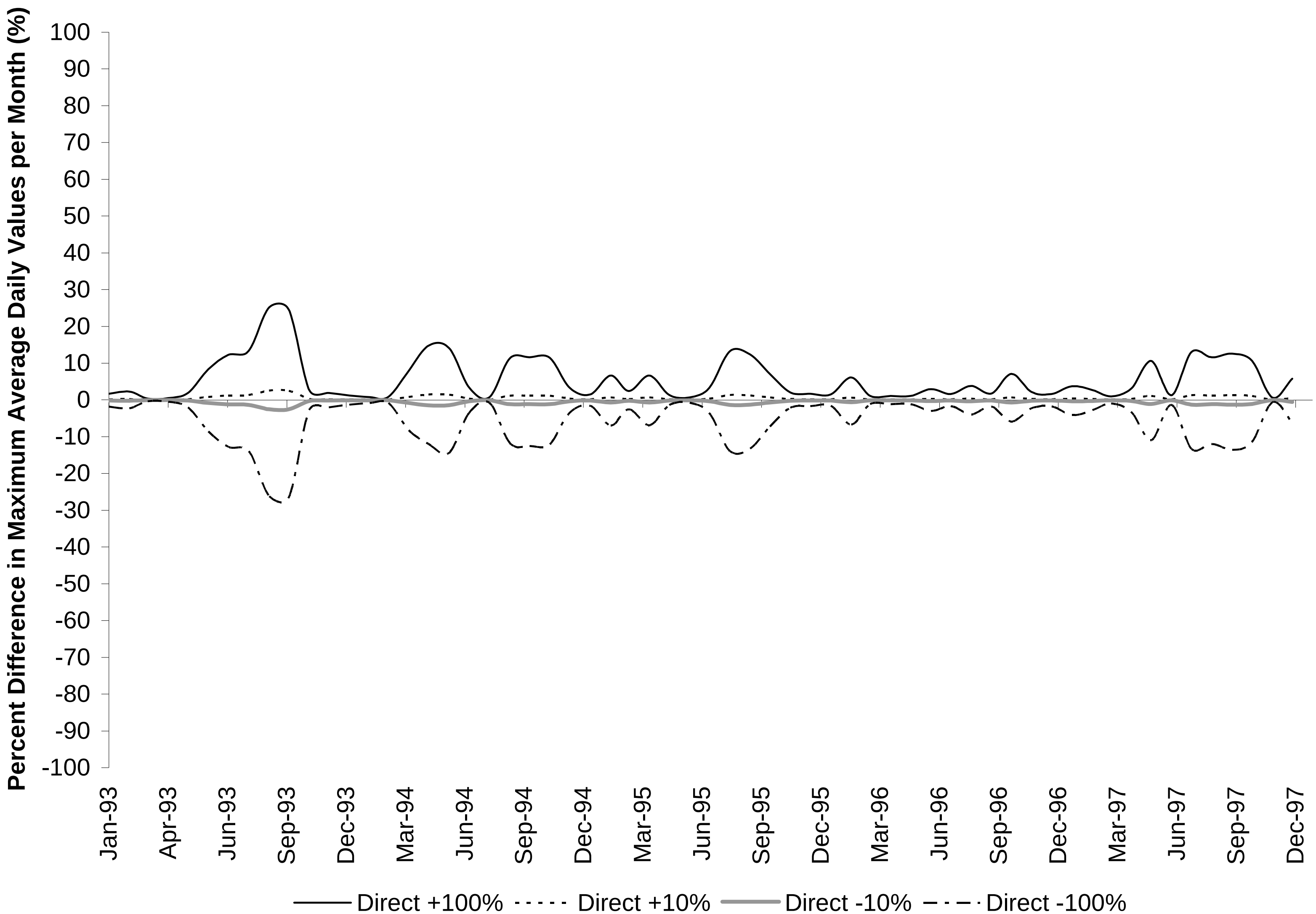

Figure 5.23. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-2) of Hughes River (VAN-E03R-01) watershed, as affected by direct load changes.

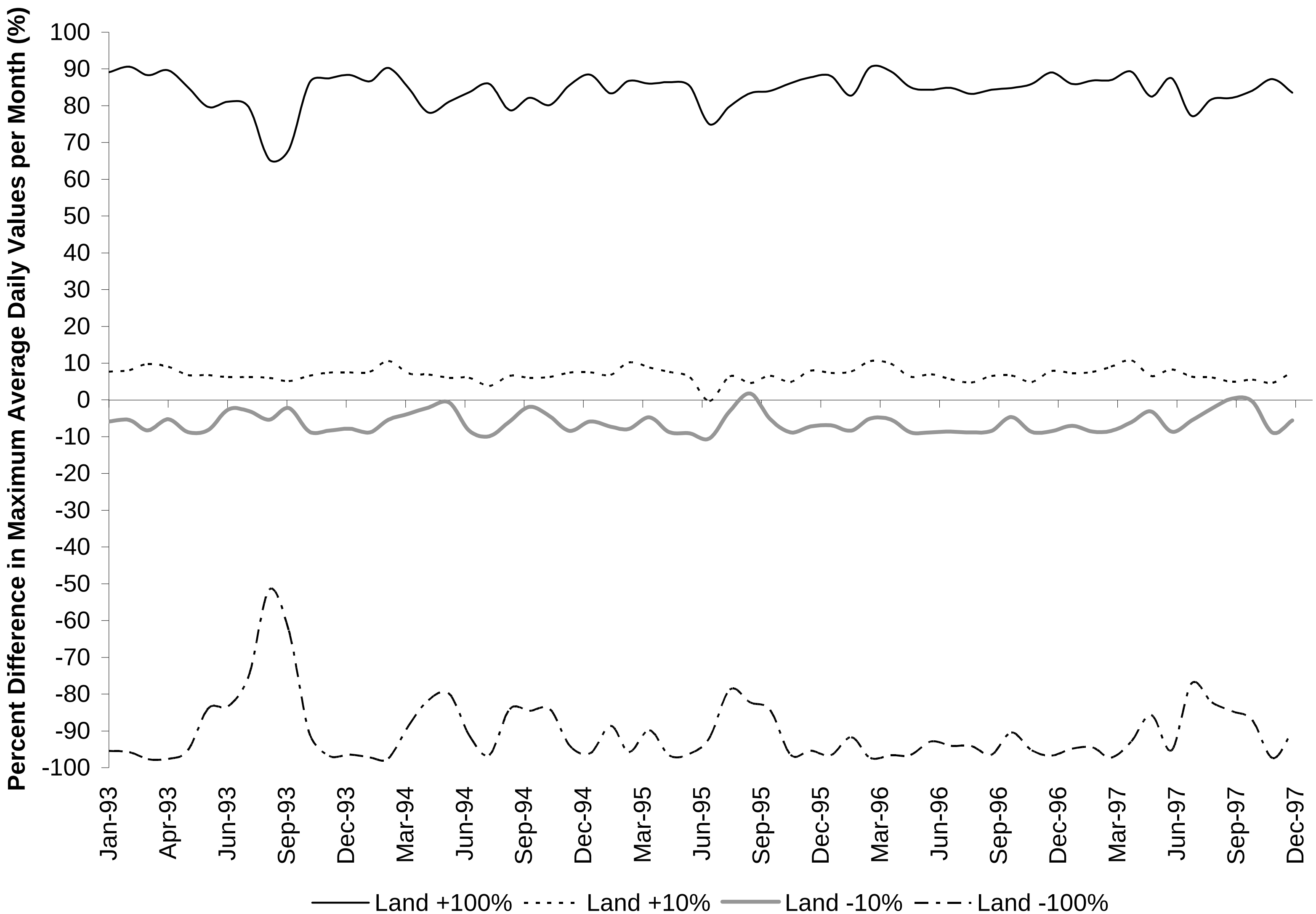

Figure 5.24. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-2) of Hughes River (VAN-E03R-01) watershed, as affected by land-based load changes.

5.3.2 Hazel River (VAN-E04R-01)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.25 and 5.26, respectively. Figures 5.27 and 5.28, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.25 with Figure 5.26 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.27 to Figure 5.28 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

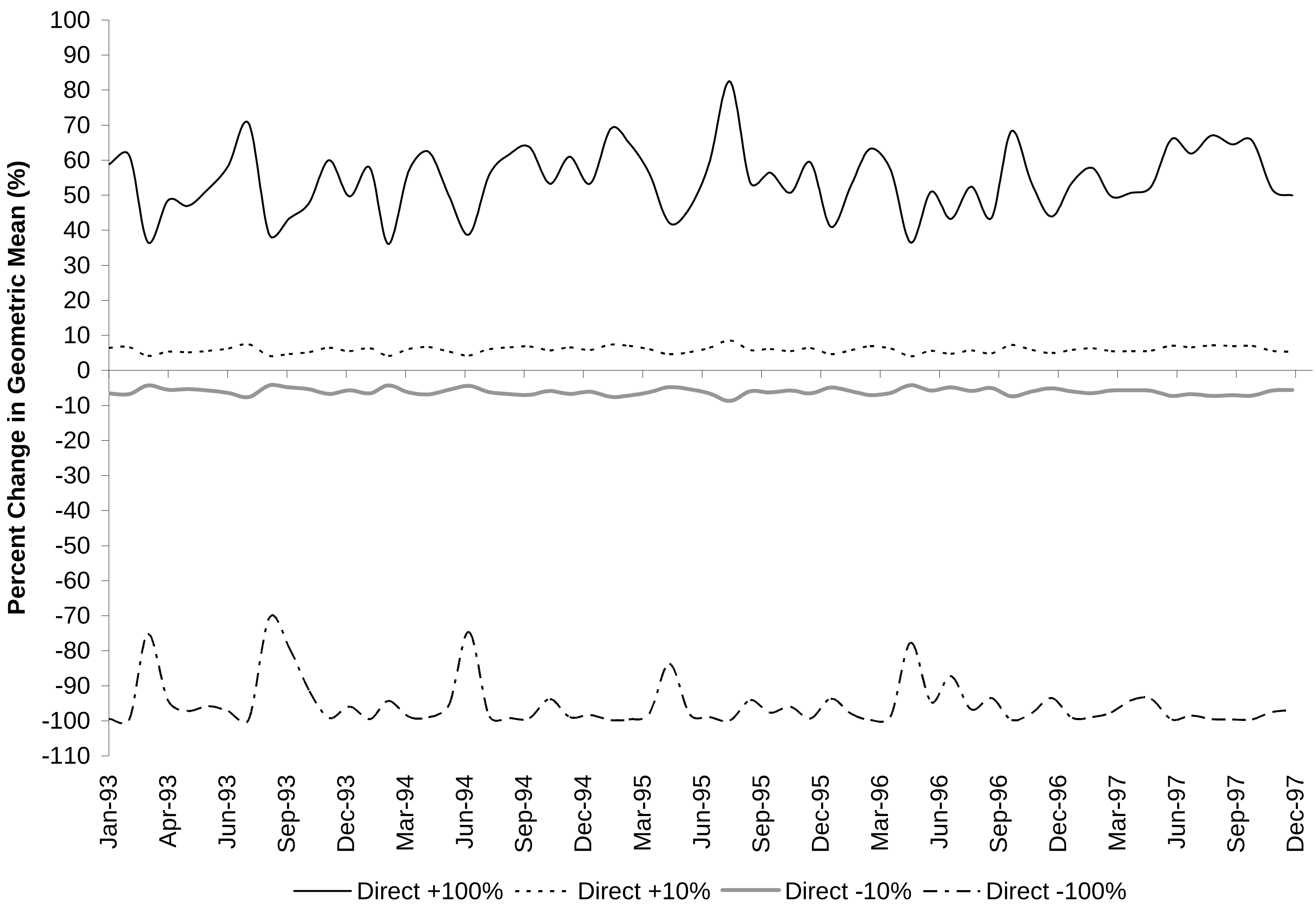

Figure 5.25. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-8) of Hazel River (VAN-E04R-01) watershed, as affected by direct load changes.

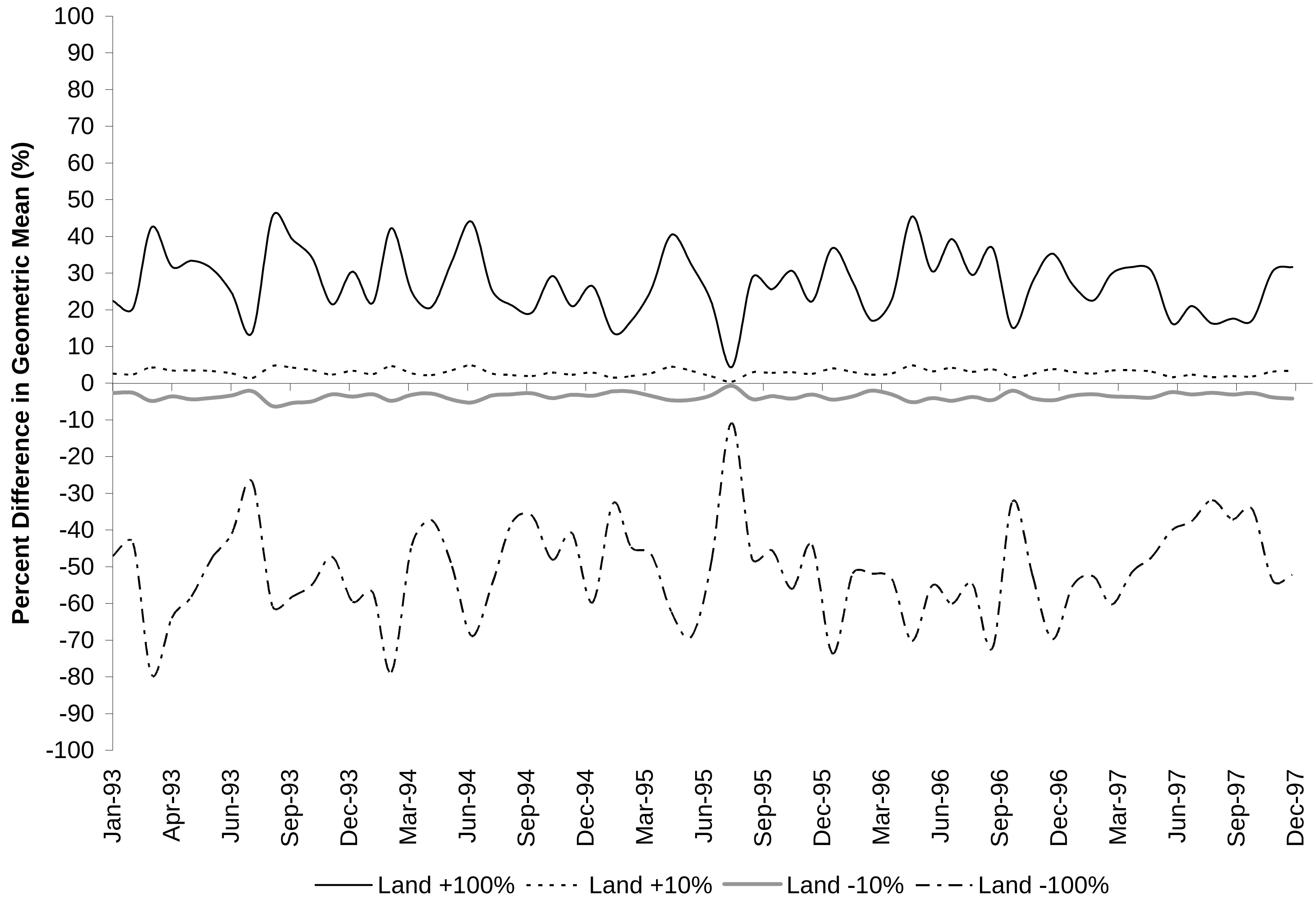

Figure 5.26. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-8) of Hazel River (VAN-E04R-01) watershed, as affected by land-based load changes.

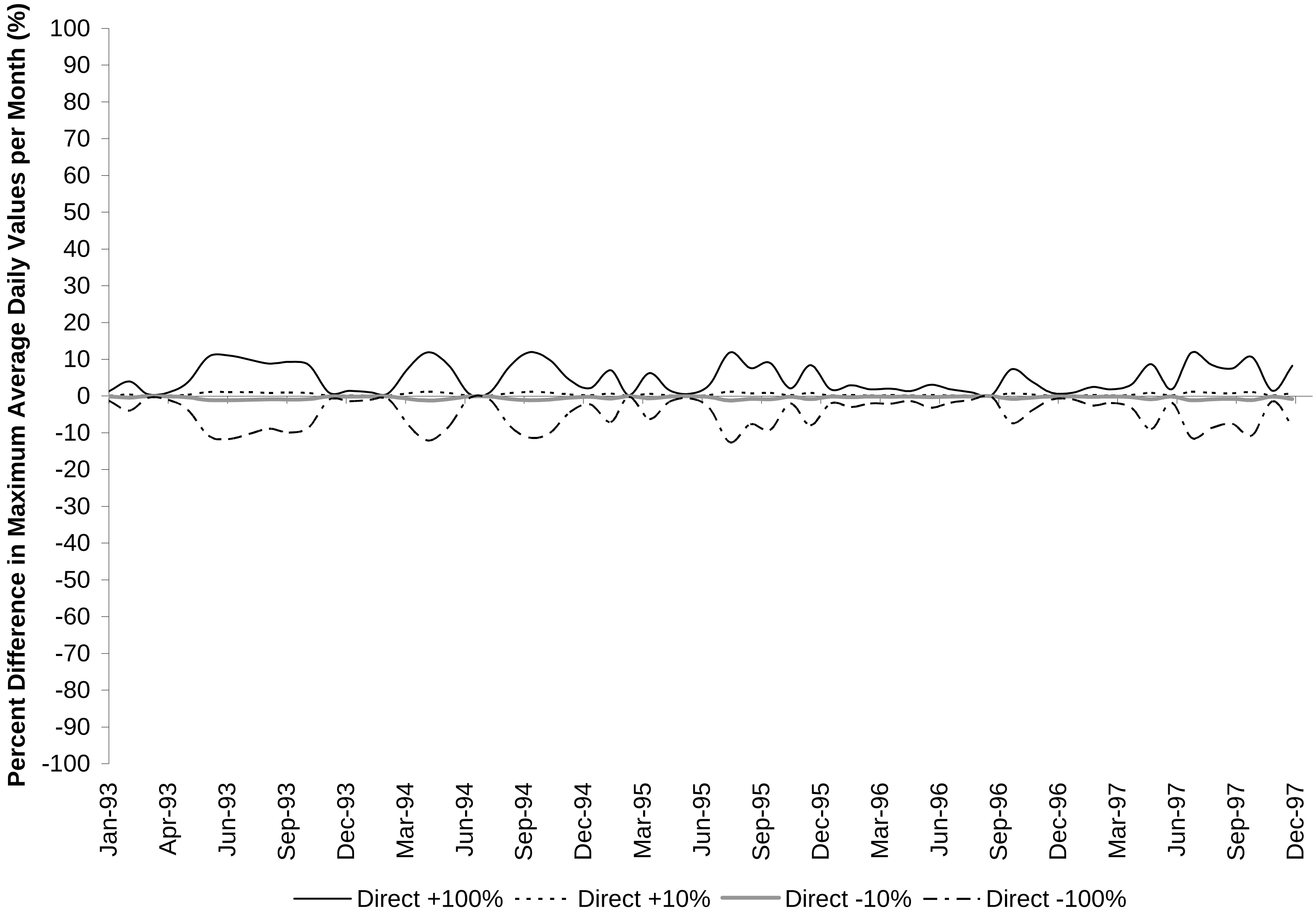

Figure 5.27. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-8) of Hazel River (VAN-E04R-01) watershed, as affected by direct load changes.

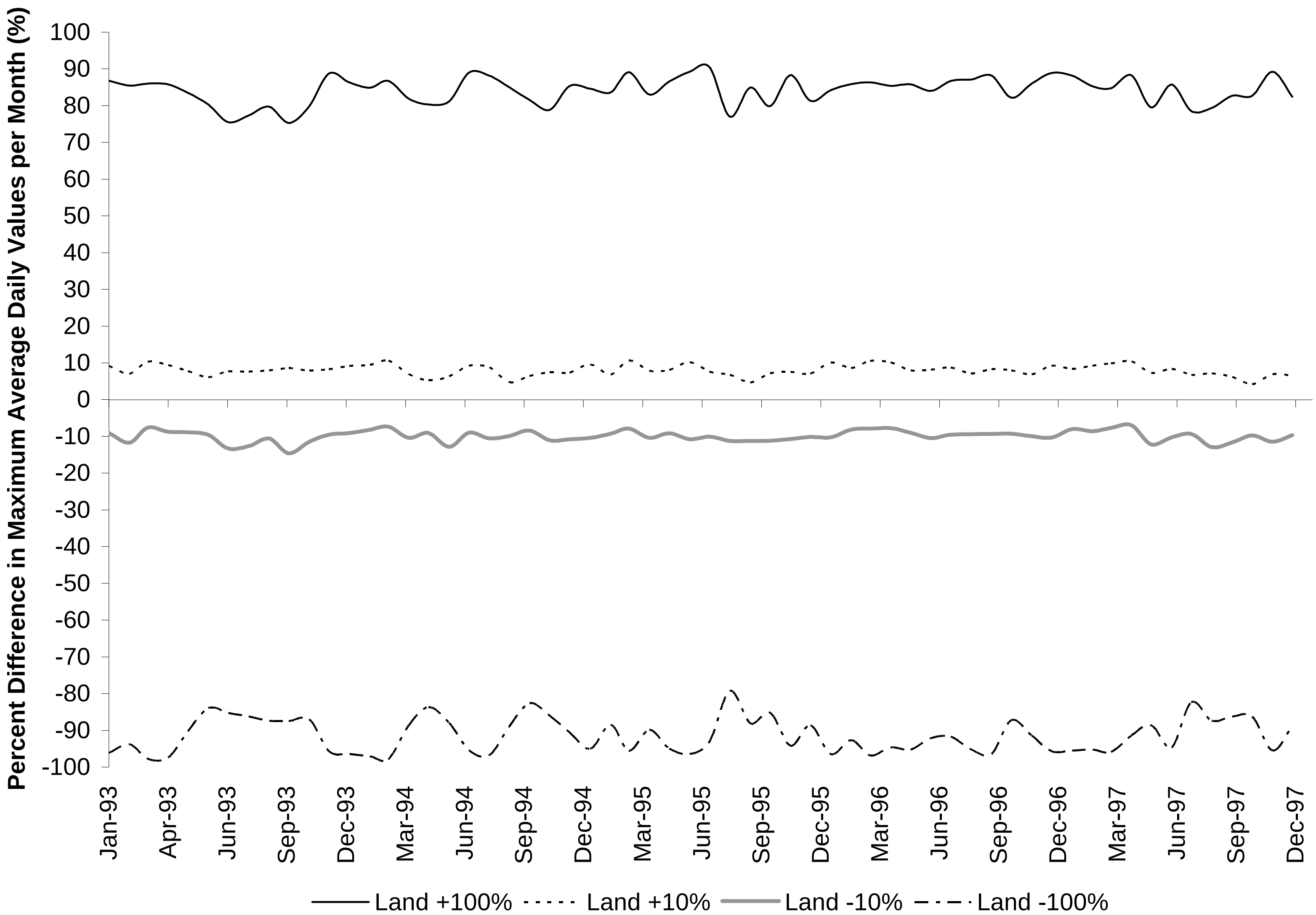

Figure 5.28. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-8) of Hazel River (VAN-E04R-01) watershed, as affected by land-based load changes.

5.3.3 Rush River (VAN-E05R-01)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.29 and 5.30, respectively. Figures 5.31 and 5.32, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.29 with Figure 5.30 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.31 to Figure 5.32 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

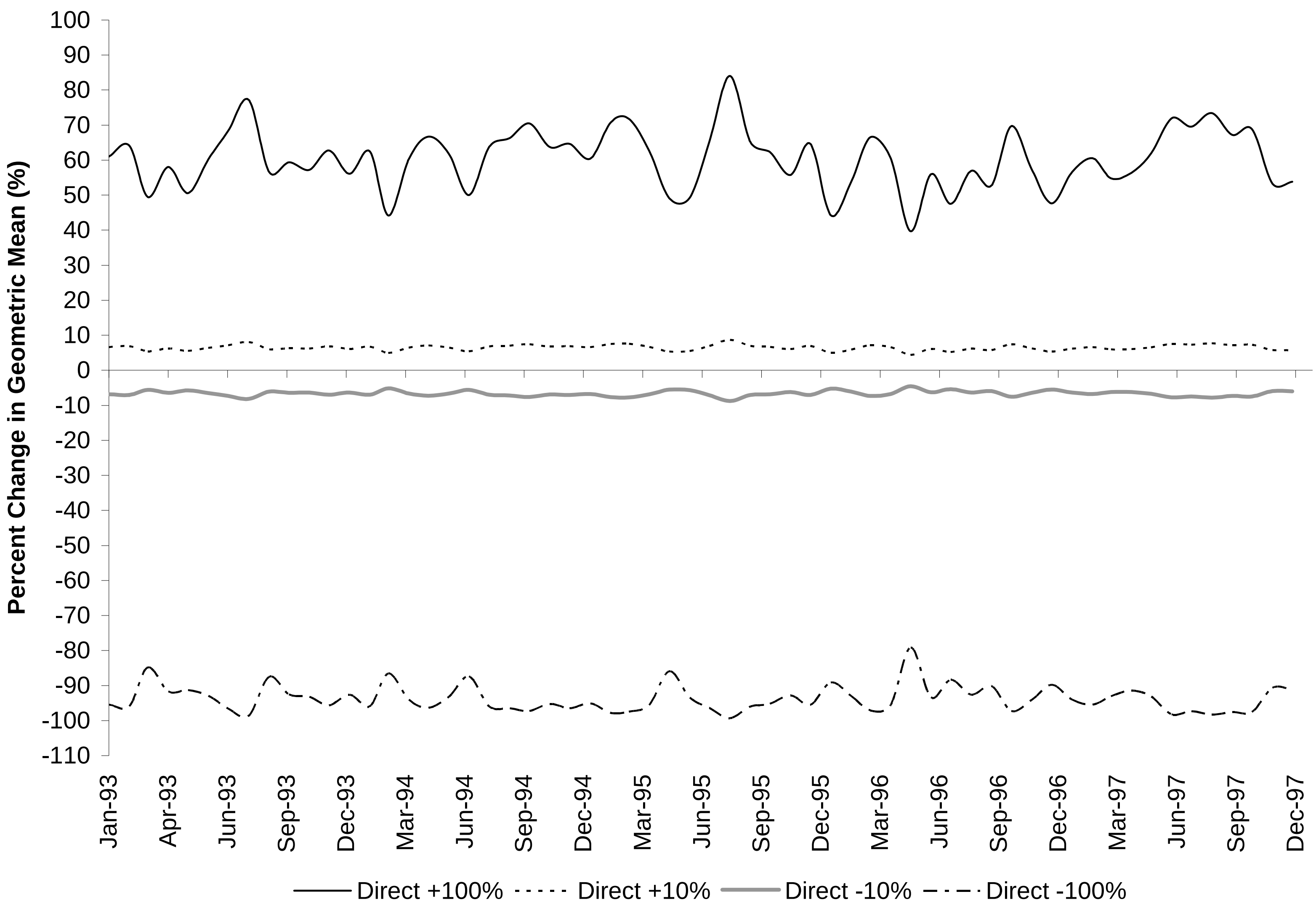

Figure 5.29. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-12) of Rush River (VAN-E05R-01) watershed, as affected by direct load changes.

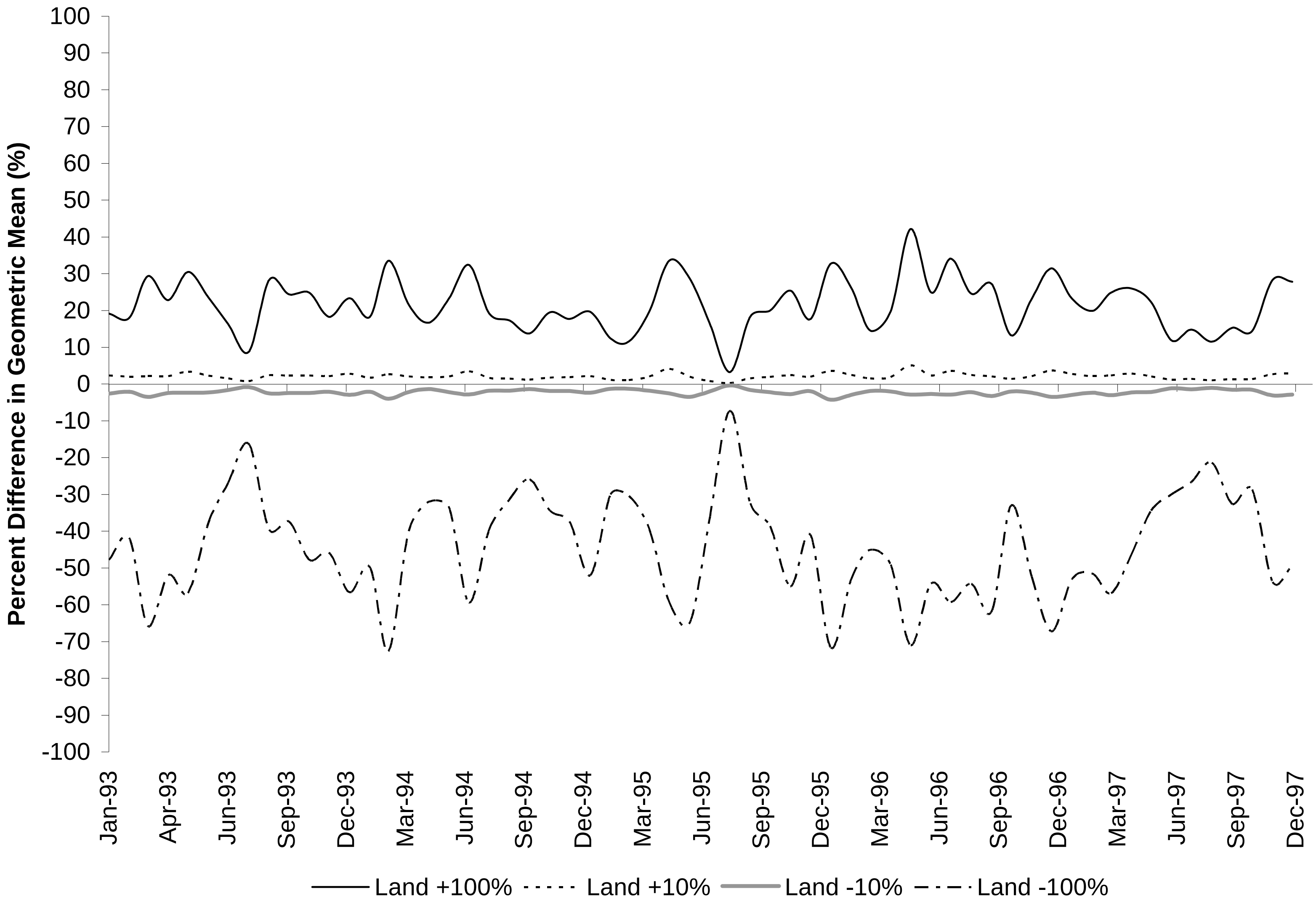

Figure 5.30. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-12) of Rush River (VAN-E05R-01) watershed, as affected by land-based load changes.

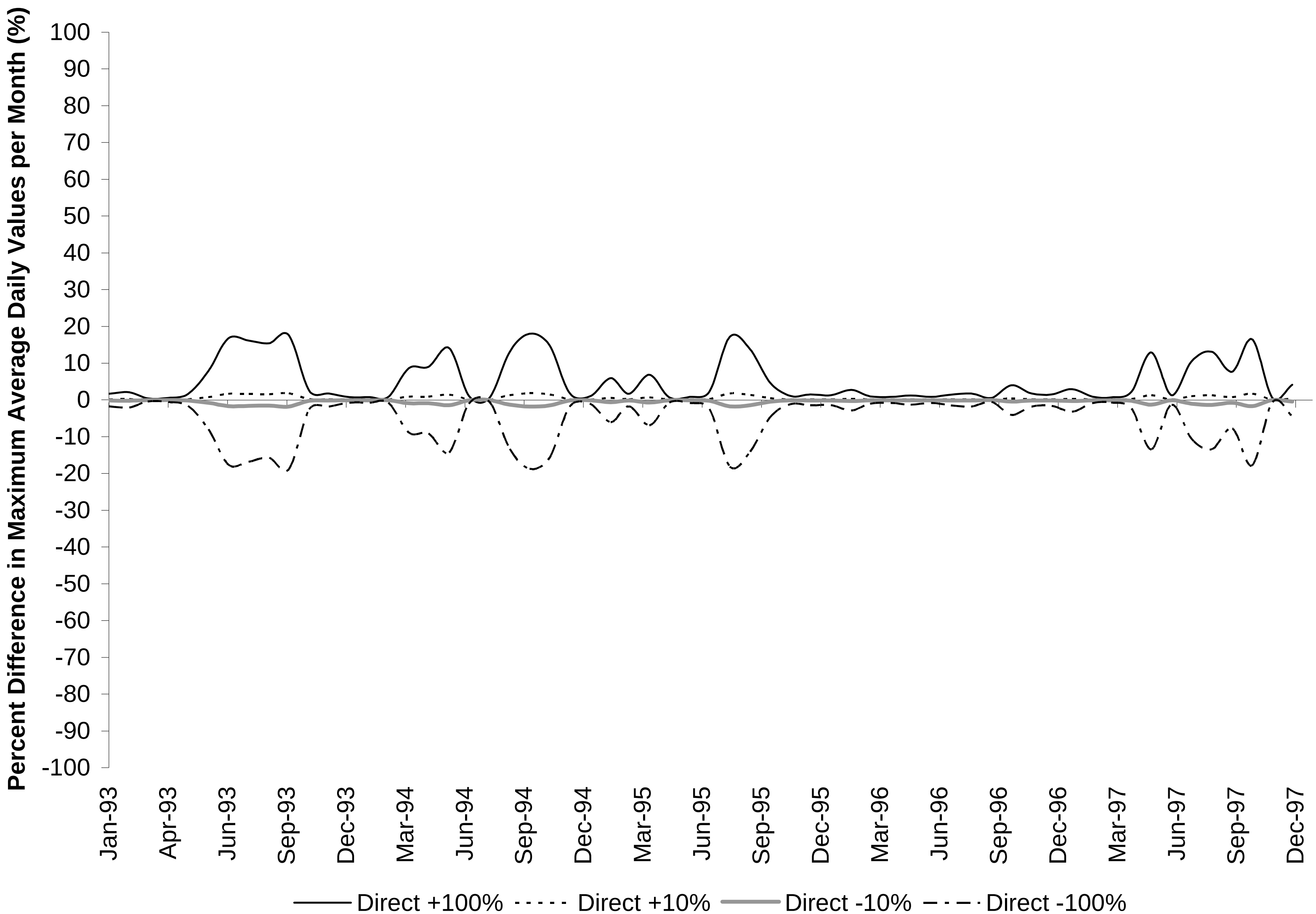

Figure 5.31. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-12) of Rush River (VAN-E05R-01) watershed, as affected by direct load changes.

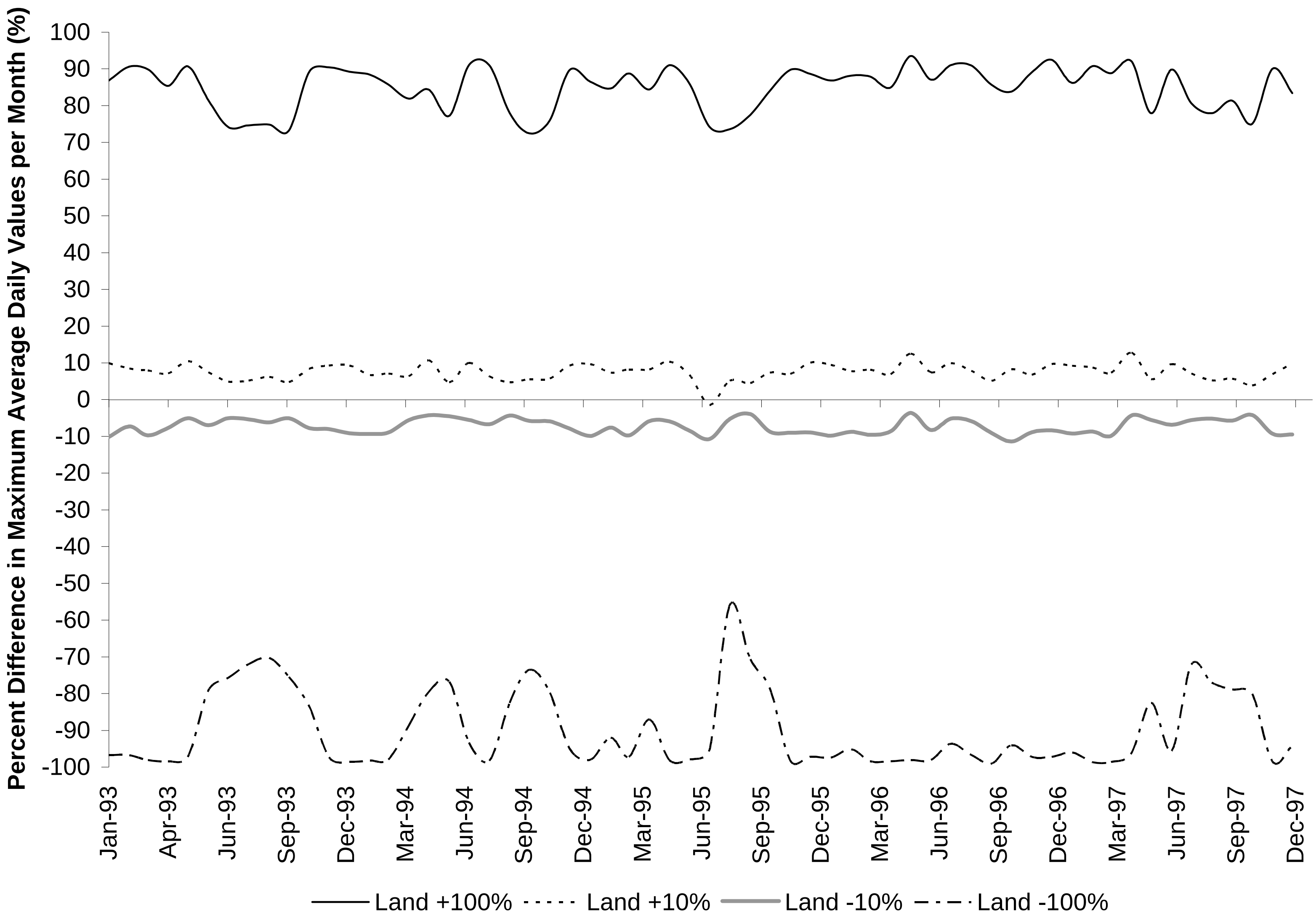

Figure 5.32. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-12) of Rush River (VAN-E05R-01) watershed, as affected by land-based load changes.

5.3.4 Hazel River (60076)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.33 and 5.34, respectively. Figures 5.35 and 5.36, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.33 with Figure 5.34 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.35 to Figure 5.36 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

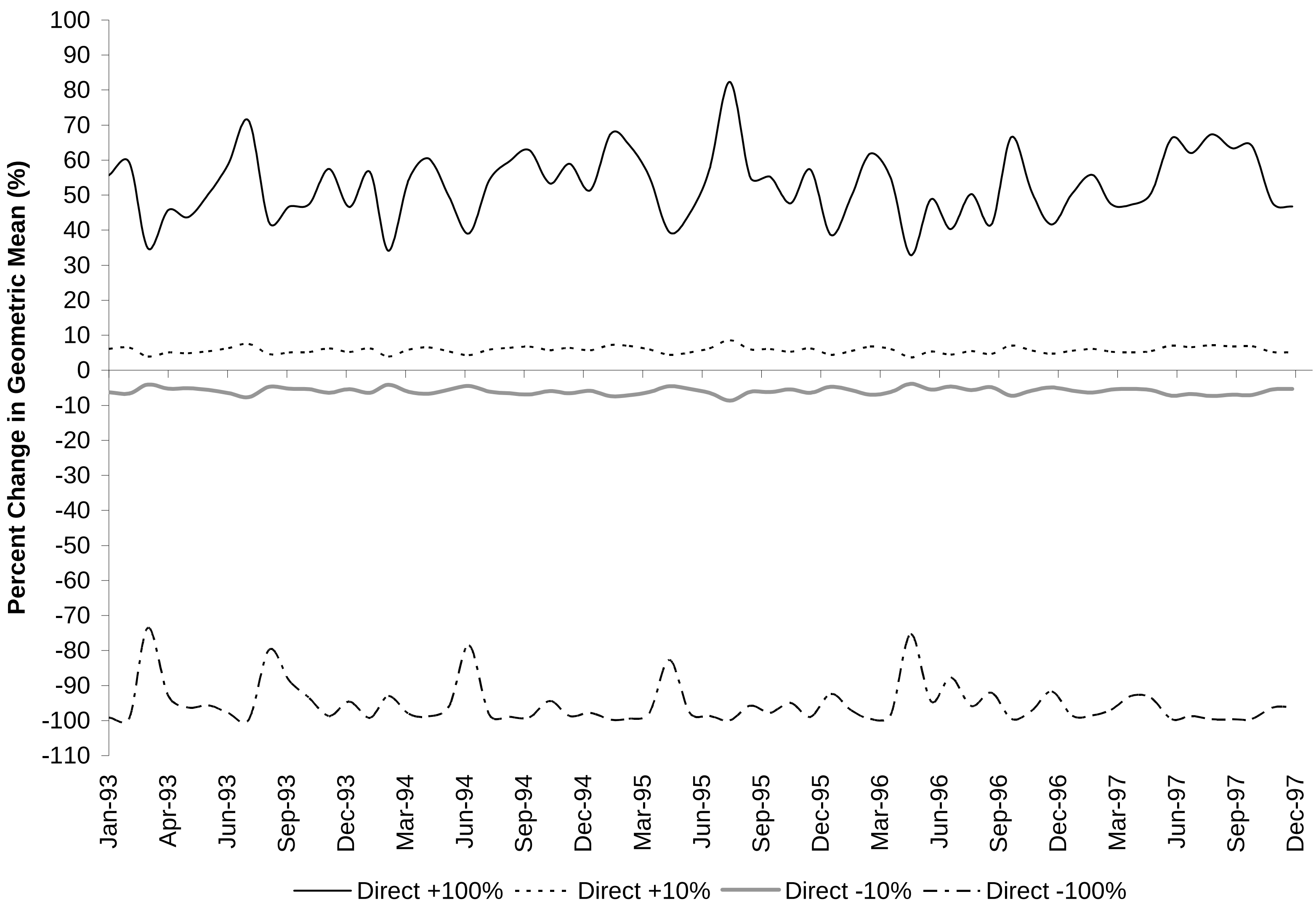

Figure 5.33. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-19) of Hazel River (60076) watershed, as affected by direct load changes.

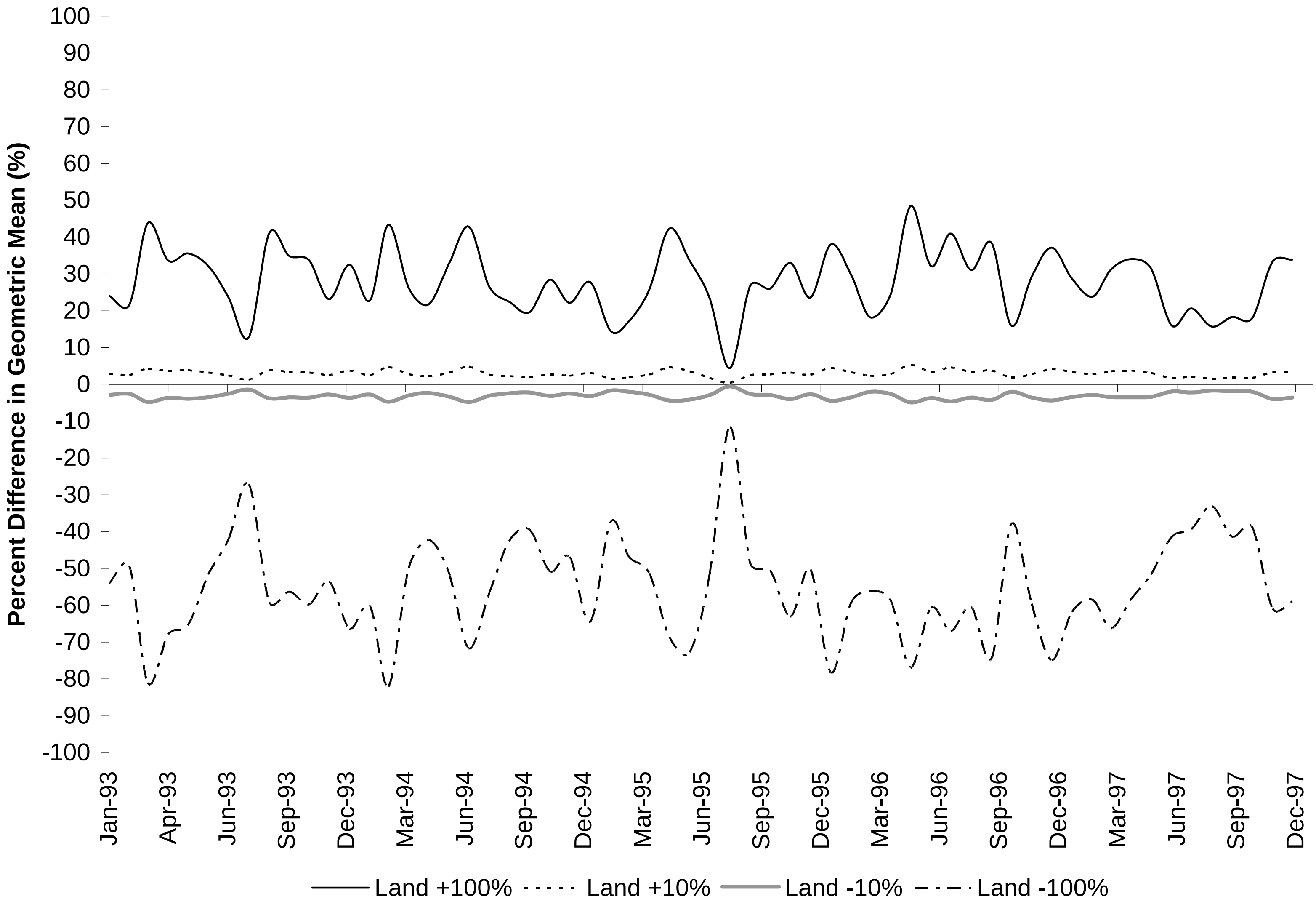

Figure 5.34. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed HAR-19) of Hazel River (60076) watershed, as affected by land-based load changes.

