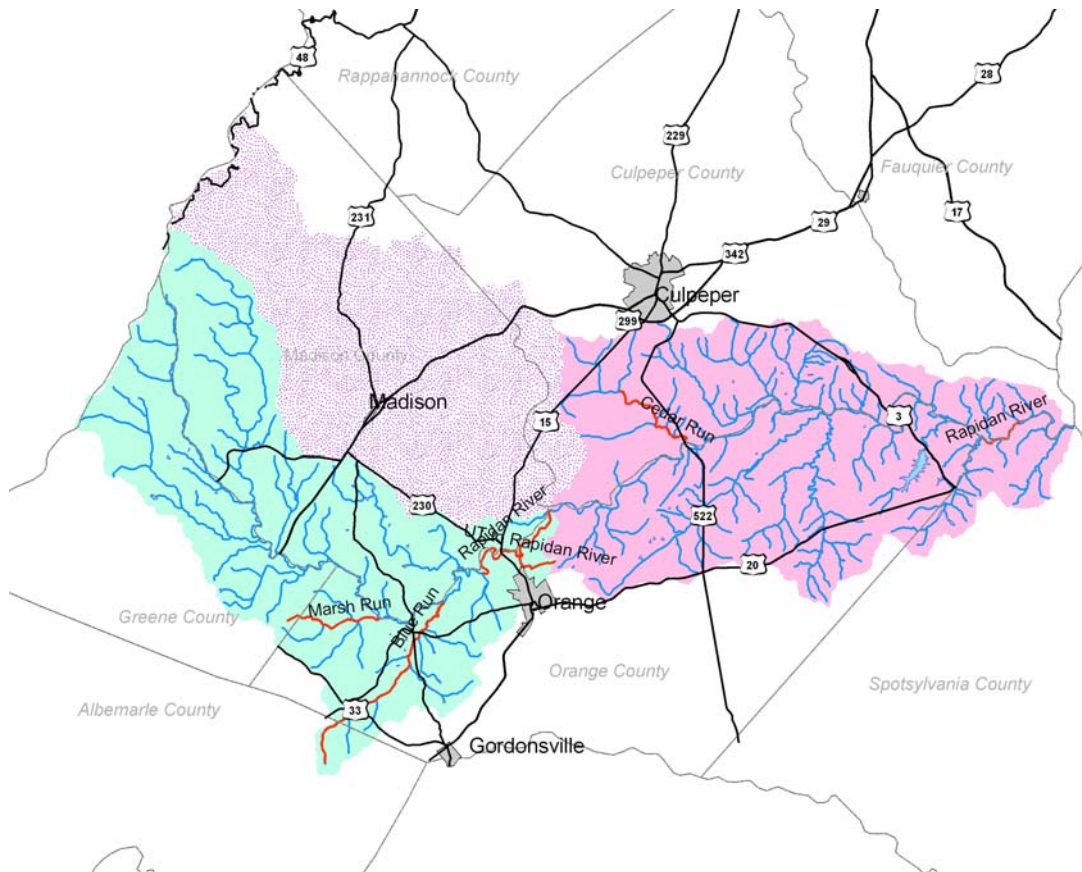


Bacteria Total Maximum Daily Load Development for the Rapidan River Basin



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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

Blue Run (VAN-E13R-01), Rapidan River (VAN-E13R-02), and Rapidan River (VAN-E18R-01) were first listed as impaired streams in 2002 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002) indicating that the recreational use goal was not being met. The stream segments were further listed in 2004 and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. Cedar Run (VAN-E16R-01), an Unnamed Tributary to the Rapidan River (VAN-E13R-04), and Marsh Run (VAN-E13R-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 stream segments were further listed in 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006).

The impaired portion of Marsh Run (VAN-E13R-03) delineated by VADEQ, beginning at headwaters of Marsh Run and continuing downstream approximately 5.19 miles to the confluence with the Rapidan 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 station 3-MAS001.55 at Route 644.

The impaired portion of Blue Run (VAN-E13R-01) delineated by VADEQ, beginning at headwaters of Blue Run and continuing downstream approximately 11.61 miles to the confluence with the Rapidan 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-BLU002.60 at Route 20 and station 3-BLU006.44 the bridge for an unnamed road through Tibbstown. A portion of the impaired segment of Blue Run 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 an Unnamed Tributary to the Rapidan River (VAN-E13R-04) delineated by VADEQ, beginning at headwaters of the Unnamed Tributary to the Rapidan River and continuing downstream approximately 2.57 miles to the confluence with Rapidan 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 stations 3-XEZ000.12 at Route 634.