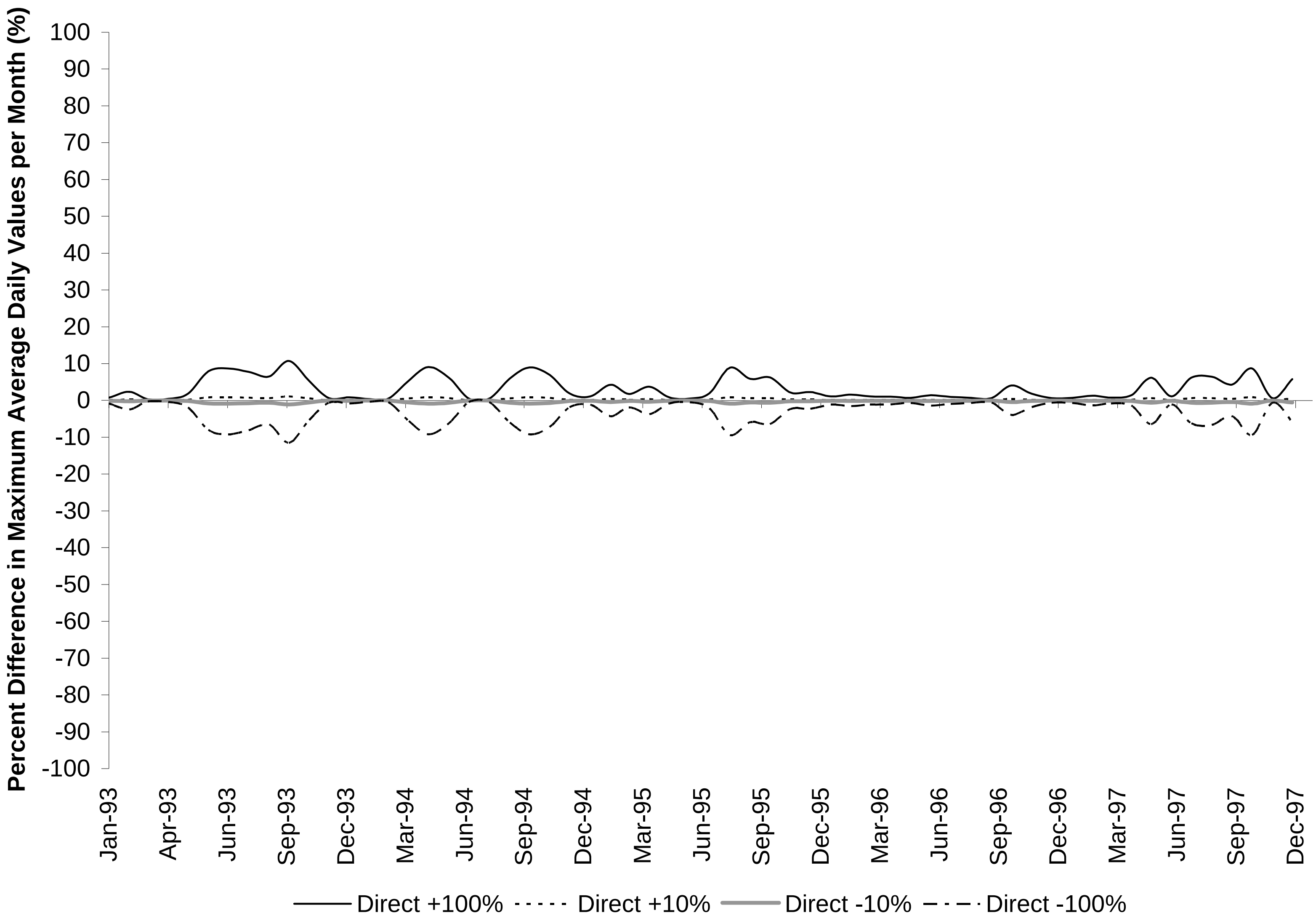

Figure 5.35. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-19) of Hazel River (60076) watershed, as affected by direct load changes.

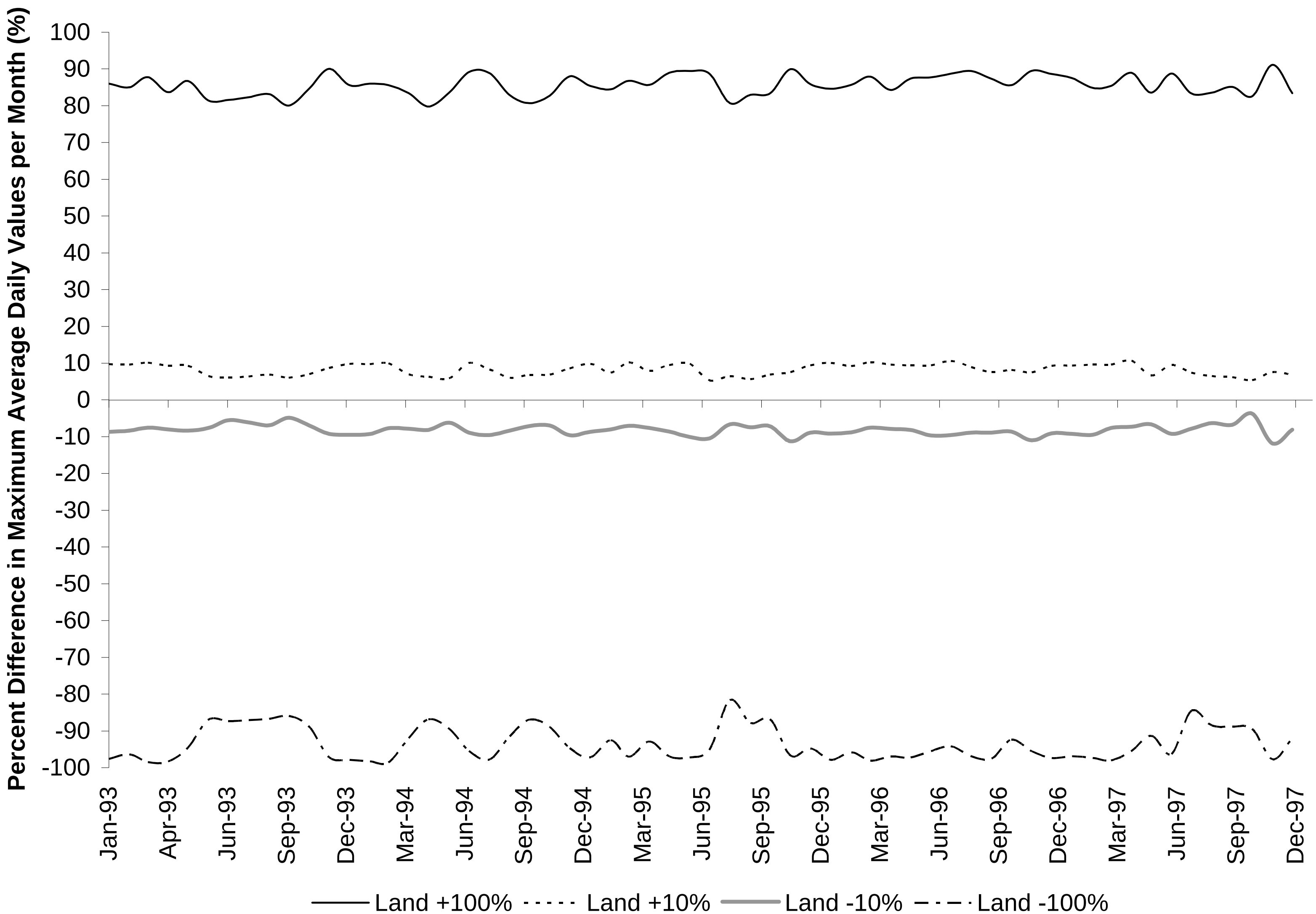

Figure 5.36. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed HAR-19) of Hazel River (60076) watershed, as affected by land-based load changes.

5.3.5 Rappahannock River (VAN-E01R-03)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.37 and 5.38, respectively. Figures 5.39 and 5.40, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.37 with Figure 5.38 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.39 to Figure 5.40 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

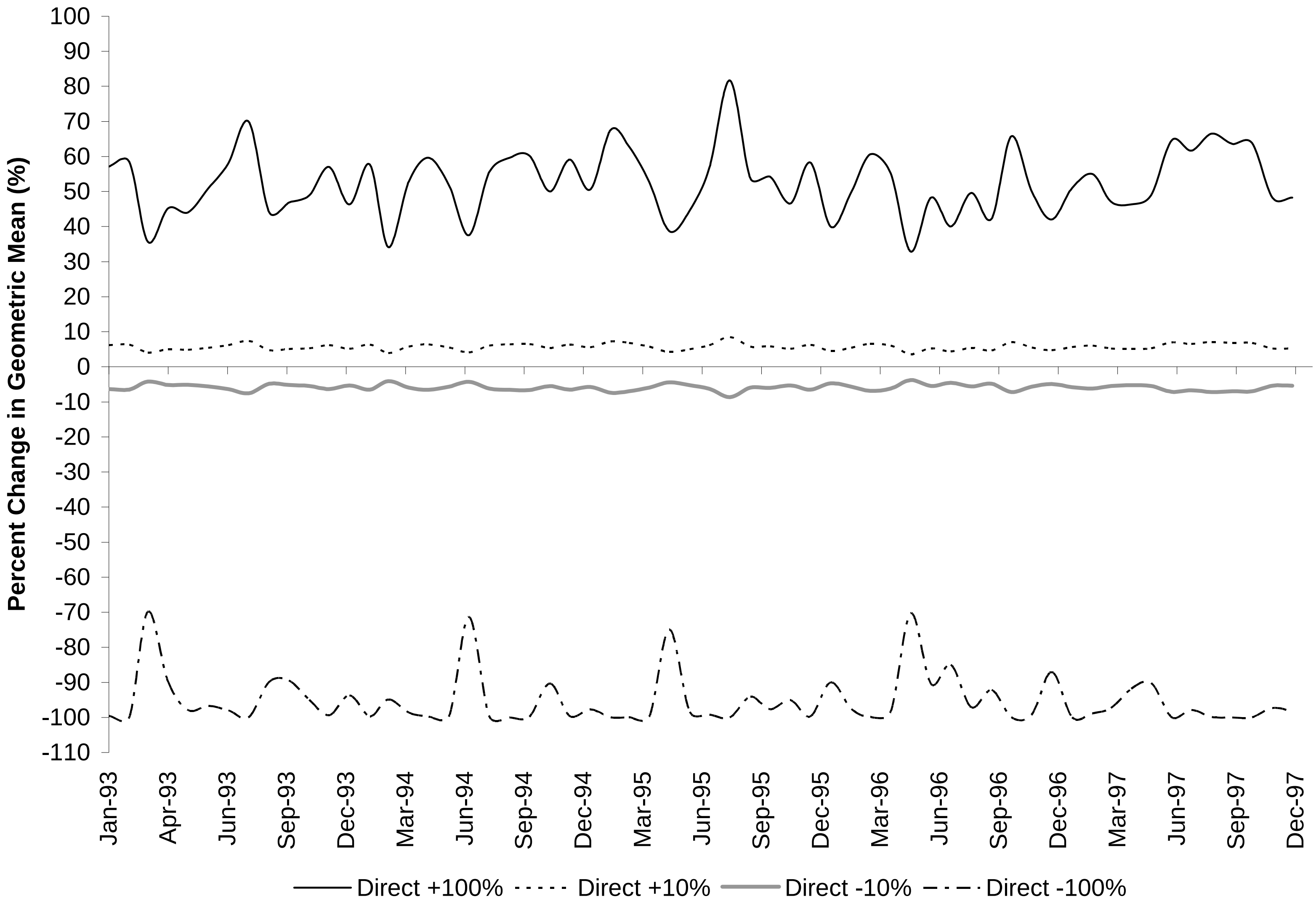

Figure 5.37. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-2) of Rappahannock River (VAN-E01R-03) watershed, as affected by direct load changes.

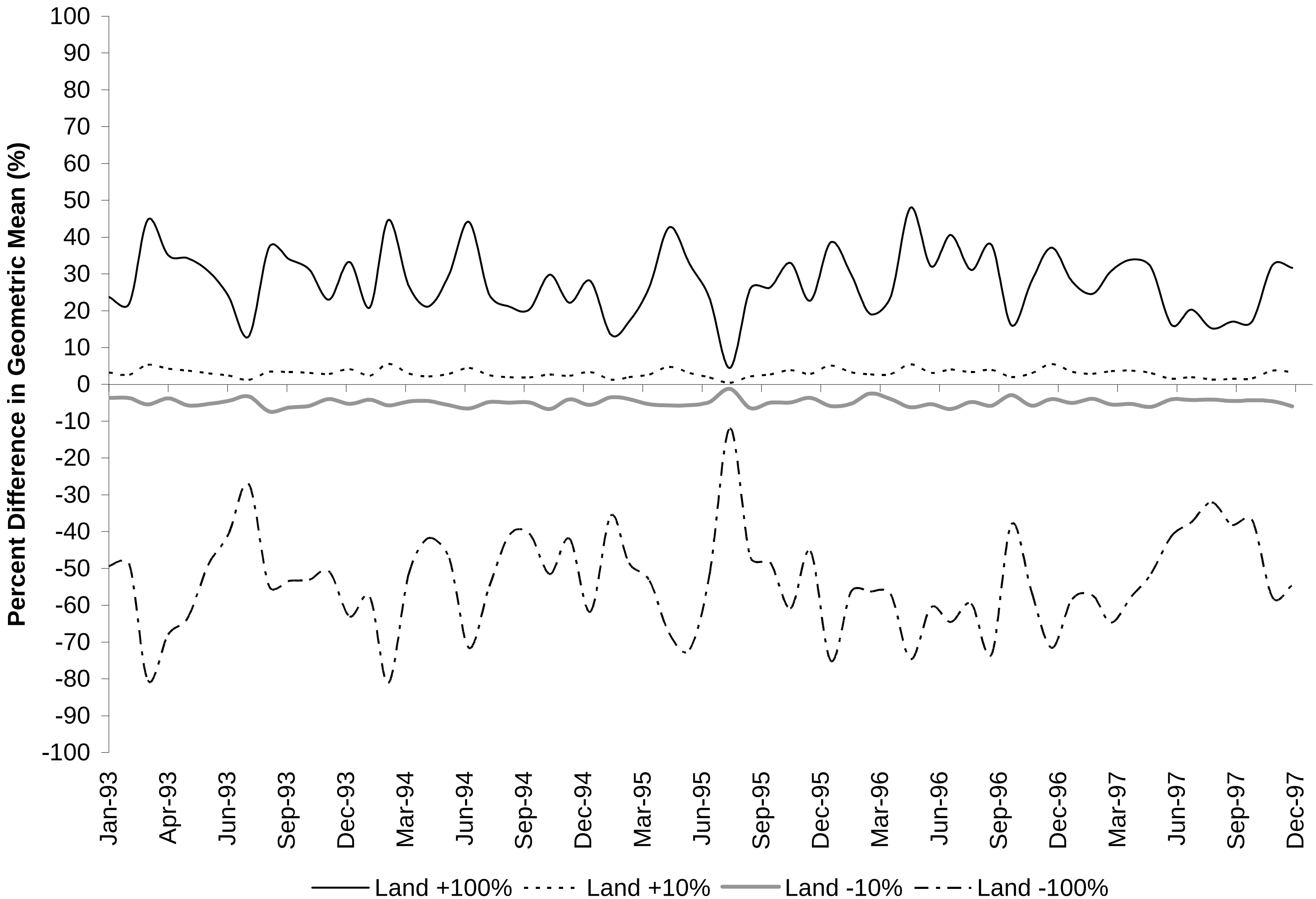

Figure 5.38. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-2) of Rappahannock River (VAN-E01R-03) watershed, as affected by land-based load changes.

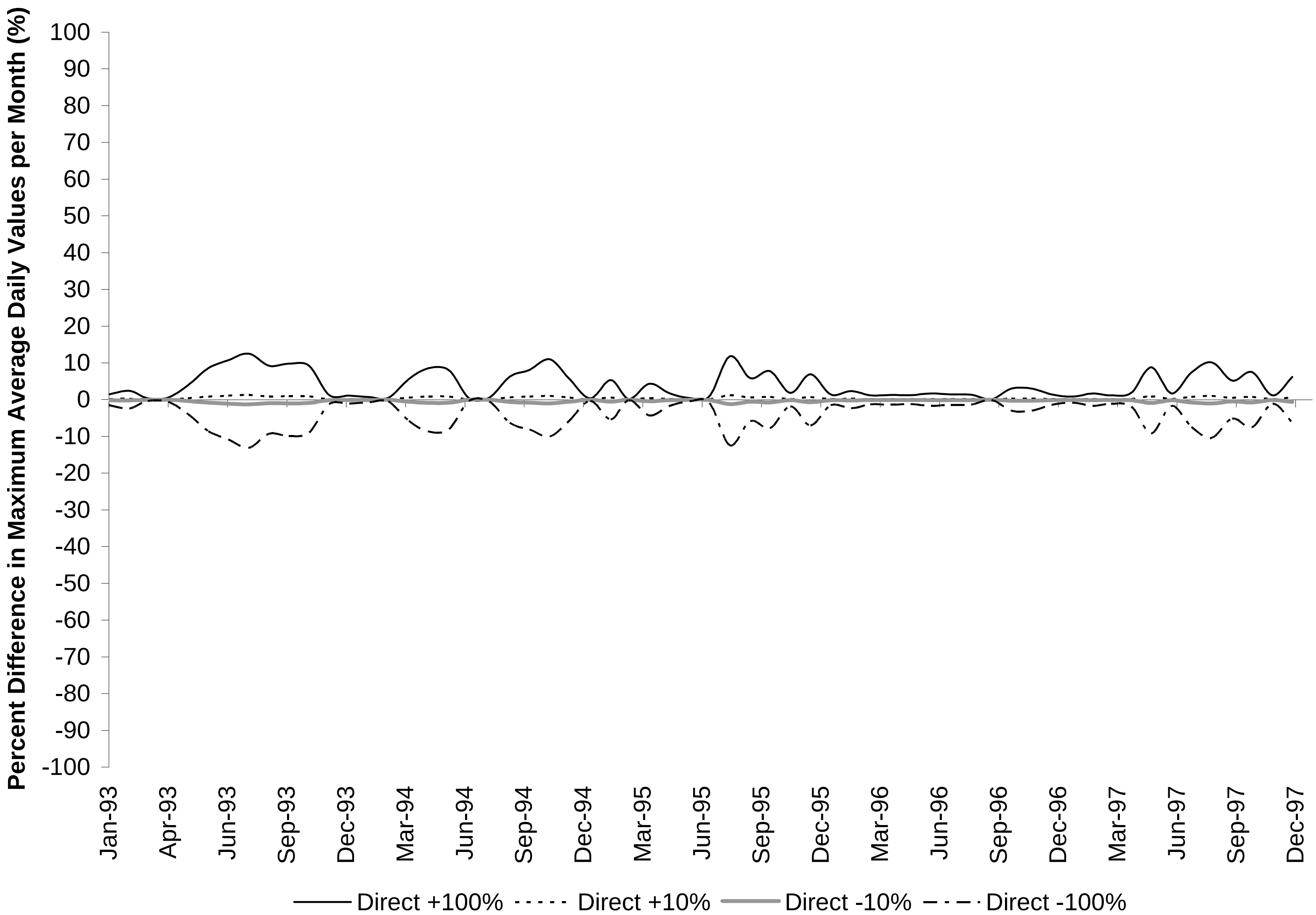

Figure 5.39. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-2) of Rappahannock River (VAN-E01R-03) watershed, as affected by direct load changes.

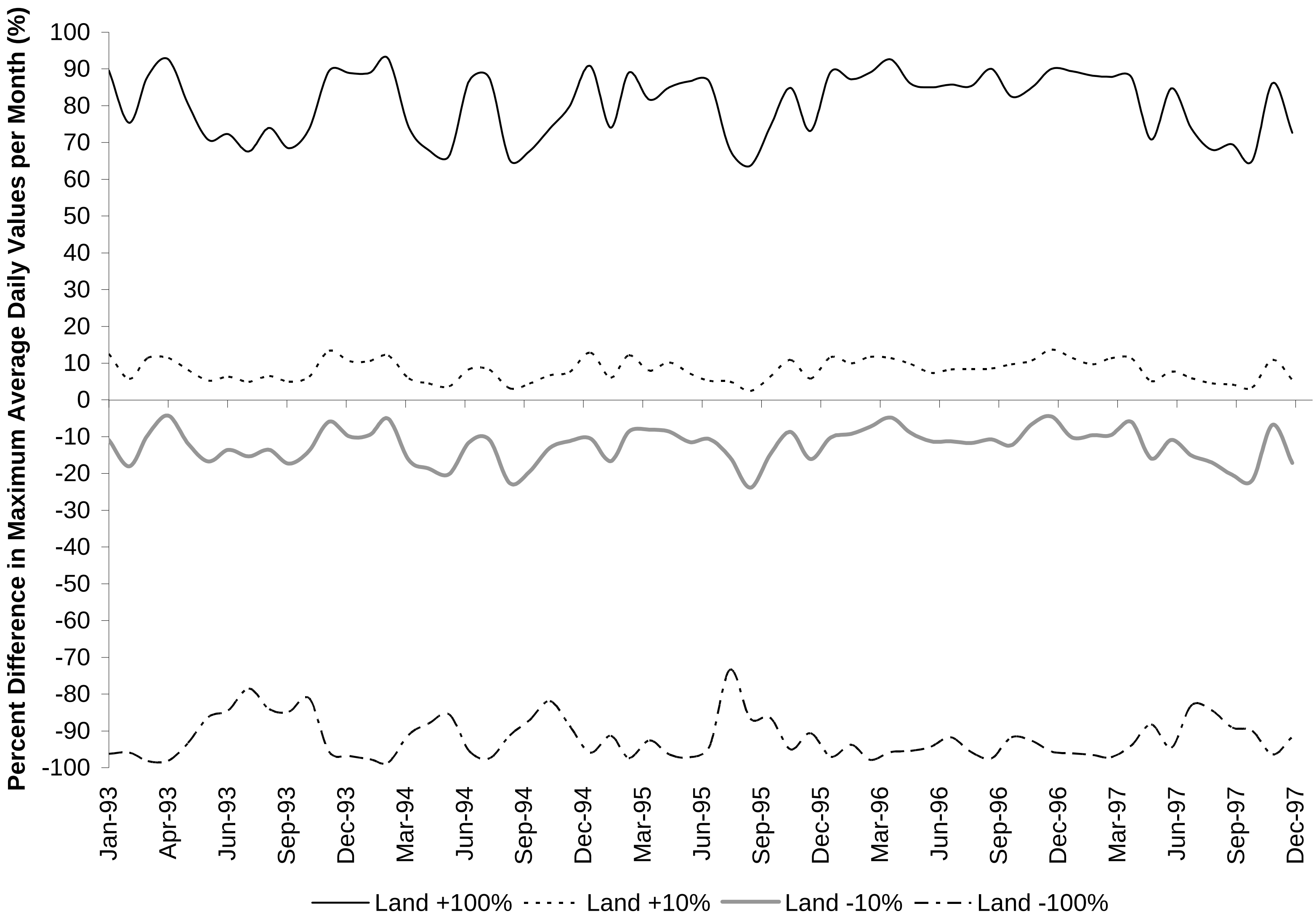

Figure 5.40. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-2) of Rappahannock River (VAN-E01R-03) watershed, as affected by land-based load changes.

5.3.6 Rappahannock River (VAN-E08R-04)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.41 and 5.42, respectively. Figures 5.43 and 5.44, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.41 with Figure 5.42 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.43 to Figure 5.44 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

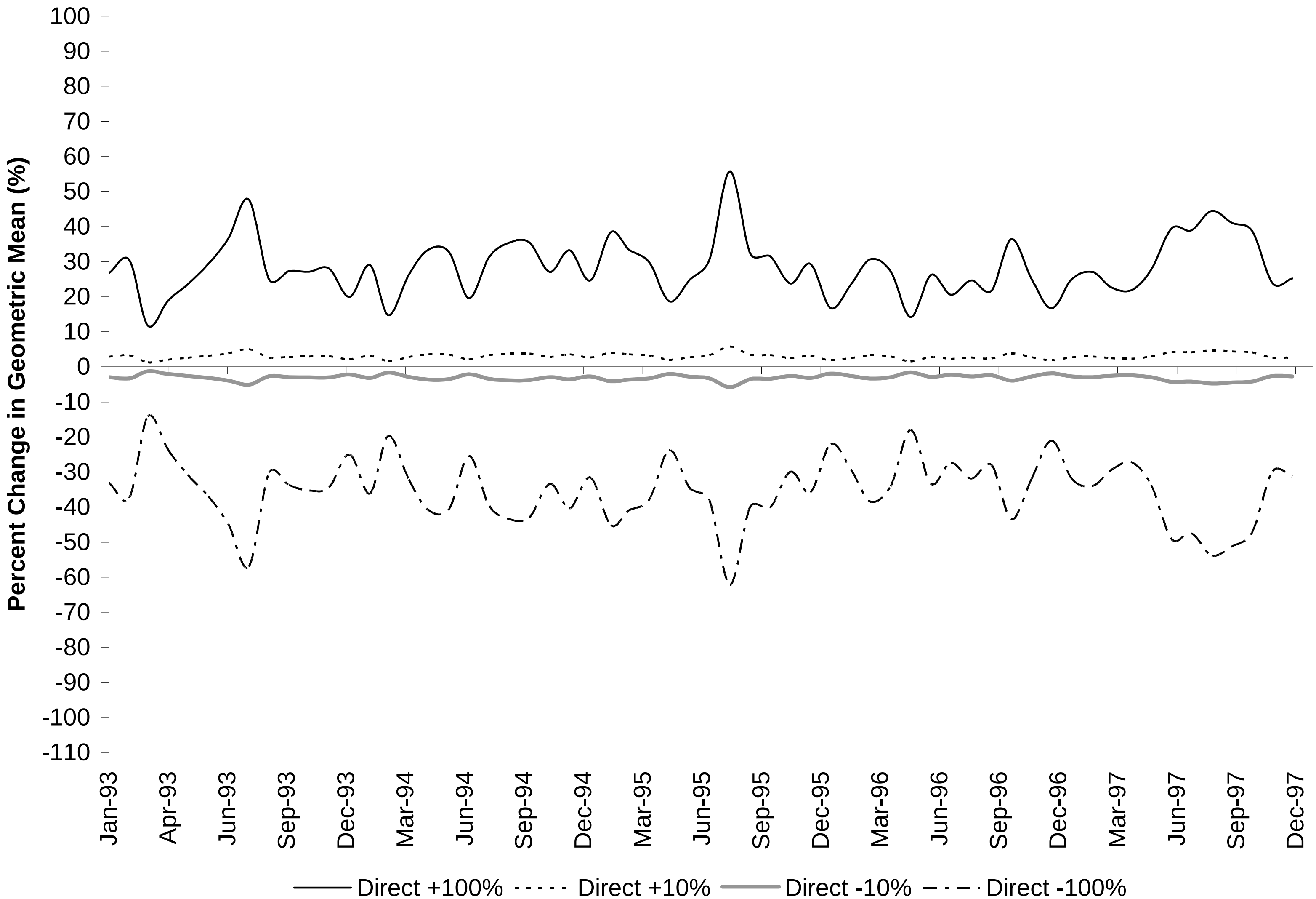

Figure 5.41. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-11) of Rappahannock River (VAN-E08R-04) watershed, as affected by direct load changes.

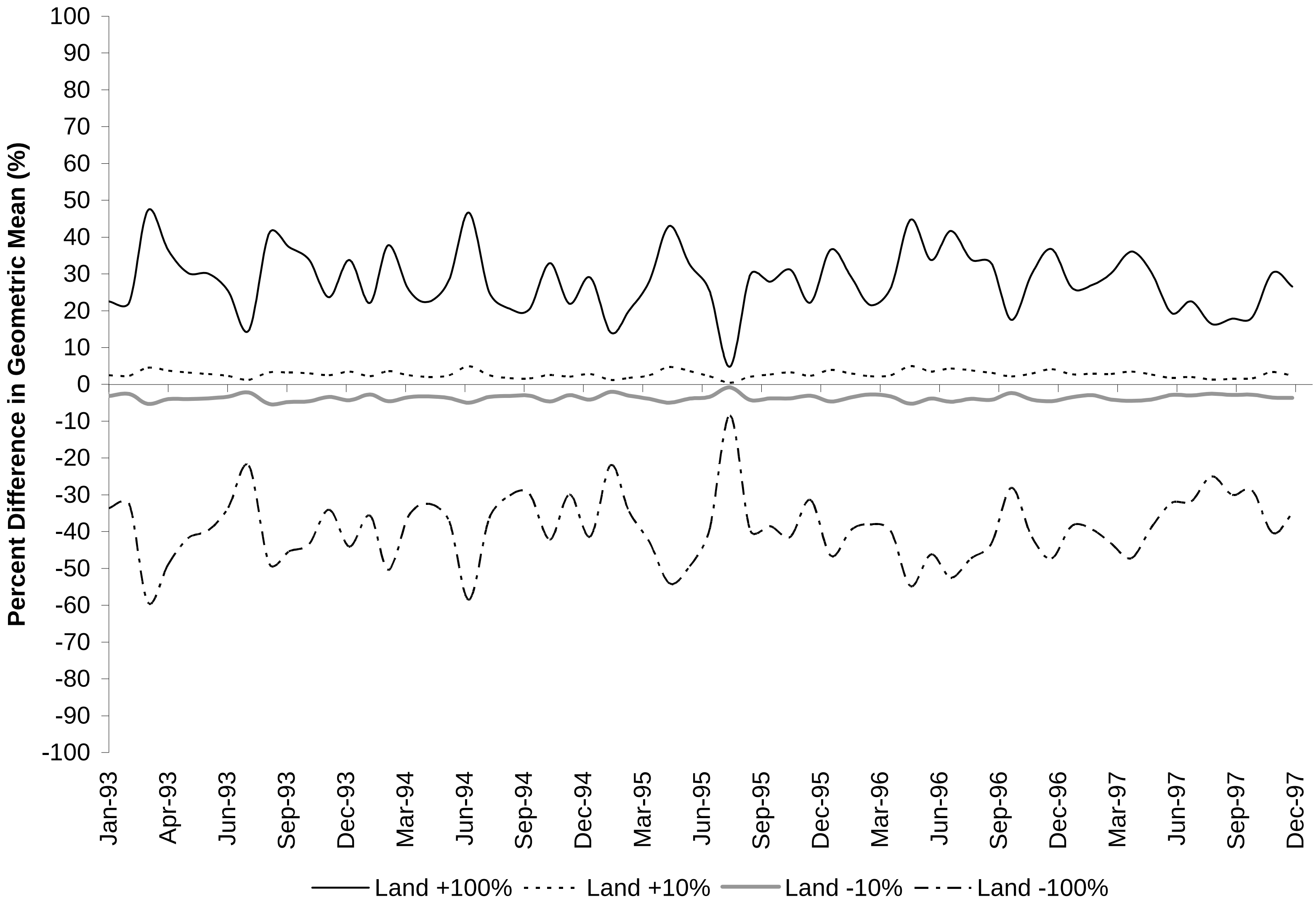

Figure 5.42. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-11) of Rappahannock River (VAN-E08R-04) watershed, as affected by land-based load changes.

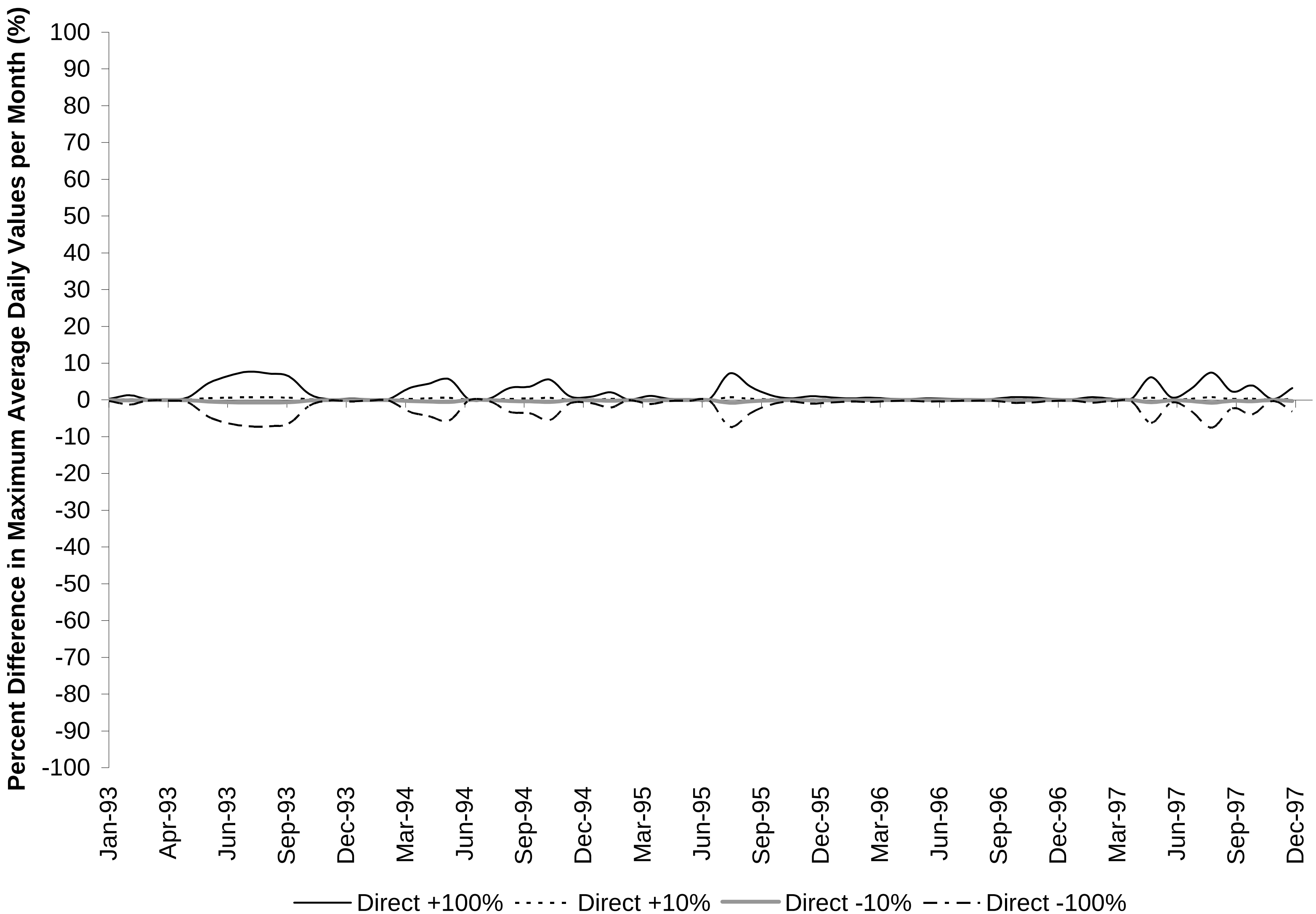

Figure 5.43. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-11) of Rappahannock River (VAN-E08R-04) watershed, as affected by direct load changes.

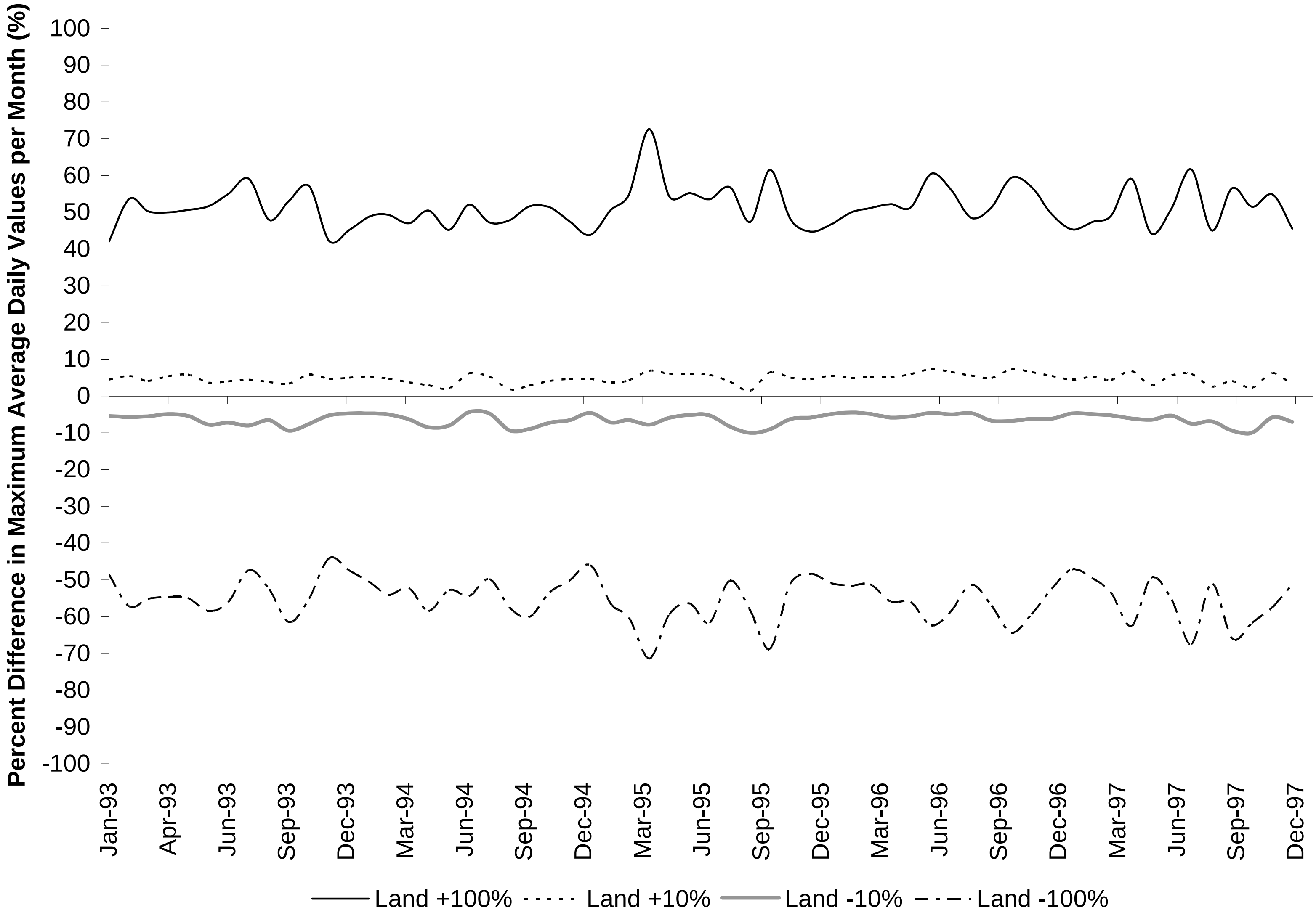

Figure 5.44. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-11) of Rappahannock River (VAN-E08R-04) watershed, as affected by land-based load changes.

5.3.7 Rappahannock River (60081)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.45 and 5.46, respectively. Figures 5.47 and 5.48, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.45 with Figure 5.46 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.47 to Figure 5.48 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

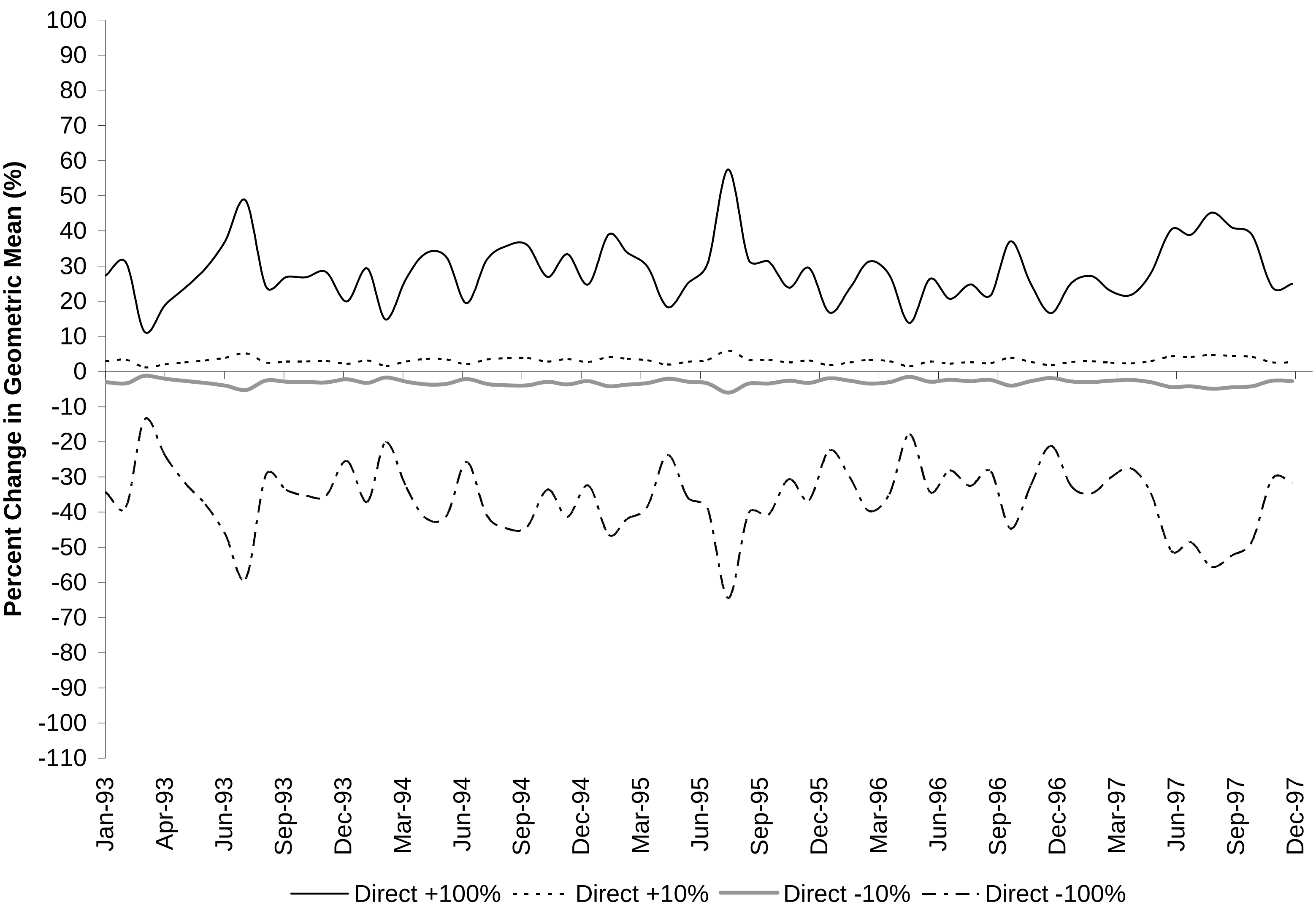

Figure 5.45. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-13) of Rappahannock River (60081) watershed, as affected by direct load changes.

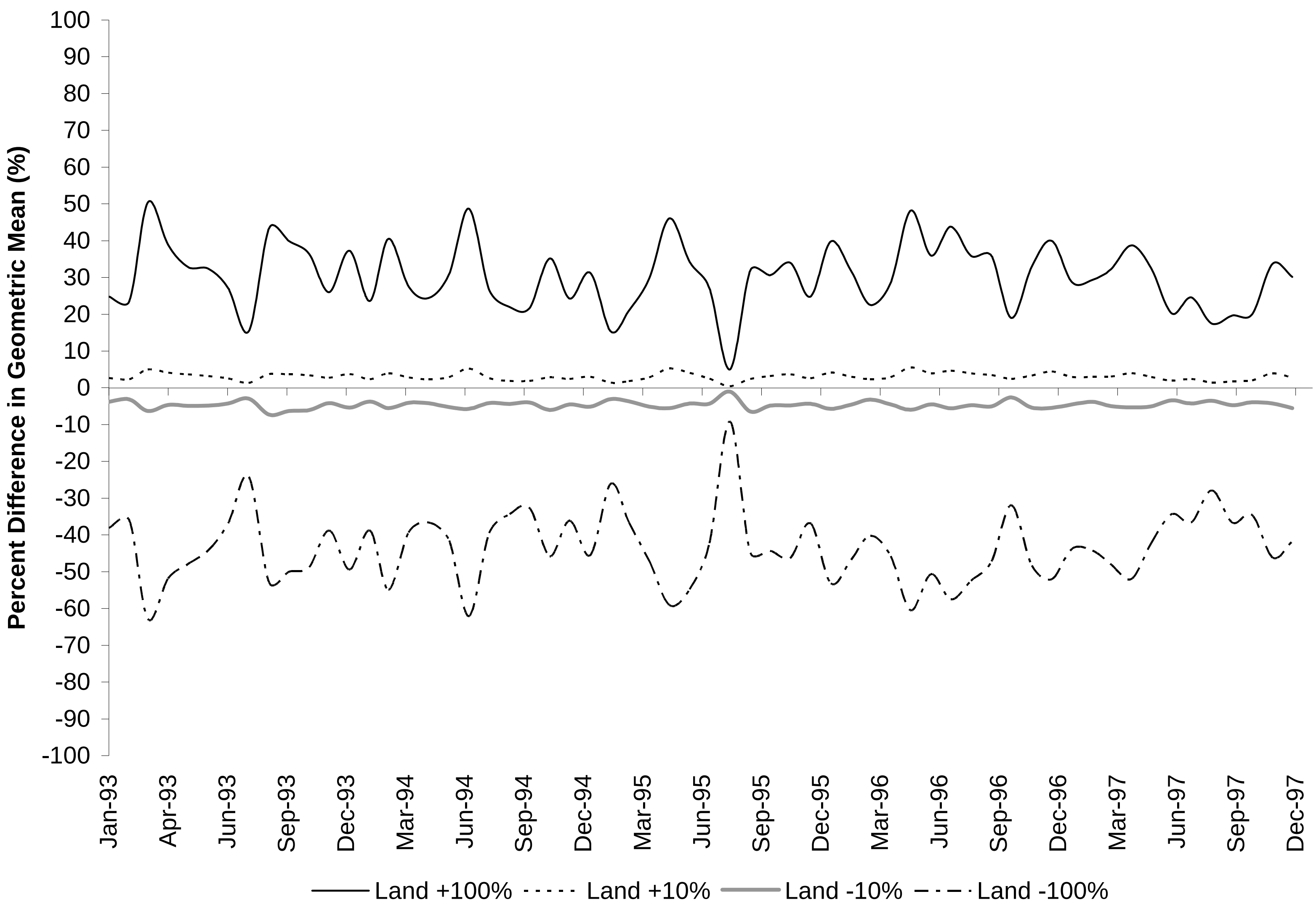

Figure 5.46. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-13) of Rappahannock River (60081) watershed, as affected by land-based load changes.

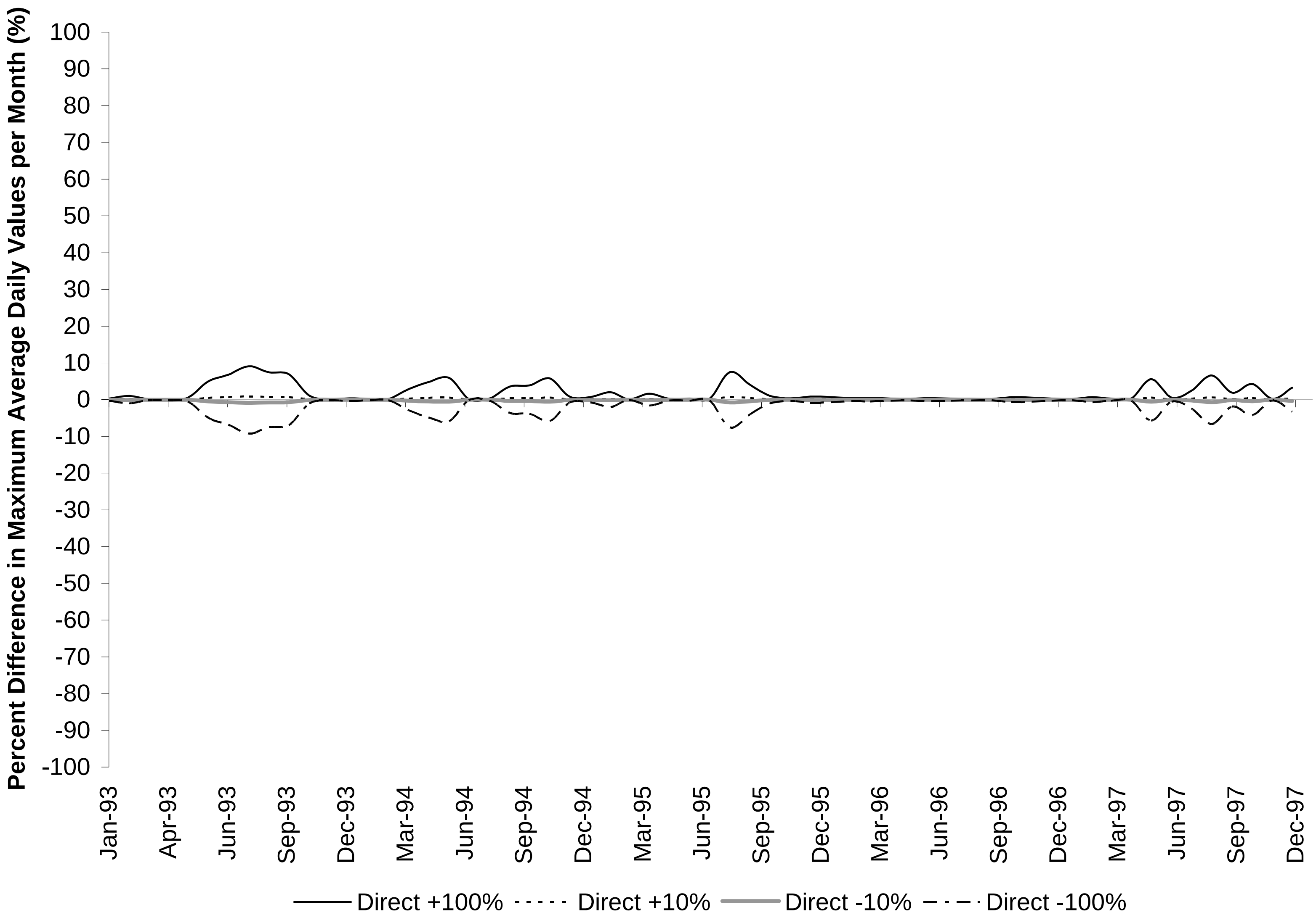

Figure 5.47. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-13) of Rappahannock River (60081) watershed, as affected by direct load changes.

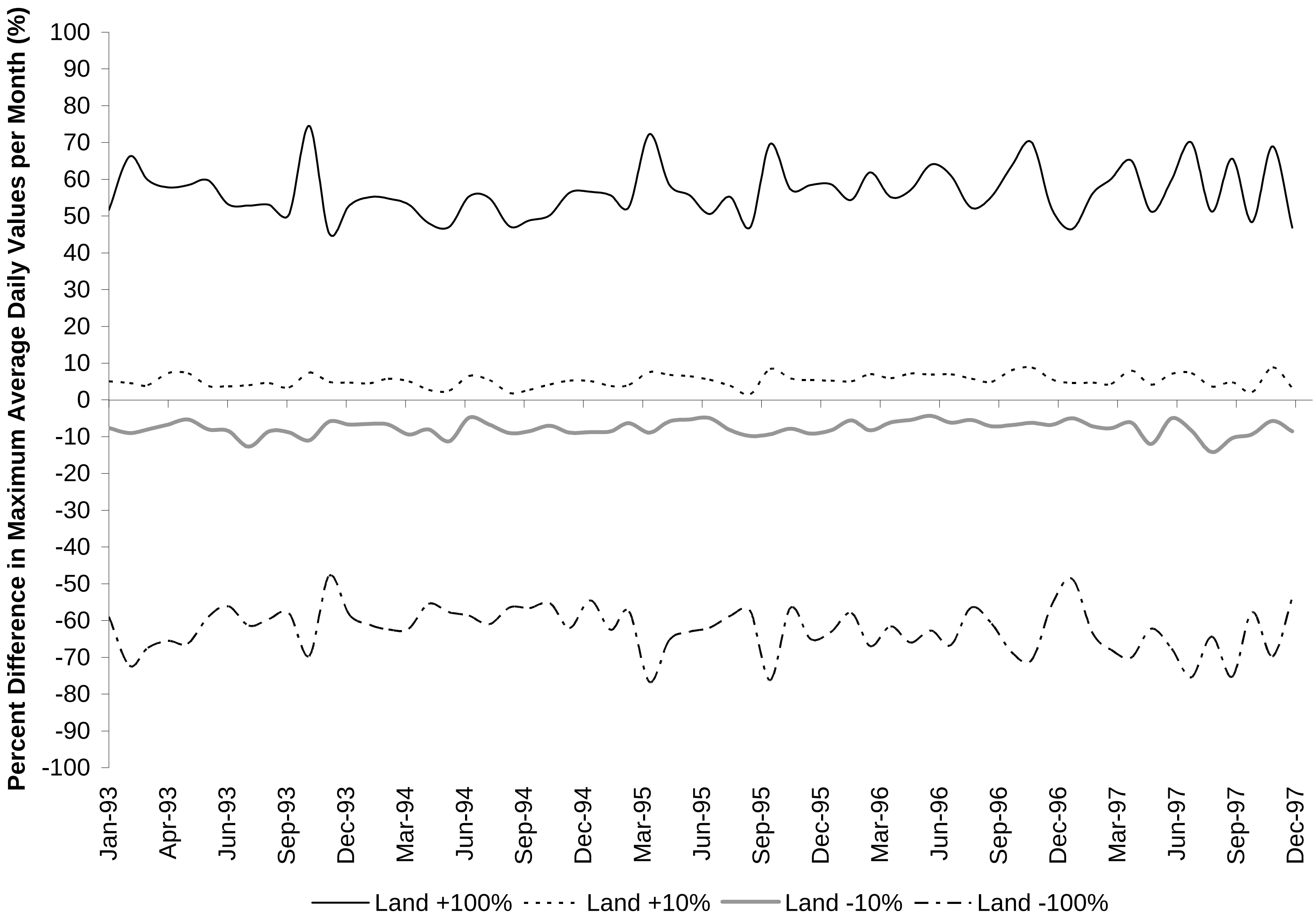

Figure 5.48. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-13) of Rappahannock River (60081) watershed, as affected by land-based load changes.

5.3.8 Craig Run (VAN-E08R-03)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.49 and 5.50, respectively. Figures 5.51 and 5.52, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.49 with Figure 5.50 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.51 to Figure 5.52 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

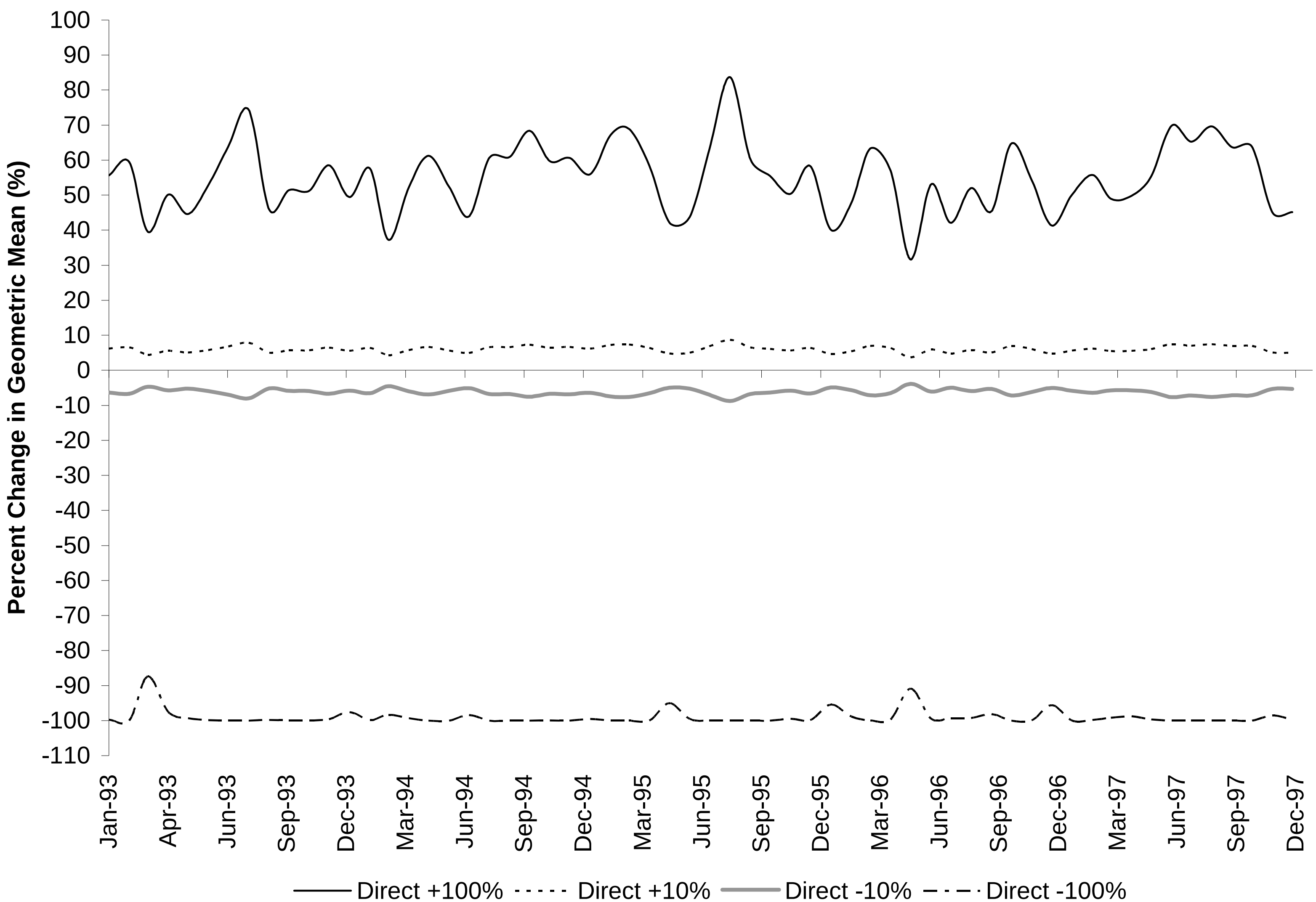

Figure 5.49. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-14) of Craig Run (VAN-E08R-03) watershed, as affected by direct load changes.

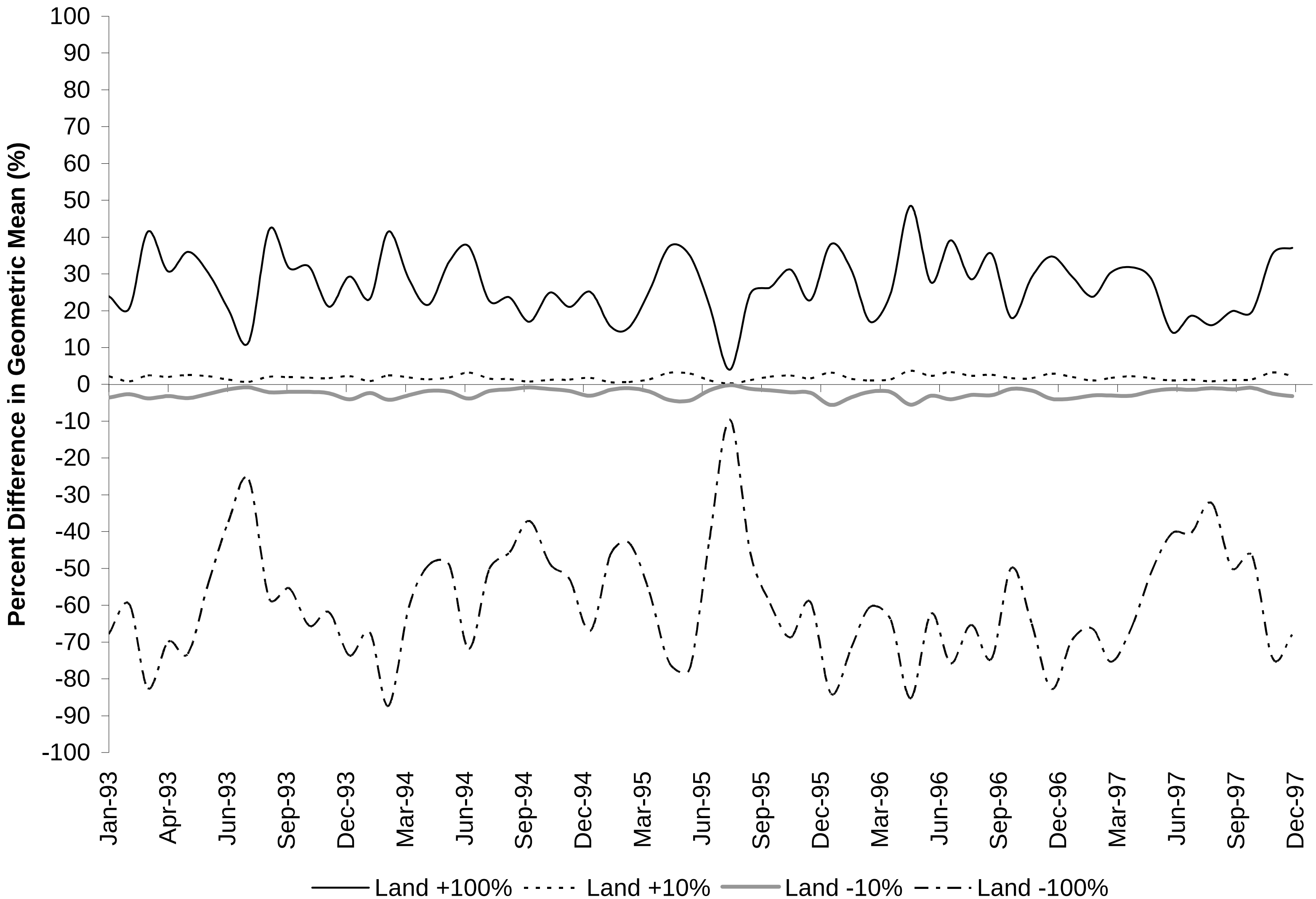

Figure 5.50. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-14) of Craig Run (VAN-E08R-03) watershed, as affected by land-based load changes.

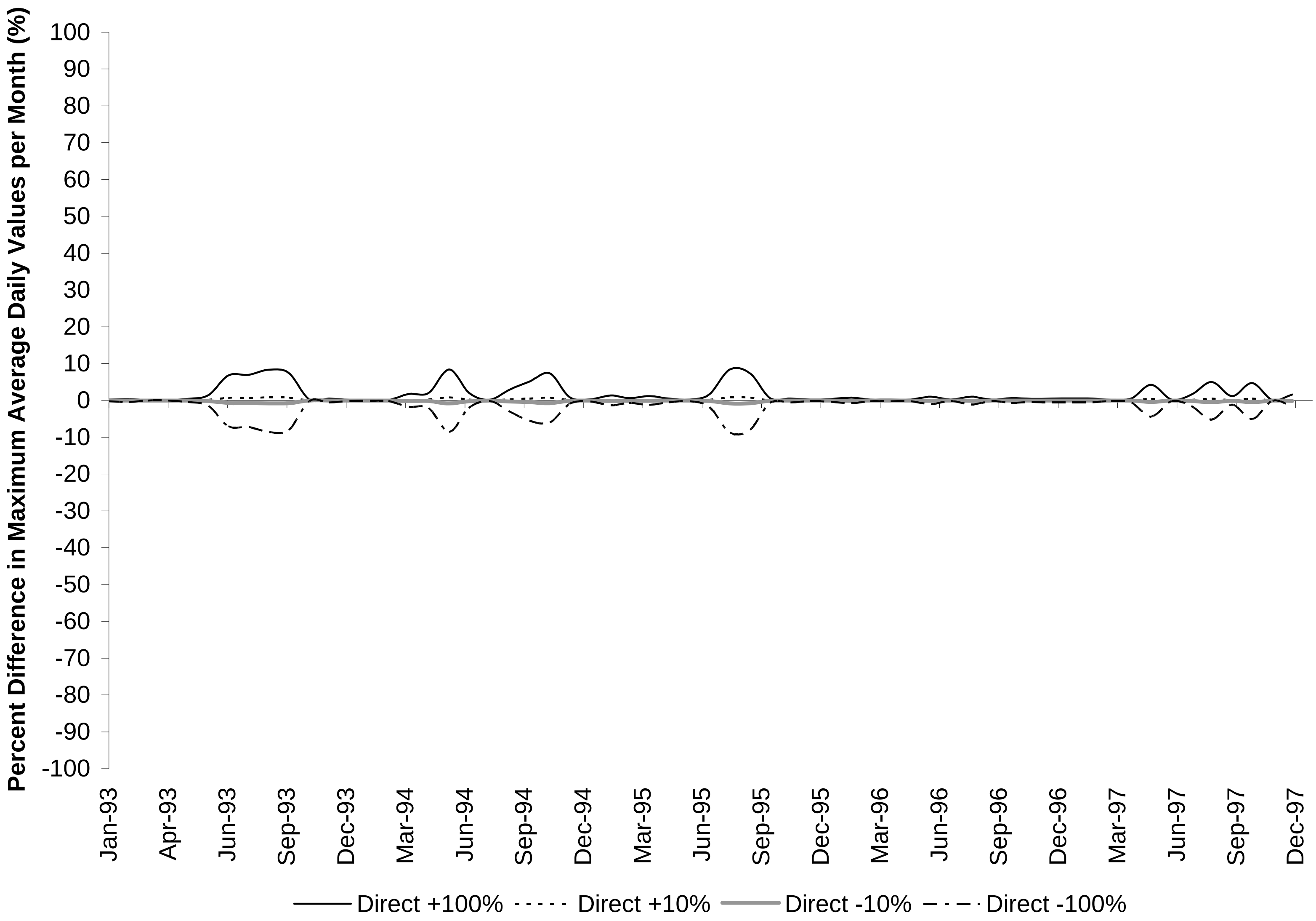

Figure 5.51. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-14) of Craig Run (VAN-E08R-03) watershed, as affected by direct load changes.

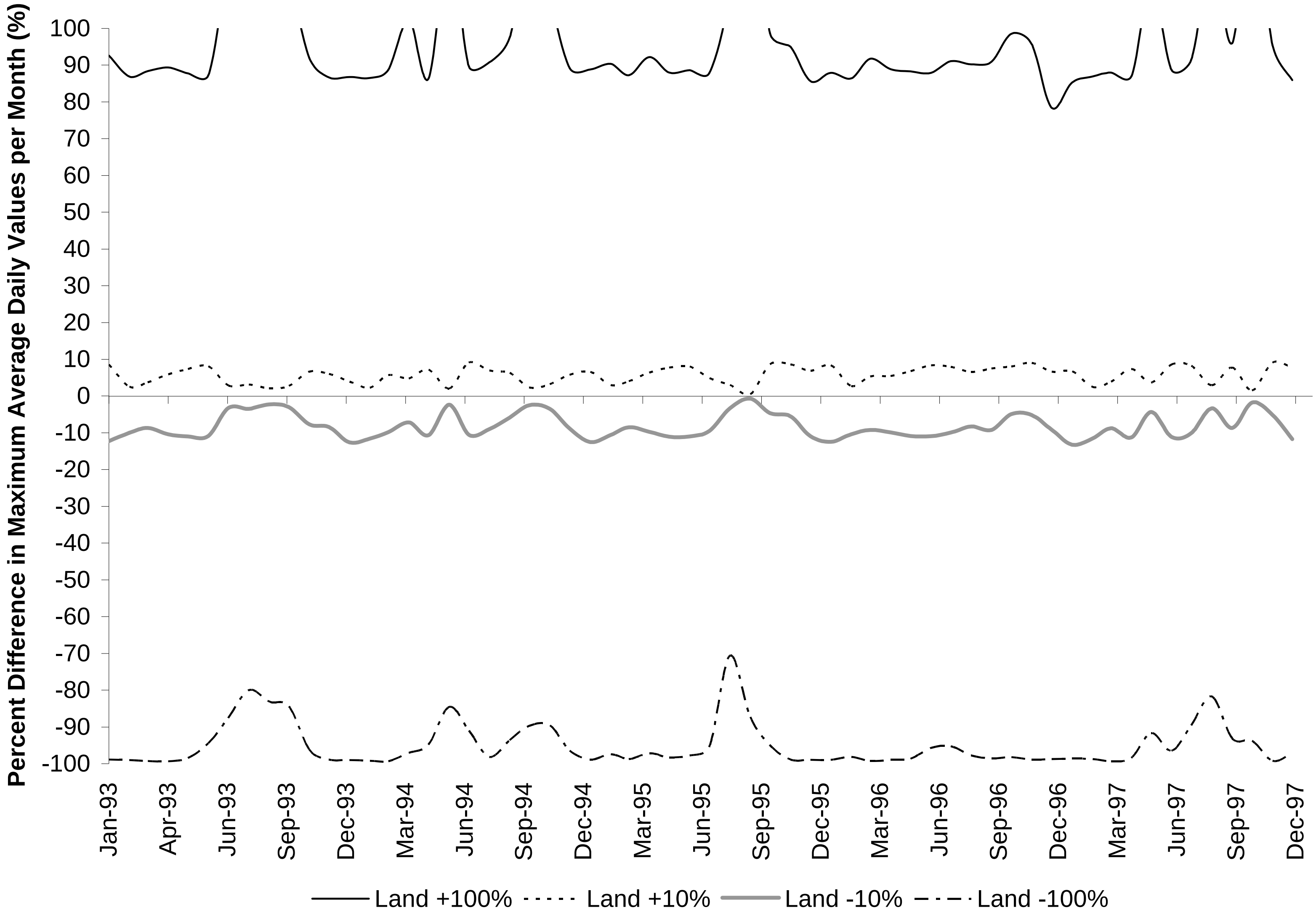

Figure 5.52. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-14) of Craig Run (VAN-E08R-03) watershed, as affected by land-based load changes.

5.3.9 Browns Run (VAN-E08R-02)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.53 and 5.54, respectively. Figures 5.55 and 5.56, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.53 with Figure 5.54 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.55 to Figure 5.56 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

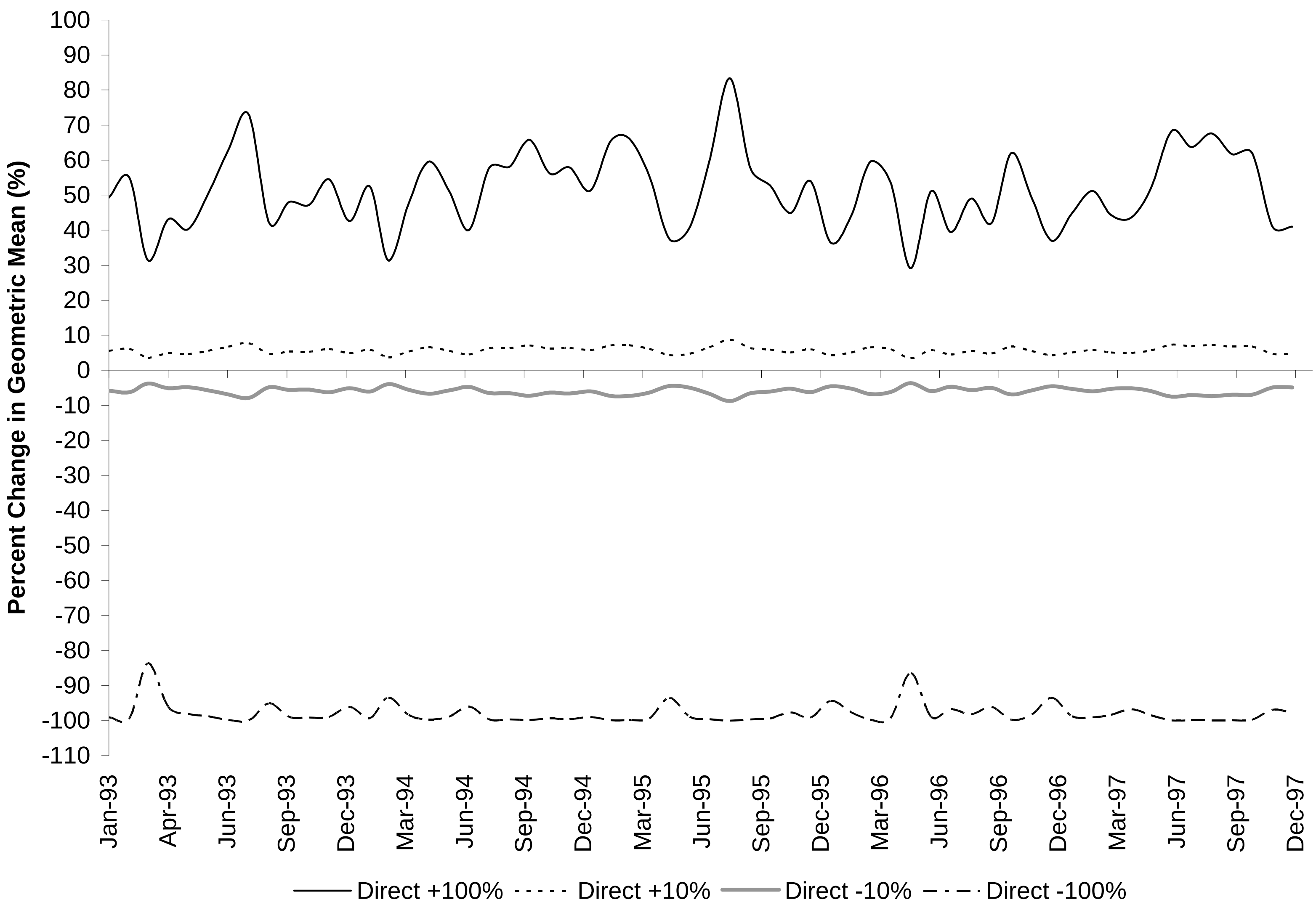

Figure 5.53. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-18) of Browns Run (VAN-E08R-02) watershed, as affected by direct load changes.

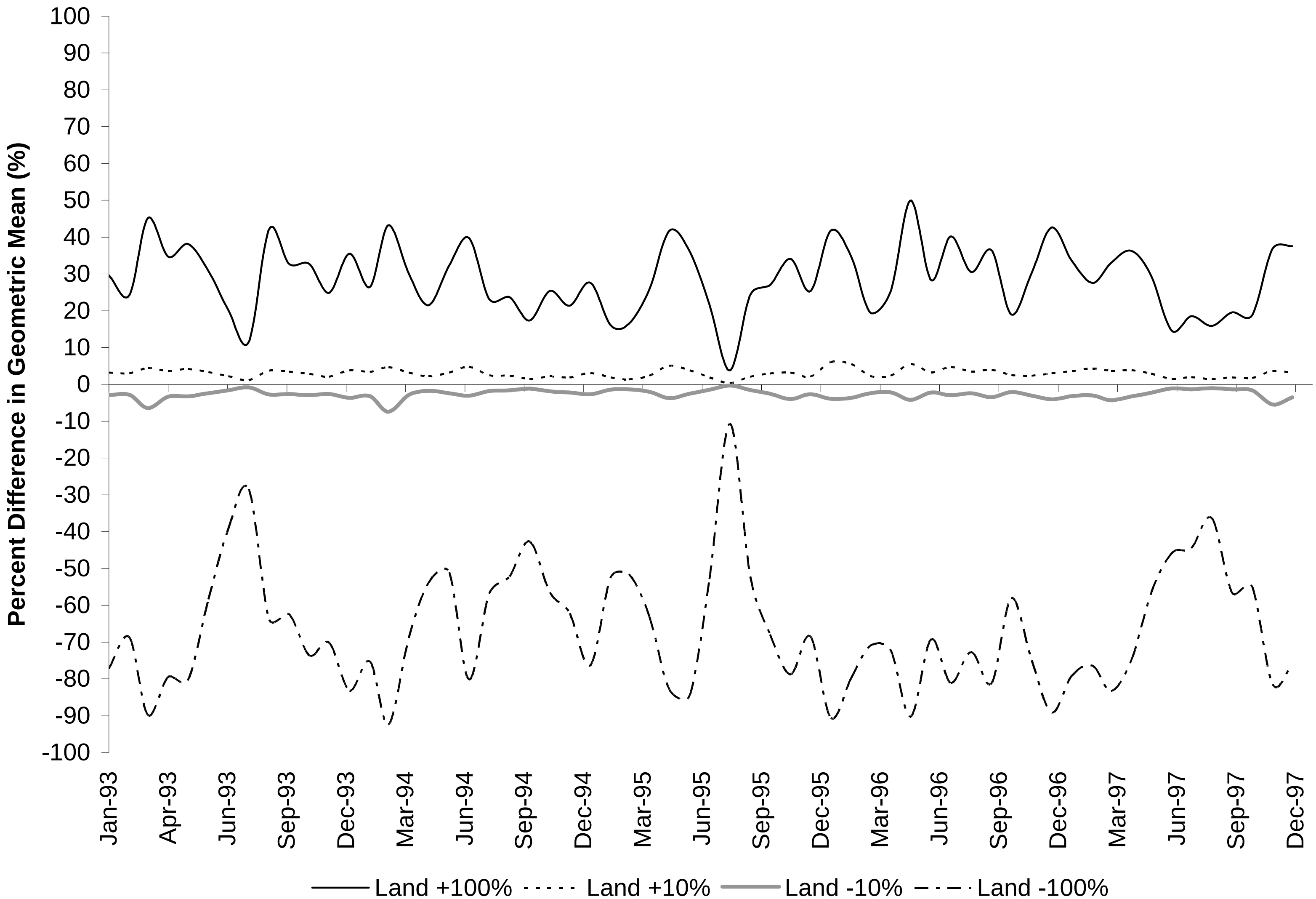

Figure 5.54. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-18) of Browns Run (VAN-E08R-02) watershed, as affected by land-based load changes.

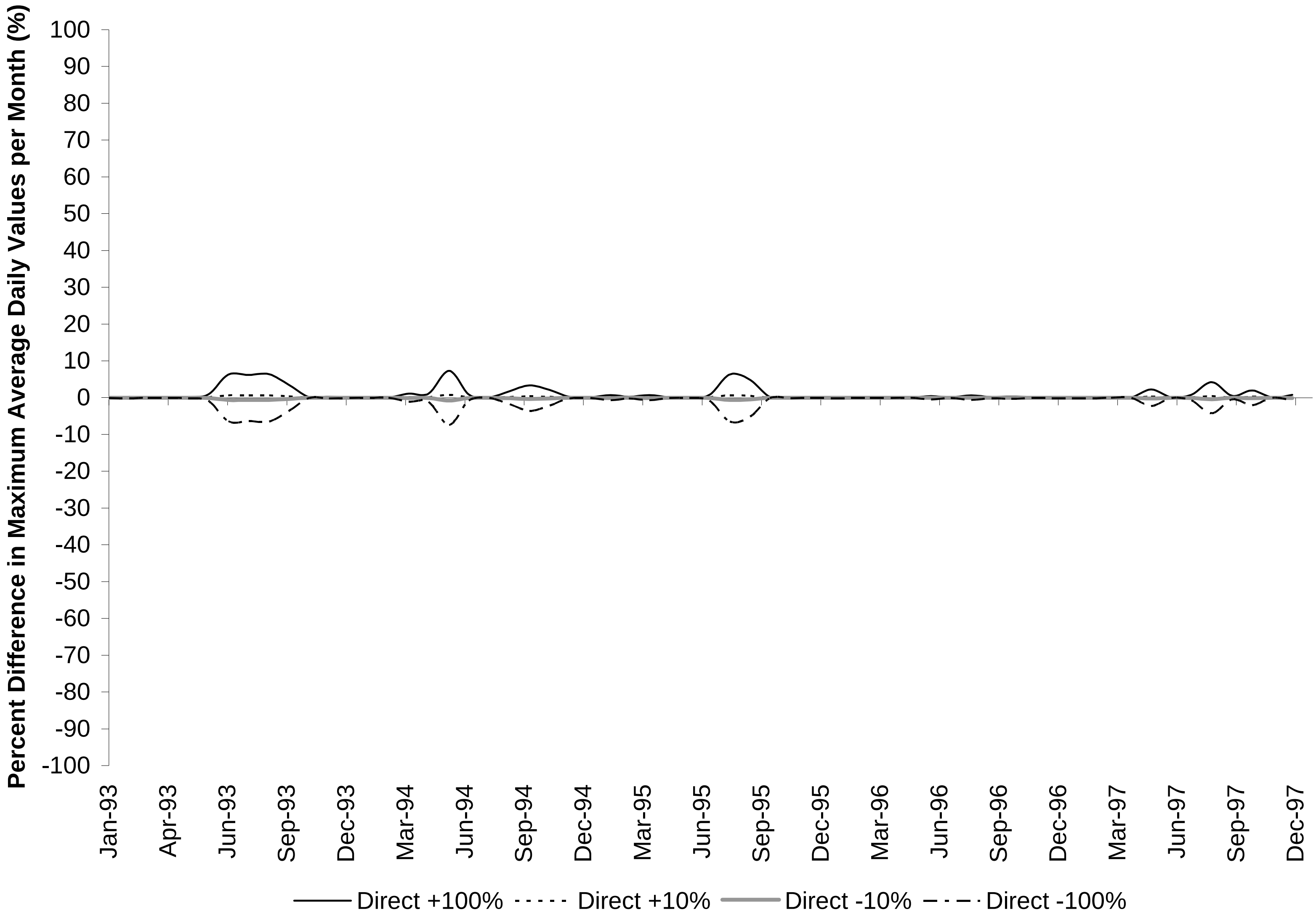

Figure 5.55. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-18) of Browns Run (VAN-E08R-02) watershed, as affected by direct load changes.

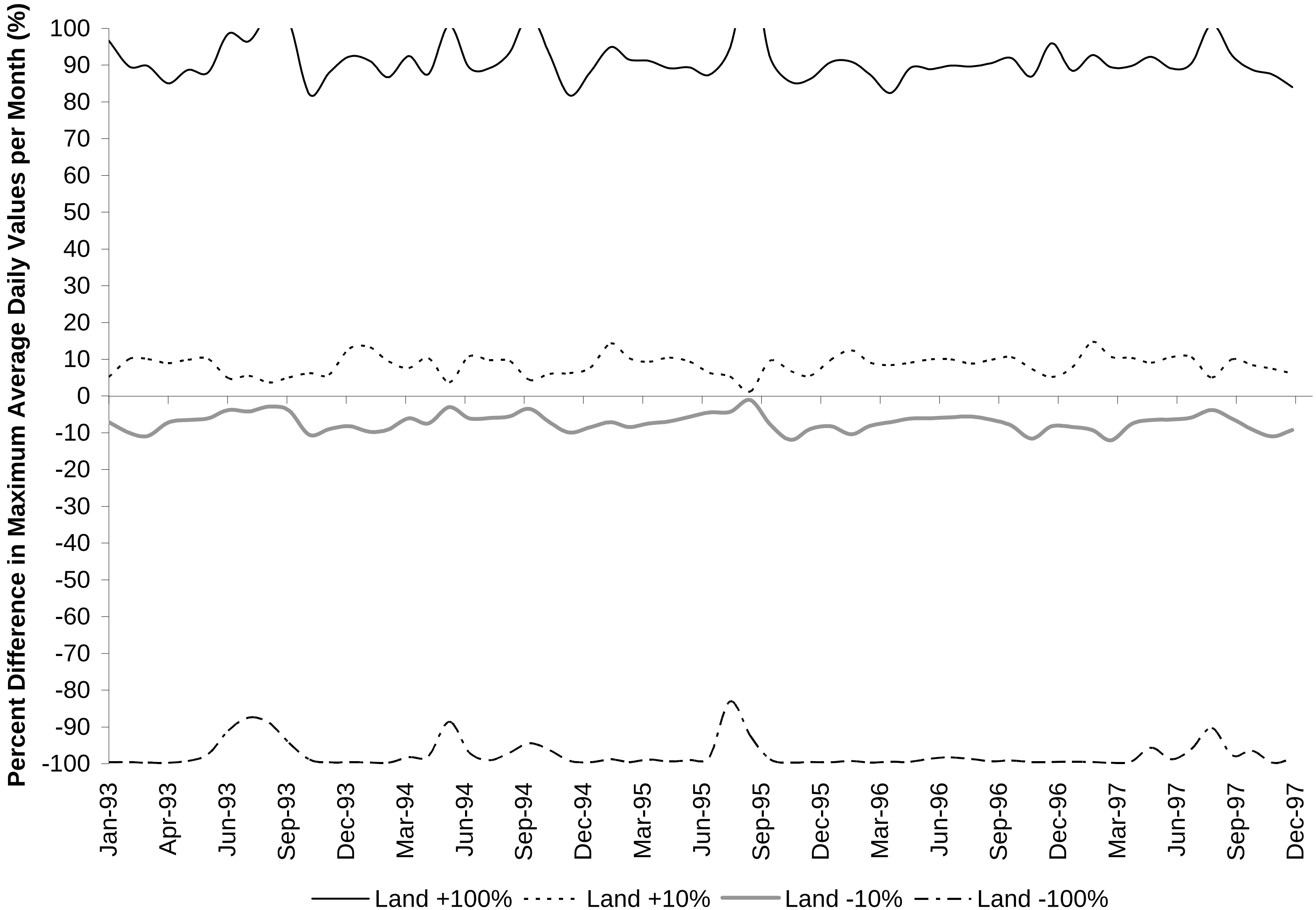

Figure 5.56. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-18) of Browns Run (VAN-E08R-02) watershed, as affected by land-based load changes.

5.3.10 Marsh Run (VAN-E08R-01)

Percent difference in monthly geometric mean *E. coli* concentration for each direct and land-based load change to base value was calculated and plotted in Figures 5.57 and 5.58, respectively. Figures 5.59 and 5.60, respectively, show the percent difference in the maximum daily average *E. coli* concentration per month for each direct load and land load change to base value. It is apparent by comparing Figure 5.57 with Figure 5.58 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.59 to Figure 5.60 indicates that the maximum daily average *E. coli* concentrations are affected greatly by increasing land-based loads and affected by increasing directly deposited loads during lower flow periods.

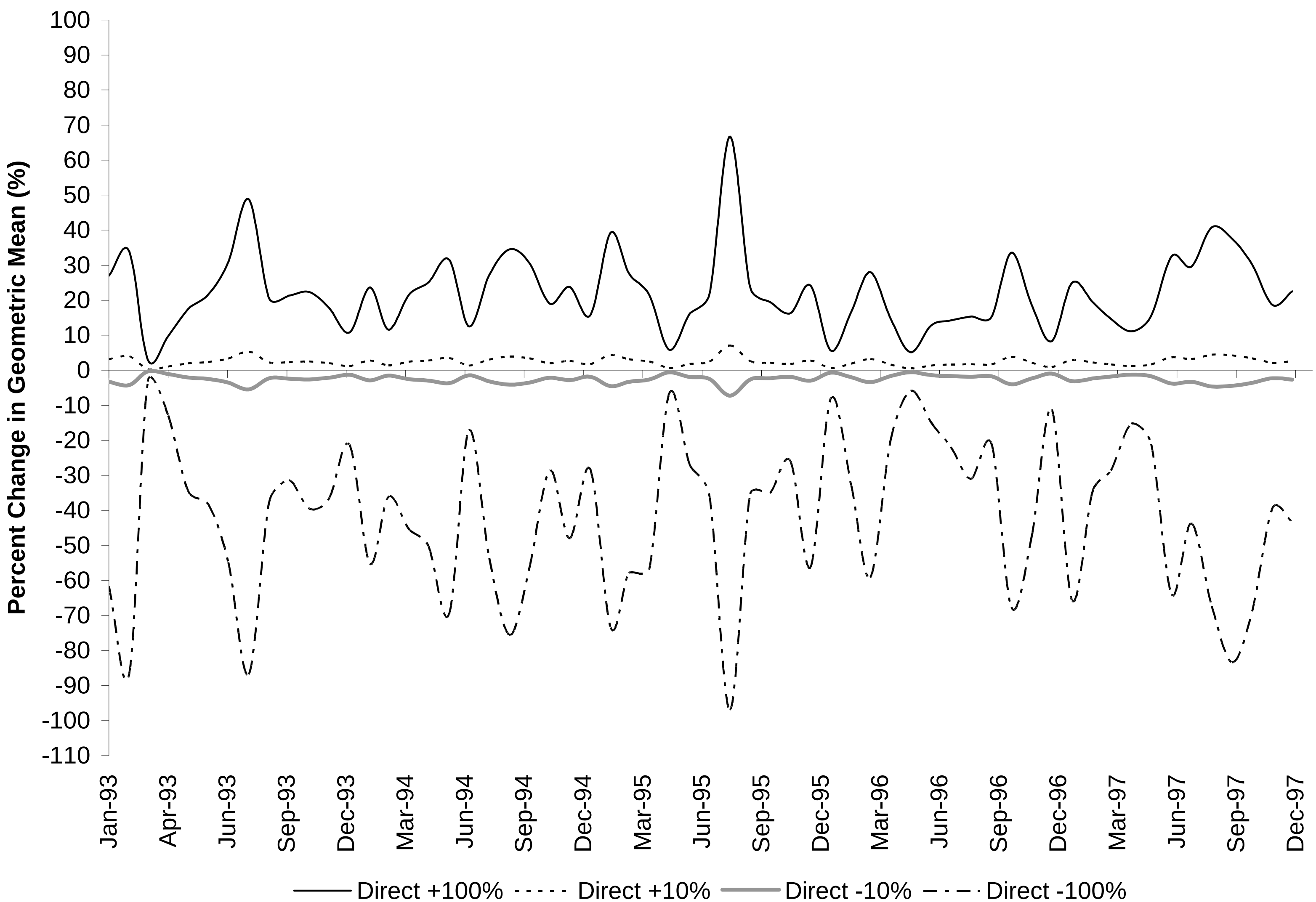

Figure 5.57. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-20) of Marsh Run (VAN-E08R-01) watershed, as affected by direct load changes.

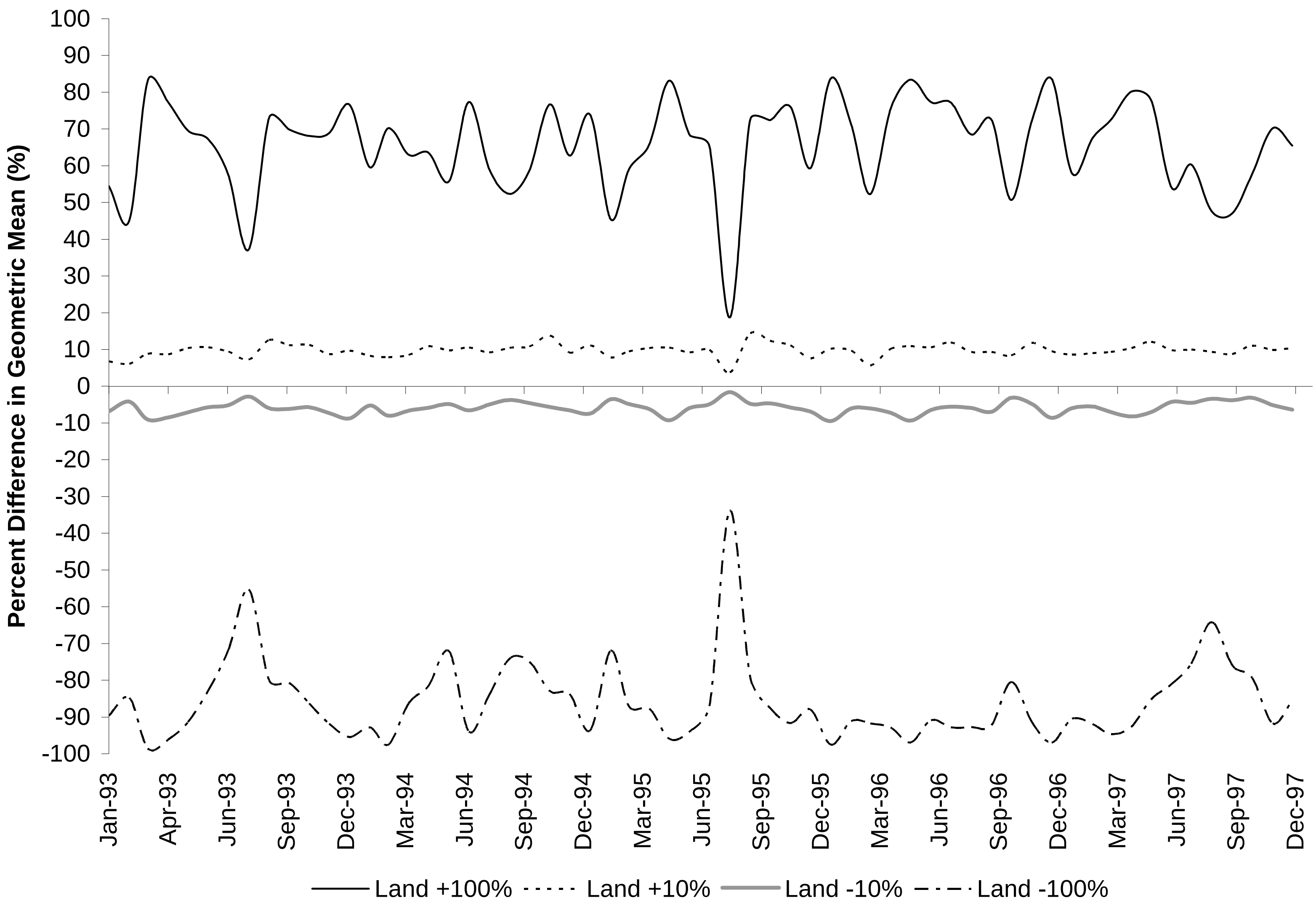

Figure 5.58. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed RAR-20) of Marsh Run (VAN-E08R-01) watershed, as affected by land-based load changes.

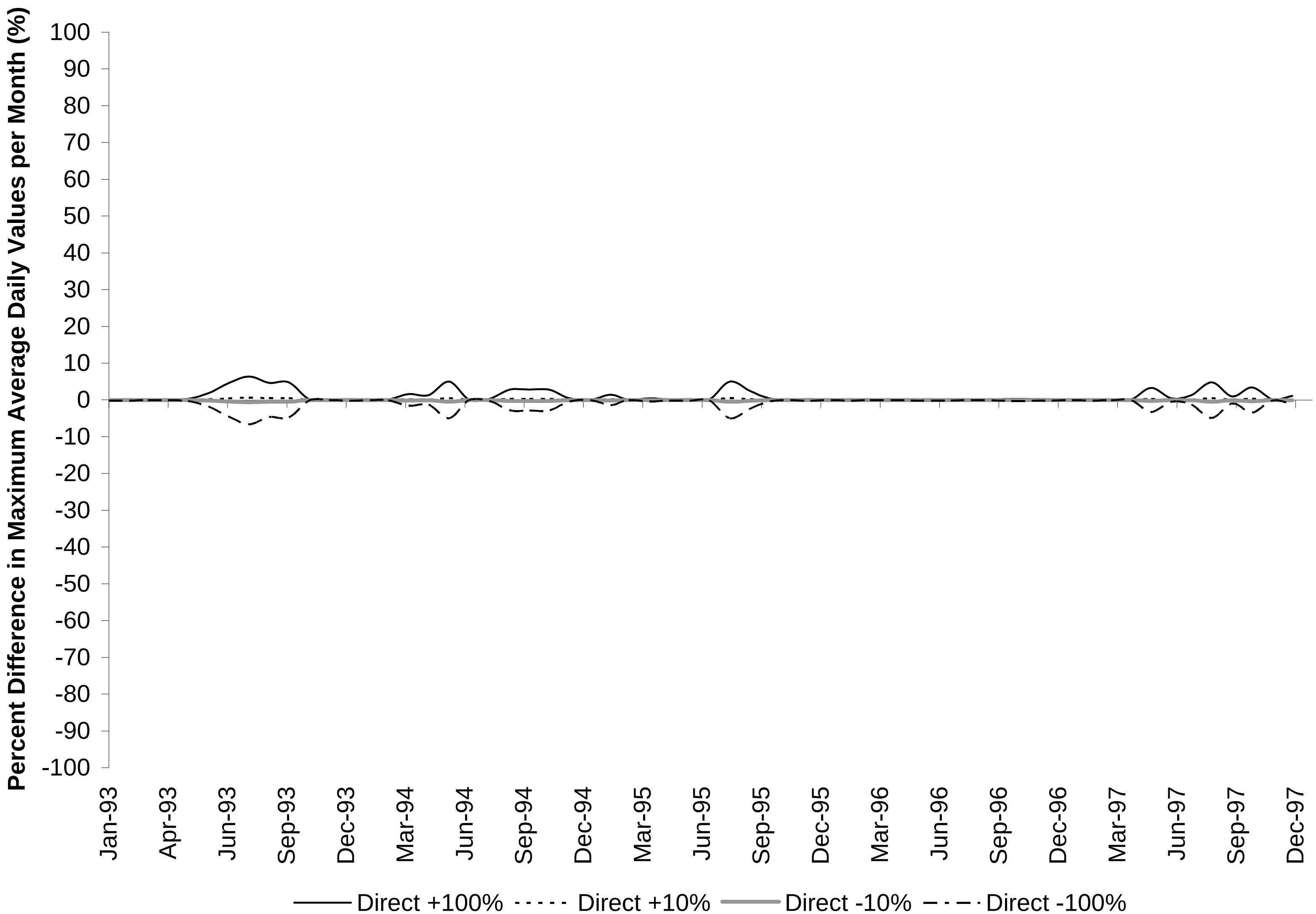

Figure 5.59. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-20) of Marsh Run (VAN-E08R-01) watershed, as affected by direct load changes.