The impaired portion of Rapidan River (VAN-E13R-02) delineated by VADEQ, beginning at the confluence with Poplar Run and continuing downstream approximately 7.5 miles to the confluence with Robinson River, 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-RAP045.08 at Route 15.

The impaired portion of Cedar Run (VAN-E16R-01) delineated by VADEQ, beginning at the confluence of Buck Run and continuing downstream approximately 5.40 miles to the

confluence with the Rapidan 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-CED000.59 at Route 522 and station 3-CED003.52 at Route 652. A portion of the impaired segment of Cedar Run was listed in Attachment B (Waters to be identified to Virginia for listing consideration during the 2002 Assessment) of the 1999 Consent Decree for fecal coliform.

The impaired portion of Rapidan River (VAN-E18R-01) delineated by VADEQ, beginning at the confluence with Wilderness Run and continuing downstream approximately 2.68 miles to the confluence with Middle 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-RAP006.53 at Route 610. This impaired segment of the Rapidan River was 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 Marsh Run (VAN-E13R-03) watershed is approximately 10,710 acres in size. Marsh Run (VAN-E13R-03) is mainly a forested watershed (about 75%) with pasture/cropland, residential, and water/wetland comprising 23%, 1%, and 1% of the area, respectively. The Blue Run (VAN-E13R-01) watershed area is approximately 20,935 acres consisting mainly of forest (55%) and pasture/cropland (41%). The remaining area is split between residential (2%) and water/wetland (2%) land uses. The Unnamed Tributary to the Rapidan River (VAN-E13R-04) watershed area of approximately 1,540 acres is comprised of forest (45%), pasture/cropland (52%), residential (1%), and water/wetland (2%). The 157,000 acres in the Rapidan River (VAN-E13R-02) watershed consists of approximately 62% forest, 36% pasture/cropland, 1% residential, and 1% water/wetland land uses. The approximately 18,100 acres of Cedar Run (VAN-E16R-01) watershed consists of 43% forest, 55% pasture/cropland, and the remaining 2% split between residential and water/wetland land uses. The Rapidan River (VAN-E18R-01) watershed area of 153,800 acres is comprised of forest (62%), pasture/cropland (36%), residential (1%), and water/wetland (1%).

VADEQ personnel monitored pollutant concentrations throughout the Marsh Run (3-MAS001.55), Blue Run (3-BLU002.60), UT to Rapidan River (3-XEZ000.12), Cedar Run (3-CED000.59), and Rapidan River (3-RAP045.08 and 3-RAP006.53) watersheds. Of the 13 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 3-MAS001.55, 30.8% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Consequently, this segment of Marsh Run (VAN-E13R-03) 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 seven of 20 (35.0%) samples collected during the 2006 Section 303(d) assessment period at station 3-BLU002.60. This segment of Blue Run (VAN-E13R-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 (seven samples) at station 3-XEZ000.12 yielded sufficient exceedance (42.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of UT of Rapidan River (VAN-E13R-04) as not

supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Rapidan River (VAN-E13R-02) does not support the Recreation Use goal due to six of 14 (42.8%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-RAP045.08. 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 two of 13 (15.4%) samples collected during the 2006 Section 303(d) assessment period at station 3-CED000.59. This segment of Cedar Run (VAN-E16R-01) was assessed as not supporting the Recreation Use goal and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Sampling (12 samples) at station 3-RAP006.53 yielded sufficient exceedance (58.3%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rapidan River (VAN-E18R-01) as not supporting the Recreation Use goal and subsequent placement on 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 seven, 11, and 34 active point discharges with a VPDES permit within the Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 Upper Rapidan River model was calibrated using observed flow values from USGS station #01665500 on Rapidan River near Ruckersville, VA for the period October 1, 1989 to September 30, 1994. 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 for the period October 1, 1994 to September 30, 1999. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable. The Lower Rapidan River model was calibrated using observed flow values from USGS station #01667500 on Rapidan River near Culpeper, Virginia for the period October 1, 1989 to September 30, 1994. The model was validated for the period October 1, 1994 to September 30, 1999. 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-MAS001.55, 3-BLU002.60, 3-XEZ000.12, 3-RAP045.08, 3-CED000.59, and 3-RAP006.53 within the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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
Marsh Run (VAN-E13R-03)	100	98	98	98	98	0	0
Blue Run (VAN-E13R-01)	100	99	99	99	99	30	0
UT to Rapidan River (VAN-E13R-04)	100	99	99	99	99	38	0
Rapidan River (VAN-E13R-02)	100	98	98	98	98	0	0
Cedar Run (VAN-E16R-01)	100	98	98	98	98	0	0
Rapidan River (VAN-E18R-01)	100	96	96	96	96	0	0

DD – direct deposition

Using equation [E.1], summaries of the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) bacteria TMDLs for the selected allocation scenario are shown in Tables E.2 through E.13, respectively.