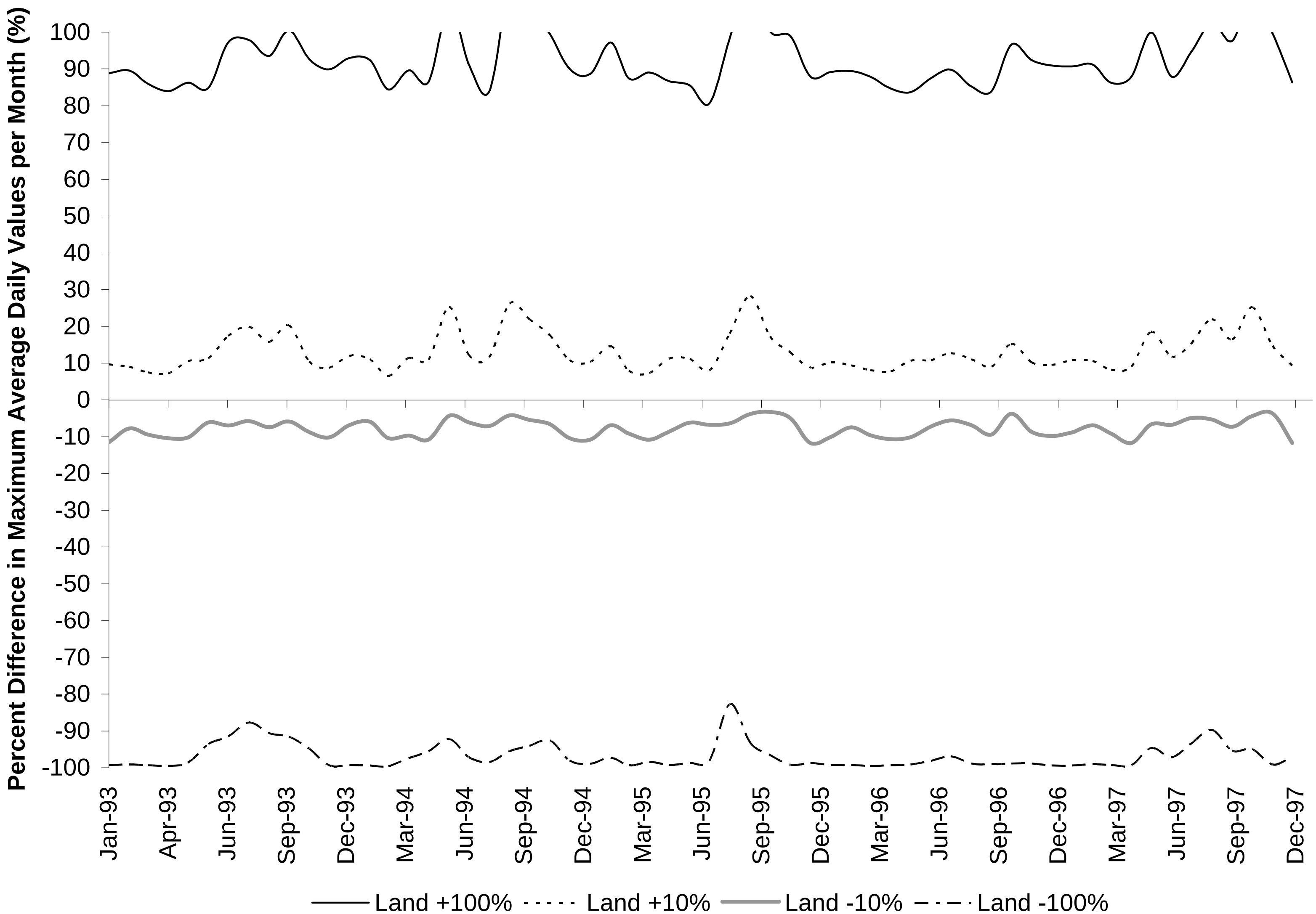

Figure 5.60. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed RAR-20) of Marsh Run (VAN-E08R-01) watershed, as affected by land-based load changes.

5.4 TMDL Allocation Scenarios

Direct and land-based loads representing existing conditions were reduced in a variety of allocation scenarios (addressing anthropogenic sources first) until the *E. coli* TMDL goals of a calendar-month geometric mean of 126 cfu/100mL and the single sample maximum limit of 235 cfu/100mL were met. The representative modeling period selected for allocation scenarios was January 1993 through December 1997. This period incorporates average rainfall, low rainfall, and high rainfall years allowing the representation of both low and high flow conditions. The general approach to allocation scenario development was to develop a scenario that allowed the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments to meet bacteria water quality standards. As each impairment met bacteria standards, the loads that allowed it to do so were adopted for those segments for subsequent runs. Due to similarities in the ten impairments, the final allocation scenarios for the ten segments were similar.

One active point discharge in the Hughes River (VAN-E03R-01), two in Hazel River (VAN-E04R-01), two in Rush River (VAN-E05R-01), seven in Hazel River (60076), eight in Rappahannock River (VAN-E08R-04), two in Rappahannock River (60081), five in Browns Run (VAN-E08R-02), and eight in Marsh Run (VAN-E08R-01) watersheds currently have VPDES permits. No municipalities with MS4 permits were identified within the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds. The permitted point source discharges are described in Table 3.2. During allocation development, these permitted point sources were modeled with effluent fecal coliform concentrations of 200 cfu/100 mL and flows equal to their design flows as listed in Table 3.2. The ultimate waste load allocation (WLA) was calculated using the *E. coli* limit of 126 cfu/100mL, and *E. coli* loads based on the facility design flow are presented in Table 3.2.

Scenarios to address the load allocations to non-point sources were divided between direct and land-based loadings affected by both high and low stream flow conditions. Bacterial source tracking results from samples taken during 2004-2006 confirmed the presence of human, pet, livestock, and wildlife contamination. As a result, scenarios were formulated to address reductions from all sources and delivery mechanisms (See Section 6.5.4 for discussion of wildlife bacteria). In general, direct loads modeled as consistent loadings independent of the flow regime heavily influenced low flow concentrations, whereas land-applied loads reached the stream through runoff producing events during high flow conditions. Representative allocation reduction scenarios developed for the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments and their results are summarized in Sections 5.4.1 through 5.4.10.

The general approach used to determine the TMDL allocation was very similar among the six watersheds. The first scenario represents existing conditions. Scenario number 1 reduces straight pipes and livestock directly deposited loads by 100%, keeping the remaining source reductions at 0%. Scenarios numbered 2 through 4 represent a stepwise reduction of the following anthropogenic sources: residential land-based, cropland land-based, and pasture land-based. In these scenarios, wildlife loads (directly deposited and forest land-based) were not reduced and straight pipes and livestock directly deposited loads were reduced 100%. Load from straight pipes was reduced by 100% in all reduction scenarios since they are illegal. The results of Scenarios 1 through 4 were then used to formulate additional scenarios that led to the TMDL allocation. These additional scenarios were designed to first determine non-anthropogenic source reductions required to meet bacteria water quality standards, if any. Subsequent scenarios were used to determine required reductions in anthropogenic sources (Sections 5.4.1 through 5.4.11). (Further discussion of wildlife reduction allocations can be found in Section 6.5.4.)

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Discharge from the permitted point sources in the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds were increased by two and five times the existing permit levels to determine the effect of possible facility expansion, which is discussed in Sections 5.4.1, 5.4.2, 5.4.3, 5.4.4, 5.4.6, 5.4.7, 5.4.9, and 5.4.10, respectively. The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration.These increases did not result in exceedances of the water quality standard. Future growth in discharges from permitted point sources in the Rappahannock River (VAN-E01R-03) and Craig Run (VAN-E08R-03) watersheds was accounted for by developing WLAs at <1% of the TMDL (Sections 5.4.5 and 5.4.8). Growth will be allotted to point sources as determined by the VPDES permitting staff. These WLAs did not result in exceedances of the water quality standard. From information provided by the Technical Advisory Committee, it is our understanding that no major zoning changes are planned by counties in the watersheds that would result in accelerated development of the watershed. For purposes of this study, it was assumed that residential development in the study watersheds will continue at the current rates. New housing development is expected to produce no direct deposition, and a minimal land-based load increase based on the 3% failure rate associated with new septic systems and the number of pets added by this development. Data from the VASS indicated that beef cattle populations are increasing slightly per year, 2% on average throughout the Rappahannock River watershed, and there is no evidence that any new dairy or poultry operations are planned. Wildlife populations are expected to remain relatively constant over the next five years. Based on these observations and the TMDL allocations, it is anticipated that the increase in directly deposited and land-based loads in the study watersheds will be negligible over the next five years. The effects of changes in loads on the in-stream bacteria concentration is examined in the impact analysis in Section 5.3. These changes are adequately accounted for in the implicit MOS. This implies that the final TMDL allocation is valid for the next five years, accounting for the anticipated growth during that time period.

The selected *E. coli* TMDL allocation for the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) impairments that meets both the calendar-month geometric mean and single sample maximum water quality goals addresses the following issues:

- The TMDL was developed to meet the calendar-month geometric mean and single sample water quality standards.
- Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations on which the bacteria TMDL was based.
- The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
- An implicit MOS was incorporated by utilizing professional judgment and conservative estimates of model parameters.
- Both high- and low-flow stream conditions were considered while developing the TMDL.
- Both the flow regime and bacteria loading to Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) are seasonal. The TMDL accounts for these seasonal effects.
- The exceedance rates listed in the allocation scenario tables indicate exceedance rates for the watershed outlet only. Some scenarios resulted in bacteria water quality standard exceedances in subwatersheds upstream of the outlet but within the impaired reach watershed.

5.4.1 Hughes River (VAN-E03R-01)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.1. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Hughes River (VAN-E03R-01) watershed. Scenario 5 tested the land use load reductions at 85%. Table 5.1 shows that exceedances are present when the anthropogenic sources are tested at an 85% reduction rate. Scenario 6 tested the land use load reductions at 89%. Table 5.1 shows that exceedances are present when the anthropogenic land based sources are tested at an 89% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition was performed to match the land-based anthropogenic source reductions. Scenario 8 tested the land use and livestock directly deposited loads at a 90% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.61 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.2 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.3 presents the final allocated in-stream *E. coli* loads for the Hughes River (VAN-E03R-01) impairment. Table 5.4 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Hughes River (VAN-E03R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.5). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.1. TMDL allocation scenarios for Hughes River (VAN-E03R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	5.0	15.9
1	100	0	100	0	0	0	0	3.3	12.9
2	100	50	100	50	50	0	0	1.7	6.1
3	100	75	100	75	75	0	0	0.0	2.5
4	100	100	100	100	100	0	0	0.0	0.0
5	100	85	100	85	85	0	0	0.0	0.6
6	100	89	100	89	89	0	0	0.0	0.1
7	100	90	100	90	90	0	0	0.0	0.0
8	100	90	90	90	90	0	0	0.0	0.0

Table 5.2. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Hughes River (VAN-E03R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	6.41E+13	0.00E+00	100
Livestock	2.13E+13	2.13E+12	90
Wildlife	2.99E+13	2.99E+13	0
Total	*1.15E+14*	*3.20E+13*	72
Land-based			
Residential	2.98E+14	2.98E+13	90
Cropland	2.12E+12	2.12E+11	90
Pasture	2.09E+16	2.09E+15	90
Forest	1.43E+14	1.43E+14	0
Total	*2.13E+16*	*2.26E+15*	89

Table 5.3. Expansion matrix for WLA in the Hughes River (VAN-E03R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VAG406417	HAR-01	0.0010	126	1.69E+09
Existing WLA		0.0010	126	1.69E+09
Expansion Scenario: 2 x Existing WLA		0.0020	126	3.38E+09
Expansion Scenario: 5 x Existing WLA		0.0050	126	8.44E+09[a]

[a] Future growth WLA

Table 5.4. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hughes River (VAN-E03R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	8.44E+09	2.28E+13	N/A	2.28E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.5. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hughes River (VAN-E03R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.31E+07	3.70E+12	N/A	3.70E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

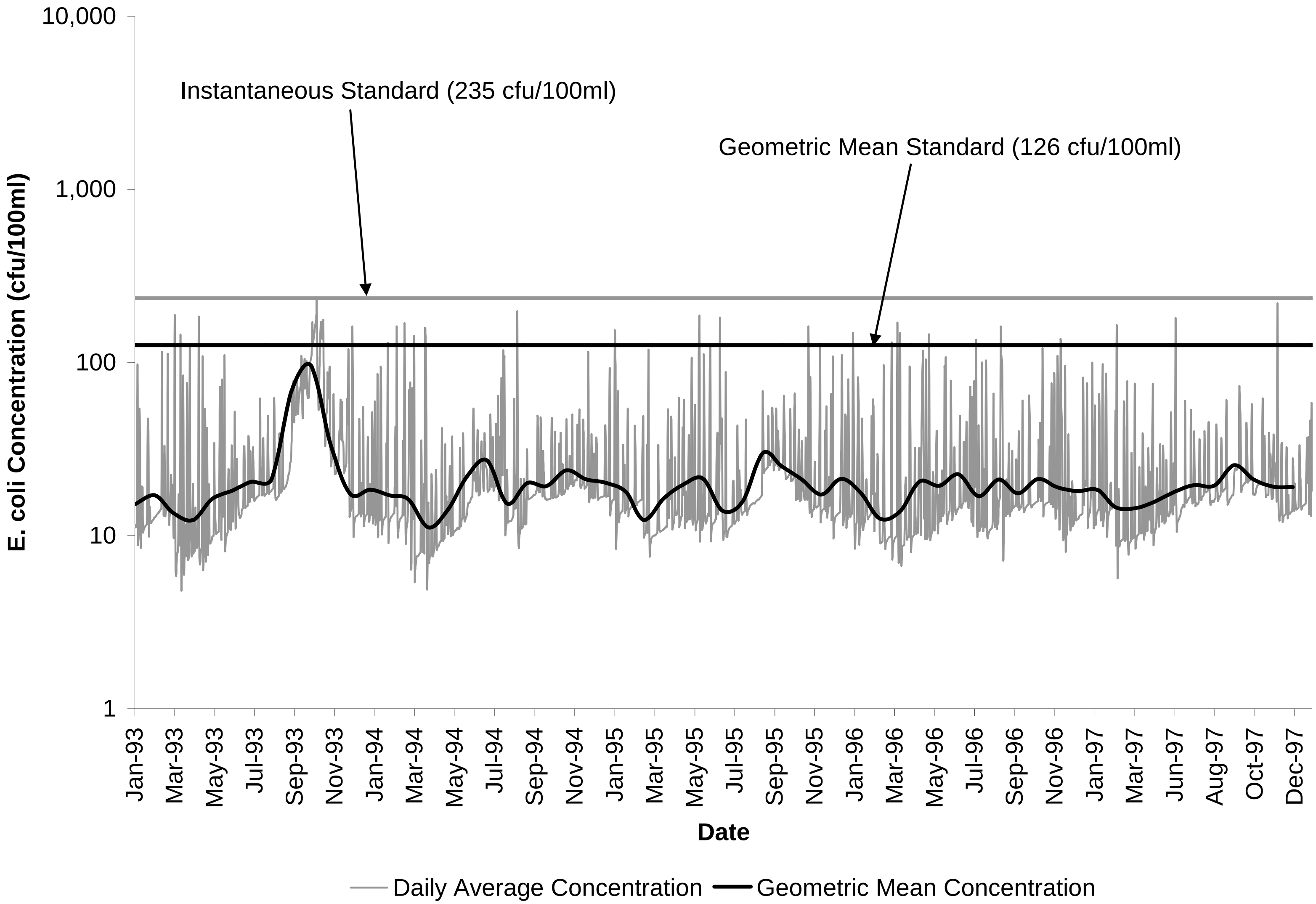

Figure 5.61. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.1) in Hughes River (VAN-E03R-01) impairment.

5.4.2 Hazel River (VAN-E04R-01)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.6. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Hazel River (VAN-E04R-01) watershed. Scenario 5 tested the anthropogenic land use load reductions at 90%. Table 5.6 shows that exceedances are present when the anthropogenic sources are tested at a 90% reduction rate. Scenario 6 tested the anthropogenic land use load reductions at 96%. Table 5.6 shows that exceedances are present when the anthropogenic sources are tested at a 96% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the anthropogenic land use load reductions. Scenario 8 tested the land use and livestock directly deposited loads at a 97% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.62 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.7 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.8 presents the final allocated in-stream *E. coli* loads for the Hazel River (VAN-E04R-01) impairment. Table 5.9 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the six study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Hazel River (VAN-E04R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.10). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.6. TMDL allocation scenarios for Hazel River (VAN-E04R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	70.0	35.1
1	100	0	100	0	0	0	0	8.3	23.6
2	100	50	100	50	50	0	0	3.3	13.1
3	100	75	100	75	75	0	0	3.3	5.2
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	1.7	0.7
6	100	96	100	96	96	0	0	0.0	0.1
7	100	97	100	97	97	0	0	0.0	0.0
8	100	97	97	97	97	0	0	0.0	0.0

Table 5.7. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Hazel River (VAN-E04R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.78E+14	0.00E+00	100
Livestock	3.43E+13	1.03E+12	97
Wildlife	5.17E+13	5.17E+13	0
Total	*2.64E+14*	*5.27E+13*	80
Land-based			
Residential	1.11E+15	3.33E+13	97
Cropland	4.38E+12	1.31E+11	97
Pasture	3.37E+16	1.01E+15	97
Forest	3.38E+14	3.38E+14	0
Total	*3.52E+16*	*1.38E+15*	96

Table 5.8. Expansion matrix for WLA in the Hazel River (VAN-E04R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0088749[a]	HAR-04	0.4500	126	7.83E+11
Existing WLA		0.4500	126	7.83E+11
Expansion Scenario: 2 x Existing WLA		0.9000	126	1.57E+12
Expansion Scenario: 5 x Existing WLA		2.2500	126	3.92E+12[b]

[a] Currently, there are two permitted treatment facilities associated with Boston Sewer and Water (VA0065358 and VA0088749). The first, VA0065358 is currently in operation, and has a design flow of 0.0150 MGD. The second, VA0088749, has not been built yet, but has a design flow of 0.4500 MGD. Once the second facility has been built, and begins operation, the first facility will go offline. Thus, it is not practical to assign a load for both facilities, since both facilities will not be operating at the same time. Rather, a load was assigned to the new facility, VA0088749, because that facility has the larger design flow. A load for the new facility will be sufficient to cover the current facility while it is in operation, and provide for the operation of the new facility, once it is built. Both permits are listed in Table 3.2"

[b] Future growth WLA

Table 5.9. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hazel River (VAN-E04R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	3.92E+12	3.38E+13	N/A	3.77E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.10. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hazel River (VAN-E04R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	1.07E+10	7.95E+12	N/A	7.96E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

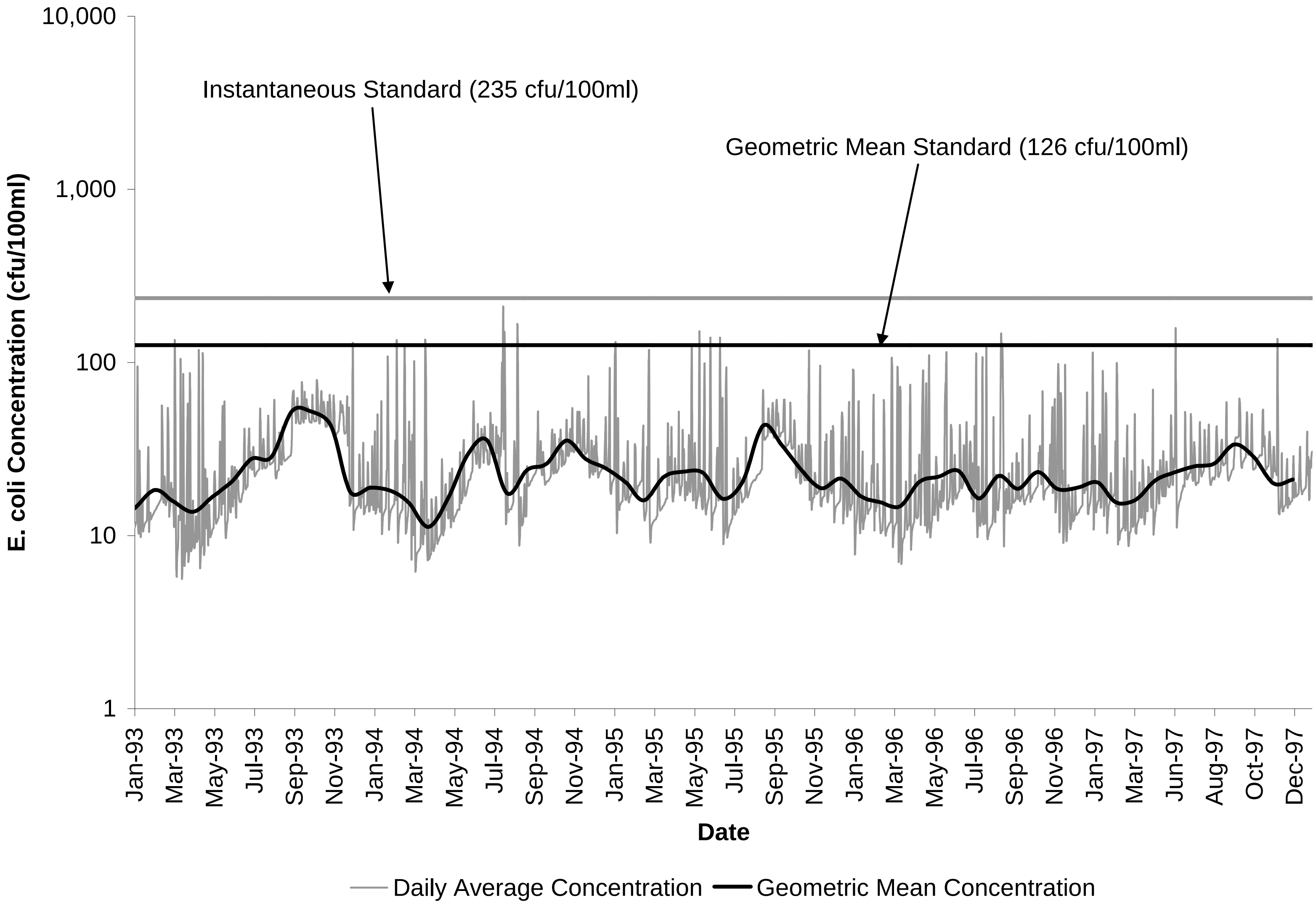

Figure 5.62. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.5) in Hazel River (VAN-E04R-01) impairment.

5.4.3 Rush River (VAN-E05R-01)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.11. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Rush River (VAN-E05R-01) watershed. Scenario 5 tested the anthropogenic land use load reductions at 99%. Table 5.11 shows that exceedances are present when the anthropogenic sources are tested at a 99% reduction rate. Scenario 6 tested the residential land-based loads at a 100% reduction rate with cropland land-based and pasture land-based loads at a 99% reduction rate. Scenario 6 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the cropland land-based and pasture land-based loads. Scenario 7 tested the cropland land-based, pasture land-based loads, and livestock directly deposited loads at a 99% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.63 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.12 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.13 presents the final allocated in-stream *E. coli* loads for the Rush River (VAN-E05R-01) impairment. Table 5.14 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Rush River (VAN-E05R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.15). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.11. TMDL allocation scenarios for Rush River (VAN-E05R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	33.3	23.5
1	100	0	100	0	0	0	0	6.7	19.1
2	100	50	100	50	50	0	0	3.3	11.5
3	100	75	100	75	75	0	0	3.3	5.8
4	100	100	100	100	100	0	0	0.0	0.0
5	100	99	100	99	99	0	0	1.7	0.0
6	100	100	100	99	99	0	0	0.0	0.0
7	100	100	99	99	99	0	0	0.0	0.0

Table 5.12. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rush River (VAN-E05R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.29E+13	0.00E+00	100
Livestock	5.97E+12	5.97E+10	99
Wildlife	1.01E+13	1.01E+13	0
Total	*3.90E+13*	*1.02E+13*	74
Land-based			
Residential	1.45E+14	0.00E+00	100
Cropland	7.65E+10	7.65E+08	99
Pasture	5.74E+15	5.74E+13	99
Forest	7.37E+13	7.37E+13	0
Total	*5.96E+15*	*1.31E+14*	98

Table 5.13. Expansion matrix for WLA in the Rush River (VAN-E05R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0087581	HAR-11	0.0061	126	0.00E+00
VA0091651	HAR-11	0.0600	126	1.04E+11
Existing WLA		0.0661	126	1.04E+11
Expansion Scenario: 2 x Existing WLA		0.1322	126	2.09E+11
Expansion Scenario: 5 x Existing WLA		0.3305	126	5.22E+11[a]

[a] Future growth WLA

Table 5.14. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rush River (VAN-E05R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	5.22E+11	1.49E+12	N/A	2.01E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.15. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rush River (VAN-E05R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	1.43E+09	1.25E+12	N/A	1.25E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

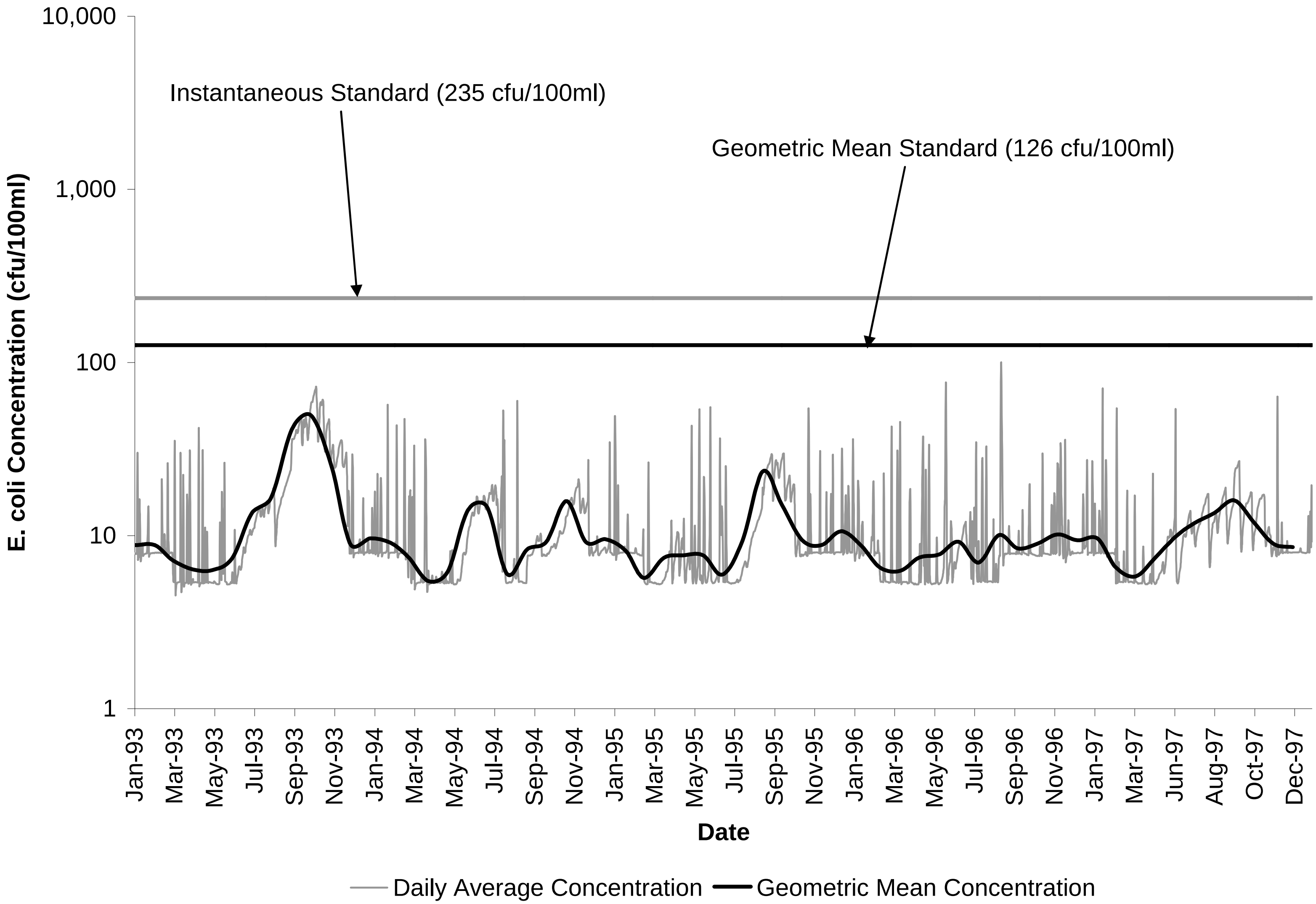

Figure 5.63. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.9) in Rush River (VAN-E05R-01) impairment.

5.4.4 Hazel River (60076)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.16. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Hazel River (60076) watershed. Scenario 5 tested the land based load reductions at 90%. Table 5.16 shows that exceedances are present when the land based sources are tested at a 90% reduction rate. Scenario 6 tested the land based load reductions at 93%. Table 5.16 shows that exceedances are present when the anthropogenic land based sources are tested at a 93% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the land based load reductions. Scenario 8 tested the land based and livestock directly deposited loads at a 94% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.64 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.17 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.18 presents the final allocated in-stream *E. coli* loads for the Hazel River (60076) impairment. Table 5.19 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Hazel River (60076) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.20). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.16. TMDL allocation scenarios for Hazel River (60076) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	31.7	23.8
1	100	0	100	0	0	0	0	5.0	21.7
2	100	50	100	50	50	0	0	3.3	12.1
3	100	75	100	75	75	0	0	0.0	4.8
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	0.0	0.6
6	100	93	100	93	93	0	0	0.0	0.2
7	100	94	100	94	94	0	0	0.0	0.0
8	100	94	94	94	94	0	0	0.0	0.0

Table 5.17. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Hazel River (60076) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.30E+14	0.00E+00	100
Livestock	1.06E+14	6.33E+12	94
Wildlife	1.20E+14	1.20E+14	0
Total	*4.56E+14*	*1.26E+14*	72
Land-based			
Residential	2.25E+15	1.35E+14	94
Cropland	5.08E+12	3.05E+11	94
Pasture	1.02E+17	6.15E+15	94
Forest	7.33E+14	7.33E+14	0
Total	*1.05E+17*	*7.02E+15*	93

Table 5.18. Expansion matrix for WLA in the Hazel River (60076) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0022471	HAR-13	0.0080	126	1.40E+10
VA0064181	HAR-13	0.0050	126	8.66E+09
VA0024449	HAR-14	0.0150	126	2.61E+10
VA0062880	HAR-14	0.0550	126	9.58E+10
VAG406399	HAR-18	0.0010	126	1.69E+09
VAG406377	HAR-19	0.0010	126	1.69E+09
VAG406383	HAR-19	0.0010	126	1.69E+09
Existing WLA		0.0860	126	1.50E+11
Expansion Scenario: 2 x Existing WLA		0.1720	126	2.99E+11
Expansion Scenario: 5 x Existing WLA		0.4300	126	7.48E+11[a]

[a] Future growth WLA

Table 5.19. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Hazel River (60076) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	7.48E+11	9.15E+13	N/A	9.22E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.20. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Hazel River (60076) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.05E+09	2.06E+13	N/A	2.06E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

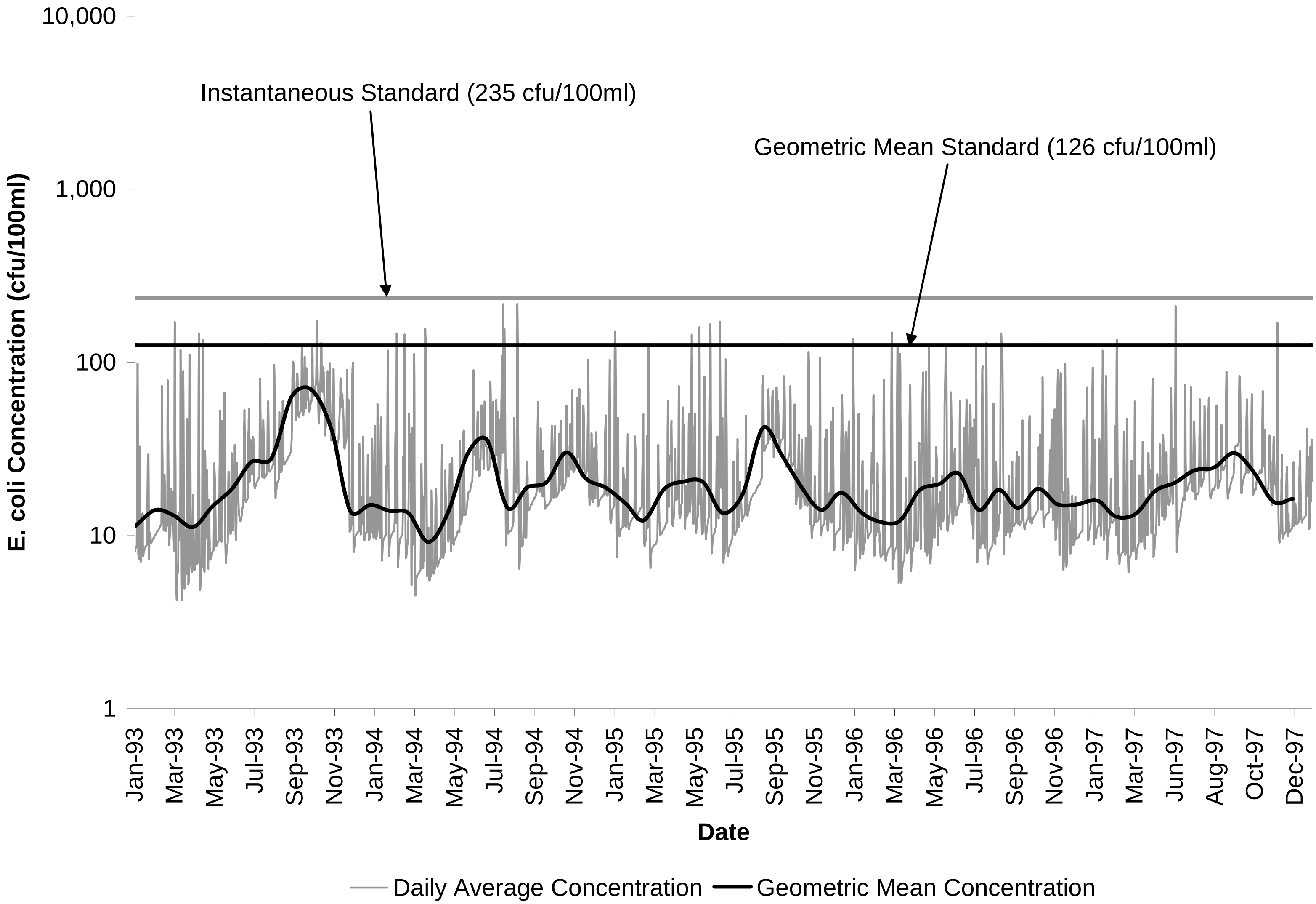

Figure 5.64. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.13) in Hazel River (60076) impairment.

5.4.5 Rappahannock River (VAN-E01R-03)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.21. Since a 100% reduction in the anthropogenic sources (Scenario 4) did not meet the required criteria, Scenario 5 through 7 represents the determination of required reductions in wildlife directly deposited loads in the Rappahannock River (VAN-E01R-03) watershed. The land based loads and livestock directly deposited loads were all tested at a 100% reduction rate for Scenario 5. The land-based loads and livestock directly deposited loads were all tested at a 99% reduction rate for Scenario 6 and 7. There was no reduction in forest land based loads for Scenario 5 through 7. Scenario 5 represents a 7% reduction of wildlife directly deposited load. This scenario met the 0% exceedance criteria of both standards, but a solution other than a 100% reduction in land-based and livestock directly deposited loads was desired. Scenario 6 represents a 7% reduction of wildlife directly deposited load. This scenario had a 1.7% exceedance in the geometric mean, but no exceedance for the instantaneous condition. Scenario 7 represents a 11% reduction of wildlife directly deposited load. Scenario 7 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.65 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.22 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.23 presents the final allocated in-stream *E. coli* loads for the Rappahannock River (VAN-E01R-03) impairment. Table 5.24 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.21. TMDL allocation scenarios for Rappahannock River (VAN-E01R-03) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	40.0	28.1
1	100	0	100	0	0	0	0	10.0	24.4
2	100	50	100	50	50	0	0	8.3	13.5
3	100	75	100	75	75	0	0	3.3	6.5
4	100	100	100	100	100	0	0	1.7	0.0
5	100	100	100	100	100	7	0	0.0	0.0
6	100	99	99	99	99	7	0	1.7	0.0
7	100	99	99	99	99	11	0	0.0	0.0

Table 5.22. Annual nonp oint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rappahannock River (VAN-E01R-03) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.92E+13	0.00E+00	100
Livestock	3.58E+13	3.58E+11	99
Wildlife	4.87E+13	4.33E+13	11
Total	*1.44E+14*	*4.37E+13*	70
Land-based			
Residential	7.66E+14	7.66E+12	99
Cropland	1.93E+12	1.93E+10	99
Pasture	3.47E+16	3.47E+14	99
Forest	2.74E+14	2.74E+14	0
Total	*3.58E+16*	*6.29E+14*	98

Table 5.23. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (VAN-E01R-03) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.79E+11	1.77E+13	N/A	1.79E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.24. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (VAN-E01R-03) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	4.35E+10	4.31E+12	N/A	4.35E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

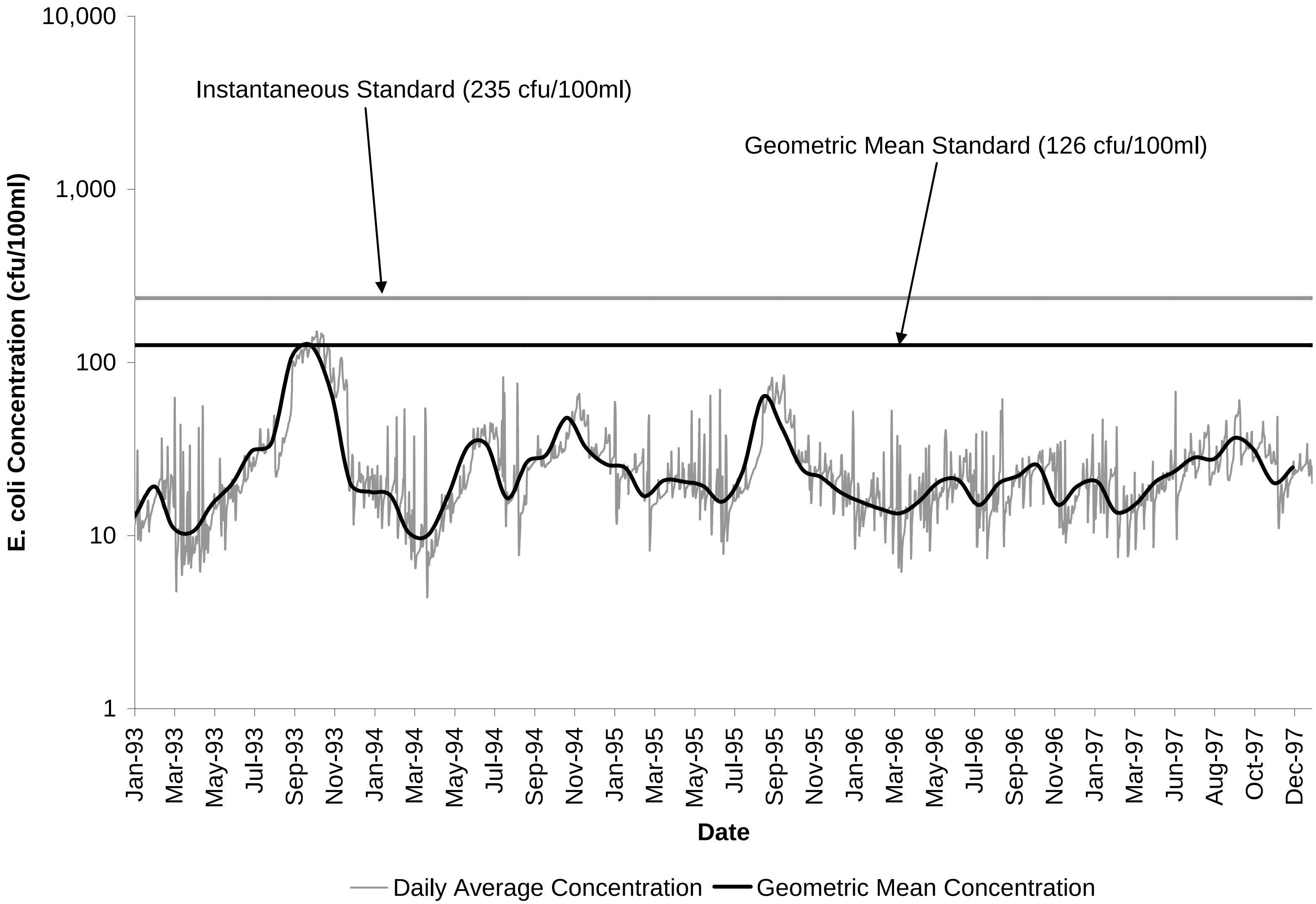

Figure 5.65. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.17) in Rappahannock River (VAN-E01R-03) impairment.

5.4.6 Rappahannock River (VAN-E08R-04)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.25. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Rappahannock River (VAN-E08R-04) watershed. Scenario 5 tested the land-based load reductions at 90%. Table 5.25 shows that exceedances are present when the land-based sources are tested at a 90% reduction rate. Scenario 6 tested the land-based reductions at 96%. Table 5.25 shows that exceedances are present when the land-based loads are tested at a 96% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the land-based load reductions. Scenario 8 tested the land based and livestock directly deposited loads at a 97% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.66 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.26 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.27 presents the final allocated in-stream *E. coli* loads for the Rappahannock River (VAN-E08R-04) impairment. Table 5.28 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Rappahannock River (VAN-E08R-04) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.29). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.25. TMDL allocation scenarios for Rappahannock River (VAN-E08R-04) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	28.3	20.2
1	100	0	100	0	0	0	0	8.3	16.1
2	100	50	100	50	50	0	0	5.0	8.3
3	100	75	100	75	75	0	0	1.7	4.1
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	0.0	0.8
6	100	96	100	96	96	0	0	0.0	0.1
7	100	97	100	97	97	0	0	0.0	0.0
8	100	97	97	97	97	0	0	0.0	0.0

Table 5.26. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rappahannock River (VAN-E08R-04) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.19E+14	0.00E+00	100
Livestock	9.41E+13	2.82E+12	97
Wildlife	1.26E+14	1.26E+14	0
Total	*3.39E+14*	*1.29E+14*	62
Land-based			
Residential	3.05E+15	9.16E+13	97
Cropland	6.33E+13	1.90E+12	97
Pasture	9.33E+16	2.80E+15	97
Forest	7.14E+14	7.14E+14	0
Total	*9.71E+16*	*3.61E+15*	96

Table 5.27. Expansion matrix for WLA in the Rappahannock River (VAN-E08R-04) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0077411	RAR-07	0.0200	126	3.48E+10
VA0080527[a]	RAR-07	0.8568	126	1.49E+12
VA0088731	RAR-07	0.0500	126	8.71E+10
VA0068586	RAR-11	0.3000	126	5.22E+11
VA0090603	RAR-11	0.9000	126	1.57E+12
VAG406358	RAR-11	0.0010	126	1.69E+09
VAG406023	RAR-11	0.0010	126	1.69E+09
Existing WLA		2.1288	126	3.71E+12
Expansion Scenario: 2 x Existing WLA		4.2576	126	7.41E+12
Expansion Scenario: 5 x Existing WLA		10.6440	126	1.85E+13[b]

[a] Currently, there are two permitted treatment facilities associated with Clevengers Village (VA0029238 and VA0080527). The first, VA0029238 is currently in operation, and has a design flow of 0.0700 MGD. The second, VA0080527, has not been built yet, but has a design flow of 0.8568 MGD. Once the second facility has been built, and begins operation, the first facility will go offline. p; Thus, it was not practical to assign a load for both facilities, since both facilities will not be operating at the same time. Rather, a load was assigned to the new facility, VA0080527, because that facility has the larger design flow. A load for the new facility will be sufficient to cover the current facility while it is in operation, and provide for the operation of the new facility, once it is built. Both permits are listed in Table 3.2.

[b] Future growth WLA

Table 5.28. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (VAN-E08R-04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.85E+13	3.20E+14	N/A	3.38E+14

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.29. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (VAN-E08R-04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.07E+10	3.74E+13	N/A	3.74E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

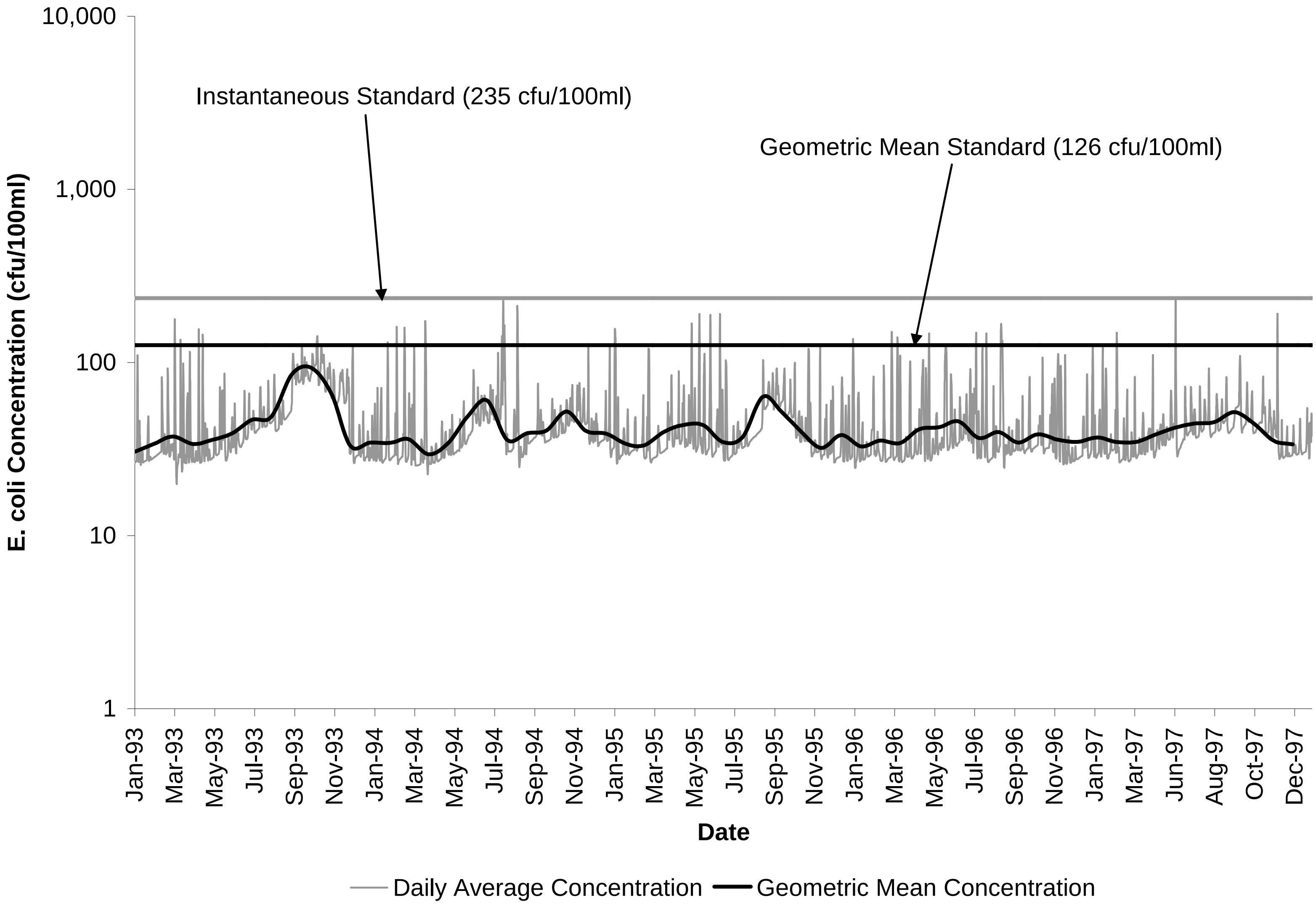

Figure 5.66. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.20) in Rappahannock River (VAN-E08R-04) impairment.

5.4.7 Rappahannock River (60081)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.30. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Rappahannock River (60081) watershed. Scenario 5 tested the land based load reductions at 90%. Table 5.30 shows that exceedances are present when the anthropogenic land based loads are tested at a 90% reduction rate. Scenario 6 tested the land based load reductions at 98% and resulted in exceedances. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the land-based load reductions. Scenario 8 tested the land-based and livestock directly deposited loads at a 99% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.67 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.31 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.32 presents the final allocated in-stream *E. coli* loads for the Rappahannock River (60081) impairment. Table 5.33 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the Rappahannock River (60081) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.34). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.30. TMDL allocation scenarios for Rappahannock River (60081) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	38.3	25.6
1	0	100	0	0	0	0	0	16.7	21.9
2	50	100	50	50	50	0	0	6.7	13.0
3	75	100	75	75	75	0	0	3.3	6.4
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	0.0	1.5
6	100	98	100	98	98	0	0	0.0	0.1
7	100	99	100	99	99	0	0	0.0	0.0
8	100	99	99	99	99	0	0	0.0	0.0

Table 5.31. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rappahannock River (60081) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.90E+12	0.00E+00	100
Livestock	1.28E+13	1.28E+11	99
Wildlife	1.40E+13	1.40E+13	0
Total	*3.66E+13*	*1.41E+13*	62
Land-based			
Residential	5.13E+14	5.13E+12	99
Cropland	3.78E+12	3.78E+10	99
Pasture	1.28E+16	1.28E+14	99
Forest	5.70E+13	5.70E+13	0
Total	*1.33E+16*	*1.90E+14*	99

Table 5.32. Expansion matrix for WLA in the Rappahannock River (60081) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0076805	RAR-12	2.5000	126	4.35E+12
VA0067750	RAR-12	0.0038	126	6.53E+09
Existing WLA		2.5038	126	4.36E+12
Expansion Scenario: 2 x Existing WLA		5.0075	126	8.72E+12
Expansion Scenario: 5 x Existing WLA		12.5188	126	2.18E+13[a]

[a] Future growth WLA

Table 5.33. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rappahannock River (60081) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.18E+13	3.34E+14	N/A	3.56E+14

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.34. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rappahannock River (60081) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.97E+10	3.96E+13	N/A	3.97E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

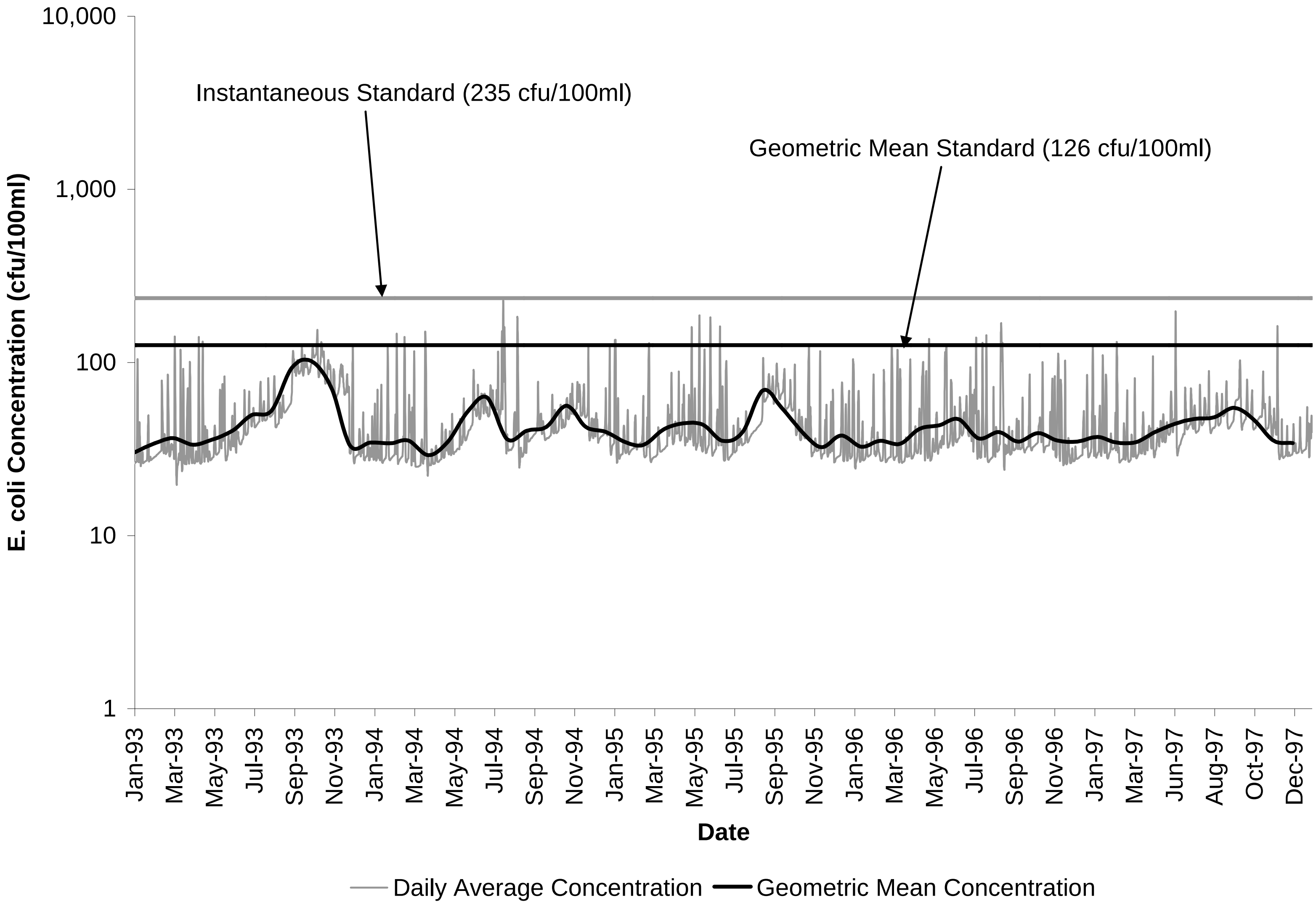

Figure 5.67. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.24) in Rappahannock River (60081) impairment.

5.4.8 Craig Run (VAN-E08R-03)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.35. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Craig Run (VAN-E08R-03) watershed. Scenario 5 tested the land-based load reductions at 90%. Table 5.35 shows that exceedances are present when the anthropogenic land-based loads are tested at a 90% reduction rate. Scenario 6 tested the land-based load reductions at 96% and resulted in exceedances. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the anthropogenic land-based load reductions. Scenario 8 tested the land-based and livestock directly deposited loads at a 97% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.68 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.36 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.37 presents the final allocated in-stream *E. coli* loads for the Craig Run (VAN-E08R-03) impairment. Table 5.38 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.35. TMDL allocation scenarios for Craig Run (VAN-E08R-03) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	33.3	27.2
1	100	0	100	0	0	0	0	6.7	25.5
2	100	50	100	50	50	0	0	3.3	18.5
3	100	75	100	75	75	0	0	0.0	12.4
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	0.0	3.7
6	100	96	100	96	96	0	0	0.0	0.1
7	100	97	100	97	97	0	0	0.0	0.0
8	100	97	97	97	97	0	0	0.0	0.0

Table 5.36. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Craig Run (VAN-E08R-03) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.04E+12	0.00E+00	100
Livestock	8.70E+12	2.61E+11	97
Wildlife	6.11E+12	6.11E+12	0
Total	*1.99E+13*	*6.37E+12*	68
Land-based			
Residential	2.41E+14	7.24E+12	97
Cropland	2.28E+13	6.85E+11	97
Pasture	8.47E+15	2.54E+14	97
Forest	3.00E+13	3.00E+13	0
Total	*8.77E+15*	*2.92E+14*	97

Table 5.37. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Craig Run (VAN-E08R-03) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.72E+10	2.69E+12	N/A	2.72E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.38. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Craig Run (VAN-E08R-03) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	8.93E+09	8.84E+11	N/A	8.93E+11

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

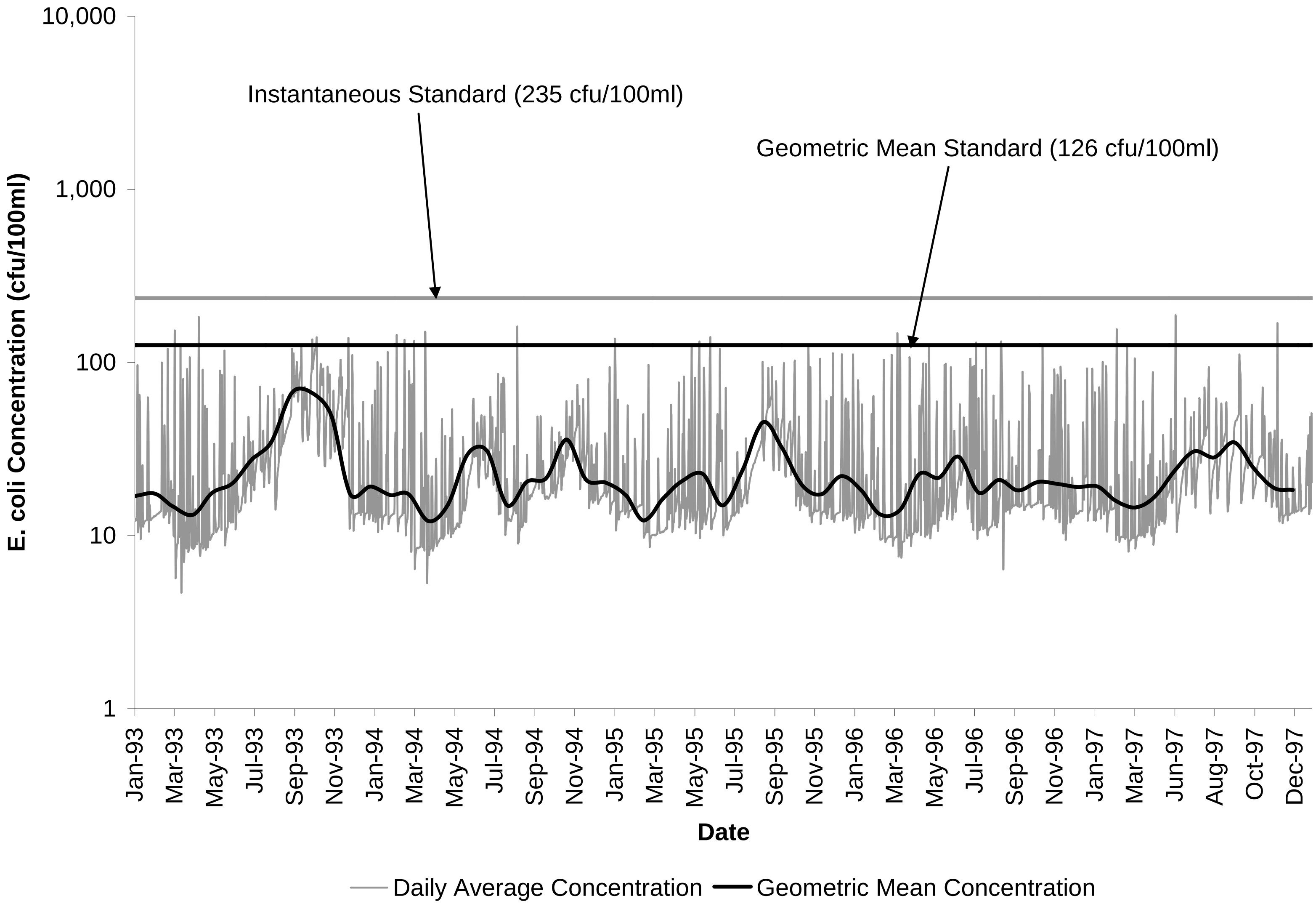

Figure 5.68. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.28) in Craig Run (VAN-E08R-03) impairment.

5.4.9 Browns Run (VAN-E08R-02)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.39. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Browns Run (VAN-E08R-02) watershed. Scenario 5 tested the land-based load reductions at 90%. Table 5.39 shows that exceedances are present when the anthropogenic land-based loads are tested at a 90% reduction rate. Scenario 6 tested the land-based load reductions at 95% and resulted in exceedances. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the anthropogenic land-based load reductions. Scenario 8 tested the land-based and livestock directly deposited loads at a 96% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.69 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.40 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.41 presents the final allocated in-stream *E. coli* loads for the Browns Run (VAN-E08R-02) impairment. Table 5.42 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharge from the permitted point source in the Browns Run (VAN-E08R-02) watershed was increased by two and five times the existing permit level to determine the effect of possible facility expansion (Table 5.43). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.39. TMDL allocation scenarios for Browns Run (VAN-E08R-02) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	5.0	20.2
1	100	0	100	0	0	0	0	0.0	19.4
2	100	50	100	50	50	0	0	0.0	13.1
3	100	75	100	75	75	0	0	0.0	7.9
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	0.0	3.2
6	100	95	100	95	95	0	0	0.0	0.2
7	100	96	100	96	96	0	0	0.0	0.0
8	100	96	96	96	96	0	0	0.0	0.0

Table 5.40. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Browns Run (VAN-E08R-02) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	4.49E+12	0.00E+00	100
Livestock	8.84E+12	3.54E+11	96
Wildlife	1.52E+13	1.52E+13	0
Total	*2.86E+13*	*1.56E+13*	45
Land-based			
Residential	2.78E+14	1.11E+13	96
Cropland	3.13E+13	1.25E+12	96
Pasture	8.59E+15	3.44E+14	96
Forest	5.99E+13	5.99E+13	0
Total	*8.96E+15*	*4.16E+14*	95

Table 5.41. Expansion matrix for WLA in the Browns Run (VAN-E08R-02) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0051675	RAR-17	0.0005	126	0.00E+00
VAG406119	RAR-17	0.0010	126	1.69E+09
VAG406232	RAR-17	0.0010	126	1.69E+09
VAG406145	RAR-17	0.0010	126	1.69E+09
VAG406312	RAR-17	0.0010	126	1.69E+09
Existing WLA		0.0045	126	6.75E+09
Expansion Scenario: 2 x Existing WLA		0.0090	126	1.35E+10
Expansion Scenario: 5 x Existing WLA		0.0225	126	3.38E+10[a]

[a] Future growth WLA

Table 5.42. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Browns Run (VAN-E08R-02) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	3.38E+10	2.26E+12	N/A	2.29E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.43. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Browns Run (VAN-E08R-02) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	9.25E+07	9.23E+11	N/A	9.23E+11

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

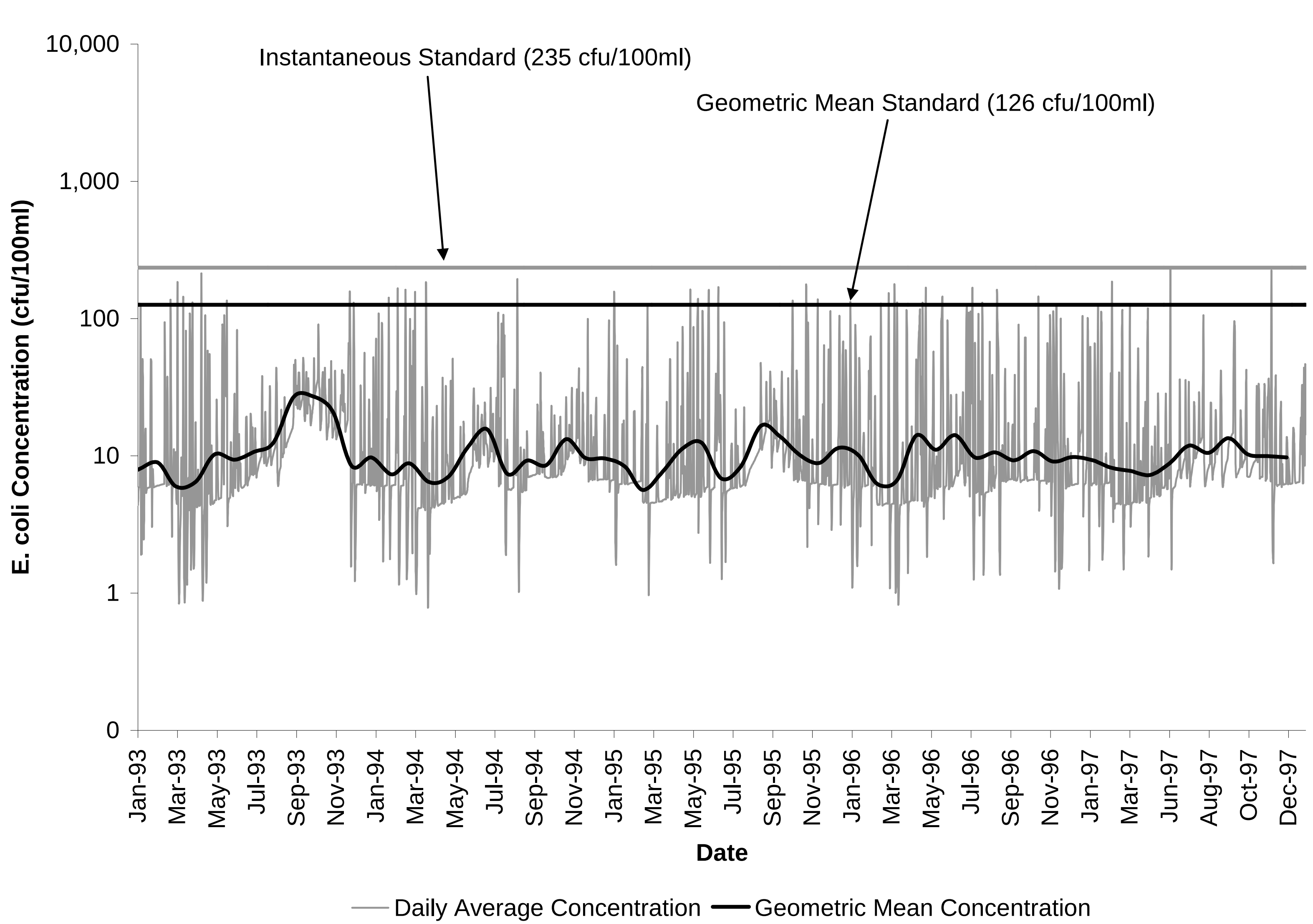

Figure 5.69. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.31) in Browns Run (VAN-E08R-02) impairment.

5.4.10 Marsh Run (VAN-E08R-01)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.44. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Marsh Run (VAN-E08R-01) watershed. Scenario 5 tested the land-based load reductions at 90%. Table 5.44 shows that exceedances are present when the anthropogenic land-based loads are tested at a 90% reduction rate. Scenario 6 tested the land-based load reductions at 96% and resulted in exceedances. Scenario 7 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the anthropogenic land-based load reductions. Scenario 8 tested the land use and livestock directly deposited loads at a 97% reduction rate. Scenario 8 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.70 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.45 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.46 presents the final allocated in-stream *E. coli* loads for the Marsh Run (VAN-E08R-01) impairment. Table 5.47 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharge from the permitted point source in the Marsh Run (VAN-E08R-01) watershed was increased by two and five times the existing permit level to determine the effect of possible facility expansion (Table 5.48). The increases did not result in additional exceedances of the water quality standards.

The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. The factor of five was introduced as a conservative measure to account for potential growth. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process.

Table 5.44. TMDL allocation scenarios for Marsh Run (VAN-E08R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedances of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	91.7	53.5
1	100	0	100	0	0	0	0	88.3	51.6
2	100	50	100	50	50	0	0	53.3	37.3
3	100	75	100	75	75	0	0	21.7	22.1
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	6.7	7.2
6	100	96	100	96	96	0	0	0.0	0.3
7	100	97	100	97	97	0	0	0.0	0.0
8	100	97	97	97	97	0	0	0.0	0.0

Table 5.45. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Marsh Run (VAN-E08R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.98E+12	0.00E+00	100
Livestock	1.72E+13	5.17E+11	97
Wildlife	1.79E+13	1.79E+13	0
Total	*3.71E+13*	*1.84E+13*	50
Land-based			
Residential	1.31E+15	3.92E+13	97
Cropland	4.39E+13	1.32E+12	97
Pasture	1.69E+16	5.08E+14	97
Forest	8.17E+13	8.17E+13	0
Total	*1.84E+16*	*6.30E+14*	97

Table 5.46. Expansion matrix for WLA in the Marsh Run (VAN-E08R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VAG406084	RAR-15	0.0010	126	1.69E+09
VAG406138	RAR-15	0.0010	126	1.69E+09
VAG406311	RAR-15	0.0010	126	1.69E+09
VA0092053	RAR-16	0.0900	126	1.57E+11
VA0091022	RAR-16	0.0000	126	0.00E+00
VA0091448	RAR-16	0.0000	126	0.00E+00
VAG406365	RAR-20	0.0010	126	1.69E+09
VA0064726	RAR-20	0.0067	126	1.17E+10
Existing WLA		0.1007	126	1.75E+11
Expansion Scenario: 2 x Existing WLA		0.2014	126	3.50E+11
Expansion Scenario: 5 x Existing WLA		0.5035	126	8.76E+11[a]

[a] Future growth WLA

Table 5.47. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Marsh Run (VAN-E08R-01) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	8.76E+11	2.77E+13	N/A	2.86E+13

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented as the average annual load for the allocation period.

Table 5.48. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Marsh Run (VAN-E08R-01) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	2.40E+09	3.07E+12	N/A	3.07E+12

N/A – not applicable because MOS was implicit.

1 – The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe. The WLA is calculated as the average annual load divided by 365.

2 – The LA is calculated as the TMDL minus the WLA.

3 – The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

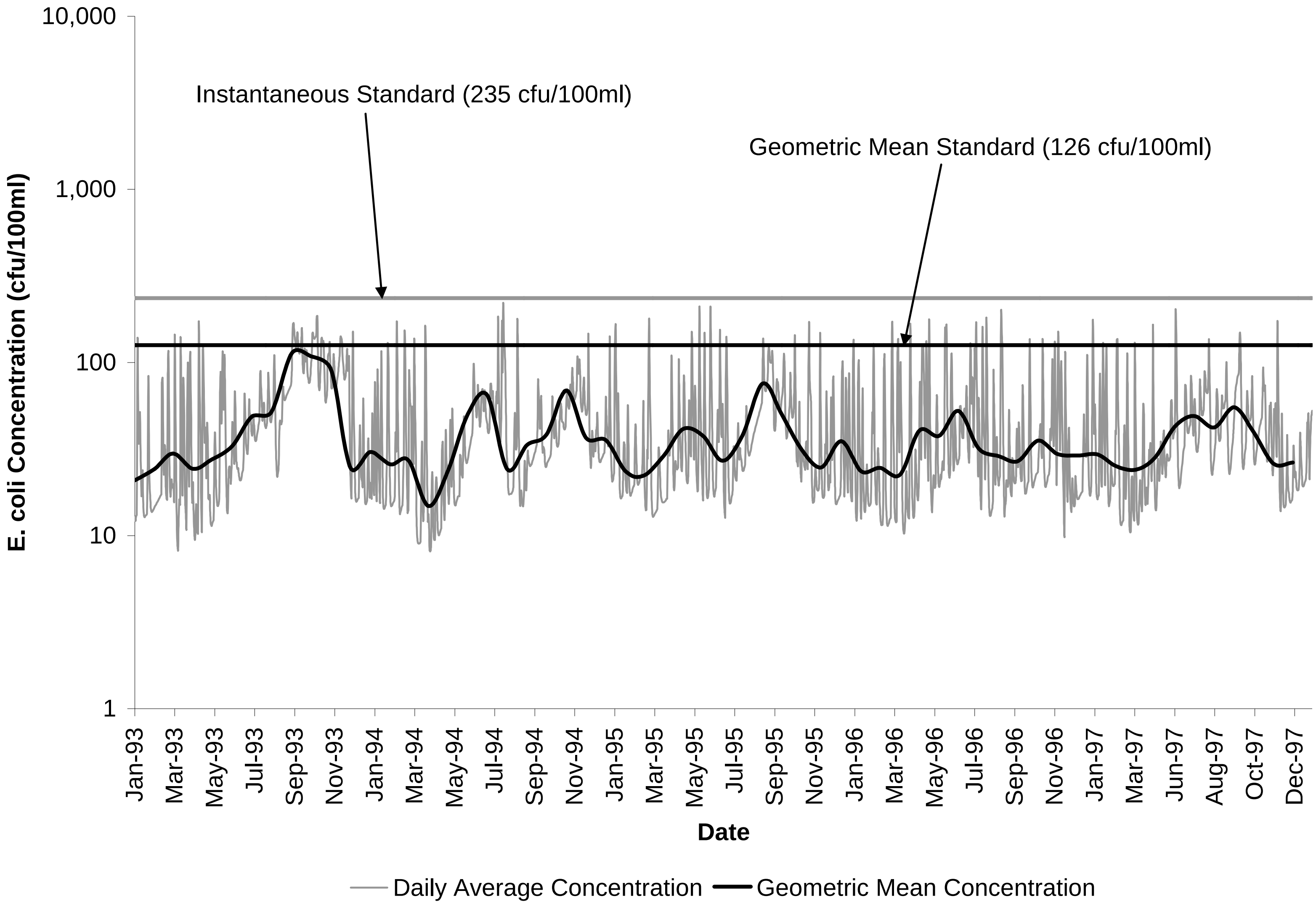

Figure 5.70. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.35) in Marsh Run (VAN-E08R-01) impairment.

Chapter 6. TMDL Implementation and Reasonable Assurance

Once a TMDL has been approved by USEPA, measures must be taken to reduce pollution levels from both point and non point sources in the stream (see section 6.4.2). 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 USEPA 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. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

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 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.

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

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

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support; through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have 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 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 Scenarios

The goal of the Stage 1 implementation scenarios is to reduce the bacteria loading reductions from controllable sources (excluding wildlife) such that exceedances of the single sample maximum criterion (235 cfu/100ml) are less than 10 percent, with no reduction from wildlife sources. The less than 10 percent exceedance rate is a conservative estimate of the extent of implementation needed to have each impaired segment de-listed, currently; a less than 10.5% exceedance rate is required. For the implementation scenarios, HSPF was run with a one-hour time step for the period January 1993 to December 1997, as with the TMDL allocation scenarios. The implicit MOS used in allocation scenarios was utilized in determining the Stage 1 implementation scenarios. Several scenarios were run until the Stage 1 goal was met. Stage 1 allocation results are presented in Sections 6.2.1 through 6.2.10.

6.2.1 Hughes River (VAN-E03R-01)

The Stage 1 allocation for the Hughes River (VAN-E03R-01) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 20% reduction in nonpoint source loadings to residential land use, a 20% reduction in nonpoint source loadings to pasture land use, a 20% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.86% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.1 for the Hughes River (VAN-E03R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.1.

Table 6.1. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Hughes River (VAN-E03R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	6.41E+13	0.00E+00	100
Livestock	2.13E+13	5.33E+12	75
Wildlife	2.99E+13	2.99E+13	0
Total	*1.15E+14*	*3.52E+13*	69
Land-based			
Residential	2.98E+14	2.38E+14	20
Cropland	2.12E+12	1.70E+12	20
Pasture	2.09E+16	1.67E+16	20
Forest	1.43E+14	1.43E+14	0
Total	*2.13E+16*	*1.71E+16*	20

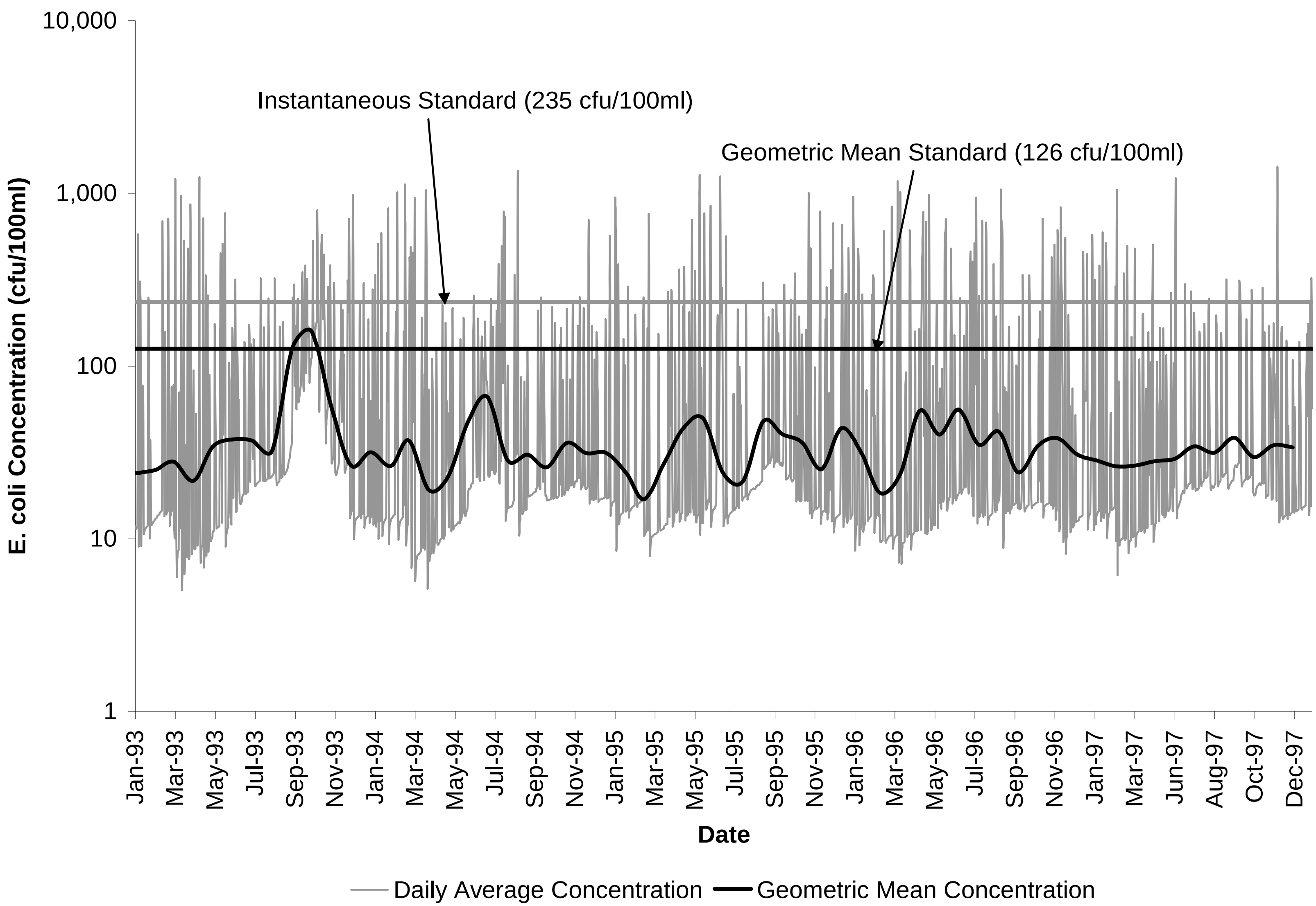

Figure 6.1. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Hughes River (VAN-E03R-01) impairment.

6.2.2 Hazel River (VAN-E04R-01)

The Stage 1 allocation for the Hazel River (VAN-E04R-01) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, a 0% reduction in wildlife direct deposition, a 71% reduction in nonpoint source loadings to residential, pasture, and cropland land uses, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.80% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.2 for the Hazel River (VAN-E04R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.2.

Table 6.2. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Hazel River (VAN-E04R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.78E+14	0.00E+00	100
Livestock	3.43E+13	8.59E+12	75
Wildlife	5.17E+13	5.17E+13	0
Total	*2.64E+14*	*6.03E+13*	77
Land-based			
Residential	1.11E+15	3.22E+14	71
Cropland	4.38E+12	1.27E+12	71
Pasture	3.37E+16	9.78E+15	71
Forest	3.38E+14	3.38E+14	0
Total	*3.52E+16*	*1.04E+16*	70

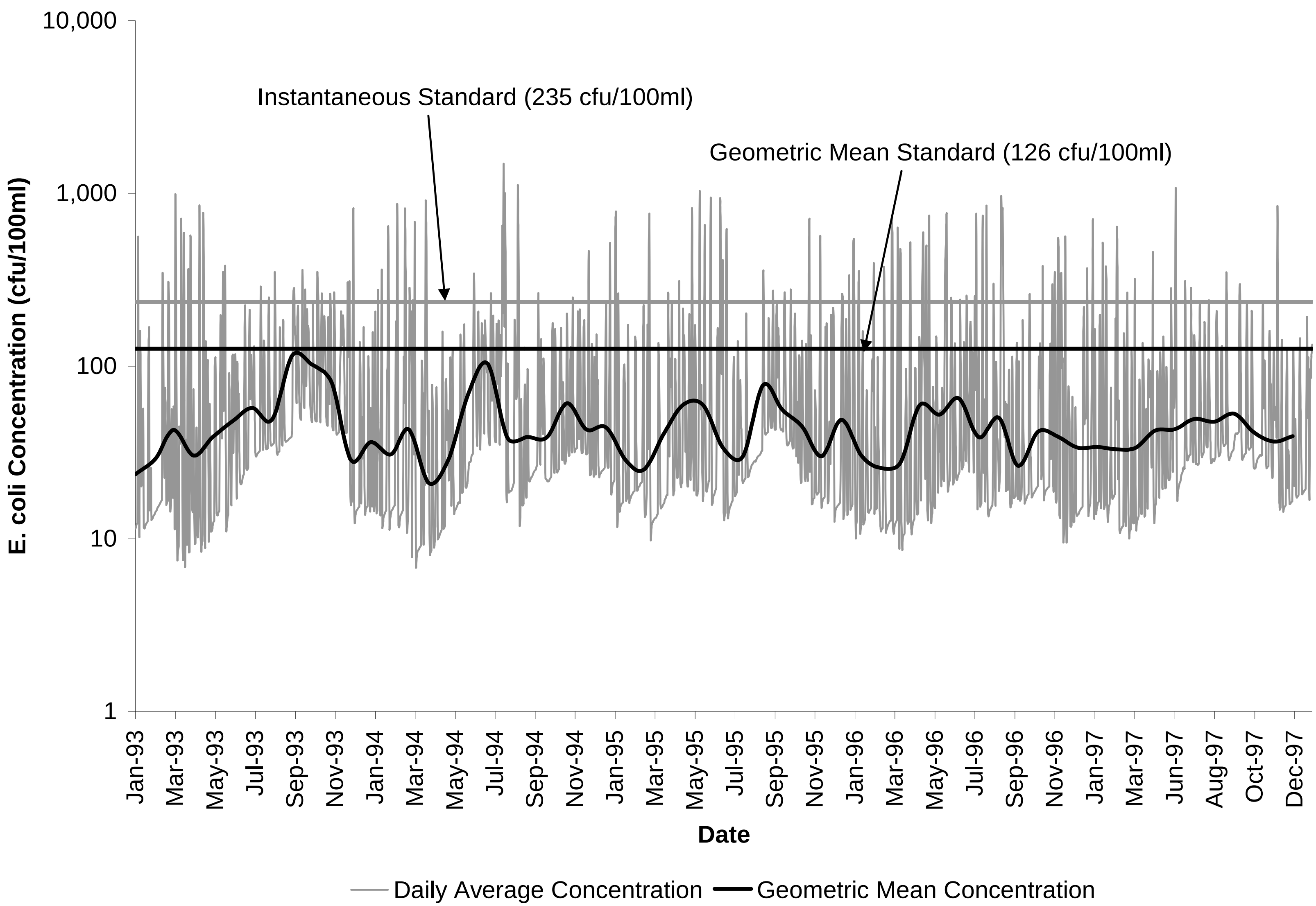

Figure 6.2. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Hazel River (VAN-E04R-01) impairment.

6.2.3 Rush River (VAN-E05R-01)

The Stage 1 allocation for the Rush River (VAN-E05R-01) impairment requires a 100% reduction in straight pipes, 80% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 60% reduction in nonpoint source loadings to residential land use, a 60% reduction in nonpoint source loadings to pasture land use, a 60% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.97% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.3 for the Rush River (VAN-E05R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.3.

Table 6.3. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rush River (VAN-E05R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.29E+13	0.00E+00	100
Livestock	5.97E+12	1.19E+12	80
Wildlife	1.01E+13	1.01E+13	0
Total	*3.90E+13*	*1.13E+13*	71
Land-based			
Residential	1.45E+14	5.80E+13	60
Cropland	7.65E+10	3.06E+10	60
Pasture	5.74E+15	2.30E+15	60
Forest	7.37E+13	7.37E+13	0
Total	*5.96E+15*	*2.43E+15*	59

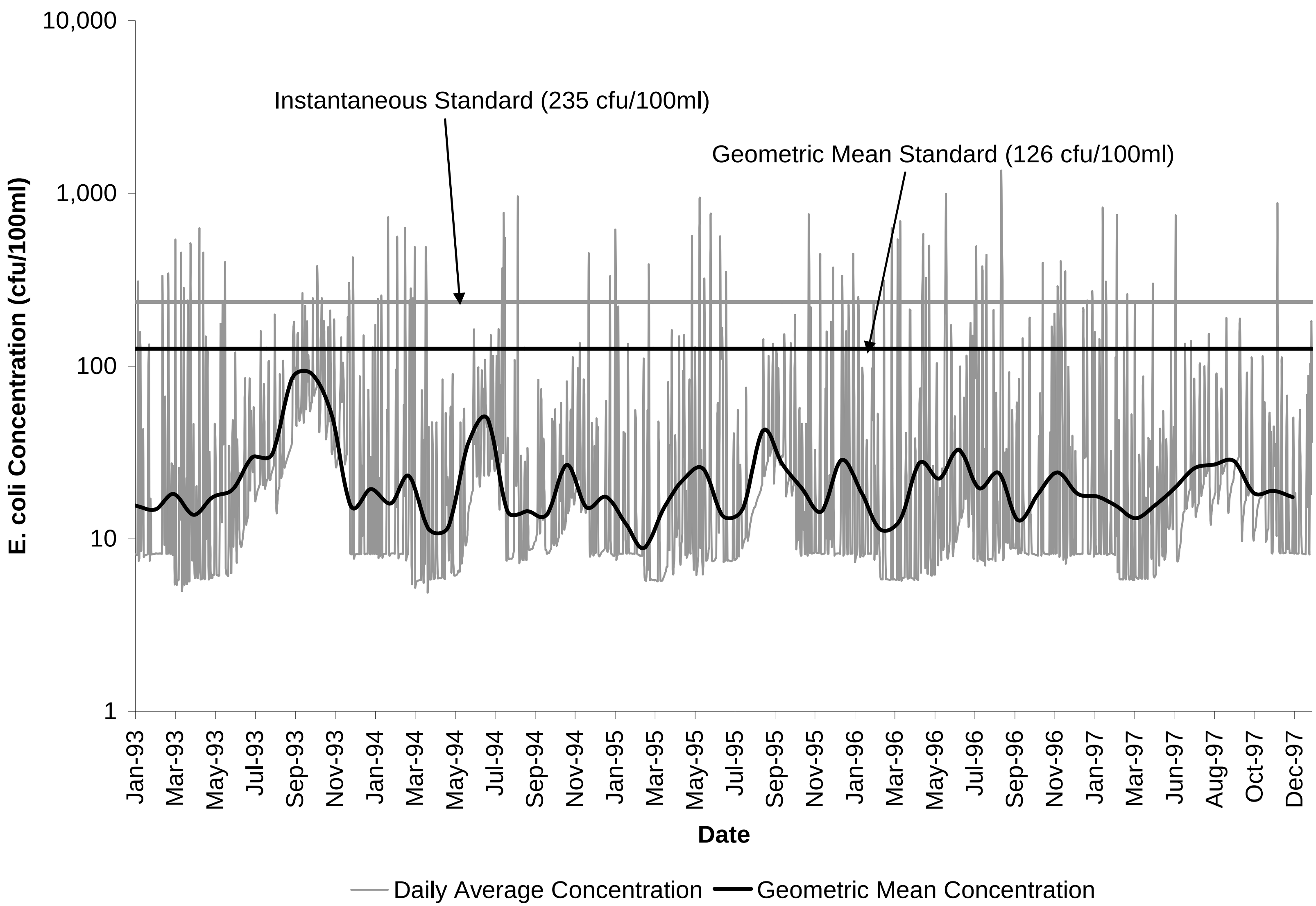

Figure 6.3. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rush River (VAN-E05R-01) impairment.

6.2.4 Hazel River (60076)

The Stage 1 allocation for the Hazel River (60076) impairment requires a 100% reduction in straight pipes, 80% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 59% reduction in nonpoint source loadings to residential land use, a 59% reduction in nonpoint source loadings to pasture land use, a 59% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.91% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.4 for the Hazel River (60076) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.4.

Table 6.4. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Hazel River (60076) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.30E+14	0.00E+00	100
Livestock	1.06E+14	2.11E+13	80
Wildlife	1.20E+14	1.20E+14	0
Total	*4.56E+14*	*1.41E+14*	69
Land-based			
Residential	2.25E+15	9.21E+14	59
Cropland	5.08E+12	2.08E+12	59
Pasture	1.02E+17	4.20E+16	59
Forest	7.33E+14	7.33E+14	0
Total	*1.05E+17*	*4.37E+16*	59

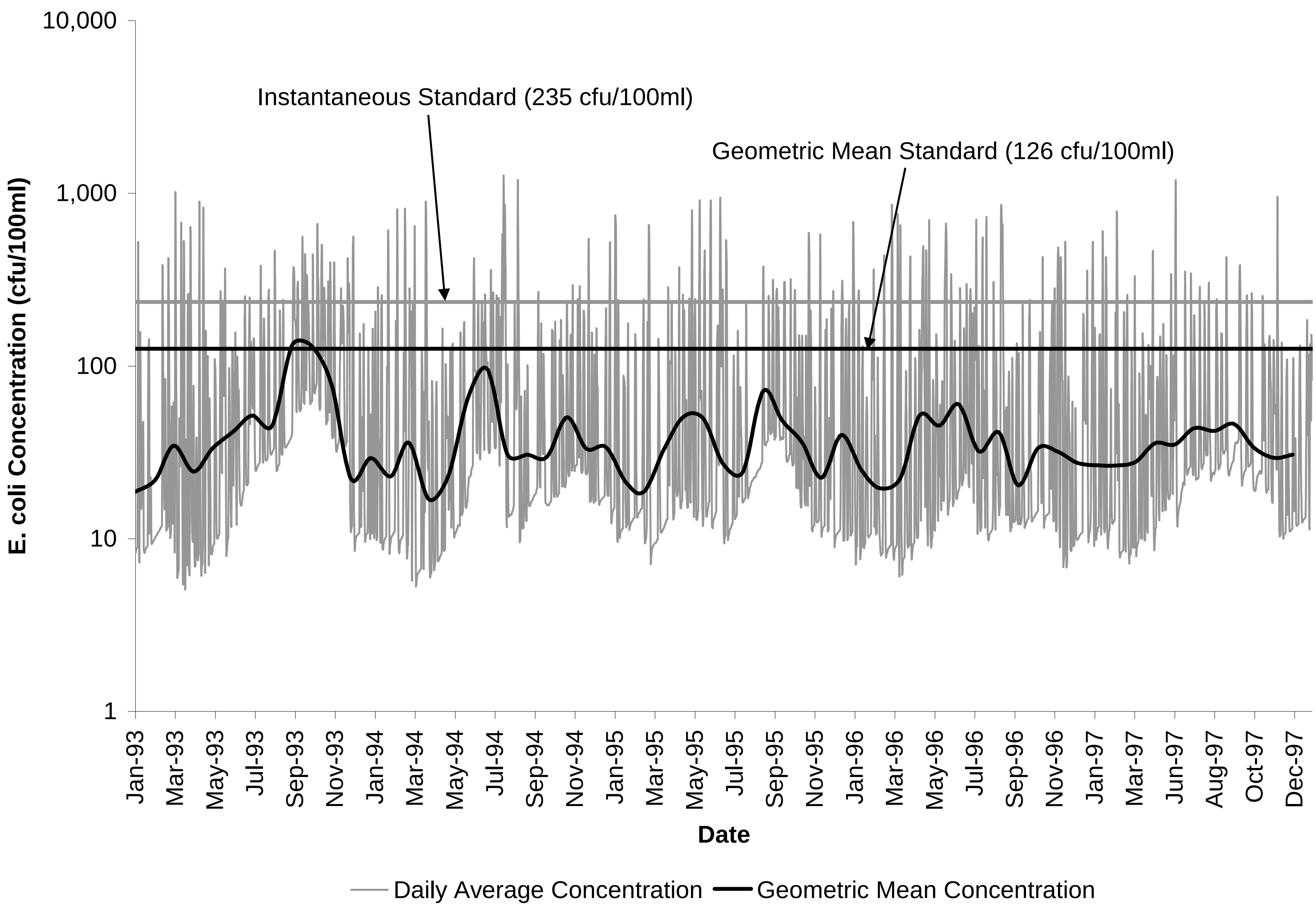

Figure 6.4. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in South Anna River (60076) impairment.

6.2.5 Rappahannock River (VAN-E01R-03)

The Stage 1 allocation for the Rappahannock River (VAN-E01R-03) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 66% reduction in nonpoint source loadings to residential and pasture land uses, a 66% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.97% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.5 for the Rappahannock River (VAN-E01R-03) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.5.

Table 6.5. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rappahannock River (VAN-E01R-03) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.92E+13	0.00E+00	100
Livestock	3.58E+13	8.96E+12	75
Wildlife	4.87E+13	4.87E+13	0
Total	*1.44E+14*	*5.76E+13*	60
Land-based			
Residential	7.66E+14	2.60E+14	66
Cropland	1.93E+12	6.58E+11	66
Pasture	3.47E+16	1.18E+16	66
Forest	2.74E+14	2.74E+14	0
Total	*3.58E+16*	*1.23E+16*	65

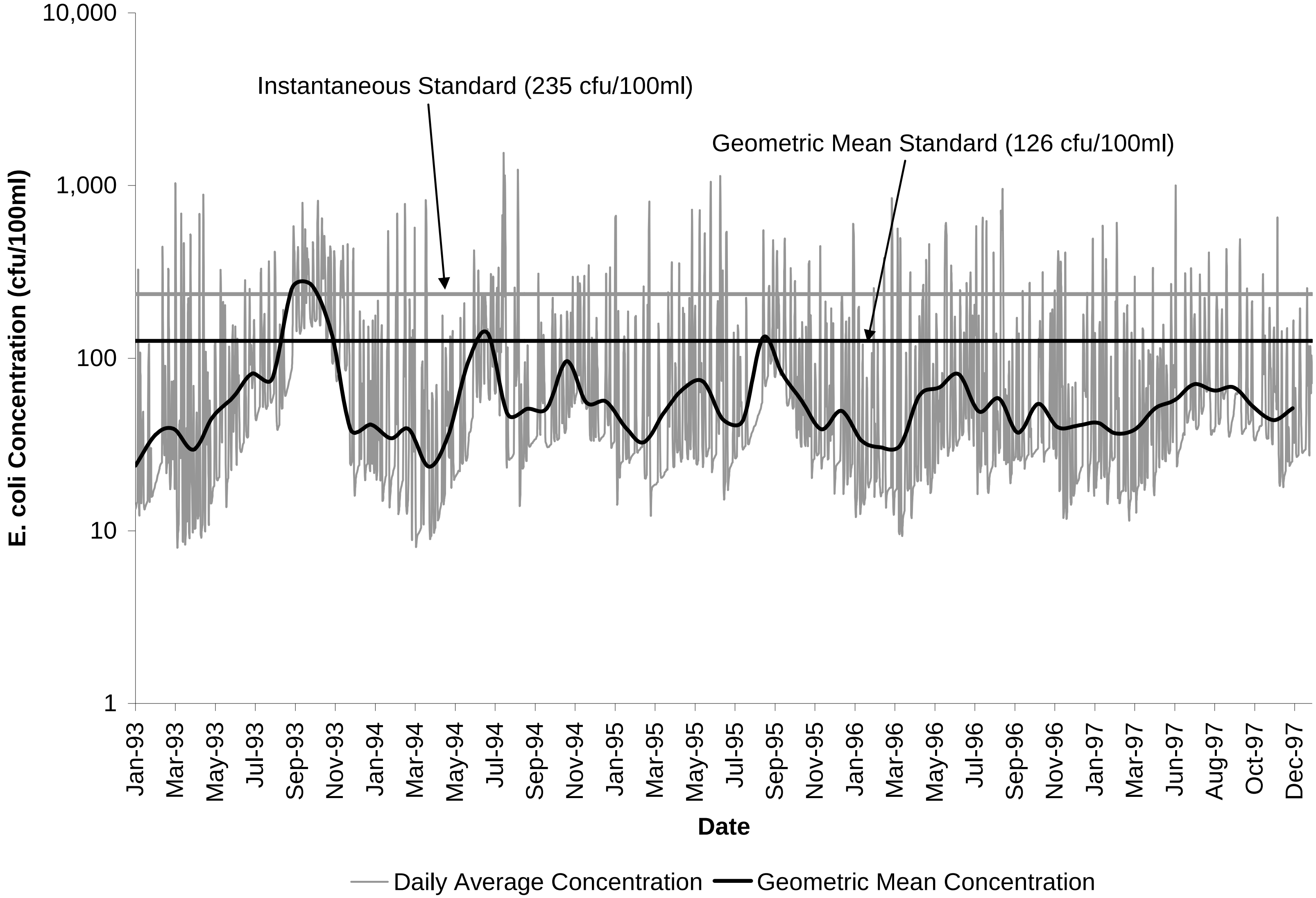

Figure 6.5. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rappahannock River (VAN-E01R-03) impairment.