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \quad [\text{E.1}]$$

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 Marsh Run (VAN-E13R-03) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	6.72E+10	6.65E+12	N/A	6.72E+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.3. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Marsh Run (VAN-E13R-03) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	7.61E+09	7.53E+11	N/A	7.61E+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.4. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Blue Run (VAN-E13R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	8.75E+10	8.66E+12	N/A	8.75E+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.5. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Blue Run (VAN-E13R-01) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	1.74E+10	1.72E+12	N/A	1.74E+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 UT to Rapidan River (VAN-E13R-04) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	6.99E+09	6.92E+11	N/A	6.99E+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.

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 UT to Rapidan River (VAN-E13R-04) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	9.67E+08	9.57E+10	N/A	9.67E+10

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 Rapidan River (VAN-E13R-02) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	3.26E+13	5.59E+13	N/A	8.85E+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 Rapidan River (VAN-E13R-02) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	8.94E+10	1.42E+13	N/A	1.43E+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 Cedar Run (VAN-E16R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	1.82E+12	8.13E+12	N/A	9.95E+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.11. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cedar Run (VAN-E16R-01) impairment.

Pollutant	WLA ¹ (cfu/d)	LA (cfu/d)	MOS	TMDL ² (cfu/d)
<i>E. coli</i>	4.99+09	2.15E+12	N/A	2.15E+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 TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. 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 Rapidan River (VAN-E18R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	1.98E+13	2.18E+14	N/A	2.38E+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 Rapidan River (VAN-E18R-01) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	5.42E+10	4.23E+13	N/A	4.24E+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.

Stage 1 Implementation

Staged implementation is a key component to restoring water quality in Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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. 14.

Table E. 14. Stage 1 reduction scenarios.

Impairment	Percent Reduction in Fecal Coliform Loading from Existing Conditions						
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest
Marsh Run (VAN-E13R-03)	100	75	75	75	75	0	0
Blue Run (VAN-E13R-01)	100	78	90	78	78	0	0
UT to Rapidan River (VAN-E13R-04)	100	75	75	75	75	0	0
Rapidan River (VAN-E13R-02)	100	78	95	78	78	0	0
Cedar Run (VAN-E16R-01)	100	89	89	89	89	0	0
Rapidan River (VAN-E18R-01)	100	46	75	46	46	0	0

DD – direct deposition

Public Participation

During development of the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) TMDLs, public participation was encouraged through two sets of public meetings.

The first public meetings were held at the Mt. Nebo Church in Rochelle, Virginia and Germanna Community College in Locust Grove, Virginia on October 4, 2006 and October 18, 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 Mt. Nebo Church in Rochelle Virginia on March 19, 2007 and March 27, 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 the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) TMDLs, a TMDL Technical Advisory Committee (TAC) was also established to help advise the TMDL developers. 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, Greene County Government, Rural Madison, Spotsylvania County Utilities, Piedmont Environmental Council, Rapidan Service Authority, U.S. Department of Agriculture – Natural Resources Conservation Service, Artery Development.

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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Randy Farrar, **Virginia Department of Game and Inland Fisheries**

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Virginia Cooperative Extension

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

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

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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

Blue Run (VAN-E13R-01), Rapidan River (VAN-E13R-02), and Rapidan River (VAN-E18R-01) were first listed as impaired streams in 2002 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002) indicating that the recreational use goal was not being met. The stream segments were further listed in 2004 and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. Cedar Run (VAN-E16R-01), an Unnamed Tributary to the Rapidan River (VAN-E13R-04), and Marsh Run (VAN-E13R-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 stream segments were further listed in 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006).

The impaired portion of Marsh Run (VAN-E13R-03) delineated by VADEQ, beginning at headwaters of Marsh Run and continuing downstream approximately 5.19 miles to the confluence with the Rapidan 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 station 3-MAS001.55 at Route 644.

The impaired portion of Blue Run (VAN-E13R-01) delineated by VADEQ, beginning at headwaters of Blue Run and continuing downstream approximately 11.61 miles to the confluence with the Rapidan 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-BLU002.60 at Route 20 and station 3-BLU006.44 the bridge for an unnamed road through Tibbstown. A portion of the impaired segment of Blue Run 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 an Unnamed Tributary to the Rapidan River (VAN-E13R-04) delineated by VADEQ, beginning at headwaters of the Unnamed Tributary to the Rapidan River

and continuing downstream approximately 2.57 miles to the confluence with Rapidan 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 stations 3-XEZ000.12 at Route 634.