6.2.6 Rappahannock River (VAN-E08R-04)

The Stage 1 allocation for the Rappahannock River (VAN-E08R-04) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 48% reduction in nonpoint source loadings to residential, pasture, and cropland land uses, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.53% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.6 for the Rappahannock River (VAN-E08R-04) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.6.

Table 6.6. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rappahannock River (VAN-E08R-04) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.19E+14	0.00E+00	100
Livestock	9.41E+13	2.35E+13	75
Wildlife	1.26E+14	1.26E+14	0
Total	*3.39E+14*	*1.50E+14*	0
Land-based			
Residential	3.05E+15	1.59E+15	48
Cropland	6.33E+13	3.29E+13	48
Pasture	9.33E+16	4.85E+16	48
Forest	7.14E+14	7.14E+14	0
Total	*9.71E+16*	*5.08E+16*	48

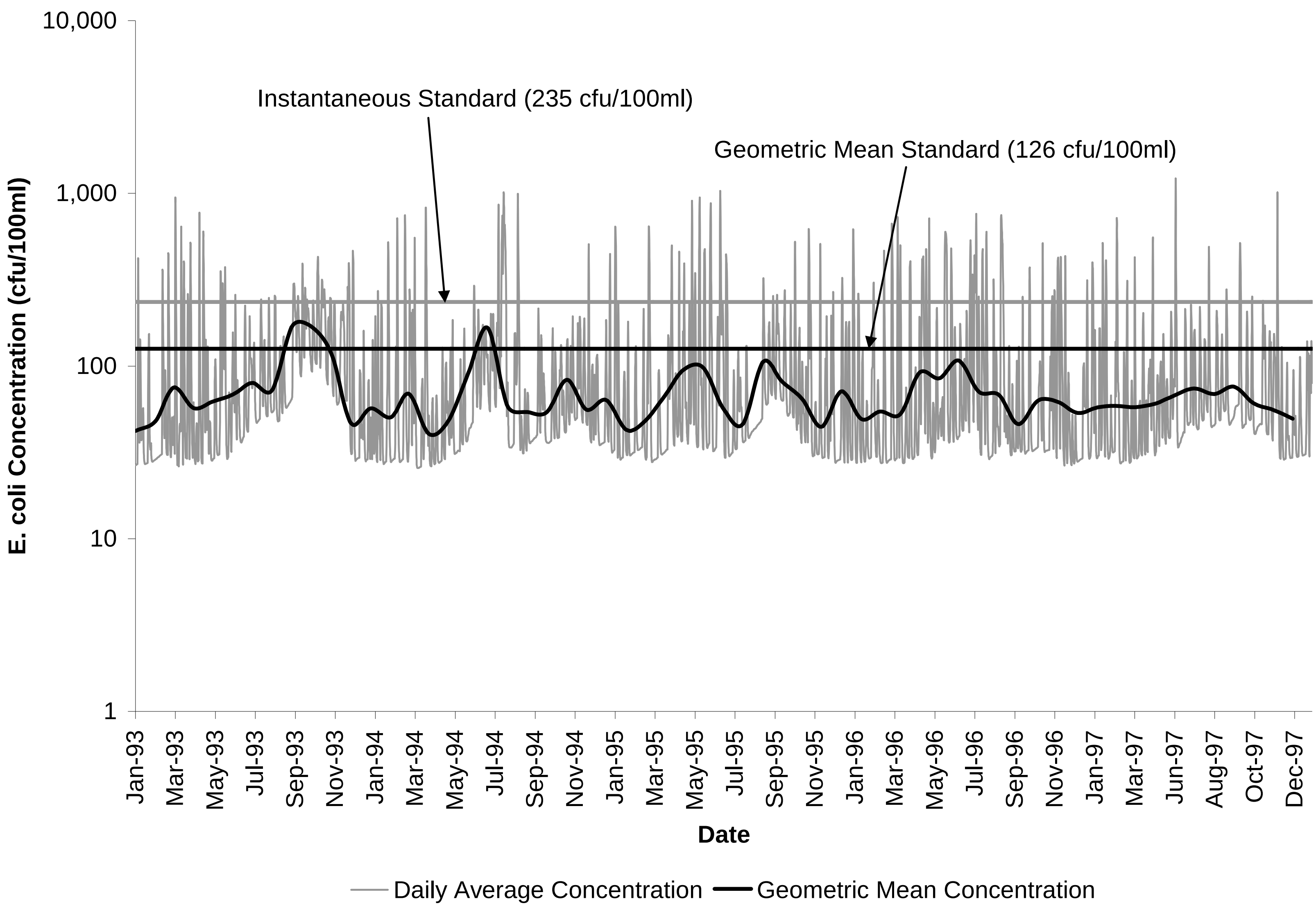

Figure 6.6. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rappahannock River (VAN-E08R-04) impairment.

6.2.7 Rappahannock River (60081)

The Stage 1 allocation for the Rappahannock River (60081) impairment requires a 100% reduction in straight pipes, 90% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 90% reduction in nonpoint source loadings to residential land use, a 90% reduction in nonpoint source loadings to pasture land use, a 90% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.80% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.7 for the Rappahannock River (60081) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.7.

Table 6.7. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rappahannock River (60081) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.90E+12	0.00E+00	100
Livestock	1.28E+13	1.28E+12	90
Wildlife	1.40E+13	1.40E+13	0
Total	*3.66E+13*	*1.52E+13*	58
Land-based			
Residential	5.13E+14	5.13E+13	90
Cropland	3.78E+12	3.78E+11	90
Pasture	1.28E+16	1.28E+15	90
Forest	5.70E+13	5.70E+13	0
Total	*1.33E+16*	*1.38E+15*	90

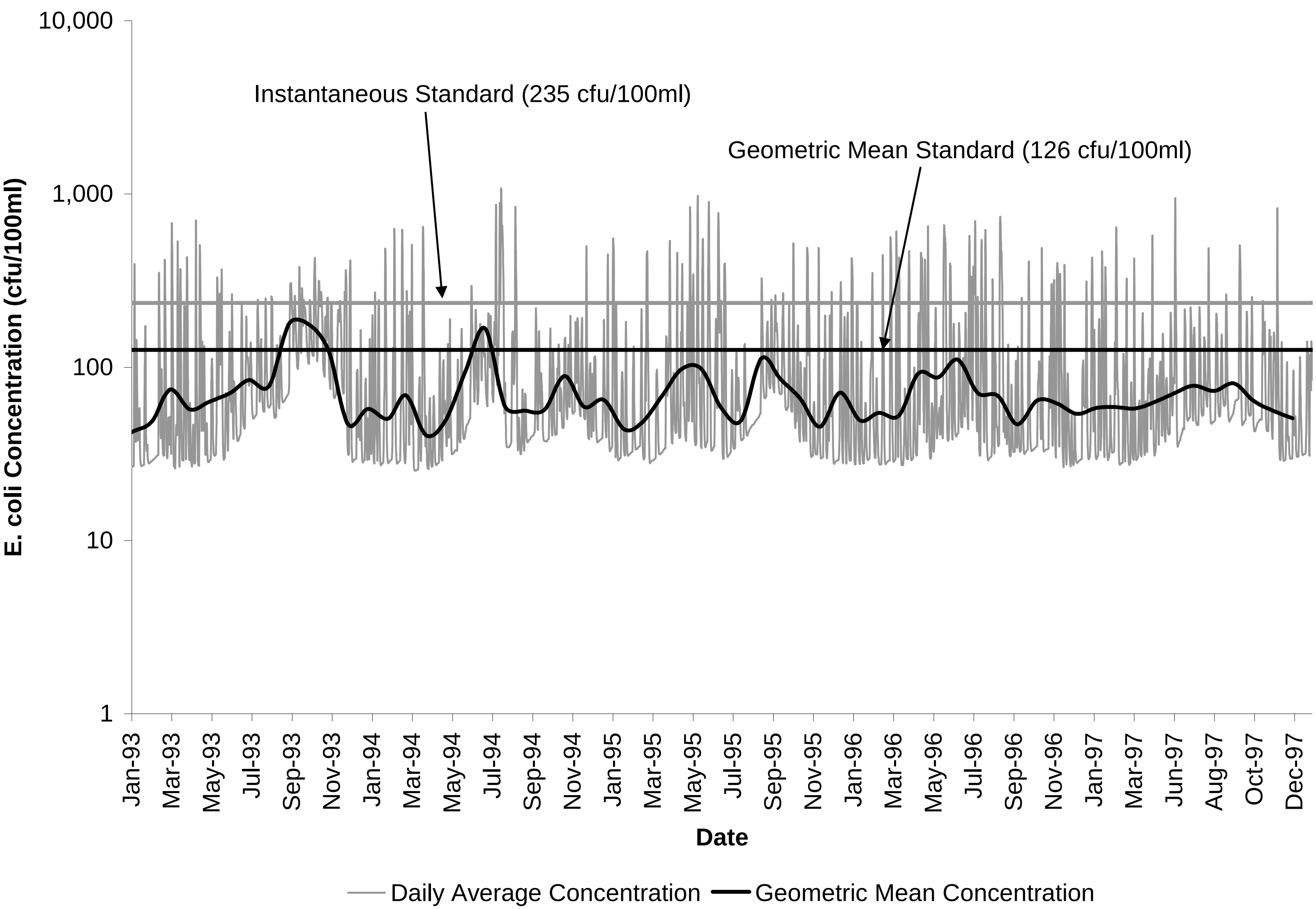

Figure 6.7. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rappahannock River (60081) impairment.

6.2.8 Craig Run (VAN-E08R-03)

The Stage 1 allocation for the Craig Run (VAN-E08R-03) impairment requires a 100% reduction in straight pipes, 81% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 81% reduction in nonpoint source loadings to residential land use, a 81% reduction in nonpoint source loadings to pasture land use, a 81% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.58% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.8 for the Craig Run (VAN-E08R-03) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.8.

Table 6.8. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Craig Run (VAN-E08R-03) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.04E+12	0.00E+00	100
Livestock	8.70E+12	1.65E+12	81
Wildlife	6.11E+12	6.11E+12	0
Total	*1.99E+13*	*7.77E+12*	61
Land-based			
Residential	2.41E+14	4.58E+13	81
Cropland	2.28E+13	4.34E+12	81
Pasture	8.47E+15	1.61E+15	81
Forest	3.00E+13	3.00E+13	0
Total	*8.77E+15*	*1.69E+15*	81

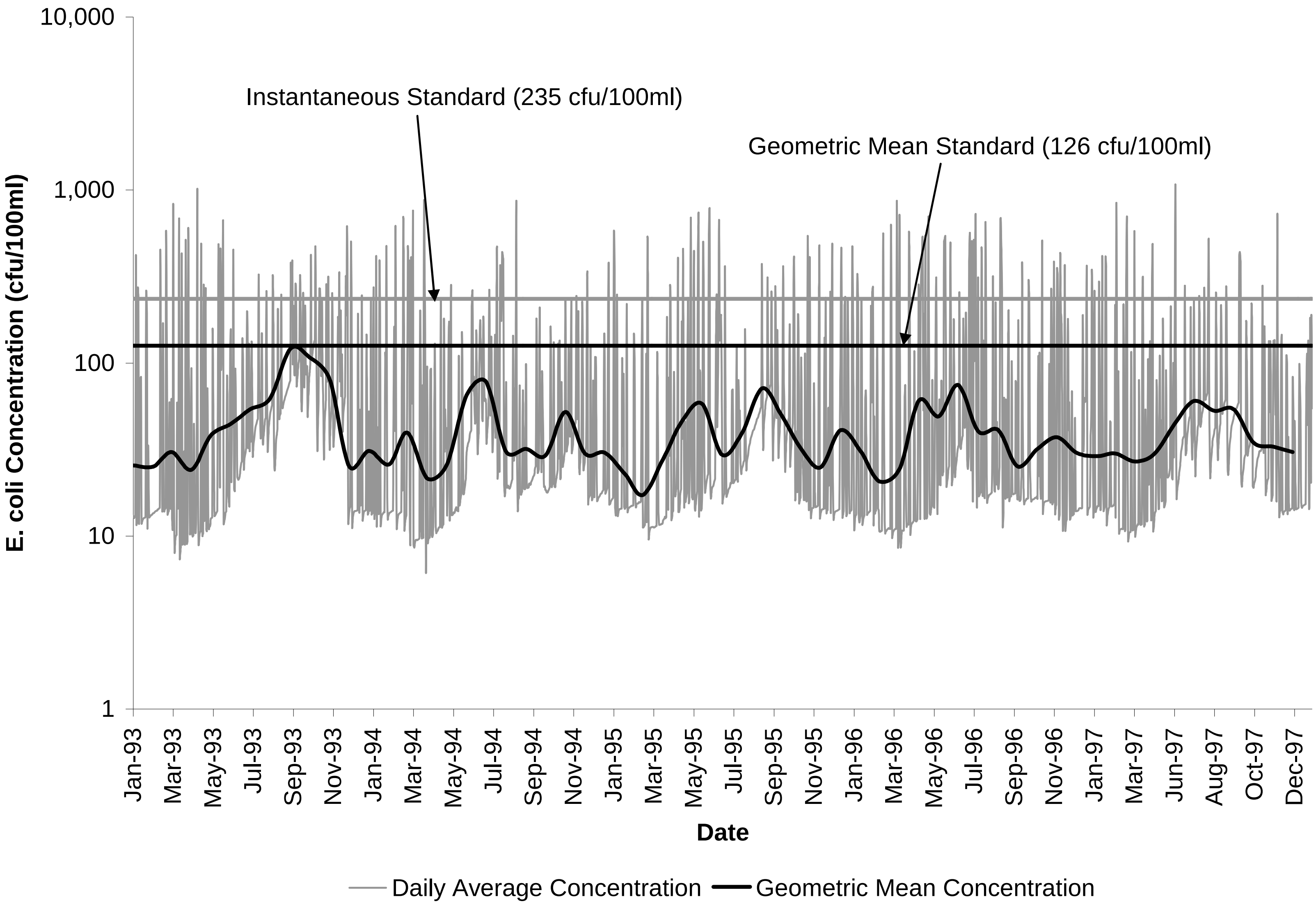

Figure 6.8. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Craig Run (VAN-E08R-03) impairment.

6.2.9 Browns Run (VAN-E08R-02)

The Stage 1 allocation for the Browns Run (VAN-E08R-02) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 67% reduction in nonpoint source loadings to residential land use, a 67% reduction in nonpoint source loadings to pasture land use, a 67% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.69% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.9 for the Browns Run (VAN-E08R-02) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.9.

Table 6.9. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Browns Run (VAN-E08R-02) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	4.49E+12	0.00E+00	100
Livestock	8.84E+12	2.21E+12	75
Wildlife	1.52E+13	1.52E+13	0
Total	*2.86E+13*	*1.75E+13*	39
Land-based			
Residential	2.78E+14	9.18E+13	67
Cropland	3.13E+13	1.03E+13	67
Pasture	8.59E+15	2.84E+15	67
Forest	5.99E+13	5.99E+13	0
Total	*8.96E+15*	*3.00E+15*	67

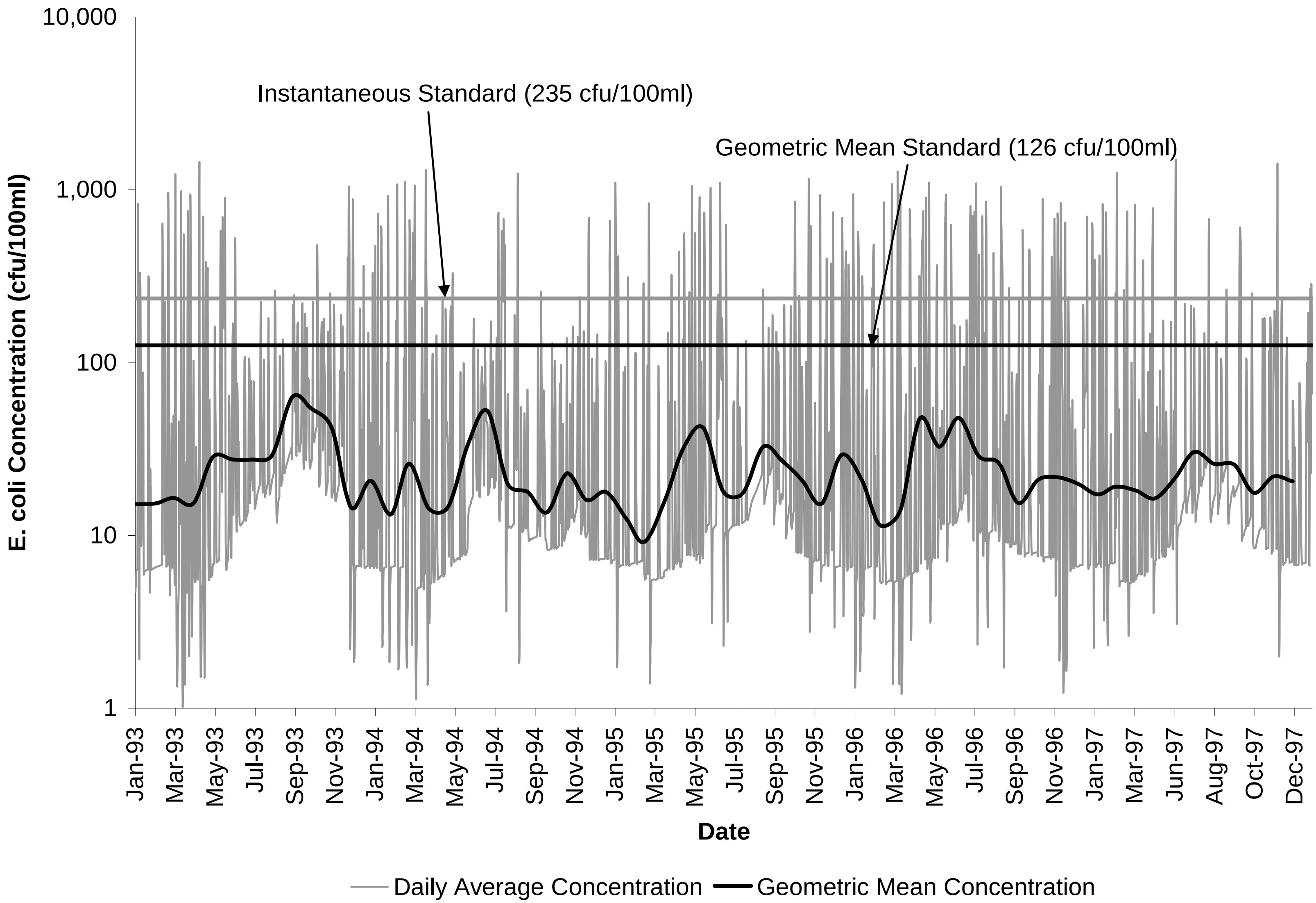

Figure 6.9. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Browns Run (VAN-E08R-02) impairment.

6.2.10 Marsh Run (VAN-E08R-01)

The Stage 1 allocation for the Marsh Run (VAN-E08R-01) impairment requires a 100% reduction in straight pipes, 90% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 90% reduction in nonpoint source loadings to residential land use, a 90% reduction in nonpoint source loadings to pasture land use, a 90% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.80% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.10 for the Marsh Run (VAN-E08R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.10.

Table 6.10. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Marsh Run (VAN-E08R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.98E+12	0.00E+00	100
Livestock	1.72E+13	1.72E+12	90
Wildlife	1.79E+13	1.79E+13	0
Total	*3.71E+13*	*1.96E+13*	47
Land-based			
Residential	1.31E+15	1.31E+14	90
Cropland	4.39E+13	4.39E+12	90
Pasture	1.69E+16	1.69E+15	90
Forest	8.17E+13	8.17E+13	0
Total	*1.84E+16*	*1.91E+15*	90

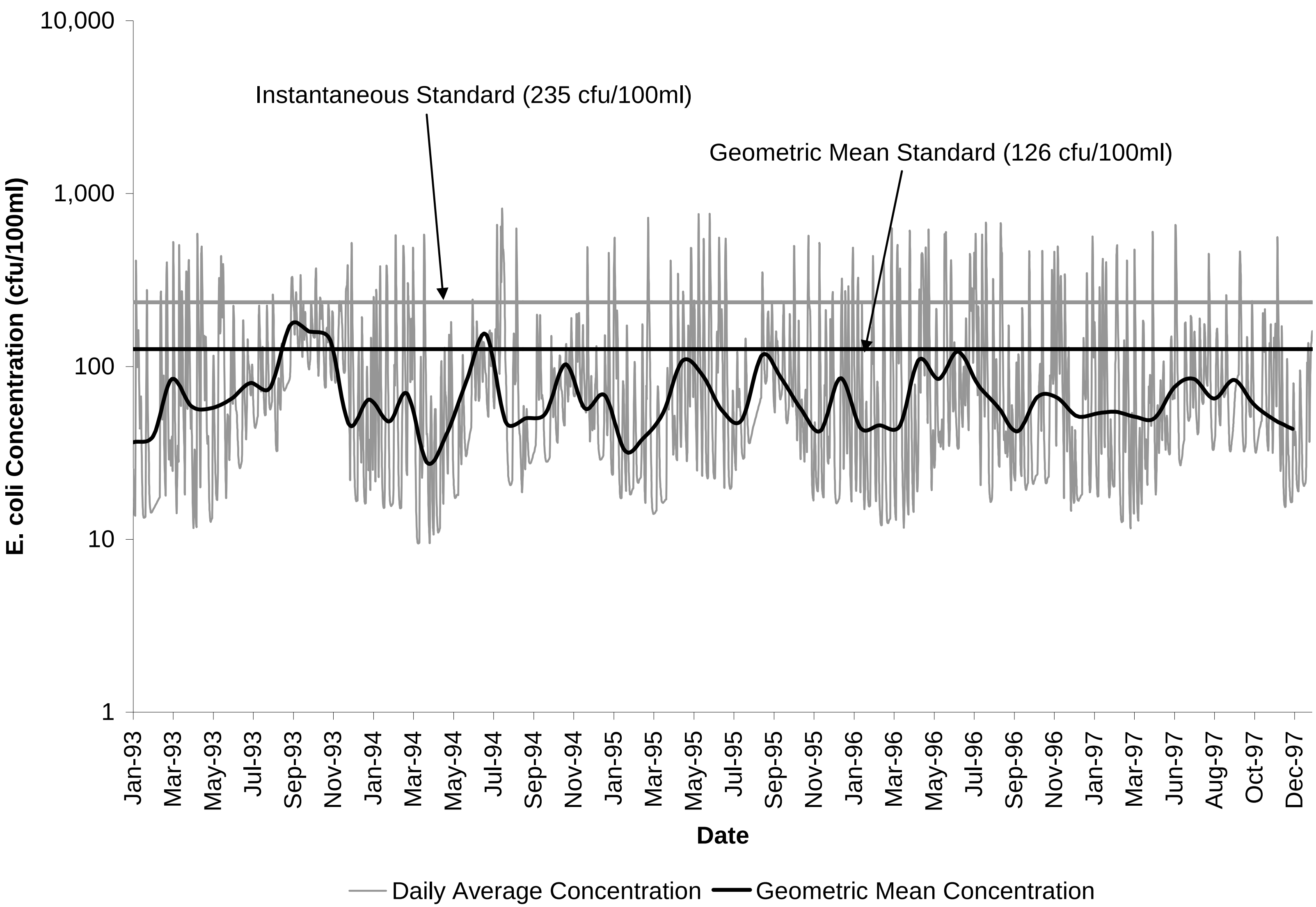

Figure 6.10. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Marsh Run (VAN-E08R-01) impairment.

6.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the 2004 Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategy for the Rappahannock 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 (2004 Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategy for the Rappahannock River Basin). 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/Initiatives/WaterQuality/FinalizedTribStrats/rappahanock.pdf

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-up Monitoring

Following the development of the TMDL, the VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological 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 DEQ Guidance Memo No. 03-2004 (http://www.deq.virginia.gov/waterguidance/pdf/032004.pdf), 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. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR staff, the Implementation Plan Steering Committee and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. 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 Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the

Implementation Plan (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 DEQ's standard monitoring plan. Ancillary monitoring by citizens' or 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 quality assurance/quality control (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 of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/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 Implementation Plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

6.4.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current USEPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. USEPA 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 USEPA for review.

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

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

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. An exception are the municipal separate storm sewer systems (MS4s) which are both covered by NPDES permits and 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 implementation plan. 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 USEPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to USEPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

VADEQ staff will present both USEPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate Water Quality Management Plan (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 VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf

6.4.3 Stormwater Permits

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

USEPA approved VADCR's VPDES storm water program on December 30, 2004. VADCR's regulations became effective on January 29, 2005. VADEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES MS4 and construction storm water permitting programs. More information is available on VADCR's web site through the following link: http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is DCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible,…".

Currently, no portion of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) watersheds is covered by a MS4 permit. For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent USEPA guidance (USEPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered an exceedance of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 6.4.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL implementation plans. An implementation plan will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL implementation plans since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia's Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml

6.4.4 Implementation Funding Sources

The implementation on pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, USEPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding stream for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at http://www.dcr.virginia.gov/soil_&_water/wqia.shtml.

6.4.5 Addressing Wildlife Contributions

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. Virginia and USEPA are not proposing the elimination of natural wildlife to allow for the attainment of water quality standards. However, managing overpopulations of wildlife remains an option available to local stakeholders. Should during the implementation plan development phase of a TMDL process, and in consultation with a local government or land owner, the Department of Game and Inland Fisheries (VDGIF) determine that a population of resident geese, deer or other wildlife is a at "nuisance" levels, measures to reduce such populations may be deemed acceptable if undertaken under the supervision, or issued permit, of the VDGIF or the U.S. Fish and Wildlife Service as appropriate. Additional information on VDGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/.

Based on the above, USEPA and Virginia have developed a process to address the wildlife issue. First in this process 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 only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct.

If water quality standards are not being met, a use attainability analysis (UAA) may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

6.4.6 Attainability of Designated Use

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the USEPA, will be able to provide comment during this process.

For bacteria, Virginia has adopted a new “secondary contact” category for protecting the recreational use in state waters. “Secondary contact recreation” 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)”. In order to re-designate a state water from primary to secondary contact recreation use, a UAA as described above is necessary. The secondary contact recreation criteria can be found at http://www.deq.state.va.us/wqs/documents/WQS06_EDIT_001.pdf.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E. provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a use attainability analysis according to the criteria listed above and a schedule established by the Board. The amendment further states that “If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed.”

Chapter 7. Public Participation

The development of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and Marsh Run (VAN-E08R-01) TMDLs would not have been possible without public participation.

The first public meetings were held at the Rappahannock County Library in Washington, Virginia and St. Luke's Church in Remington, Virginia on October 11, 2006 and October 17, 2006, respectively, to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. Twenty-nine people attended the Washington meeting and 11 people attended the Remington meeting. Copies of the presentation materials, watershed history results, source assessment per subwatershed, and various TMDL information handouts were available for public distribution. Public notice of the meetings was printed in the Virginia Register on October 2, 2006 and advertised on the VADEQ and Rappahannock-Rapidan Regional Commission websites. Notification regarding the meetings was sent to area appointed and elected officials and Technical Advisory Committee (TAC) members. Members of the TAC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meetings through advertisements in the community calendar section of local newspapers, and through post card mailings, randomly distributed throughout the watershed. There was a 30-day public comment period for the public meetings (October 4, 2006 to November 2, 2006), however, no written comments were received.

The second and final public meetings were held at the Culpeper Train Depot in Culpeper, Virginia and Rappahannock County Library in Washington, Virginia on March 19, 2007 and March 22, 2007, respectively, to discuss the source allocations and reductions required to meet the TMDL. Eleven people attended the Culpeper meeting and 21 people attended the Washington meeting. Copies of the draft TMDL report were available for public review and comment. Public notice of the meetings was printed in the Virginia Register on March 5, 2007 and advertised on the VADEQ and Rappahannock-Rapidan Regional Commission websites. Notification regarding the meeting was sent to area appointed and elected officials, TAC members, and prior public meeting attendees. Members of the TAC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meeting through advertisements in the community calendar section of local newspapers and environmental web forums, and through advertisements on the local cable television channels. In addition, postcard mailings were randomly distributed throughout the watershed. There was a 30-day public comment period for these meetings that extends from March 19, 2007 to April 18, 2007. No written comments were received.

In addition to keeping the public apprised of progress in the development of the Hughes River (VAN-E03R-01), Hazel River (VAN-E04R-01), Rush River (VAN-E05R-01), Hazel River (60076), Rappahannock River (VAN-E01R-03), Rappahannock River (VAN-E08R-04), Rappahannock River (60081), Craig Run (VAN-E08R-03), Browns Run (VAN-E08R-02), and

Marsh Run (VAN-E08R-01) TMDLs, a TMDL TAC was also established to help advise the TMDL developers. TAC meetings were held prior to public meetings. TAC meetings were held for this project on July 27, 2006, December 15, 2006, and February 27, 2007 at the Culpeper Train Depot in Culpeper. Public notice was provided for these meetings in the Virginia Register on July 24, 2006, December 11, 2006, and February 19, 2007, respectively. A public comment period (February 27, 2007 to March 29, 2007) was held for the final TAC meeting. The TAC meetings were also advertised on the VADEQ and Rappahannock-Rapidan Regional Commission websites. Notification regarding the meeting was sent to area appointed and elected officials and TAC members. The TAC membership for the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), Unnamed Tributary to the Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01), and Rapidan River (VAN-E18R-01) TMDLs included representatives from the following agencies and organizations:

- Virginia Department of Environmental Quality
- Virginia Department of Conservation and Recreation
- Virginia Department of Health
- Virginia Department of Forestry
- Virginia Cooperative Extension
- Rappahannock-Rapidan Regional Commission
- Thomas Jefferson, Culpeper, John Marshall, and Tri-County/City SWCDs
- Rappahannock and Fauquier County Governments
- RappFLOW
- Piedmont Environmental Council
- Friends of the Rush River
- U.S. Department of Agriculture – Natural Resources Conservation Service
- Centex Homes
- Rappahannock County Farm Bureau
- Walsh, Colucci, Lubeley, Emrich and Walsh

Nineteen, nineteen, and fifteen people attended the July, December, and February meetings, respectively. TAC meetings were used as a forum to review data and assumptions used in the modeling, and to provide local government agencies an opportunity to raise concerns about the implications of the TMDL for their jurisdictions. The generous assistance of the staff of these agencies is gratefully acknowledged.

Glossary

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

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

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution. A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

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

Bacterial Source Tracking (BST)
A collection of scientific methods used to track sources of fecal coliform.

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

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

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

E-911 digital data
Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

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

Fecal coliform
A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

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

Mathematically the geometric mean, $\bar{x}_g$, is expressed as: $\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$ where n is the number of samples, and x_i is the value of sample i.

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

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

Instantaneous criterion
The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in exceedance of the state water quality standard.

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

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

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

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

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

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

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

Reach
Segment of a stream or river.

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

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

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

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

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

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

Validation (of a model)
Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

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

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

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

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Appendix A – Historic Water Quality Data

Table A.1. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HUE000.20 in Hughes River (VAN-E03R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HUE000.20	06/13/1991	340		2.23
3-HUE000.20	12/18/1991	93		0
3-HUE000.20	02/20/1992	220		0.3
3-HUE000.20	09/15/1992	1400		0
3-HUE000.20	12/03/1992	100		0.55
3-HUE000.20	03/01/1993	100		0
3-HUE000.20	06/07/1993	300		0.41
3-HUE000.20	09/30/1993	100		1.15
3-HUE000.20	12/14/1993	140		1.21
3-HUE000.20	06/16/1994	700		0.27
3-HUE000.20	09/20/1994	100		0.36
3-HUE000.20	12/20/1994	100		1.76
3-HUE000.20	03/15/1995	100		1.24
3-HUE000.20	06/01/1995	500		4.43
3-HUE000.20	09/11/1995	400		0.79
3-HUE000.20	12/13/1995	100		0.22
3-HUE000.20	03/28/1996	100		0.05
3-HUE000.20	06/17/1996	500		0.64
3-HUE000.20	09/18/1996	200		0
3-HUE000.20	01/06/1997	100		15.45
3-HUE000.20	04/15/1997	100		#N/A
3-HUE000.20	07/21/1997	100		1.49
3-HUE000.20	10/02/1997	400		2.53
3-HUE000.20	01/26/1998	100		0.78
3-HUE000.20	04/22/1998	200		1.4
3-HUE000.20	09/29/1998	300		0.26
3-HUE000.20	01/25/1999	100		0
3-HUE000.20	03/25/1999	100		0.4

N/A – Data not available

Table A.2. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HUE000.20 in Hughes River (VAN-E03R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HUE000.20	06/17/1999	400		0.16
3-HUE000.20	08/11/1999	100		1.27
3-HUE000.20	10/21/1999	100		1.75
3-HUE000.20	12/14/1999	2100		0.27
3-HUE000.20	04/19/2000	400		0.75
3-HUE000.20	06/15/2000	100		0.63
3-HUE000.20	08/17/2000	800		1.61
3-HUE000.20	10/11/2000	100		1.38
3-HUE000.20	12/19/2000	100		1.26
3-HUE000.20	02/14/2001	200		0.22
3-HUE000.20	04/10/2001	300		0.95
3-HUE000.20	06/27/2001	100		0.9
3-HUE000.20	05/21/2003	300	320	0.23
3-HUE000.20	08/06/2003	100	25	0.44
3-HUE000.20	10/15/2003	900	1000	5.39
3-HUE000.20	12/08/2003	25	25	1.25
3-HUE000.20	02/26/2004	25	25	0.02
3-HUE000.20	07/28/2004	250	330	3.59
3-HUE000.20	08/30/2004	50	80	0
3-HUE000.20	09/28/2004	2600	550	0.43
3-HUE000.20	10/21/2004	130	120	0.12
3-HUE000.20	11/30/2004	220	100	1.17
3-HUE000.20	02/08/2005	80	169	0.18
3-HUE000.20	03/08/2005	140	140	0.49
3-HUE000.20	04/13/2005	120	261	0.2
3-HUE000.20	05/25/2005	370	334	2.48
3-HUE000.20	06/28/2005	120	221	0
3-HUE000.20	07/26/2005	390	217	0.9

N/A – Data not available

Table A.3. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ018.29 in Hasel River (VAN-E04R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ018.29	07/13/1987	900		0.47
3-HAZ018.29	08/06/1987	3800		0.83
3-HAZ018.29	10/26/1987	100		0
3-HAZ018.29	11/24/1987	100		0.06
3-HAZ018.29	12/17/1987	100		0
3-HAZ018.29	01/27/1988	100		0.04
3-HAZ018.29	02/04/1988	100		0.07
3-HAZ018.29	03/17/1988	100		0.14
3-HAZ018.29	04/21/1988	100		0.09
3-HAZ018.29	09/26/1988	300		0.93
3-HAZ018.29	11/29/1988	900		0.44
3-HAZ018.29	01/30/1989	1100		1.13
3-HAZ018.29	05/28/1991	78		0.1
3-HAZ018.29	06/26/1991	110		0.5
3-HAZ018.29	07/29/1991	2400		0.31
3-HAZ018.29	08/27/1991	93		0
3-HAZ018.29	10/21/1991	18		1.82
3-HAZ018.29	12/16/1991	260		0
3-HAZ018.29	02/25/1992	230		0.14
3-HAZ018.29	03/25/1992	45		0.11
3-HAZ018.29	04/09/1992	230		0.11
3-HAZ018.29	05/05/1992	1700		0.15
3-HAZ018.29	07/09/1992	100		0.19
3-HAZ018.29	08/13/1992	400		0.86
3-HAZ018.29	09/14/1992	100		0.25
3-HAZ018.29	10/20/1992	100		0
3-HAZ018.29	11/23/1992	8000		0.04
3-HAZ018.29	12/21/1992	200		0.12

N/A – Data not available

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ018.29 in Hasel River (VAN-E04R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ018.29	01/26/1993	600		0.34
3-HAZ018.29	02/23/1993	1200		0.21
3-HAZ018.29	03/22/1993	300		0.35
3-HAZ018.29	04/19/1993	900		2.27
3-HAZ018.29	05/17/1993	5900		0.7
3-HAZ018.29	07/15/1993	100		0.02
3-HAZ018.29	08/12/1993	100		1.91
3-HAZ018.29	09/07/1993	100		1.68
3-HAZ018.29	10/07/1993	100		0.57
3-HAZ018.29	11/22/1993	100		1.49
3-HAZ018.29	02/17/1994	1000		1.32
3-HAZ018.29	03/17/1994	100		0.78
3-HAZ018.29	05/12/1994	100		0.57
3-HAZ018.29	06/02/1994	100		2.43
3-HAZ018.29	07/19/1994	6800		3.23
3-HAZ018.29	08/11/1994	600		0.01
3-HAZ018.29	09/08/1994	100		0.13
3-HAZ018.29	10/18/1994	100		0.36
3-HAZ018.29	10/23/1995	600		0
3-HAZ018.29	04/01/1996	200		0.27
3-HAZ018.29	07/29/1996	1800		0.3
3-HAZ018.29	10/30/1996	100		0.24
3-HAZ018.29	02/19/1997	100		0.03
3-HAZ018.29	05/28/1997	100		0.9
3-HAZ018.29	08/20/1997	600		1.41
3-HAZ018.29	11/25/1997	100		0.12
3-HAZ018.29	02/17/1998	500		0.35
3-HAZ018.29	05/27/1998	100		1.25

N/A – Data not available

Table A.5. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ018.29 in Hasel River (VAN-E04R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ018.29	08/20/1998	100		1.36
3-HAZ018.29	11/05/1998	300		0.7
3-HAZ018.29	02/16/1999	100		0.57
3-HAZ018.29	04/19/1999	100		0.25
3-HAZ018.29	07/01/1999	100		0.41
3-HAZ018.29	09/02/1999	100		0.78
3-HAZ018.29	11/03/1999	5200		0.07
3-HAZ018.29	04/19/2000	1200		0.75
3-HAZ018.29	06/15/2000	100		0.63
3-HAZ018.29	08/17/2000	100		1.61
3-HAZ018.29	10/11/2000	100		1.38
3-HAZ018.29	12/19/2000	200		1.26
3-HAZ018.29	02/14/2001	100		0.22
3-HAZ018.29	03/28/2001	100		0.48
3-HAZ018.29	05/08/2001	300		1.27
3-HAZ018.29	08/07/2001	100		0.37
3-HAZ018.29	10/25/2001	1600		0.76
3-HAZ018.29	12/10/2001	400		0.46
3-HAZ018.29	04/16/2003	25	50	0.14
3-HAZ018.29	05/21/2003	530	250	0.23
3-HAZ018.29	08/07/2003	180	200	0.44
3-HAZ018.29	02/26/2004	25	25	0.02
3-HAZ018.29	08/30/2004	20	30	0
3-HAZ018.29	09/28/2004	240	380	0.43
3-HAZ018.29	10/21/2004	120	70	0.12
3-HAZ018.29	11/30/2004	290	236	1.17
3-HAZ018.29	12/16/2004	50	20	0.03
3-HAZ018.29	02/08/2005	10	12	0.18

N/A – Data not available

Table A.6. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ018.29 in Hasel River (VAN-E04R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ018.29	03/08/2005	20	46	0.49
3-HAZ018.29	04/13/2005	70	58	0.2
3-HAZ018.29	05/25/2005	390	318	2.48
3-HAZ018.29	06/28/2005	10	20	0
3-HAZ018.29	07/26/2005	100	78	0.9
3-HAZ018.29	03/08/2005	20	46	0.49
3-HAZ018.29	04/13/2005	70	58	0.2
3-HAZ018.29	05/25/2005	390	318	2.48
3-HAZ018.29	06/28/2005	10	20	0
3-HAZ018.29	07/26/2005	100	78	0.9
3-HAZ018.29	03/08/2005	20	46	0.49
3-HAZ018.29	04/13/2005	70	58	0.2
3-HAZ018.29	05/25/2005	390	318	2.48
3-HAZ018.29	06/28/2005	10	20	0
3-HAZ018.29	07/26/2005	100	78	0.9

N/A – Data not available

Table A.7. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RUS005.66 in Rush River (VAN-E05R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RUS005.66	06/13/1991	460		2.23
3-RUS005.66	12/18/1991	2		0
3-RUS005.66	02/20/1992	120		0.3
3-RUS005.66	09/15/1992	1300		0
3-RUS005.66	12/03/1992	100		0.55
3-RUS005.66	03/01/1993	100		0
3-RUS005.66	06/07/1993	700		0.41
3-RUS005.66	09/30/1993	100		1.15
3-RUS005.66	12/14/1993	20		1.21
3-RUS005.66	06/16/1994	500		0.27
3-RUS005.66	12/20/1994	100		1.76
3-RUS005.66	03/15/1995	100		1.24
3-RUS005.66	06/01/1995	700		4.43
3-RUS005.66	09/11/1995	200		0.79
3-RUS005.66	12/13/1995	100		0.22
3-RUS005.66	03/28/1996	900		0.05
3-RUS005.66	06/17/1996	200		0.64
3-RUS005.66	09/18/1996	200		0
3-RUS005.66	01/06/1997	300		15.45
3-RUS005.66	04/15/1997	100		#N/A
3-RUS005.66	07/21/1997	500		1.49
3-RUS005.66	01/26/1998	100		0.78
3-RUS005.66	04/22/1998	100		1.4
3-RUS005.66	01/25/1999	100		0
3-RUS005.66	03/25/1999	100		0.4
3-RUS005.66	06/17/1999	3300		0.16
3-RUS005.66	10/21/1999	1400		1.75
3-RUS005.66	12/14/1999	3600		0.27

N/A – Data not available

Table A.8. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RUS005.66 in Rush River (VAN-E05R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RUS005.66	04/19/2000	100		0.75
3-RUS005.66	06/15/2000	100		0.63
3-RUS005.66	08/17/2000	600		1.61
3-RUS005.66	10/11/2000	100		1.38
3-RUS005.66	12/19/2000	100		1.26
3-RUS005.66	02/14/2001	100		0.22
3-RUS005.66	03/28/2001	100		0.48
3-RUS005.66	05/08/2001	200		1.27
3-RUS005.66	05/08/2001	200		1.27
3-RUS005.66	05/08/2001	100		1.27
3-RUS005.66	05/08/2001	100		1.27
3-RUS005.66	05/08/2001	100		1.27
3-RUS005.66	12/27/2001	100		0.41
3-RUS005.66	04/18/2002	25	10	0.66
3-RUS005.66	02/12/2003	100		0.09
3-RUS005.66	05/21/2003	100		0.23
3-RUS005.66	07/23/2003		600	0.19
3-RUS005.66	09/15/2003		320	1.67
3-RUS005.66	07/28/2004	410	400	3.59
3-RUS005.66	08/30/2004	50	70	0
3-RUS005.66	09/28/2004	4500	6000	0.43
3-RUS005.66	10/21/2004	480	142	0.12
3-RUS005.66	11/30/2004	240	164	1.17
3-RUS005.66	12/16/2004	170	90	0.03
3-RUS005.66	02/08/2005	60	20	0.18
3-RUS005.66	03/08/2005	780	790	0.49
3-RUS005.66	04/13/2005	170	171	0.2
3-RUS005.66	05/25/2005	60	90	2.48

N/A – Data not available

Table A.9. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RUS005.66 in Rush River (VAN-E05R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RUS005.66	06/28/2005	80	122	0
3-RUS005.66	07/26/2005	460	150	0.9

N/A – Data not available

Table A.10. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ005.98 in Hazel River (60076) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ005.98	04/09/1973	300	NULL	1.63
3-HAZ005.98	05/11/1973	700	NULL	0.49
3-HAZ005.98	06/22/1973	6000	NULL	0.07
3-HAZ005.98	07/12/1973	400	NULL	0.39
3-HAZ005.98	08/06/1973	100	NULL	2.9
3-HAZ005.98	09/17/1973	6000	NULL	0.12
3-HAZ005.98	10/09/1973	700	NULL	0.2
3-HAZ005.98	11/01/1973	200	NULL	0.15
3-HAZ005.98	12/28/1973	300	NULL	0
3-HAZ005.98	01/18/1974	100	NULL	0.25
3-HAZ005.98	01/24/1974	100	NULL	0.1
3-HAZ005.98	02/27/1974	100	NULL	0.05
3-HAZ005.98	04/09/1974	700	NULL	1.41
3-HAZ005.98	05/16/1974	1100	NULL	0.5
3-HAZ005.98	06/05/1974	1000	NULL	0.61
3-HAZ005.98	07/07/1974	100	NULL	0.77
3-HAZ005.98	08/21/1974	100	NULL	0.3
3-HAZ005.98	08/14/2001	300	NULL	5.7
3-HAZ005.98	10/25/2001	200	NULL	0.76
3-HAZ005.98	12/17/2001	200	NULL	0.12
3-HAZ005.98	04/17/2002	100	NULL	0.64
3-HAZ005.98	01/30/2003	25	30	0.19
3-HAZ005.98	02/11/2003	150	10	0.09
3-HAZ005.98	05/29/2003	250	170	2.13
3-HAZ005.98	06/18/2003	1500	800	1.31
3-HAZ005.98	07/17/2003	950	380	0.02
3-HAZ005.98	09/24/2003	2000	600	2.6
3-HAZ005.98	11/13/2003	780	750	1.52

N/A – Data not available

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-HAZ005.98 in Hazel River (60076) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-HAZ005.98	03/30/2004	25	50	0.13
3-HAZ005.98	07/22/2004	300	220	1.06
3-HAZ005.98	09/30/2004	1000	820	2.68
3-HAZ005.98	01/18/2005	150	50	2.84
3-HAZ005.98	03/23/2005	450	480	0.49
3-HAZ005.98	06/22/2005	50	25	0
3-HAZ005.98	07/25/2005	100	100	1.4
3-HAZ005.98	08/25/2005	25	25	0.03
3-HAZ005.98	09/15/2005	120	100	0.37
3-HAZ005.98	03/30/2004	25	50	0.13
3-HAZ005.98	07/22/2004	300	220	1.06
3-HAZ005.98	09/30/2004	1000	820	2.68
3-HAZ005.98	01/18/2005	150	50	2.84
3-HAZ005.98	03/23/2005	450	480	0.49
3-HAZ005.98	06/22/2005	50	25	0
3-HAZ005.98	07/25/2005	100	100	1.4
3-HAZ005.98	08/25/2005	25	25	0.03
3-HAZ005.98	09/15/2005	120	100	0.37