The impaired portion of Rapidan River (VAN-E13R-02) delineated by VADEQ, beginning at the confluence with Poplar Run and continuing downstream approximately 7.5 miles to the confluence with Robinson River, 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-RAP045.08 at Route 15.

The impaired portion of Cedar Run (VAN-E16R-01) delineated by VADEQ, beginning at the confluence of Buck Run and continuing downstream approximately 5.40 miles to the confluence with the Rapidan 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-CED000.59 at Route 522 and station 3-CED003.52 at Route 652. A portion of the impaired segment of Cedar Run was listed in Attachment B (Waters to be identified to Virginia for listing consideration during the 2002 Assessment) of the 1999 Consent Decree for fecal coliform.

The impaired portion of Rapidan River (VAN-E18R-01) delineated by VADEQ, beginning at the confluence with Wilderness Run and continuing downstream approximately 2.68 miles to the confluence with Middle 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-RAP006.53 at Route 610. This impaired segment of the Rapidan River was 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.

1.1.3 Watershed Location and Description

Marsh Run impairment watershed is located in Greene, Madison, and Orange Counties, Virginia. Blue Run impairment watersheds are located in Madison, Albemarle, and Orange Counties, Virginia. The Unnamed Tributary to the Rapidan River impairment watershed is located in Orange County, Virginia. Rapidan River (VAN-E13R-02) impairment watershed is located in Culpeper, Madison, and Orange Counties, Virginia. Cedar Run impairment watershed is located in Culpeper County, Virginia and Orange County, Virginia. Rapidan River (VAN-E18R-01) impairment watershed is located in Culpeper County, Virginia, and Spotsylvania 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
Marsh Run (VAN-E13R-03)	10,710	75	23	1	1
Blue Run (VAN-E13R-01)	20,935	55	41	2	2
UT to Rapidan River (VAN-E13R-04)	1,540	45	52	1	2
Rapidan River (VAN-E13R-02)	157,000	62	36	1	1
Cedar Run (VAN-E16R-01)	18,100	43	55	1	1
Rapidan River (VAN-E18R-01)	153,800	62	36	1	1

The Rapidan River begins slightly south of the Big Meadows, Virginia and continues downstream to confluence with Rappahannock River northwest of Fredericksburg, Virginia. The Rappahannock River empties into the Chesapeake Bay. Marsh Run, Blue Run, UT to Rapidan River, and Cedar Run drain directly into the Rapidan River.

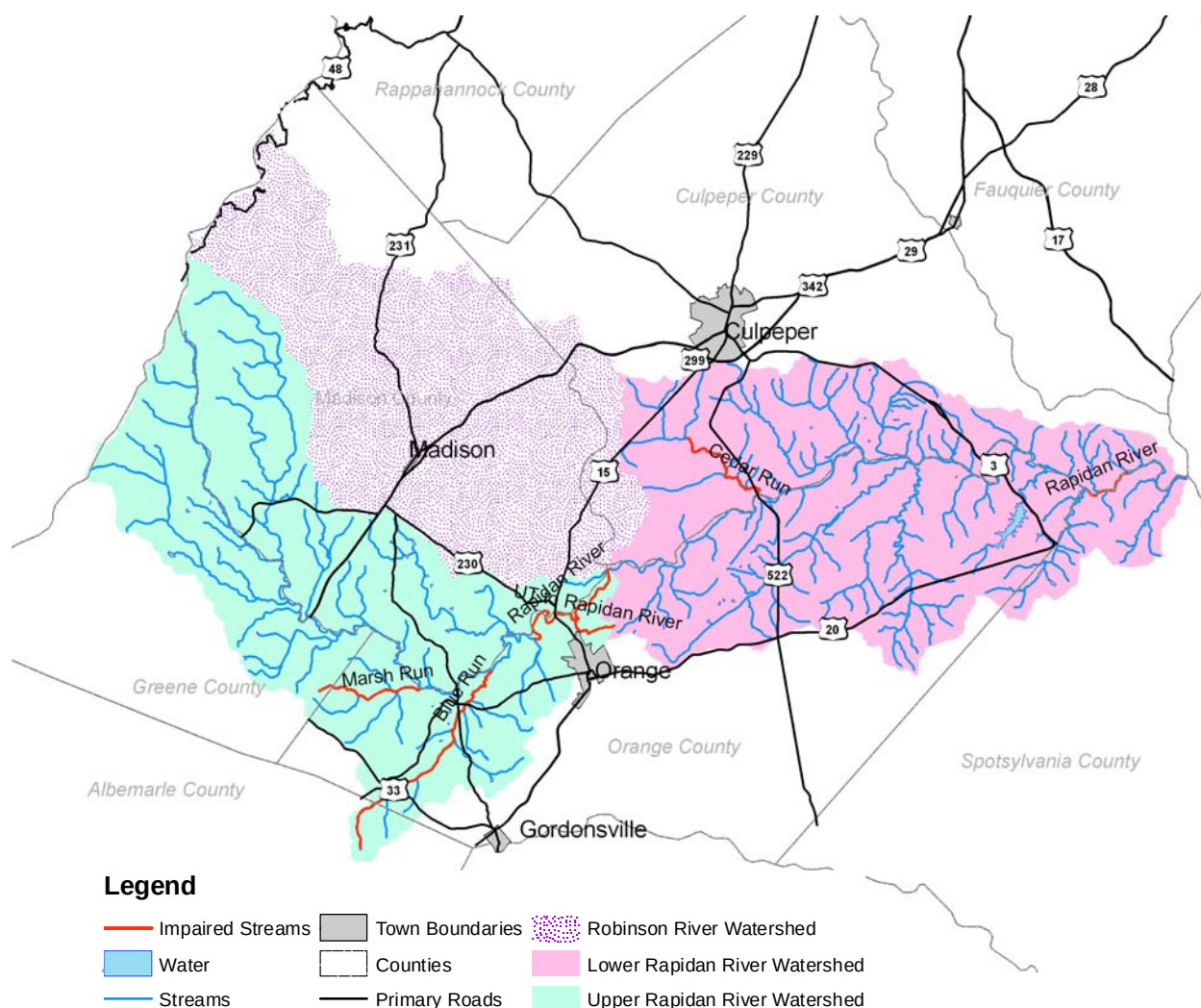


Figure 1.1. Location of Blue Run (VAN-E13R-01), Marsh Run (VAN-E13R-03), Unnamed Tributary to the Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01), and Rapidan River (VAN-E18R-01) watersheds.

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 exceedances 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.

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 Blue Run, Marsh Run, Unnamed Tributary to the Rapidan River, Cedar Run, and Rapidan River 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 Blue Run (VAN-E13R-01), Marsh Run (VAN-E13R-03), 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) 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 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) watersheds were subdivided into sub-watersheds for fecal coliform modeling purposes, as discussed in Section 4.2. The Rapidan River runs for approximately 47.5 miles from the headwaters to the confluence with Robinson River. This portion of Rapidan River was delineated as the Upper Rapidan River subwatersheds. The Rapidan River running approximately 37.9 miles from the confluence with the Robinson River to the confluence with the Rappahannock River was delineated as the Lower Rapidan River subwatersheds. Marsh Run flows for approximately 5.2 miles from the headwaters to the confluence with Rapidan River. Blue Run flows for approximately 11.5 miles from the headwaters to the confluence with Rapidan River. UT to Rapidan River flows for approximately 2.6 miles from the headwaters to the confluence with Rapidan River. Cedar Run flows for approximately 10.4 miles from the headwaters to the confluence with Rapidan River. Marsh Run, Blue Run, Unnamed Tributary to the Rapidan River, Cedar Run, and Rapidan River are all perennial streams with a trapezoidal channel cross-section.

2.2 Ecoregion

Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), Unnamed Tributary to the Rapidan River (VAN-E13R-04), and Cedar Run (VAN-E16R-01) lie entirely in the Northern Piedmont Ecoregion. Portions of subwatersheds URR-01, URR-02, URR-03, URR-04, and URR-05 (See Figures 4.1 and 4.2 for subwatershed delineation) lie in the Blue Ridge Ecoregion and the remaining subwatersheds draining to Rapidan River (VAN-E13R-02) impairment lie in the Northern Piedmont Ecoregion. Portion of subwatersheds LRR-12, LRR-14, and LRR-15 lie in the Piedmont Ecoregion Rapidan River (VAN-E18R-01) and the remaining subwatersheds draining to Rapidan River (VAN-E18R-01) impairment 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). The Piedmont ecoregion is predominantly wooded (i.e., successional pine and oak-hickory forests) and consists of irregular plains, low rounded hills and ridges, shallow valleys, and scattered monad nocks (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. The soils tend to be finer-textured than in coastal plain regions. Once largely cultivated, much of this region has reverted to successional pine and hardwood woodlands, with an increasing conversion to an urban and suburban land cover.