N/A – Data not available

Table A.12. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP175.51	09/17/1974	2100		0.71
3-RPP175.51	11/20/1974	400		0.1
3-RPP175.51	01/28/1975	100		1.31
3-RPP175.51	03/25/1975	100		0.94
3-RPP175.51	06/28/1975	500		0
3-RPP175.51	07/25/1975	300		0.41
3-RPP175.51	09/23/1975	2300		0
3-RPP175.51	01/27/1976	1300		0
3-RPP175.51	03/29/1976	100		4.19
3-RPP175.51	05/18/1976	500		0.45
3-RPP175.51	07/19/1976	100		0.59
3-RPP175.51	09/24/1976	6000		0.28
3-RPP175.51	11/29/1976	500		0
3-RPP175.51	03/08/1977	100		0
3-RPP175.51	05/25/1977	500		1.45
3-RPP175.51	07/27/1977	100		0.3
3-RPP175.51	09/20/1977	1000		0.55
3-RPP175.51	11/22/1977	100		0
3-RPP175.51	01/05/1978	100		0.01
3-RPP175.51	05/03/1978	100		0.9
3-RPP175.51	07/21/1978	300		1.02
3-RPP175.51	09/21/1978	2400		0.66
3-RPP175.51	11/02/1978	100		1
3-RPP175.51	01/16/1979	100		0.24
3-RPP175.51	03/14/1979	100		0
3-RPP175.51	05/15/1979	500		3.65
3-RPP175.51	07/13/1987	700		0.47
3-RPP175.51	08/06/1987	300		0.83

N/A – Data not available

Table A.13. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP175.51	09/28/1987	100		0.48
3-RPP175.51	10/26/1987	100		0
3-RPP175.51	11/24/1987	100		0.06
3-RPP175.51	12/17/1987	100		0
3-RPP175.51	01/27/1988	100		0.04
3-RPP175.51	02/04/1988	100		0.07
3-RPP175.51	03/17/1988	100		0.14
3-RPP175.51	04/21/1988	100		0.09
3-RPP175.51	09/26/1988	700		0.93
3-RPP175.51	10/25/1988	100		1.32
3-RPP175.51	11/29/1988	100		0.44
3-RPP175.51	01/30/1989	170		1.13
3-RPP175.51	05/28/1991	2400		0.1
3-RPP175.51	06/26/1991	210		0.5
3-RPP175.51	07/29/1991	330		0.31
3-RPP175.51	08/27/1991	330		0
3-RPP175.51	10/21/1991	18		1.82
3-RPP175.51	11/18/1991	110		0.72
3-RPP175.51	12/16/1991	16000		0
3-RPP175.51	02/25/1992	140		0.14
3-RPP175.51	03/25/1992	68		0.11
3-RPP175.51	04/09/1992	110		0.11
3-RPP175.51	05/05/1992	130		0.15
3-RPP175.51	07/09/1992	100		0.19
3-RPP175.51	08/13/1992	100		0.86
3-RPP175.51	09/14/1992	100		0.25
3-RPP175.51	10/20/1992	100		0
3-RPP175.51	11/23/1992	1900		0.04

N/A – Data not available

Table A.14. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP175.51	12/21/1992	200		0.12
3-RPP175.51	01/26/1993	100		0.34
3-RPP175.51	02/23/1993	600		0.21
3-RPP175.51	03/22/1993	200		0.35
3-RPP175.51	04/19/1993	200		2.27
3-RPP175.51	05/17/1993	800		0.7
3-RPP175.51	07/15/1993	900		0.02
3-RPP175.51	08/12/1993	800		1.91
3-RPP175.51	09/07/1993	100		1.68
3-RPP175.51	10/07/1993	300		0.57
3-RPP175.51	11/22/1993	100		1.49
3-RPP175.51	02/17/1994	2400		1.32
3-RPP175.51	03/17/1994	100		0.78
3-RPP175.51	05/12/1994	300		0.57
3-RPP175.51	06/02/1994	100		2.43
3-RPP175.51	07/19/1994	2700		3.23
3-RPP175.51	08/11/1994	1000		0.01
3-RPP175.51	09/08/1994	100		0.13
3-RPP175.51	10/18/1994	100		0.36
3-RPP175.51	04/13/1995	7300		0.11
3-RPP175.51	10/23/1995	700		0
3-RPP175.51	04/01/1996	100		0.27
3-RPP175.51	07/29/1996	1700		0.3
3-RPP175.51	10/30/1996	100		0.24
3-RPP175.51	02/19/1997	100		0.03
3-RPP175.51	05/28/1997	400		0.9
3-RPP175.51	08/20/1997	300		1.41
3-RPP175.51	11/25/1997	100		0.12

N/A – Data not available

Table A.15. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP175.51	02/17/1998	2000		0.35
3-RPP175.51	05/27/1998	100		1.25
3-RPP175.51	08/20/1998	100		1.36
3-RPP175.51	11/05/1998	100		0.7
3-RPP175.51	02/16/1999	100		0.57
3-RPP175.51	04/19/1999	100		0.25
3-RPP175.51	07/01/1999	300		0.41
3-RPP175.51	11/03/1999	2800		0.07
3-RPP175.51	04/19/2000	400		0.75
3-RPP175.51	06/15/2000	300		0.63
3-RPP175.51	08/17/2000	200		1.61
3-RPP175.51	10/11/2000	100		1.38
3-RPP175.51	12/19/2000	100		1.26
3-RPP175.51	02/14/2001	100		0.22
3-RPP175.51	03/28/2001	100		0.48
3-RPP175.51	05/08/2001	1200		1.27
3-RPP175.51	02/13/2002	100		1.21
3-RPP175.51	03/27/2002	200		0.02
3-RPP175.51	04/18/2002	75	50	0.66
3-RPP175.51	02/03/2003	25	10	0.1
3-RPP175.51	04/24/2003	50	60	0.61
3-RPP175.51	05/22/2003	2000	800	0.4
3-RPP175.51	06/19/2003	1230	800	0.91
3-RPP175.51	08/07/2003	350	300	0.44
3-RPP175.51	12/15/2003	220	180	2.83
3-RPP175.51	12/15/2003	200	180	2.83
3-RPP175.51	12/15/2003	25	25	2.83
3-RPP175.51	02/26/2004	200	180	0.02

N/A – Data not available

Table A.16. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP175.51	07/28/2004	260	140	3.59
3-RPP175.51	08/30/2004	60	120	0
3-RPP175.51	09/28/2004	3700	3600	0.43
3-RPP175.51	10/21/2004	180	120	0.12
3-RPP175.51	11/30/2004	280	198	1.17
3-RPP175.51	12/16/2004	150	68	0.03
3-RPP175.51	02/08/2005	20	20	0.18
3-RPP175.51	03/08/2005	70	260	0.49
3-RPP175.51	04/13/2005	410	400	0.2
3-RPP175.51	05/25/2005	80	155	2.48
3-RPP175.51	06/28/2005	150	68	0
3-RPP175.51	07/26/2005	320	72	0.9
3-RAP045.08	05/22/1997	100		0.56
3-RAP045.08	06/26/1997	100		0.01
3-RAP045.08	08/28/1997	300		0.25
3-RAP045.08	09/10/1997	100		3.15
3-RAP045.08	10/08/1997	200		0.27
3-RAP045.08	11/18/1997	100		1.42
3-RAP045.08	12/17/1997	100		0.02
3-RAP045.08	01/21/1998	100		0.04
3-RAP045.08	02/26/1998	100		0.85
3-RAP045.08	03/18/1998	100		0.45
3-RAP045.08	04/09/1998	1200		0
3-RAP045.08	05/12/1998	800		0.04
3-RAP045.08	06/25/1998	1400		0.05
3-RAP045.08	08/19/1998	100		1.59
3-RAP045.08	09/16/1998	100		2.2
3-RAP045.08	12/16/1998	1400		1.71

N/A – Data not available

Table A.17. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	01/13/1999	400		0
3-RAP045.08	03/16/1999	900		2.37
3-RAP045.08	04/14/1999	100		0
3-RAP045.08	05/13/1999	400		0.29
3-RAP045.08	06/22/1999	100		0.2
3-RAP045.08	07/20/1999	100		0.3
3-RAP045.08	08/17/1999	100		0.97
3-RAP045.08	09/08/1999	400		0.1
3-RAP045.08	10/06/1999	400		0
3-RAP045.08	12/13/1999	1500		0.14
3-RAP045.08	01/12/2000	2700		0
3-RAP045.08	02/10/2000	300		0.55
3-RAP045.08	03/23/2000	800		0
3-RAP045.08	05/04/2000	100		0.21
3-RAP045.08	06/13/2000	7400		1.73
3-RAP045.08	07/12/2000	100		1.6
3-RAP045.08	09/13/2000	200		1.15
3-RAP045.08	10/03/2000	200		0.17
3-RAP045.08	11/01/2000	100		1.37
3-RAP045.08	01/18/2001	100		0
3-RAP045.08	02/06/2001	100		0.19
3-RAP045.08	03/06/2001	100		0.2
3-RAP045.08	04/03/2001	200		0.8
3-RAP045.08	05/01/2001	100		0.8
3-RAP045.08	06/06/2001	8000		0.41
3-RAP045.08	01/31/2002	100		0.9
3-RAP045.08	02/12/2003	275	80	0.09
3-RAP045.08	02/12/2003	275	80	0.09

N/A – Data not available

Table A.18. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP175.51 in Rappahannock River (VAN-E01R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	02/12/2003	275	80	0.09
3-RAP045.08	03/18/2003	25	20	0.84
3-RAP045.08	04/30/2003	75	130	0.86
3-RAP045.08	05/27/2003	1300	800	2.53
3-RAP045.08	06/17/2003	880	800	1.33
3-RAP045.08	07/14/2003		330	1.2
3-RAP045.08	11/20/2003	2000	2000	0.12
3-RAP045.08	01/22/2004	25	25	0.32
3-RAP045.08	03/11/2004	25	25	0.3
3-RAP045.08	07/15/2004	210	120	0.52
3-RAP045.08	08/17/2004	80	50	0.72
3-RAP045.08	09/21/2004	310	300	2.25
3-RAP045.08	10/19/2004	120	74	0.15
3-RAP045.08	12/08/2004	80	403	0.42
3-RAP045.08	01/19/2005	260	199	2.84
3-RAP045.08	02/03/2005	110	94	0.39
3-RAP045.08	03/02/2005	50	88	0.74
3-RAP045.08	04/06/2005	180	241	2.17
3-RAP045.08	05/03/2005	80	78	0.96
3-RAP045.08	06/08/2005	110	98	0.75
3-RAP045.08	10/26/2005	200	820	1.66
3-RAP045.08	12/28/2005	25	100	0.64

N/A – Data not available

Table A.19. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	11/25/1970			0.45
3-RPP147.10	12/09/1970	100		0.4
3-RPP147.10	02/10/1971	2100		2.1
3-RPP147.10	03/18/1971	100		1.65
3-RPP147.10	04/25/1971	100		0.85
3-RPP147.10	05/04/1971	100		0
3-RPP147.10	06/01/1971	100		0.4
3-RPP147.10	07/15/1971	900		2.05
3-RPP147.10	08/28/1971	1500		0
3-RPP147.10	09/27/1971	100		0.55
3-RPP147.10	10/03/1971	2000		0.13
3-RPP147.10	11/10/1971	100		0
3-RPP147.10	12/14/1971	100		0.36
3-RPP147.10	01/23/1972	200		0.07
3-RPP147.10	02/21/1972	100		1.7
3-RPP147.10	03/02/1972	100		0.15
3-RPP147.10	04/05/1972	100		0.56
3-RPP147.10	05/03/1972	2700		0.65
3-RPP147.10	06/03/1972	200		0.8
3-RPP147.10	07/20/1972	100		0.35
3-RPP147.10	08/10/1972	100		0.75
3-RPP147.10	09/21/1972	6000		0.15
3-RPP147.10	10/04/1972	100		0.75
3-RPP147.10	11/15/1972	2300		0.07
3-RPP147.10	12/08/1972	400		0.83
3-RPP147.10	01/22/1973	200		1.55
3-RPP147.10	02/22/1973	100		1.95
3-RPP147.10	03/13/1973	100		0

N/A – Data not available

Table A.20. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	04/11/1973	800		0.95
3-RPP147.10	05/13/1973	100		1.03
3-RPP147.10	08/24/1973	200		1.08
3-RPP147.10	10/15/1973	200		1.45
3-RPP147.10	11/13/1973	100		0
3-RPP147.10	12/06/1973	1200		0.3
3-RPP147.10	01/24/1974	100		0.1
3-RPP147.10	02/11/1974	100		0.17
3-RPP147.10	03/08/1974	100		0.53
3-RPP147.10	05/21/1974	100		0.35
3-RPP147.10	06/01/1974	400		0.4
3-RPP147.10	07/09/1974	100		0.77
3-RPP147.10	08/24/1974	100		0.36
3-RPP147.10	09/17/1974	100		0.71
3-RPP147.10	10/27/1974	100		0
3-RPP147.10	11/20/1974	200		0.1
3-RPP147.10	01/28/1975	100		1.31
3-RPP147.10	03/25/1975	100		0.94
3-RPP147.10	04/10/1975	100		0.48
3-RPP147.10	05/19/1975	100		0.52
3-RPP147.10	06/28/1975	3600		0
3-RPP147.10	07/25/1975	6000		0.41
3-RPP147.10	08/04/1975	100		0.82
3-RPP147.10	09/23/1975	33000		0
3-RPP147.10	10/02/1975	100		0.36
3-RPP147.10	12/17/1975	100		0.09
3-RPP147.10	01/27/1976	2100		0
3-RPP147.10	02/27/1976	100		0

N/A – Data not available

Table A.21. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	03/29/1976	100		4.19
3-RPP147.10	04/28/1976	100		1.04
3-RPP147.10	05/19/1976	2900		0.45
3-RPP147.10	06/02/1976	400		0.17
3-RPP147.10	07/27/1976	200		0.76
3-RPP147.10	08/11/1976	100		0.6
3-RPP147.10	08/31/1976	100		0.1
3-RPP147.10	10/28/1976	200		0.15
3-RPP147.10	11/15/1976	100		0.28
3-RPP147.10	12/08/1976	800		0.67
3-RPP147.10	02/24/1977	100		0.25
3-RPP147.10	03/29/1977	100		0.3
3-RPP147.10	04/14/1977	100		0.15
3-RPP147.10	05/27/1977	100		1.49
3-RPP147.10	06/28/1977	100		0.75
3-RPP147.10	07/19/1977	100		0
3-RPP147.10	09/07/1977	4900		0
3-RPP147.10	10/06/1977	100		0.34
3-RPP147.10	11/14/1977	300		1.5
3-RPP147.10	12/29/1977	100		0
3-RPP147.10	01/06/1978	100		0.01
3-RPP147.10	03/15/1978	100		0.55
3-RPP147.10	03/31/1978	100		3.24
3-RPP147.10	06/28/1978	2300		0
3-RPP147.10	07/25/1978	500		1.07
3-RPP147.10	08/24/1978	300		0.05
3-RPP147.10	09/28/1978	100		0.36
3-RPP147.10	10/24/1978	100		1.07

N/A – Data not available

Table A.22. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	12/07/1978	300		1.97
3-RPP147.10	01/03/1979	600		0.06
3-RPP147.10	03/28/1979	100		0.39
3-RPP147.10	04/25/1979	100		0.4
3-RPP147.10	05/10/1979	100		0.11
3-RPP147.10	06/14/1979	700		0
3-RPP147.10	07/23/1979	200		0.62
3-RPP147.10	08/17/1979	100		0.13
3-RPP147.10	09/24/1979	1000		1.01
3-RPP147.10	10/30/1979	100		0.4
3-RPP147.10	11/14/1979	100		0.5
3-RPP147.10	12/13/1979	300		0.85
3-RPP147.10	01/07/1980	100		0.63
3-RPP147.10	02/14/1980	100		0
3-RPP147.10	03/24/1980	500		0.71
3-RPP147.10	04/09/1980	8000		0.22
3-RPP147.10	06/05/1980	500		0.27
3-RPP147.10	07/30/1980	600		0.11
3-RPP147.10	11/17/1980	100		0.02
3-RPP147.10	12/17/1980	100		0.47
3-RPP147.10	01/26/1981	100		0.7
3-RPP147.10	02/18/1981	100		0
3-RPP147.10	03/17/1981	100		0.24
3-RPP147.10	04/27/1981	100		1.8
3-RPP147.10	05/14/1981	700		0.11
3-RPP147.10	06/10/1981	4700		0.36
3-RPP147.10	08/10/1981	100		0.14
3-RPP147.10	09/22/1981	8000		0.06

N/A – Data not available

Table A.23. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	10/12/1981	100		0.5
3-RPP147.10	11/18/1981	200		0.24
3-RPP147.10	02/17/1982	8000		0.29
3-RPP147.10	03/30/1982	0		0
3-RPP147.10	04/20/1982	100		1.1
3-RPP147.10	05/20/1982	200		0.47
3-RPP147.10	06/09/1982	200		1.16
3-RPP147.10	07/29/1982	200		0.16
3-RPP147.10	09/21/1982	100		2.44
3-RPP147.10	10/06/1982	6200		0.27
3-RPP147.10	11/16/1982	100		0.22
3-RPP147.10	12/06/1982	100		2.65
3-RPP147.10	01/12/1983	1600		3.1
3-RPP147.10	03/22/1983	300		0
3-RPP147.10	04/11/1983	4300		0.5
3-RPP147.10	05/09/1983	600		0.41
3-RPP147.10	06/08/1983	200		0.98
3-RPP147.10	07/13/1983	400		0.3
3-RPP147.10	08/16/1983	100		0.43
3-RPP147.10	09/12/1983	600		0.12
3-RPP147.10	10/25/1983	1000		0
3-RPP147.10	11/01/1983	800		1.81
3-RPP147.10	12/07/1983	100		0.28
3-RPP147.10	01/09/1984	100		12.76
3-RPP147.10	02/08/1984	100		1.7
3-RPP147.10	03/05/1984	1700		0.73
3-RPP147.10	04/23/1984	3100		0.02
3-RPP147.10	07/16/1984	100		0.43

N/A – Data not available

Table A.24. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	09/25/1984	400		0.35
3-RPP147.10	10/31/1984	100		0
3-RPP147.10	11/07/1984	100		0
3-RPP147.10	01/08/1985	400		0.81
3-RPP147.10	03/12/1985	100		1.01
3-RPP147.10	04/02/1985	100		0.31
3-RPP147.10	06/18/1985	100		0.09
3-RPP147.10	07/15/1985	100		2.97
3-RPP147.10	08/27/1985	1000		1.52
3-RPP147.10	09/09/1985	300		0.03
3-RPP147.10	12/02/1985	500		0.17
3-RPP147.10	01/13/1986	100		1.01
3-RPP147.10	02/06/1986	100		1.48
3-RPP147.10	03/17/1986	200		0.93
3-RPP147.10	04/29/1986	200		0.75
3-RPP147.10	05/19/1986	100		6.61
3-RPP147.10	06/09/1986	300		0
3-RPP147.10	07/17/1986	500		1.62
3-RPP147.10	08/14/1986	100		0.94
3-RPP147.10	09/10/1986	100		0.57
3-RPP147.10	10/02/1986	300		0
3-RPP147.10	11/24/1986	200		4.82
3-RPP147.10	12/04/1986	1300		0.01
3-RPP147.10	01/05/1987	100		0.02
3-RPP147.10	02/02/1987	100		0.04
3-RPP147.10	03/02/1987	200		2.17
3-RPP147.10	05/13/1987	600		0.92
3-RPP147.10	06/24/1987	200		0.07

N/A – Data not available

Table A.25. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	08/24/1987	100		3.78
3-RPP147.10	09/03/1987	100		0.73
3-RPP147.10	10/01/1987	100		0.69
3-RPP147.10	11/04/1987	100		0.39
3-RPP147.10	12/02/1987	500		3.92
3-RPP147.10	03/07/1988	100		0.23
3-RPP147.10	04/07/1988	2100		0
3-RPP147.10	10/05/1988	100		0.54
3-RPP147.10	11/02/1988	100		1.15
3-RPP147.10	12/01/1988	100		0.37
3-RPP147.10	02/01/1989	100		0.95
3-RPP147.10	05/28/1991	170		0.1
3-RPP147.10	06/26/1991	170		0.5
3-RPP147.10	08/27/1991	20		0
3-RPP147.10	11/18/1991	83		0.72
3-RPP147.10	12/16/1991	1700		0
3-RPP147.10	02/25/1992	170		0.14
3-RPP147.10	03/25/1992	45		0.11
3-RPP147.10	04/09/1992	45		0.11
3-RPP147.10	05/05/1992	490		0.15
3-RPP147.10	07/09/1992	800		0.19
3-RPP147.10	08/13/1992	300		0.86
3-RPP147.10	09/14/1992	100		0.25
3-RPP147.10	10/20/1992	100		0
3-RPP147.10	11/23/1992	8000		0.04
3-RPP147.10	12/21/1992	200		0.12
3-RPP147.10	01/26/1993	1000		0.34
3-RPP147.10	02/23/1993	200		0.21

N/A – Data not available

Table A.26. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	03/22/1993	1100		0.35
3-RPP147.10	04/19/1993	400		2.27
3-RPP147.10	05/17/1993	4300		0.7
3-RPP147.10	07/15/1993	300		0.02
3-RPP147.10	08/12/1993	700		1.91
3-RPP147.10	09/07/1993	100		1.68
3-RPP147.10	10/07/1993	100		0.57
3-RPP147.10	11/22/1993	100		1.49
3-RPP147.10	02/17/1994	2100		1.32
3-RPP147.10	03/17/1994	100		0.78
3-RPP147.10	05/12/1994	100		0.57
3-RPP147.10	06/02/1994	100		2.43
3-RPP147.10	07/19/1994	6000		3.23
3-RPP147.10	08/11/1994	700		0.01
3-RPP147.10	09/08/1994	100		0.13
3-RPP147.10	10/18/1994	100		0.36
3-RPP147.10	12/20/1994	100		1.76
3-RPP147.10	01/25/1995	200		4.06
3-RPP147.10	02/14/1995	100		2.72
3-RPP147.10	03/23/1995	100		0.32
3-RPP147.10	04/26/1995	100		2.71
3-RPP147.10	05/24/1995	200		1.55
3-RPP147.10	06/21/1995	100		0.71
3-RPP147.10	07/20/1995	400		0
3-RPP147.10	08/23/1995	500		0.37
3-RPP147.10	11/08/1995	100		1.03
3-RPP147.10	01/24/1996	400		0.99
3-RPP147.10	02/22/1996	400		0.41

N/A – Data not available

Table A.27. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	03/21/1996	2500		0.25
3-RPP147.10	04/15/1996	100		3.44
3-RPP147.10	05/21/1996	300		0.16
3-RPP147.10	06/27/1996	400		0.65
3-RPP147.10	07/24/1996	200		1.12
3-RPP147.10	08/27/1996	400		0.01
3-RPP147.10	11/20/1996	200		0
3-RPP147.10	01/29/1997	100		1.29
3-RPP147.10	02/20/1997	100		0.03
3-RPP147.10	03/26/1997	100		0.66
3-RPP147.10	04/23/1997	100		#N/A
3-RPP147.10	05/22/1997	100		0.56
3-RPP147.10	06/26/1997	200		0.01
3-RPP147.10	07/24/1997	900		0.79
3-RPP147.10	08/28/1997	100		0.25
3-RPP147.10	09/10/1997	700		3.15
3-RPP147.10	10/08/1997	100		0.27
3-RPP147.10	11/18/1997	100		1.42
3-RPP147.10	12/17/1997	200		0.02
3-RPP147.10	01/21/1998	100		0.04
3-RPP147.10	02/26/1998	100		0.85
3-RPP147.10	03/18/1998	200		0.45
3-RPP147.10	04/09/1998	300		0
3-RPP147.10	05/12/1998	2600		0.04
3-RPP147.10	06/25/1998	200		0.05
3-RPP147.10	08/19/1998	200		1.59
3-RPP147.10	09/16/1998	400		2.2
3-RPP147.10	11/18/1998	100		0.29

N/A – Data not available

Table A.28. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	12/16/1998	300		1.71
3-RPP147.10	01/13/1999	600		0
3-RPP147.10	03/16/1999	500		2.37
3-RPP147.10	04/14/1999	100		0
3-RPP147.10	05/13/1999	100		0.29
3-RPP147.10	06/22/1999	100		0.2
3-RPP147.10	07/20/1999	100		0.3
3-RPP147.10	08/17/1999	100		0.97
3-RPP147.10	09/08/1999	1400		0.1
3-RPP147.10	12/13/1999	200		0.14
3-RPP147.10	01/12/2000	100		0
3-RPP147.10	02/10/2000	100		0.55
3-RPP147.10	03/23/2000	900		0
3-RPP147.10	04/12/2000	200		0.33
3-RPP147.10	05/04/2000	100		0.21
3-RPP147.10	06/13/2000	7600		1.73
3-RPP147.10	07/12/2000	100		1.6
3-RPP147.10	08/08/2000	100		1.03
3-RPP147.10	09/13/2000	100		1.15
3-RPP147.10	10/03/2000	200		0.17
3-RPP147.10	11/01/2000	100		1.37
3-RPP147.10	01/18/2001	100		0
3-RPP147.10	02/06/2001	100		0.19
3-RPP147.10	03/06/2001	100		0.2
3-RPP147.10	04/03/2001	100		0.8
3-RPP147.10	05/01/2001	100		0.8
3-RPP147.10	06/06/2001	1400		0.41
3-RPP147.10	01/30/2003	75	40	0.19

N/A – Data not available

Table A.29. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	02/11/2003	50	10	0.09
3-RPP147.10	05/29/2003	250	150	2.13
3-RPP147.10	06/18/2003	1800	680	1.31
3-RPP147.10	07/17/2003		200	0.02
3-RPP147.10	09/24/2003	2000	2000	2.6
3-RPP147.10	11/13/2003	2000	2000	1.52
3-RPP147.10	03/30/2004	25	75	0.13
3-RPP147.10	07/22/2004	100	250	1.06
3-RPP147.10	08/18/2004	220	180	0.7
3-RPP147.10	09/30/2004	2000	2000	2.68
3-RPP147.10	10/05/2004	200	150	0.08
3-RPP147.10	12/02/2004	180	220	0.92
3-RPP147.10	01/18/2005	380	75	2.84
3-RPP147.10	02/08/2005	25	25	0.18
3-RPP147.10	03/02/2005	25	25	0.74
3-RPP147.10	04/20/2005	50	25	0
3-RPP147.10	05/18/2005	25	100	0.2
3-RPP147.10	06/23/2005	50	25	0
3-RPP147.10	07/06/2005	2000	780	0
3-RPP147.10	07/06/2005	160	220	0
3-RPP147.10	08/17/2005	1175	84	0.82
3-RPP147.10	08/23/2005	320	25	0.58
3-RPP147.10	09/14/2005	130	100	0
3-RPP147.10	09/26/2005	50	25	0.27
3-RPP147.10	10/18/2005		74	0
3-RPP147.10	10/27/2005	380	450	1.63
3-RPP147.10	11/15/2005		60	0
3-RPP147.10	12/08/2005	180	25	0.56

N/A – Data not available

Table A.30. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP147.10 in Rappahannock River (VAN-E08R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP147.10	12/12/2005		163	0.7
3-RPP147.10	01/10/2006	50	25	0

N/A – Data not available

Table A.31. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP142.36 in Rappahannock River (60081) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP142.36	11/25/1970	100		0.45
3-RPP142.36	12/09/1970	100		0.4
3-RPP142.36	03/18/1971	100		1.65
3-RPP142.36	04/25/1971	400		0.85
3-RPP142.36	05/04/1971	200		0
3-RPP142.36	06/01/1971	100		0.4
3-RPP142.36	09/27/1971	100		0.55
3-RPP142.36	10/03/1971	3500		0.13
3-RPP142.36	11/10/1971	100		0
3-RPP142.36	12/14/1971	400		0.36
3-RPP142.36	01/23/1972	500		0.07
3-RPP142.36	03/02/1972	100		0.15
3-RPP142.36	04/05/1972	100		0.56
3-RPP142.36	05/03/1972	1900		0.65
3-RPP142.36	06/03/1972	200		0.8
3-RPP142.36	07/20/1972	100		0.35
3-RPP142.36	08/10/1972	100		0.75
3-RPP142.36	09/21/1972	400		0.15
3-RPP142.36	10/04/1972	100		0.75
3-RPP142.36	11/15/1972	2300		0.07
3-RPP142.36	12/08/1972	500		0.83
3-RPP142.36	01/22/1973	100		1.55
3-RPP142.36	02/22/1973	100		1.95
3-RPP142.36	03/13/1973	200		0
3-RPP142.36	04/11/1973	500		0.95
3-RPP142.36	05/13/1973	100		1.03
3-RPP142.36	08/24/1973	300		1.08
3-RPP142.36	10/15/1973	100		1.45

N/A – Data not available

Table A.32. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP142.36 in Rappahannock River (60081) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP142.36	11/13/1973	100		0
3-RPP142.36	12/06/1973	2200		0.3
3-RPP142.36	01/24/1974	200		0.1
3-RPP142.36	02/11/1974	100		0.17
3-RPP142.36	03/08/1974	100		0.53
3-RPP142.36	05/21/1974	100		0.35
3-RPP142.36	06/01/1974	100		0.4
3-RPP142.36	07/09/1974	100		0.77
3-RPP142.36	08/24/1974	300		0.36
3-RPP142.36	08/12/2003		1500	1.78
3-RPP142.36	10/28/2003		2000	1.12
3-RPP142.36	02/25/2004		25	0.02
3-RPP142.36	06/15/2004		25	0.59
3-RPP142.36	08/17/2004		100	0.72
3-RPP142.36	10/27/2004		25	0.31
3-RPP142.36	12/27/2004		25	0.92
3-RPP142.36	01/20/2005		150	0.01
3-RPP142.36	03/16/2005		25	0.31
3-RPP142.36	05/24/2005		300	1.98
3-RPP142.36	06/27/2005		25	0
3-RPP142.36	07/06/2005	1400	4000	0
3-RPP142.36	08/17/2005	600	50	0.82
3-RPP142.36	09/14/2005	50	50	0
3-RPP142.36	10/18/2005	50	50	0
3-RPP142.36	11/15/2005	100	150	0
3-RPP142.36	12/12/2005	50	100	0.7
3-RPP142.36	01/09/2006	50	50	0.01
3-RPP142.36	02/07/2006	50	50	#N/A

N/A – Data not available

Table A.33. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RPP142.36 in Rappahannock River (60081) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RPP142.36	03/14/2006	100	50	#N/A
3-RPP142.36	05/02/2006	100	50	#N/A
3-RPP142.36	06/13/2006	50	50	#N/A

N/A – Data not available

Table A.34. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-CRA000.82 in Craig Run (VAN-E08R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-CRA000.82	07/13/1999	100		0.83
3-CRA000.82	10/12/1999	100		0.97
3-CRA000.82	11/08/1999	100		1.26
3-CRA000.82	12/07/1999	400		1.02
3-CRA000.82	01/05/2000	3400		0.2
3-CRA000.82	05/24/2000	1000		1.79
3-CRA000.82	06/12/2000	500		1.71
3-CRA000.82	07/13/1999	100		0.83
3-CRA000.82	10/12/1999	100		0.97
3-CRA000.82	11/08/1999	100		1.26
3-CRA000.82	12/07/1999	400		1.02
3-CRA000.82	01/05/2000	3400		0.2
3-CRA000.82	05/24/2000	1000		1.79
3-CRA000.82	06/12/2000	500		1.71

N/A – Data not available

Table A.35. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-BOS000.72 in Browns Run (VAN-E08R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-BOS000.72	08/10/1999	200		4.64
3-BOS000.72	10/12/1999	100		0.97
3-BOS000.72	11/08/1999	100		1.26
3-BOS000.72	12/07/1999	1500		1.02
3-BOS000.72	01/05/2000	8000		0.2
3-BOS000.72	05/24/2000	1900		1.79
3-BOS000.72	06/12/2000	1300		1.71
3-BOS000.72	07/06/2005	100	82	0
3-BOS000.72	08/17/2005	260	125	0.82
3-BOS000.72	10/18/2005		308	0
3-BOS000.72	11/15/2005		44	0
3-BOS000.72	12/12/2005		348	0.7

N/A – Data not available

Table A.36. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-MAH000.19 in Marsh Run (VAN-E08R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-MAH000.19	04/11/1973	100		0.95
3-MAH000.19	05/13/1973	500		1.03
3-MAH000.19	08/24/1973	200		1.08
3-MAH000.19	11/13/1973	100		0
3-MAH000.19	12/06/1973	6000		0.3
3-MAH000.19	01/24/1974	100		0.1
3-MAH000.19	02/11/1974	100		0.17
3-MAH000.19	03/08/1974	100		0.53
3-MAH000.19	05/21/1974	100		0.35
3-MAH000.19	06/01/1974	300		0.4
3-MAH000.19	07/09/1974	100		0.77
3-MAH000.19	08/24/1974	100		0.36
3-MAH000.19	10/27/1974	100		0
3-MAH000.19	04/10/1975	100		0.48
3-MAH000.19	08/04/1975	200		0.82
3-MAH000.19	10/02/1975	100		0.36
3-MAH000.19	12/17/1975	200		0.09
3-MAH000.19	04/28/1976	100		1.04
3-MAH000.19	06/02/1976	1000		0.17
3-MAH000.19	08/11/1976	100		0.6
3-MAH000.19	10/28/1976	900		0.15
3-MAH000.19	02/24/1977	100		0.25
3-MAH000.19	06/28/1977	200		0.75
3-MAH000.19	10/06/1977	100		0.34
3-MAH000.19	03/31/1978	100		3.24
3-MAH000.19	08/24/1978	100		0.05
3-MAH000.19	10/24/1978	100		1.07
3-MAH000.19	12/07/1978	3800		1.97

N/A – Data not available

Table A.37. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-MAH000.19 in Marsh Run (VAN-E08R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-MAH000.19	04/25/1979	100		0.4
3-MAH000.19	06/14/1979	300		0
3-MAH000.19	08/29/1991	18		0
3-MAH000.19	02/27/1992	3500		0.25
3-MAH000.19	09/14/1992	400		0.25
3-MAH000.19	12/01/1992	400		0.54
3-MAH000.19	02/22/1993	7400		0.17
3-MAH000.19	05/19/1993	5400		1.76
3-MAH000.19	08/16/1993	100		1.97
3-MAH000.19	12/13/1993	5400		1.22
3-MAH000.19	02/28/1994	100		0.03
3-MAH000.19	08/18/1994	8000		1.13
3-MAH000.19	12/08/1994	700		0
3-MAH000.19	03/13/1995	600		1.13
3-MAH000.19	06/12/1995	800		0.01
3-MAH000.19	08/14/1995	100		0.72
3-MAH000.19	03/19/1996	200		0.23
3-MAH000.19	05/22/1996	1600		0.96
3-MAH000.19	09/25/1996	400		4.2
3-MAH000.19	02/03/1997	100		1
3-MAH000.19	03/31/1997	2200		0.8
3-MAH000.19	06/30/1997	100		0.01
3-MAH000.19	10/06/1997	100		0.13
3-MAH000.19	01/08/1998	1800		0.02
3-MAH000.19	03/30/1998	100		2.4
3-MAH000.19	06/22/1998	300		0
3-MAH000.19	09/24/1998	100		0.26
3-MAH000.19	01/28/1999	100		0.92

N/A – Data not available

Table A.38. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-MAH000.19 in Marsh Run (VAN-E08R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-MAH000.19	03/22/1999	1500		0.42
3-MAH000.19	05/26/1999	100		0.31
3-MAH000.19	12/13/1999	1600		0.14
3-MAH000.19	04/25/2000	300		0.12
3-MAH000.19	08/16/2000	100		1.62
3-MAH000.19	10/05/2000	100		0.17
3-MAH000.19	02/13/2001	100		0.93
3-MAH000.19	03/28/2001	100		0.48
3-MAH000.19	05/15/2001	100		0.3
3-MAH000.19	08/12/2003		2000	1.78
3-MAH000.19	10/28/2003		2000	1.12
3-MAH000.19	02/25/2004		25	0.02
3-MAH000.19	06/15/2004		100	0.59
3-MAH000.19	08/17/2004		100	0.72
3-MAH000.19	10/27/2004		50	0.31
3-MAH000.19	12/27/2004		180	0.92
3-MAH000.19	03/16/2005		50	0.31
3-MAH000.19	05/24/2005		150	1.98
3-MAH000.19	06/27/2005		25	0
3-MAH000.19	07/06/2005	50	72	0
3-MAH000.19	08/17/2005	310	50	0.82
3-MAH000.19	09/14/2005	50	12	0
3-MAH000.19	10/18/2005		22	0
3-MAH000.19	11/15/2005		14	0
3-MAH000.19	12/12/2005		287	0.7

N/A – Data not available

Appendix B – Bacteria Source Tracking Report

The bacterial source tracking (BST) data were generated in a separate study for VADEQ performed by MapTech, Inc. and New River Highlands RC&D. The reader should refer to data and analyses for stations 3-HAZ018.29, 3-RUS005.66, 3-RPP175.51, 3-RPP147.10, 3-CRA000.46, 3-BOS000.72, and 3-MAH000.19.

Bacterial Source Tracking Analyses to Support Virginia's TMDLs: *Non-Shellfish Stations*

Incorporated by Reference

Please refer to full document posted at: http://www.deq.virginia.gov/tmdl/reports/bst05.pdf

and http://www.deq.virginia.gov/tmdl/reports/bst06.pdf

or contact VDEQ-NRO

Appendix C – Fecal Coliform Loading in Subwatersheds

Table C.1. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-1.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	16	93,572	23,675	5,788	1,149	1,747	0
Fe.	14	99,737	25,198	6,180	1,047	1,592	0
Mar.	16	112,603	28,441	6,979	827	1,747	0
Apr.	15	112,025	28,289	6,946	800	1,691	0
May.	16	118,897	30,017	7,374	827	1,747	0
Jun.	15	117,986	29,782	7,319	800	1,691	0
Jul.	16	125,088	31,568	7,761	827	1,747	0
Aug.	16	128,257	32,362	7,960	827	1,747	0
Sep.	15	127,342	32,125	7,905	1,112	1,691	0
Oct.	16	81,643	20,688	5,041	1,149	1,747	0
Nov.	15	82,861	20,985	5,120	1,112	1,691	0
Dec.	16	89,604	22,681	5,540	1,149	1,747	0
Total	187	1,289,615	325,810	79,911	11,623	20,587	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.2. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-2.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	21,735	5,526	1,339	258	781	0
Fe.	2	23,129	5,868	1,428	235	712	0
Mar.	2	26,106	6,621	1,613	204	781	0
Apr.	2	25,965	6,583	1,605	198	756	0
May.	2	27,551	6,982	1,703	204	781	0
Jun.	2	27,334	6,925	1,690	198	756	0
Jul.	2	28,973	7,339	1,792	204	781	0
Aug.	2	29,700	7,521	1,838	204	781	0
Sep.	2	29,482	7,463	1,825	250	756	0
Oct.	2	18,996	4,840	1,168	258	781	0
Nov.	2	19,268	4,905	1,185	250	756	0
Dec.	2	20,824	5,298	1,282	258	781	0
Total	25	299,063	75,871	18,467	2,721	9,203	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.3. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-3.

	Fecal Coliform loadings (x10^{10} cfu/month)						
Month	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	60,992	15,341	3,868	1,009	1,270	0
Fe.	5	65,206	16,390	4,128	920	1,157	0
Mar.	5	73,654	18,512	4,661	825	1,270	0
Apr.	5	73,310	18,424	4,638	799	1,229	0
May.	5	77,841	19,561	4,923	825	1,270	0
Jun.	5	77,277	19,417	4,886	799	1,229	0
Jul.	5	81,961	20,592	5,181	825	1,270	0
Aug.	5	84,069	21,120	5,313	825	1,270	0
Sep.	5	83,502	20,976	5,276	977	1,229	0
Oct.	5	53,054	13,353	3,371	1,009	1,270	0
Nov.	5	53,906	13,564	3,423	977	1,229	0
Dec.	5	58,352	14,680	3,703	1,009	1,270	0
Total	62	843,124	211,930	53,372	10,801	14,958	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.4. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-4.