2.3 Climate

The climate of 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) watersheds is characterized based on the meteorological observations from 08/02/1948 to 09/30/2005 assembled by the Southeast Regional Climate Center for the Piedmont Research STN, Virginia (446712) station. Average annual precipitation is 42.19 inches with 55.8% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2006). Average annual snowfall is 20.4 inches with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 55.6°F. The highest average daily temperature of 86.8°F occurs in July while the lowest average daily temperature of 24.1°F occurs in January (SERCC, 2006).

2.4 Land Use

General depiction of land use draining to impairments is discussed in Section 1.1.3. Details of land use used in this study are described in Section 4.3 with land use per subwatershed listed in Tables 4.2 and 4.3.

For purposes of this study, it was assumed that residential development Marsh Run (VAN-E13R-03) watershed will continue at the overall average rate of 5.9% annually. Residential development in the Blue Run (VAN-E13R-01) watershed was assumed to continue at a rate of 3.9% per year. It was assumed that residential development in the UT to Rapidan River (VAN-E13R-04) watershed would continue at an average rate of 7.0% annually. Residential development in the Rapidan River (VAN-E13R-02) watershed was assumed to continue at a rate of 7.7% per year. It was assumed that residential development in the Cedar Run (VAN-E16R-01) watershed would continue at an average rate of 4.2% annually. Residential development in the Rapidan River (VAN-E18R-01) watershed was assumed to continue at an average rate of 19.0% per year.

2.5 Water Quality Data

2.5.1 Historic Data for Fecal Coliform

Of the 13 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 3-MAS001.55, 30.8% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Consequently, this segment of Marsh Run (VAN-E13R-03) 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 seven of 20 (35.0%) samples collected during the 2006 Section 303(d) assessment period at station 3-BLU002.60 and two of five (40%) at station 3-BLU006.44. This segment of Blue Run (VAN-E13R-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 (seven samples) at station 3-XEZ000.12 yielded sufficient exceedance (42.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of UT of Rapidan River (VAN-E13R-04) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006). Rapidan River (VAN-E13R-02) does not support the Recreation Use goal due to six of 14 (42.8%) samples exceeding the instantaneous fecal coliform bacteria standard at station 3-RAP045.08. 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 two of 13 (15.4%) samples collected during the 2006 Section 303(d) assessment period at station 3-CED000.59 and 3 of 8 (38%) at station 3-CED003.52. This segment of Cedar Run (VAN-E16R-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 (12 samples) at station 3-RAP006.53 yielded sufficient exceedance (58.3%) of the fecal coliform bacteria instantaneous standard to assess this segment of Rapidan River (VAN-E18R-01) as not supporting the Recreation Use goal and subsequent placement on the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

Table 2.1. Impairment name, monitoring stations with location and fecal coliform and E. coli water quality standard exceedance rates for the 2006 Section 303(d) List of Impaired Waters.

TMDL ID	Stream Name	Monitoring Station	Station Location	2006 Exceedance Rate	
				Fecal Coliform Standard	E. Coli Standard
VAN-E13R-03	Marsh Run	3-MAS001.55	Route 644	31% (4 of 13)	N/A
VAN-E13R-01	Blue Run	3-BLU002.60	Route 20	35% (7 of 20)	50% (3 of 6)
		3-BLU006.44	Bridge for an unnamed road through Tibbstown	40% (2 of 5)	N/A
VAN-E13R-04	Unnamed Tributary to Rapidan River	3-XEZ000.12	Route 634	43% (3 of 7)	40% (2 of 5)
VAN-E13R-02	Rapidan River	3-RAP045.08	Route 15	N/A	43% (6 of 14)
VAN-E16R-01	Cedar Run	3-CED000.59	Route 522	15% (2 of 13)	N/A
		3-CED003.52	Route 652	38% (3 of 8)	100% (3 of 3)
VAN-E18R-01	Rapidan River	3-RAP006.53	Route 610	N/A	58% (7 of 12)

▲ 3-MAS001.55 — Listing Instantaneous Standard — New Instantaneous Standard

2-4

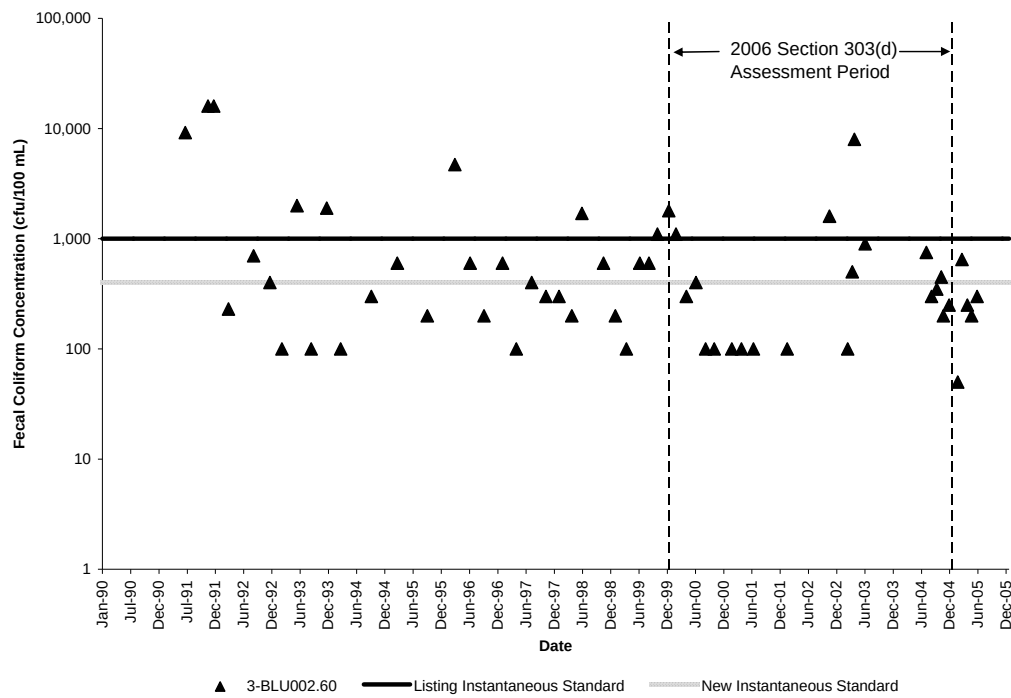


Figure 2.2. Fecal coliform concentrations (VADEQ station 3-BLU002.60) in the Blue Run (VAN-E13R-01) impairment.

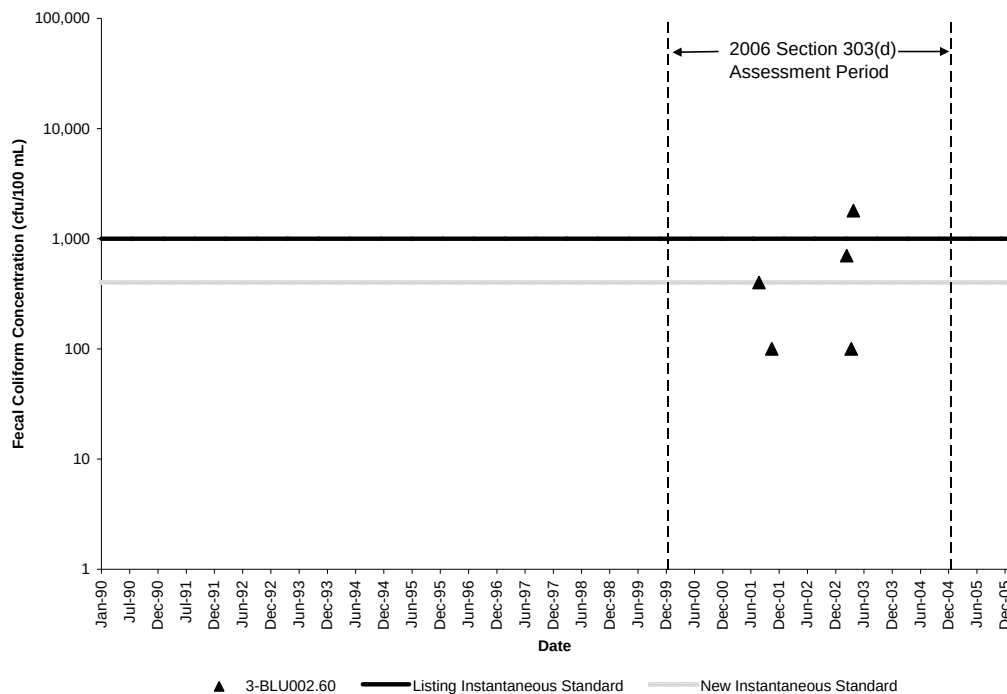


Figure 2.3. Fecal coliform concentrations (VADEQ station 3-BLU006.44) in the Blue Run (VAN-E13R-01) impairment.