	Fecal Coliform loadings (x10^{10} cfu/month)						
Month	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	6	15,326	3,921	931	277	930	0
Fe.	5	16,266	4,149	992	252	848	0
Mar.	6	18,351	4,679	1,121	223	930	0
Apr.	6	18,245	4,650	1,115	216	900	0
May.	6	19,352	4,930	1,183	223	930	0
Jun.	6	19,192	4,887	1,174	216	900	0
Jul.	6	20,336	5,176	1,245	223	930	0
Aug.	6	20,840	5,302	1,276	223	930	0
Sep.	6	20,680	5,259	1,267	268	900	0
Oct.	6	13,429	3,446	812	277	930	0
Nov.	6	13,608	3,488	824	268	900	0
Dec.	6	14,695	3,763	892	277	930	0
Total	67	210,318	53,651	12,833	2,939	10,960	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.5. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-5.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	14	29,144	7,473	1,760	320	1,551	0
Fe.	13	30,903	7,898	1,876	292	1,413	0
Mar.	14	34,859	8,904	2,117	246	1,551	0
Apr.	14	34,652	8,847	2,107	238	1,501	0
May.	14	36,749	9,377	2,236	246	1,551	0
Jun.	14	36,442	9,295	2,219	238	1,501	0
Jul.	14	38,608	9,843	2,352	246	1,551	0
Aug.	14	39,560	10,081	2,412	246	1,551	0
Sep.	14	39,251	9,998	2,395	310	1,501	0
Oct.	14	25,562	6,576	1,535	320	1,551	0
Nov.	14	25,894	6,653	1,558	310	1,501	0
Dec.	14	27,953	7,174	1,685	320	1,551	0
Total	169	399,576	102,120	24,251	3,329	18,271	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.6. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-6.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	9	49,896	12,610	3,126	857	1,991	0
Fe.	8	53,235	13,436	3,335	781	1,815	0
Mar.	9	60,112	15,168	3,765	699	1,991	0
Apr.	9	59,812	15,090	3,747	676	1,927	0
May.	9	63,490	16,014	3,977	699	1,991	0
Jun.	9	63,012	15,891	3,947	676	1,927	0
Jul.	9	66,814	16,847	4,185	699	1,991	0
Aug.	9	68,515	17,273	4,291	699	1,991	0
Sep.	9	68,035	17,149	4,261	829	1,927	0
Oct.	9	43,492	11,006	2,725	857	1,991	0
Nov.	9	44,157	11,169	2,766	829	1,927	0
Dec.	9	47,766	12,076	2,992	857	1,991	0
Total	104	688,334	173,729	43,117	9,158	23,463	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.7. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-7.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	7,968	2,025	493	299	968	0
Fe.	1	8,482	2,151	525	272	882	0
Mar.	1	9,574	2,427	593	251	968	0
Apr.	1	9,523	2,413	590	243	937	0
May.	1	10,105	2,560	627	251	968	0
Jun.	1	10,026	2,539	622	243	937	0
Jul.	1	10,628	2,691	659	251	968	0
Aug.	1	10,895	2,758	676	251	968	0
Sep.	1	10,816	2,737	671	289	937	0
Oct.	1	6,961	1,772	430	299	968	0
Nov.	1	7,061	1,797	436	289	937	0
Dec.	1	7,633	1,941	472	299	968	0
Total	8	109,670	27,808	6,794	3,236	11,404	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.8. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-8.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	14,575	3,738	881	241	1,527	0
Fe.	1	15,454	3,950	939	219	1,391	0
Mar.	1	17,433	4,454	1,060	194	1,527	0
Apr.	1	17,329	4,425	1,054	188	1,478	0
May.	1	18,378	4,690	1,119	194	1,527	0
Jun.	1	18,224	4,649	1,110	188	1,478	0
Jul.	1	19,307	4,923	1,177	194	1,527	0
Aug.	1	19,783	5,042	1,207	194	1,527	0
Sep.	1	19,629	5,001	1,198	233	1,478	0
Oct.	1	12,784	3,289	769	241	1,527	0
Nov.	1	12,950	3,328	780	233	1,478	0
Dec.	1	13,980	3,589	843	241	1,527	0
Total	14	199,826	51,079	12,135	2,562	17,990	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.9. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-9.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	8,289	2,126	500	166	1,191	0
Fe.	1	8,789	2,246	533	151	1,085	0
Mar.	1	9,914	2,533	602	136	1,191	0
Apr.	1	9,855	2,516	599	132	1,153	0
May.	1	10,451	2,667	636	136	1,191	0
Jun.	1	10,364	2,644	631	132	1,153	0
Jul.	1	10,980	2,800	669	136	1,191	0
Aug.	1	11,250	2,867	686	136	1,191	0
Sep.	1	11,162	2,844	681	161	1,153	0
Oct.	1	7,270	1,871	437	166	1,191	0
Nov.	1	7,365	1,893	443	161	1,153	0
Dec.	1	7,950	2,041	479	166	1,191	0
Total	14	113,638	29,046	6,897	1,781	14,034	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.10. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-10.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	5,758	1,448	365	281	468	0
Fe.	0	6,155	1,547	390	256	426	0
Mar.	0	6,953	1,748	440	235	468	0
Apr.	0	6,920	1,739	438	227	453	0
May.	0	7,348	1,847	465	235	468	0
Jun.	0	7,295	1,833	461	227	453	0
Jul.	0	7,737	1,944	489	235	468	0
Aug.	0	7,936	1,994	502	235	468	0
Sep.	0	7,882	1,980	498	272	453	0
Oct.	0	5,008	1,261	318	281	468	0
Nov.	0	5,089	1,281	323	272	453	0
Dec.	0	5,508	1,386	350	281	468	0
Total	1	79,591	20,007	5,039	3,035	5,513	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.11. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-11.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	20,422	5,137	1,295	375	694	0
Fe.	0	21,833	5,488	1,382	342	632	0
Mar.	0	24,661	6,199	1,561	310	694	0
Apr.	0	24,546	6,169	1,553	300	671	0
May.	0	26,063	6,550	1,649	310	694	0
Jun.	0	25,874	6,502	1,636	300	671	0
Jul.	0	27,443	6,895	1,735	310	694	0
Aug.	0	28,149	7,072	1,779	310	694	0
Sep.	0	27,959	7,024	1,767	363	671	0
Oct.	0	17,764	4,471	1,129	375	694	0
Nov.	0	18,049	4,542	1,146	363	671	0
Dec.	0	19,538	4,916	1,240	375	694	0
Total	2	282,302	70,964	17,874	4,032	8,175	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.12. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-12.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	5,396	1,357	342	30	69	0
Fe.	0	5,769	1,450	365	27	63	0
Mar.	0	6,517	1,638	412	22	69	0
Apr.	0	6,486	1,630	410	21	67	0
May.	0	6,887	1,730	435	22	69	0
Jun.	0	6,837	1,718	432	21	67	0
Jul.	0	7,252	1,822	458	22	69	0
Aug.	0	7,438	1,868	470	22	69	0
Sep.	0	7,388	1,856	467	29	67	0
Oct.	0	4,694	1,181	298	30	69	0
Nov.	0	4,769	1,200	303	29	67	0
Dec.	0	5,163	1,298	327	30	69	0
Total	4	74,597	18,747	4,719	303	813	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.13. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-13.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	7	81,321	20,454	5,157	1,070	1,702	0
Fe.	6	86,940	21,853	5,503	975	1,551	0
Mar.	7	98,204	24,682	6,214	867	1,702	0
Apr.	6	97,746	24,564	6,184	839	1,647	0
May.	7	103,787	26,080	6,564	867	1,702	0
Jun.	6	103,035	25,889	6,515	839	1,647	0
Jul.	7	109,280	27,456	6,908	867	1,702	0
Aug.	7	112,091	28,160	7,084	867	1,702	0
Sep.	6	111,335	27,967	7,034	1,036	1,647	0
Oct.	7	70,738	17,803	4,495	1,070	1,702	0
Nov.	6	71,873	18,085	4,564	1,036	1,647	0
Dec.	7	77,801	19,572	4,937	1,070	1,702	0
Total	78	1,124,151	282,565	71,159	11,406	20,056	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.14. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-14.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	3	123,234	30,994	7,814	2,222	1,971	0
Fe.	3	131,750	33,115	8,339	2,025	1,796	0
Mar.	3	148,820	37,401	9,416	1,824	1,971	0
Apr.	3	148,126	37,223	9,369	1,765	1,907	0
May.	3	157,281	39,521	9,946	1,824	1,971	0
Jun.	3	156,141	39,231	9,871	1,765	1,907	0
Jul.	3	165,605	41,605	10,467	1,824	1,971	0
Aug.	3	169,866	42,672	10,734	1,824	1,971	0
Sep.	3	168,719	42,381	10,659	2,150	1,907	0
Oct.	3	107,195	26,977	6,810	2,222	1,971	0
Nov.	3	108,916	27,404	6,915	2,150	1,907	0
Dec.	3	117,899	29,658	7,480	2,222	1,971	0
Total	39	1,703,551	428,182	107,819	23,818	23,223	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.15. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-15.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	3	123,234	30,994	7,814	2,222	1,971	0
Fe.	3	131,750	33,115	8,339	2,025	1,796	0
Mar.	3	148,820	37,401	9,416	1,824	1,971	0
Apr.	3	148,126	37,223	9,369	1,765	1,907	0
May.	3	157,281	39,521	9,946	1,824	1,971	0
Jun.	3	156,141	39,231	9,871	1,765	1,907	0
Jul.	3	165,605	41,605	10,467	1,824	1,971	0
Aug.	3	169,866	42,672	10,734	1,824	1,971	0
Sep.	3	168,719	42,381	10,659	2,150	1,907	0
Oct.	3	107,195	26,977	6,810	2,222	1,971	0
Nov.	3	108,916	27,404	6,915	2,150	1,907	0
Dec.	3	117,899	29,658	7,480	2,222	1,971	0
Total	39	1,703,551	428,182	107,819	23,818	23,223	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.16. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-16.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	9,338	2,395	564	130	1,036	0
Fe.	2	9,901	2,531	601	118	944	0
Mar.	2	11,168	2,854	679	102	1,036	0
Apr.	2	11,102	2,835	675	99	1,002	0
May.	2	11,774	3,005	717	102	1,036	0
Jun.	2	11,675	2,979	711	99	1,002	0
Jul.	2	12,369	3,154	754	102	1,036	0
Aug.	2	12,674	3,231	773	102	1,036	0
Sep.	2	12,575	3,204	768	126	1,002	0
Oct.	2	8,191	2,108	492	130	1,036	0
Nov.	2	8,297	2,133	500	126	1,002	0
Dec.	2	8,957	2,300	540	130	1,036	0
Total	23	128,021	32,727	7,774	1,366	12,201	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.17. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-17.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	27,322	7,005	1,651	350	2,479	0
Fe.	5	28,972	7,404	1,759	319	2,259	0
Mar.	5	32,681	8,347	1,986	276	2,479	0
Apr.	5	32,488	8,293	1,976	267	2,399	0
May.	5	34,454	8,791	2,097	276	2,479	0
Jun.	5	34,167	8,714	2,081	267	2,399	0
Jul.	5	36,198	9,228	2,207	276	2,479	0
Aug.	5	37,090	9,451	2,262	276	2,479	0
Sep.	5	36,802	9,374	2,246	339	2,399	0
Oct.	5	23,962	6,163	1,440	350	2,479	0
Nov.	5	24,273	6,236	1,462	339	2,399	0
Dec.	5	26,204	6,725	1,581	350	2,479	0
Total	62	374,612	95,730	22,750	3,685	29,212	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.18. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-18.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	40,105	10,277	2,427	659	4,079	0
Fe.	3	42,538	10,866	2,587	601	3,717	0
Mar.	4	47,986	12,251	2,921	529	4,079	0
Apr.	4	47,703	12,172	2,906	512	3,947	0
May.	4	50,593	12,904	3,084	529	4,079	0
Jun.	4	50,172	12,791	3,060	512	3,947	0
Jul.	4	53,157	13,546	3,245	529	4,079	0
Aug.	4	54,469	13,874	3,327	529	4,079	0
Sep.	4	54,047	13,761	3,303	638	3,947	0
Oct.	4	35,165	9,040	2,118	659	4,079	0
Nov.	4	35,625	9,148	2,150	638	3,947	0
Dec.	4	38,462	9,865	2,325	659	4,079	0
Total	44	550,021	140,494	33,453	6,992	48,055	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.19. Monthly nonpoint fecal coliform loadings in sub-watershed HAR-19.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	18,222	4,675	1,099	143	815	0
Fe.	1	19,317	4,939	1,171	131	743	0
Mar.	1	21,789	5,568	1,322	106	815	0
Apr.	1	21,659	5,532	1,315	103	789	0
May.	1	22,969	5,864	1,396	106	815	0
Jun.	1	22,776	5,812	1,385	103	789	0
Jul.	1	24,129	6,154	1,469	106	815	0
Aug.	1	24,723	6,303	1,506	106	815	0
Sep.	1	24,530	6,251	1,495	139	789	0
Oct.	1	15,986	4,115	959	143	815	0
Nov.	1	16,192	4,163	973	139	789	0
Dec.	1	17,478	4,489	1,052	143	815	0
Total	8	249,769	63,865	15,141	1,468	9,603	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.20. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-1.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	16	189,305	47,788	11,941	2,569	6,360	0
Fe.	15	202,109	50,961	12,735	2,341	5,796	0
Mar.	16	228,244	57,540	14,379	1,994	6,360	0
Apr.	16	227,131	57,249	14,306	1,930	6,155	0
May.	16	241,121	60,765	15,185	1,994	6,360	0
Jun.	16	239,329	60,304	15,070	1,930	6,155	0
Jul.	16	253,790	63,937	15,978	1,994	6,360	0
Aug.	16	260,273	65,561	16,384	1,994	6,360	0
Sep.	16	258,472	65,098	16,268	2,486	6,155	0
Oct.	16	164,895	41,675	10,413	2,569	6,360	0
Nov.	16	167,457	42,304	10,570	2,486	6,155	0
Dec.	16	181,185	45,754	11,432	2,569	6,360	0
Total	189	2,613,312	658,935	164,661	26,855	74,933	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.21. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-2.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	2,040	519	127	53	141	0
Fe.	0	2,172	551	135	48	128	0
Mar.	0	2,451	622	153	43	141	0
Apr.	0	2,438	619	152	42	136	0
May.	0	2,587	656	161	43	141	0
Jun.	0	2,567	651	160	42	136	0
Jul.	0	2,721	690	170	43	141	0
Aug.	0	2,789	707	174	43	141	0
Sep.	0	2,769	701	173	51	136	0
Oct.	0	1,783	455	111	53	141	0
Nov.	0	1,809	461	112	51	136	0
Dec.	0	1,955	498	122	53	141	0
Total	5	28,081	7,129	1,748	564	1,660	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.22. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-3.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	31,185	7,849	1,975	532	1,214	0
Fe.	1	33,331	8,383	2,107	485	1,106	0
Mar.	1	37,647	9,468	2,380	435	1,214	0
Apr.	1	37,470	9,422	2,368	421	1,175	0
May.	1	39,784	10,003	2,513	435	1,214	0
Jun.	1	39,494	9,929	2,495	421	1,175	0
Jul.	1	41,886	10,529	2,645	435	1,214	0
Aug.	1	42,962	10,799	2,712	435	1,214	0
Sep.	1	42,671	10,725	2,693	515	1,175	0
Oct.	1	27,135	6,835	1,721	532	1,214	0
Nov.	1	27,567	6,942	1,748	515	1,175	0
Dec.	1	29,838	7,512	1,891	532	1,214	0
Total	15	430,971	108,396	27,249	5,692	14,305	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.23. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-4.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	23	96,751	24,715	6,058	1,230	3,504	0
Fe.	21	102,889	26,209	6,442	1,121	3,193	0
Mar.	23	116,118	29,565	7,270	968	3,504	0
Apr.	23	115,481	29,390	7,230	937	3,391	0
May.	23	122,523	31,169	7,671	968	3,504	0
Jun.	23	121,547	30,909	7,610	937	3,391	0
Jul.	23	128,823	32,747	8,066	968	3,504	0
Aug.	23	132,048	33,554	8,268	968	3,504	0
Sep.	23	131,068	33,293	8,206	1,190	3,391	0
Oct.	23	84,611	21,674	5,298	1,230	3,504	0
Nov.	23	85,801	21,957	5,372	1,190	3,391	0
Dec.	23	92,713	23,703	5,805	1,230	3,504	0
Total	276	1,330,373	338,884	83,296	12,937	41,280	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.24. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-5.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	36,657	9,286	2,297	635	2,102	0
Fe.	3	39,083	9,884	2,449	579	1,916	0
Mar.	4	44,127	11,156	2,765	510	2,102	0
Apr.	4	43,903	11,097	2,751	494	2,034	0
May.	4	46,598	11,775	2,920	510	2,102	0
Jun.	4	46,243	11,683	2,897	494	2,034	0
Jul.	4	49,028	12,384	3,072	510	2,102	0
Aug.	4	50,272	12,695	3,150	510	2,102	0
Sep.	4	49,916	12,603	3,127	614	2,034	0
Oct.	4	31,974	8,113	2,004	635	2,102	0
Nov.	4	32,455	8,230	2,034	614	2,034	0
Dec.	4	35,099	8,896	2,200	635	2,102	0
Total	43	505,356	127,801	31,665	6,740	24,769	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.25. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-6.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	32	111,129	28,387	6,956	2,089	5,957	0
Fe.	29	118,177	30,103	7,397	1,903	5,428	0
Mar.	32	133,372	33,958	8,349	1,685	5,957	0
Apr.	31	132,640	33,756	8,303	1,631	5,765	0
May.	32	140,728	35,800	8,809	1,685	5,957	0
Jun.	31	139,607	35,501	8,739	1,631	5,765	0
Jul.	32	147,964	37,612	9,262	1,685	5,957	0
Aug.	32	151,668	38,540	9,494	1,685	5,957	0
Sep.	31	150,542	38,240	9,424	2,021	5,765	0
Oct.	32	97,186	24,895	6,083	2,089	5,957	0
Nov.	31	98,552	25,220	6,169	2,021	5,765	0
Dec.	32	106,491	27,226	6,666	2,089	5,957	0
Total	373	1,528,055	389,237	95,649	22,212	70,184	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.26. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-7.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	25	47,380	12,130	2,892	689	2,961	0
Fe.	23	50,289	12,835	3,081	628	2,699	0
Mar.	25	56,736	14,473	3,478	537	2,961	0
Apr.	24	56,408	14,382	3,460	520	2,866	0
May.	25	59,831	15,248	3,672	537	2,961	0
Jun.	24	59,339	15,116	3,643	520	2,866	0
Jul.	25	62,875	16,011	3,862	537	2,961	0
Aug.	25	64,433	16,401	3,960	537	2,961	0
Sep.	24	63,939	16,268	3,931	667	2,866	0
Oct.	25	41,514	10,661	2,525	689	2,961	0
Nov.	24	42,069	10,791	2,562	667	2,866	0
Dec.	25	45,429	11,641	2,770	689	2,961	0
Total	292	650,239	165,959	39,838	7,217	34,892	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.27. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-8.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	13	75,685	19,335	4,738	925	6,570	0
Fe.	12	80,483	20,503	5,038	843	5,987	0
Mar.	13	90,831	23,128	5,686	719	6,570	0
Apr.	13	90,332	22,991	5,655	695	6,358	0
May.	13	95,840	24,383	6,000	719	6,570	0
Jun.	13	95,077	24,179	5,952	695	6,358	0
Jul.	13	100,768	25,617	6,308	719	6,570	0
Aug.	13	103,290	26,248	6,466	719	6,570	0
Sep.	13	102,523	26,044	6,418	895	6,358	0
Oct.	13	66,190	16,957	4,143	925	6,570	0
Nov.	13	67,121	17,178	4,202	895	6,358	0
Dec.	13	72,527	18,544	4,540	925	6,570	0
Total	156	1,040,666	265,107	65,146	9,673	77,410	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.28. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-9.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	18	54,625	13,901	3,369	348	2,201	0
Fe.	17	55,827	14,182	3,449	317	2,005	0
Mar.	18	67,741	17,186	4,190	261	2,201	0
Apr.	18	68,257	17,308	4,224	252	2,130	0
May.	18	71,837	18,211	4,447	261	2,201	0
Jun.	18	70,717	17,924	4,378	252	2,130	0
Jul.	18	74,399	18,853	4,607	261	2,201	0
Aug.	18	75,724	19,185	4,690	261	2,201	0
Sep.	18	74,654	18,910	4,625	337	2,130	0
Oct.	18	56,269	14,313	3,472	348	2,201	0
Nov.	18	54,640	13,898	3,372	337	2,130	0
Dec.	18	52,966	13,485	3,265	348	2,201	0
Total	214	777,657	197,355	48,088	3,583	25,928	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.29. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-10.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	30,491	7,815	1,833	171	641	0
Fe.	9	32,328	8,259	1,955	156	584	0
Mar.	10	36,467	9,311	2,208	117	641	0
Apr.	10	36,250	9,251	2,196	113	620	0
May.	10	38,443	9,806	2,331	117	641	0
Jun.	10	38,122	9,720	2,314	113	620	0
Jul.	10	40,388	10,293	2,453	117	641	0
Aug.	10	41,383	10,542	2,515	117	641	0
Sep.	10	41,060	10,456	2,498	165	620	0
Oct.	10	26,744	6,876	1,599	171	641	0
Nov.	10	27,091	6,958	1,623	165	620	0
Dec.	10	29,245	7,503	1,755	171	641	0
Total	122	418,011	106,790	25,281	1,693	7,552	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.30. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-11.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	9	29,878	7,620	1,827	163	773	0
Fe.	8	30,876	7,858	1,894	149	705	0
Mar.	9	36,639	9,313	2,251	119	773	0
Apr.	9	36,768	9,341	2,260	115	749	0
May.	9	38,783	9,850	2,385	119	773	0
Jun.	9	38,260	9,715	2,353	115	749	0
Jul.	9	40,334	10,239	2,482	119	773	0
Aug.	9	41,133	10,439	2,532	119	773	0
Sep.	9	40,629	10,308	2,502	158	749	0
Oct.	9	29,390	7,498	1,797	163	773	0
Nov.	9	28,872	7,364	1,766	158	749	0
Dec.	9	28,878	7,370	1,765	163	773	0
Total	108	420,440	106,917	25,813	1,660	9,113	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.31. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-12.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	30	62,568	15,995	3,875	484	4,003	0
Fe.	27	66,486	16,948	4,124	441	3,648	0
Mar.	30	75,025	19,115	4,655	352	4,003	0
Apr.	29	74,604	18,999	4,630	341	3,874	0
May.	30	79,145	20,147	4,913	352	4,003	0
Jun.	29	78,506	19,976	4,875	341	3,874	0
Jul.	30	83,197	21,162	5,167	352	4,003	0
Aug.	30	85,271	21,681	5,297	352	4,003	0
Sep.	29	84,630	21,510	5,258	469	3,874	0
Oct.	30	54,760	14,040	3,387	484	4,003	0
Nov.	29	55,514	14,218	3,435	469	3,874	0
Dec.	30	59,971	15,345	3,713	484	4,003	0
Total	350	859,679	219,136	53,330	4,922	47,161	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.32. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-13.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	7,963	2,039	483	104	349	0
Fe.	4	8,449	2,157	515	94	318	0
Mar.	4	9,531	2,432	581	81	349	0
Apr.	4	9,476	2,416	578	79	338	0
May.	4	10,050	2,562	614	81	349	0
Jun.	4	9,967	2,539	609	79	338	0
Jul.	4	10,561	2,690	646	81	349	0
Aug.	4	10,822	2,755	662	81	349	0
Sep.	4	10,738	2,733	657	100	338	0
Oct.	4	6,979	1,793	422	104	349	0
Nov.	4	7,072	1,814	428	100	338	0
Dec.	4	7,636	1,957	463	104	349	0
Total	46	109,244	27,886	6,659	1,088	4,115	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.33. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-14.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	23	45,699	11,601	2,860	206	2,047	0
Fe.	21	46,400	11,763	2,904	188	1,866	0
Mar.	23	57,115	14,460	3,575	143	2,047	0
Apr.	23	57,701	14,602	3,611	138	1,981	0
May.	23	60,649	15,346	3,796	143	2,047	0
Jun.	23	59,629	15,085	3,732	138	1,981	0
Jul.	23	62,658	15,849	3,922	143	2,047	0
Aug.	23	63,700	16,110	3,987	143	2,047	0
Sep.	23	62,730	15,862	3,926	199	1,981	0
Oct.	23	48,408	12,280	3,030	206	2,047	0
Nov.	23	46,689	11,844	2,922	199	1,981	0
Dec.	23	44,394	11,275	2,778	206	2,047	0
Total	276	655,771	166,077	41,044	2,051	24,120	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.34. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-15.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	27	49,492	12,565	3,101	219	7,239	0
Fe.	25	50,170	12,719	3,143	200	6,597	0
Mar.	27	61,939	15,682	3,880	152	7,239	0
Apr.	27	62,606	15,844	3,922	147	7,006	0
May.	27	65,784	16,645	4,121	152	7,239	0
Jun.	27	64,659	16,358	4,050	147	7,006	0
Jul.	27	67,924	17,181	4,255	152	7,239	0
Aug.	27	69,034	17,459	4,324	152	7,239	0
Sep.	27	67,965	17,186	4,257	212	7,006	0
Oct.	27	52,740	13,378	3,304	219	7,239	0
Nov.	27	50,793	12,885	3,182	212	7,006	0
Dec.	27	48,102	12,217	3,014	219	7,239	0
Total	323	711,207	180,119	44,551	2,186	85,294	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.35. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-16.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	12	9,058	2,314	567	126	1,349	0
Fe.	11	9,631	2,454	603	114	1,229	0
Mar.	12	10,869	2,768	680	94	1,349	0
Apr.	11	10,809	2,752	676	91	1,305	0
May.	12	11,468	2,918	718	94	1,349	0
Jun.	11	11,377	2,894	712	91	1,305	0
Jul.	12	12,058	3,066	754	94	1,349	0
Aug.	12	12,359	3,141	773	94	1,349	0
Sep.	11	12,267	3,117	768	122	1,305	0
Oct.	12	7,922	2,030	496	126	1,349	0
Nov.	11	8,033	2,056	503	122	1,305	0
Dec.	12	8,680	2,220	543	126	1,349	0
Total	136	124,533	31,729	7,792	1,292	15,894	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.36. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-17.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	14	18,202	4,650	1,138	265	1,581	0
Fe.	13	19,355	4,930	1,210	242	1,441	0
Mar.	14	21,844	5,562	1,366	210	1,581	0
Apr.	13	21,724	5,529	1,359	203	1,530	0
May.	14	23,048	5,863	1,442	210	1,581	0
Jun.	13	22,864	5,814	1,430	203	1,530	0
Jul.	14	24,233	6,160	1,516	210	1,581	0
Aug.	14	24,839	6,312	1,554	210	1,581	0
Sep.	13	24,655	6,263	1,542	257	1,530	0
Oct.	14	15,919	4,078	995	265	1,581	0
Nov.	13	16,143	4,131	1,009	257	1,530	0
Dec.	14	17,442	4,459	1,091	265	1,581	0
Total	162	250,267	63,751	15,652	2,795	18,634	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.37. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-18.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	7	28,018	7,078	1,751	95	780	0
Fe.	6	27,279	6,887	1,705	86	711	0
Mar.	7	36,198	9,126	2,263	72	780	0
Apr.	7	37,022	9,330	2,315	70	755	0
May.	7	38,628	9,734	2,415	72	780	0
Jun.	7	37,705	9,502	2,357	70	755	0
Jul.	7	39,345	9,914	2,460	72	780	0
Aug.	7	39,727	10,010	2,484	72	780	0
Sep.	7	38,864	9,792	2,430	92	755	0
Oct.	7	34,138	8,610	2,134	95	780	0
Nov.	7	31,878	8,042	1,993	92	755	0
Dec.	7	27,539	6,958	1,721	95	780	0
Total	80	416,342	104,983	26,027	984	9,191	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.38. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-19.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	8,791	2,248	550	63	780	0
Fe.	4	9,345	2,383	585	58	711	0
Mar.	5	10,546	2,688	660	43	780	0
Apr.	4	10,488	2,672	657	42	755	0
May.	5	11,127	2,833	697	43	780	0
Jun.	4	11,038	2,809	691	42	755	0
Jul.	5	11,698	2,976	732	43	780	0
Aug.	5	11,990	3,049	751	43	780	0
Sep.	4	11,901	3,025	745	61	755	0
Oct.	5	7,690	1,972	481	63	780	0
Nov.	4	7,798	1,998	488	61	755	0
Dec.	5	8,425	2,156	527	63	780	0
Total	53	120,839	30,810	7,565	626	9,191	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.39. Monthly nonpoint fecal coliform loadings in sub-watershed RAR-20.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	3	25,036	6,398	1,566	383	1,723	0
Fe.	3	26,620	6,783	1,665	349	1,570	0
Mar.	3	30,041	7,651	1,879	307	1,723	0
Apr.	3	29,876	7,606	1,869	297	1,667	0
May.	3	31,697	8,066	1,983	307	1,723	0
Jun.	3	31,443	7,999	1,967	297	1,667	0
Jul.	3	33,325	8,474	2,085	307	1,723	0
Aug.	3	34,158	8,683	2,137	307	1,723	0
Sep.	3	33,904	8,615	2,121	371	1,667	0
Oct.	3	21,899	5,612	1,369	383	1,723	0
Nov.	3	22,205	5,685	1,389	371	1,667	0
Dec.	3	23,993	6,137	1,500	383	1,723	0
Total	13	13,183	3,390	810	389	1,269	0

[1]Includes Farmstead, Low Density Residential, and High Density Residential Loads

Appendix D – Required Reductions in Fecal Coliform Loads by Subwatershed – Allocation Scenario

Table D.1. Required annual reductions in nonpoint sources in sub-watershed HAR-01 of Hughes River (VAN-E03R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	18,732	0%	1,873	90%
Pasture	169,533,586	98%	16,953,363	90%
Loafing Lots	0	0%	0	90%
Forest	1,162,287	0.7%	1,162,287	0%
Residential	2,058,658	1%	205,866	90%
Total	172,773,263	100%	18,323,389	89%

Table D.2. Required annual reductions in direct nonpoint sources in sub-watershed HAR-01 of Hughes River (VAN-E03R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	173,333	18%	17,333	90%
Wildlife in Streams	251,554	26%	251,554	0%
Straight Pipes	551,536	56%	0	100%
Total	976,423	100%	268,887	72%

Table D.3. Required annual reductions in nonpoint sources in sub-watershed HAR-02 of Hughes River (VAN-E03R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,474	0%	247	90%
Pasture	39,340,072	97%	3,934,008	90%
Loafing Lots	0	0%	0	90%
Forest	272,109	0.7%	272,109	0%
Residential	920,310	2%	92,031	90%
Total	40,534,965	100%	4,298,395	89%

Table D.4. Required annual reductions in direct nonpoint sources in sub-watershed HAR-02 of Hughes River (VAN-E03R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	39,804	23%	3,980	90%
Wildlife in Streams	47,447	27%	47,447	0%
Straight Pipes	89,638	51%	0	100%
Total	176,889	100%	51,428	71%

Table D.5. Required annual reductions in nonpoint sources in sub-watershed HAR-03 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,162	0%	185	97%
Pasture	110,842,590	98%	3,325,275	97%
Loafing Lots	0	0%	0	97%
Forest	1,080,065	1.0%	1,080,065	0%
Residential	1,495,812	1%	44,874	97%
Total	113,424,629	100%	4,450,399	96%

Table D.6. Required annual reductions in direct nonpoint sources in sub-watershed HAR-03 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	115,328	25%	3,460	97%
Wildlife in Streams	156,719	34%	156,719	0%
Straight Pipes	184,963	40%	0	100%
Total	457,011	100%	160,179	65%

Table D.7. Required annual reductions in nonpoint sources in sub-watershed HAR-04 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,699	0%	201	97%
Pasture	27,680,267	95%	830,407	97%
Loafing Lots	0	0%	0	97%
Forest	293,942	1%	293,942	0%
Residential	1,095,993	4%	32,880	97%
Total	29,076,902	100%	1,157,430	96%

Table D.8. Required annual reductions in direct nonpoint sources in sub-watershed HAR-04 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	27,556	7%	827	97%
Wildlife in Streams	47,267	12%	47,267	0%
Straight Pipes	313,868	81%	0	100%
Total	388,691	100%	48,094	88%

Table D.9. Required annual reductions in nonpoint sources in sub-watershed HAR-05 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	16,941	0%	508	97%
Pasture	52,594,693	96%	1,577,839	97%
Loafing Lots	0	0%	0	97%
Forest	332,860	0.6%	332,860	0%
Residential	1,827,105	3%	54,813	97%
Total	54,771,600	100%	1,966,021	96%

Table D.10. Required annual reductions in direct nonpoint sources in sub-watershed HAR-05 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	52,051	9%	1,562	97%
Wildlife in Streams	68,115	12%	68,115	0%
Straight Pipes	431,270	78%	0	100%
Total	551,436	100%	69,677	87%

Table D.11. Required annual reductions in nonpoint sources in sub-watershed HAR-06 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	10,442	0%	313	97%
Pasture	90,518,060	97%	2,715,539	97%
Loafing Lots	0	0%	0	97%
Forest	915,753	1.0%	915,753	0%
Residential	2,346,277	3%	70,388	97%
Total	93,790,532	100%	3,701,994	96%

Table D.12. Required annual reductions in direct nonpoint sources in sub-watershed HAR-06 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	93,045	11%	2,791	97%
Wildlife in Streams	134,273	16%	134,273	0%
Straight Pipes	588,799	72%	0	100%
Total	816,117	100%	137,064	83%

Table D.13. Required annual reductions in nonpoint sources in sub-watershed HAR-07 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	809	0%	24	97%
Pasture	14,427,279	91%	432,818	97%
Loafing Lots	0	0%	0	97%
Forest	323,603	2%	323,603	0%
Residential	1,140,429	7%	34,213	97%
Total	15,892,120	100%	790,658	95%

Table D.14. Required annual reductions in direct nonpoint sources in sub-watershed HAR-07 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	14,629	20%	439	97%
Wildlife in Streams	39,843	54%	39,843	0%
Straight Pipes	19,755	27%	0	100%
Total	74,226	100%	40,282	46%

Table D.15. Required annual reductions in nonpoint sources in sub-watershed HAR-08 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,396	0%	42	97%
Pasture	26,304,001	93%	789,119	97%
Loafing Lots	0	0%	0	97%
Forest	256,154	0.9%	256,154	0%
Residential	1,798,999	6%	53,970	97%
Total	28,360,550	100%	1,099,285	96%

Table D.16. Required annual reductions in direct nonpoint sources in sub-watershed HAR-08 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	26,025	18%	781	97%
Wildlife in Streams	44,247	31%	44,247	0%
Straight Pipes	72,420	51%	0	100%
Total	142,692	100%	45,027	68%

Table D.17. Required annual reductions in nonpoint sources in sub-watershed HAR-09 of Hazel River (VAN-E04R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,385	0%	42	97%
Pasture	14,958,068	90%	448,742	97%
Loafing Lots	0	0%	0	97%
Forest	178,128	1%	178,128	0%
Residential	1,403,420	8%	42,103	97%
Total	16,541,001	100%	669,014	96%

Table D.18. Required annual reductions in direct nonpoint sources in sub-watershed HAR-09 of Hazel River (VAN-E04R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	14,799	7%	444	97%
Wildlife in Streams	26,498	13%	26,498	0%
Straight Pipes	167,614	80%	0	100%
Total	208,911	100%	26,942	87%

Table D.19. Required annual reductions in nonpoint sources in sub-watershed HAR-10 of Rush River (VAN-E05R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	145	0%	1	99%
Pasture	10,463,668	92%	104,637	99%
Loafing Lots	0	0%	0	99%
Forest	303,508	3%	303,508	0%
Residential	551,277	5%	0	100%
Total	11,318,596	100%	408,146	96%

Table D.20. Required annual reductions in direct nonpoint sources in sub-watershed HAR-10 of Rush River (VAN-E05R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	10,886	10%	109	99%
Wildlife in Streams	34,410	32%	34,410	0%
Straight Pipes	62,921	58%	0	100%
Total	108,218	100%	34,519	68%

Table D.21. Required annual reductions in nonpoint sources in sub-watershed HAR-11 of Rush River (VAN-E05R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	188	0%	2	99%
Pasture	37,114,032	97%	371,140	99%
Loafing Lots	0	0%	0	99%
Forest	403,159	1%	403,159	0%
Residential	817,474	2%	0	100%
Total	38,334,852	100%	774,300	98%

Table D.22. Required annual reductions in direct nonpoint sources in sub-watershed HAR-11 of Rush River (VAN-E05R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	38,613	17%	386	99%
Wildlife in Streams	59,079	25%	59,079	0%
Straight Pipes	134,829	58%	0	100%
Total	232,521	100%	59,465	74%

Table D.23. Required annual reductions in nonpoint sources in sub-watershed HAR-12 of Rush River (VAN-E05R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	432	0%	4	99%
Pasture	9,806,358	99%	98,063	99%
Loafing Lots	0	0%	0	99%
Forest	30,345	0.3%	30,345	0%
Residential	81,318	0.8%	0	100%
Total	9,918,453	100%	128,413	99%

Table D.24. Required annual reductions in direct nonpoint sources in sub-watershed HAR-12 of Rush River (VAN-E05R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	10,206	21%	102	99%
Wildlife in Streams	7,870	16%	7,870	0%
Straight Pipes	30,797	63%	0	100%
Total	48,873	100%	7,972	84%

Table D.25. Required annual reductions in nonpoint sources in sub-watershed HAR-13 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	7,826	0%	470	94%
Pasture	147,787,508	98%	8,867,251	94%
Loafing Lots	0	0%	0	94%
Forest	1,140,559	0.8%	1,140,559	0%
Residential	2,005,613	1%	120,337	94%
Total	150,941,506	100%	10,128,616	93%

Table D.26. Required annual reductions in direct nonpoint sources in sub-watershed HAR-13 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	153,771	20%	9,226	94%
Wildlife in Streams	180,363	24%	180,363	0%
Straight Pipes	416,580	55%	0	100%
Total	750,714	100%	189,589	75%

Table D.27. Required annual reductions in nonpoint sources in sub-watershed HAR-14 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,876	0%	233	94%
Pasture	223,955,165	98%	13,437,310	94%
Loafing Lots	0	0%	0	94%
Forest	2,381,839	1%	2,381,839	0%
Residential	2,322,304	1%	139,338	94%
Total	228,663,184	100%	15,958,720	93%

Table D.28. Required annual reductions in direct nonpoint sources in sub-watershed HAR-14 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	233,038	20%	13,982	94%
Wildlife in Streams	328,720	29%	328,720	0%
Straight Pipes	585,125	51%	0	100%
Total	1,146,884	100%	342,702	70%

Table D.29. Required annual reductions in nonpoint sources in sub-watershed HAR-15 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	25,339	0%	1,520	94%
Pasture	481,421,339	98%	28,885,281	94%
Loafing Lots	0	0%	0	94%
Forest	2,456,869	0.5%	2,456,869	0%
Residential	8,228,849	2%	493,731	94%
Total	492,132,396	100%	31,837,402	94%

Table D.30. Required annual reductions in direct nonpoint sources in sub-watershed HAR-15 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	499,076	31%	29,945	94%
Wildlife in Streams	445,722	27%	445,722	0%
Straight Pipes	680,409	42%	0	100%
Total	1,625,206	100%	475,666	71%

Table D.31. Required annual reductions in nonpoint sources in sub-watershed HAR-16 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,276	0%	137	94%
Pasture	16,852,253	93%	1,011,135	94%
Loafing Lots	0	0%	0	94%
Forest	136,597	0.8%	136,597	0%
Residential	1,220,078	7%	73,205	94%
Total	18,211,205	100%	1,221,074	93%

Table D.32. Required annual reductions in direct nonpoint sources in sub-watershed HAR-16 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	16,670	13%	1,000	94%
Wildlife in Streams	24,932	20%	24,932	0%
Straight Pipes	83,728	67%	0	100%
Total	125,329	100%	25,932	79%

Table D.33. Required annual reductions in nonpoint sources in sub-watershed HAR-17 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,250	0%	375	94%
Pasture	49,309,211	94%	2,958,553	94%
Loafing Lots	0	0%	0	94%
Forest	368,451	0.7%	368,451	0%
Residential	2,921,242	6%	175,275	94%
Total	52,605,153	100%	3,502,653	93%

Table D.34. Required annual reductions in direct nonpoint sources in sub-watershed HAR-17 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	48,819	19%	2,929	94%
Wildlife in Streams	69,490	27%	69,490	0%
Straight Pipes	140,717	54%	0	100%
Total	259,027	100%	72,419	72%

Table D.35. Required annual reductions in nonpoint sources in sub-watershed HAR-18 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,391	0%	263	94%
Pasture	72,396,762	93%	4,343,806	94%
Loafing Lots	0	0%	0	94%
Forest	699,160	0.9%	699,160	0%
Residential	4,805,515	6%	288,331	94%
Total	77,905,828	100%	5,331,561	93%

Table D.36. Required annual reductions in direct nonpoint sources in sub-watershed HAR-18 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	71,783	13%	4,307	94%
Wildlife in Streams	116,086	21%	116,086	0%
Straight Pipes	363,664	66%	0	100%
Total	551,532	100%	120,393	78%

Table D.37. Required annual reductions in nonpoint sources in sub-watershed HAR-19 of Hazel River (60076).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	817	0%	49	94%
Pasture	32,877,541	97%	1,972,653	94%
Loafing Lots	0	0%	0	94%
Forest	146,766	0.4%	146,766	0%
Residential	960,255	3%	57,615	94%
Total	33,985,378	100%	2,177,083	94%

Table D.38. Required annual reductions in direct nonpoint sources in sub-watershed HAR-19 of Hazel River (60076).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	32,489	33%	1,949	94%
Wildlife in Streams	35,163	36%	35,163	0%
Straight Pipes	29,599	30%	0	100%
Total	97,252	100%	37,113	62%

Table D.39. Required annual reductions in nonpoint sources in sub-watershed RAR-01 of Rappahannock River (VAN-E01R-03).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	18,884	0%	189	99%
Pasture	343,690,843	97%	3,436,905	99%
Loafing Lots	0	0%	0	99%
Forest	2,685,537	0.8%	2,685,537	0%
Residential	7,493,263	2%	74,933	99%
Total	353,888,527	100%	6,197,564	98%

Table D.40. Required annual reductions in direct nonpoint sources in sub-watershed RAR-01 of Rappahannock River (VAN-E01R-03).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	354,660	25%	3,547	99%
Wildlife in Streams	478,517	34%	425,880	11%
Straight Pipes	591,980	42%	0	100%
Total	1,425,158	100%	429,427	70%

Table D.41. Required annual reductions in nonpoint sources in sub-watershed RAR-02 of Rappahannock River (VAN-E01R-03).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	464	0%	5	99%
Pasture	3,695,894	94%	36,959	99%
Loafing Lots	0	0%	0	99%
Forest	56,361	1%	56,361	0%
Residential	165,993	4%	1,660	99%
Total	3,918,711	100%	94,984	98%

Table D.42. Required annual reductions in direct nonpoint sources in sub-watershed RAR-02 of Rappahannock River (VAN-E01R-03).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	3,742	32%	37	99%
Wildlife in Streams	8,055	68%	7,169	11%
Straight Pipes	0	0%	0	100%
Total	11,797	100%	7,206	39%

Table D.43. Required annual reductions in nonpoint sources in sub-watershed RAR-03 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,500	0%	45	97%
Pasture	56,661,598	97%	1,699,846	97%
Loafing Lots	0	0%	0	97%
Forest	569,199	1.0%	569,199	0%
Residential	1,430,550	2%	42,916	97%
Total	58,662,847	100%	2,312,007	96%

Table D.44. Required annual reductions in direct nonpoint sources in sub-watershed RAR-03 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	58,855	28%	1,766	97%
Wildlife in Streams	77,998	37%	77,998	0%
Straight Pipes	74,566	35%	0	100%
Total	211,419	100%	79,764	62%

Table D.45. Required annual reductions in nonpoint sources in sub-watershed RAR-04 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	27,580	0%	827	97%
Pasture	175,255,274	97%	5,257,653	97%
Loafing Lots	0	0%	0	97%
Forest	1,293,719	0.7%	1,293,719	0%
Residential	4,127,989	2%	123,840	97%
Total	180,704,562	100%	6,676,039	96%

Table D.46. Required annual reductions in direct nonpoint sources in sub-watershed RAR-04 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	176,395	40%	5,292	97%
Wildlife in Streams	245,259	55%	245,259	0%
Straight Pipes	22,466	5%	0	100%
Total	444,120	100%	250,551	44%

Table D.47. Required annual reductions in nonpoint sources in sub-watershed RAR-05 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,269	0%	128	97%
Pasture	66,482,266	95%	1,994,466	97%
Loafing Lots	0	0%	0	97%
Forest	674,016	1.0%	674,016	0%
Residential	2,476,883	4%	74,306	97%
Total	69,637,433	100%	2,742,916	96%

Table D.48. Required annual reductions in direct nonpoint sources in sub-watershed RAR-05 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	68,040	32%	2,041	97%
Wildlife in Streams	97,294	46%	97,294	0%
Straight Pipes	46,194	22%	0	100%
Total	211,529	100%	99,336	53%

Table D.49. Required annual reductions in nonpoint sources in sub-watershed RAR-06 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	37,350	0%	1,120	97%
Pasture	201,294,120	96%	6,038,818	97%
Loafing Lots	0	0%	0	97%
Forest	2,221,249	1%	2,221,249	0%
Residential	7,018,396	3%	210,552	97%
Total	210,571,115	100%	8,471,739	96%

Table D.50. Required annual reductions in direct nonpoint sources in sub-watershed RAR-06 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	202,590	26%	6,078	97%
Wildlife in Streams	348,282	45%	348,282	0%
Straight Pipes	231,442	30%	0	100%
Total	782,314	100%	354,359	55%

Table D.51. Required annual reductions in nonpoint sources in sub-watershed RAR-07 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	29,222	0%	877	97%
Pasture	85,603,600	95%	2,568,106	97%
Loafing Lots	0	0%	0	97%
Forest	721,728	0.8%	721,728	0%
Residential	3,489,213	4%	104,676	97%
Total	89,843,763	100%	3,395,386	96%

Table D.52. Required annual reductions in direct nonpoint sources in sub-watershed RAR-07 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	85,221	15%	2,557	97%
Wildlife in Streams	130,831	24%	130,831	0%
Straight Pipes	336,676	61%	0	100%
Total	552,728	100%	133,388	76%

Table D.53. Required annual reductions in nonpoint sources in sub-watershed RAR-08 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	15,574	0%	467	97%
Pasture	137,091,911	94%	4,112,753	97%
Loafing Lots	0	0%	0	97%
Forest	967,297	0.7%	967,297	0%
Residential	7,740,975	5%	232,229	97%
Total	145,815,758	100%	5,312,747	96%

Table D.54. Required annual reductions in direct nonpoint sources in sub-watershed RAR-08 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	137,952	21%	4,139	97%
Wildlife in Streams	183,353	28%	183,353	0%
Straight Pipes	324,371	50%	0	100%
Total	645,676	100%	187,492	71%

Table D.55. Required annual reductions in nonpoint sources in sub-watershed RAR-09 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	21,438	0%	643	97%
Pasture	100,666,579	97%	3,019,995	97%
Loafing Lots	0	0%	0	97%
Forest	358,317	0.3%	358,317	0%
Residential	2,592,808	3%	77,784	97%
Total	103,639,142	100%	3,456,739	97%

Table D.56. Required annual reductions in direct nonpoint sources in sub-watershed RAR-09 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	102,527	38%	3,076	97%
Wildlife in Streams	85,906	32%	85,906	0%
Straight Pipes	82,099	30%	0	100%
Total	270,532	100%	88,982	67%

Table D.57. Required annual reductions in nonpoint sources in sub-watershed RAR-10 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	12,177	0%	365	97%
Pasture	55,008,265	98%	1,650,246	97%
Loafing Lots	0	0%	0	97%
Forest	169,317	0.3%	169,317	0%
Residential	755,241	1%	22,657	97%
Total	55,945,000	100%	1,842,586	97%

Table D.58. Required annual reductions in direct nonpoint sources in sub-watershed RAR-10 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	54,432	37%	1,633	97%
Wildlife in Streams	49,618	34%	49,618	0%
Straight Pipes	43,432	29%	0	100%
Total	147,482	100%	51,251	65%

Table D.59. Required annual reductions in nonpoint sources in sub-watershed RAR-11 of Rappahannock River (VAN-E08R-04).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	10,847	0%	325	97%
Pasture	54,685,861	98%	1,640,574	97%
Loafing Lots	0	0%	0	97%
Forest	166,003	0.3%	166,003	0%
Residential	911,311	2%	27,339	97%
Total	55,774,022	100%	1,834,242	97%

Table D.60. Required annual reductions in direct nonpoint sources in sub-watershed RAR-11 of Rappahannock River (VAN-E08R-04).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	55,203	44%	1,656	97%
Wildlife in Streams	45,979	37%	45,979	0%
Straight Pipes	24,499	19%	0	100%
Total	125,681	100%	47,635	62%

Table D.61. Required annual reductions in nonpoint sources in sub-watershed RAR-12 of Rappahannock River (60081).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	34,973	0%	350	99%
Pasture	113,214,591	96%	1,132,145	99%
Loafing Lots	0	0%	0	99%
Forest	492,231	0.4%	492,231	0%
Residential	4,716,085	4%	47,161	99%
Total	118,457,881	100%	1,671,887	99%

Table D.62. Required annual reductions in direct nonpoint sources in sub-watershed RAR-12 of Rappahannock River (60081).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	113,457	34%	1,135	99%
Wildlife in Streams	119,307	36%	119,307	0%
Straight Pipes	99,022	30%	0	100%
Total	331,787	100%	120,442	64%

Table D.63. Required annual reductions in nonpoint sources in sub-watershed RAR-13 of Rappahannock River (60081).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,631	0%	46	99%
Pasture	14,378,923	96%	143,789	99%
Loafing Lots	0	0%	0	99%
Forest	108,826	0.7%	108,826	0%
Residential	411,543	3%	4,115	99%
Total	14,903,923	100%	256,777	98%

Table D.64. Required annual reductions in direct nonpoint sources in sub-watershed RAR-13 of Rappahannock River (60081).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	14,288	41%	143	99%
Wildlife in Streams	20,225	59%	20,225	0%
Straight Pipes	0	0%	0	100%
Total	34,514	100%	20,368	41%

Table D.65. Required annual reductions in nonpoint sources in sub-watershed RAR-14 of Craig Run (VAN-E08R-03).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	27,555	0%	827	97%
Pasture	84,645,841	97%	2,539,373	97%
Loafing Lots	0	0%	0	97%
Forest	205,114	0.2%	205,114	0%
Residential	2,412,034	3%	72,361	97%
Total	87,290,545	100%	2,817,674	97%

Table D.66. Required annual reductions in direct nonpoint sources in sub-watershed RAR-14 of Craig Run (VAN-E08R-03).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	87,048	44%	2,611	97%
Wildlife in Streams	61,138	31%	61,138	0%
Straight Pipes	50,403	25%	0	100%
Total	198,589	100%	63,750	68%

Table D.67. Required annual reductions in nonpoint sources in sub-watershed RAR-17 of Craig Run (VAN-E08R-03).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	0	0%	0	96%
Pasture	32,826,390	94%	1,313,056	96%
Loafing Lots	0	0%	0	96%
Forest	293,699	0.8%	293,699	0%
Residential	1,863,361	5%	74,534	96%
Total	34,983,450	100%	1,681,289	95%

Table D.68. Required annual reductions in direct nonpoint sources in sub-watershed RAR-17 of Craig Run (VAN-E08R-03).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	33,170	20%	1,327	96%
Wildlife in Streams	90,777	54%	90,777	0%
Straight Pipes	44,894	27%	0	100%
Total	168,841	100%	92,104	45%

Table D.69. Required annual reductions in nonpoint sources in sub-watershed RAR-18 of Craig Run (VAN-E08R-03).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	20,392	0%	816	96%
Pasture	52,990,192	98%	2,119,609	96%
Loafing Lots	0	0%	0	96%
Forest	305,744	0.6%	305,744	0%
Residential	919,138	2%	36,766	96%
Total	54,235,466	100%	2,462,934	95%

Table D.70. Required annual reductions in direct nonpoint sources in sub-watershed RAR-18 of Craig Run (VAN-E08R-03).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	55,258	47%	2,210	96%
Wildlife in Streams	61,642	53%	61,642	0%
Straight Pipes	0	0%	0	100%
Total	116,900	100%	63,852	45%

Table D.71. Required annual reductions in nonpoint sources in sub-watershed RAR-15 of Marsh Run (VAN-E08R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	32,294	0%	969	97%
Pasture	91,747,213	91%	2,752,414	97%
Loafing Lots	0	0%	0	97%
Forest	218,639	0.2%	218,639	0%
Residential	8,529,401	8%	255,882	97%
Total	100,527,549	100%	3,227,904	97%

Table D.72. Required annual reductions in direct nonpoint sources in sub-watershed RAR-15 of Marsh Run (VAN-E08R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	94,398	53%	2,832	97%
Wildlife in Streams	64,826	36%	64,826	0%
Straight Pipes	19,804	11%	0	100%
Total	179,028	100%	67,658	62%

Table D.73. Required annual reductions in nonpoint sources in sub-watershed RAR-16 of Marsh Run (VAN-E08R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13,578	0.1%	407	97%
Pasture	16,405,375	90%	492,161	97%
Loafing Lots	0	0%	0	97%
Forest	129,174	0.7%	129,174	0%
Residential	1,589,429	9%	47,683	97%
Total	18,137,556	100%	669,425	96%

Table D.74. Required annual reductions in direct nonpoint sources in sub-watershed RAR-16 of Marsh Run (VAN-E08R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	16,500	41%	495	97%
Wildlife in Streams	23,924	59%	23,924	0%
Straight Pipes	0	0%	0	100%
Total	40,424	100%	24,419	40%

Table D.75. Required annual reductions in nonpoint sources in sub-watershed RAR-19 of Marsh Run (VAN-E08R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,350	0%	160	97%
Pasture	15,921,382	94%	477,641	97%
Loafing Lots	0	0%	0	97%
Forest	62,573	0.4%	62,573	0%
Residential	919,062	5%	27,572	97%
Total	16,908,366	100%	567,946	97%

Table D.76. Required annual reductions in direct nonpoint sources in sub-watershed RAR-19 of Marsh Run (VAN-E08R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	15,989	46%	480	97%
Wildlife in Streams	19,105	54%	19,105	0%
Straight Pipes	0	0%	0	100%
Total	35,095	100%	19,585	44%

Table D.77. Required annual reductions in nonpoint sources in sub-watershed RAR-20 of Marsh Run (VAN-E08R-01).

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,932	0%	118	97%
Pasture	45,343,385	95%	1,360,300	97%
Loafing Lots	0	0%	0	97%
Forest	406,488	0.9%	406,488	0%
Residential	2,029,820	4%	60,895	97%
Total	47,783,625	100%	1,827,801	96%

Table D.78. Required annual reductions in direct nonpoint sources in sub-watershed RAR-20 of Marsh Run (VAN-E08R-01).

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	45,587	39%	1,368	97%
Wildlife in Streams	71,252	61%	71,252	0%
Straight Pipes	0	0%	0	100%
Total	116,839	100%	72,619	38%