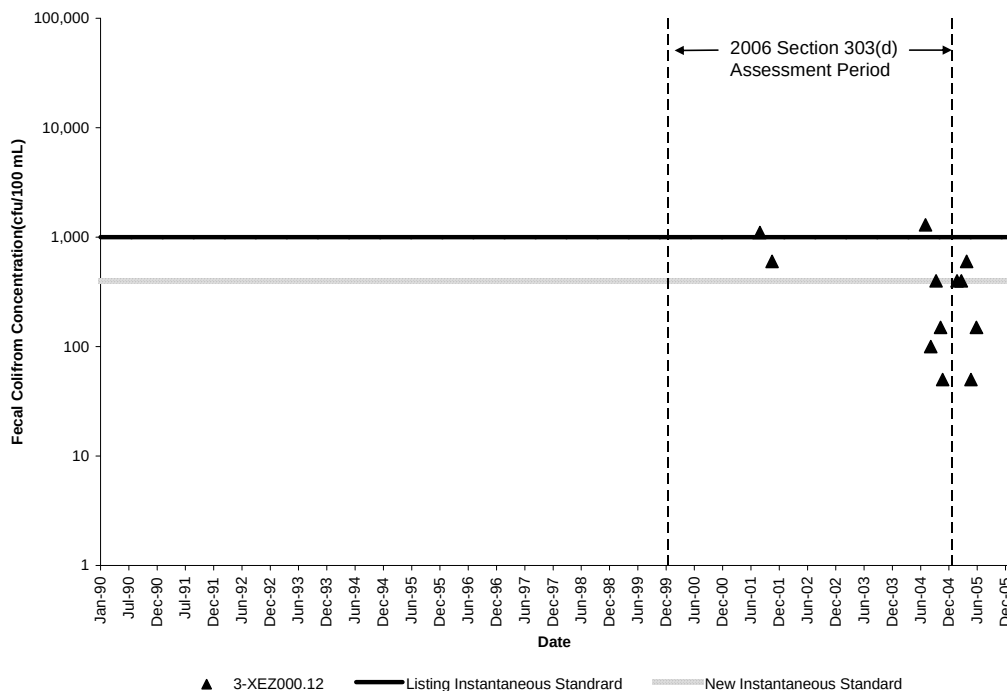


Figure 2.4. Fecal coliform concentrations (VADEQ station 3-XEZ000.12) in the Rapidan Tributary (VAN-E13R-04) impairment.

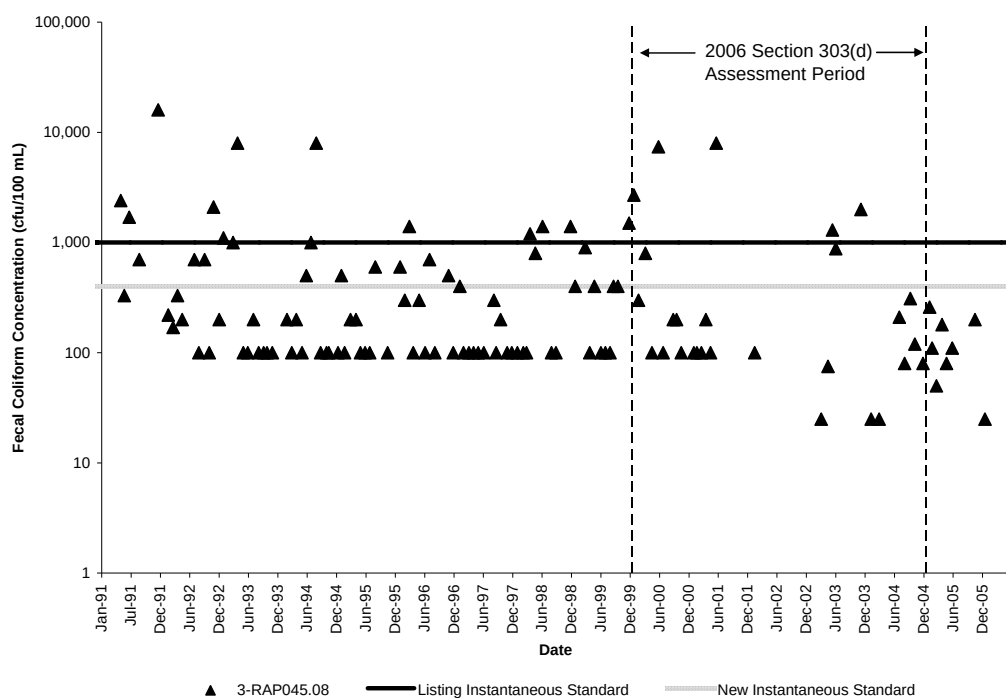


Figure 2.5. Fecal coliform concentrations (VADEQ station 3-RAP045.08) in the Rapidan River (VAN-E13R-02) impairment.

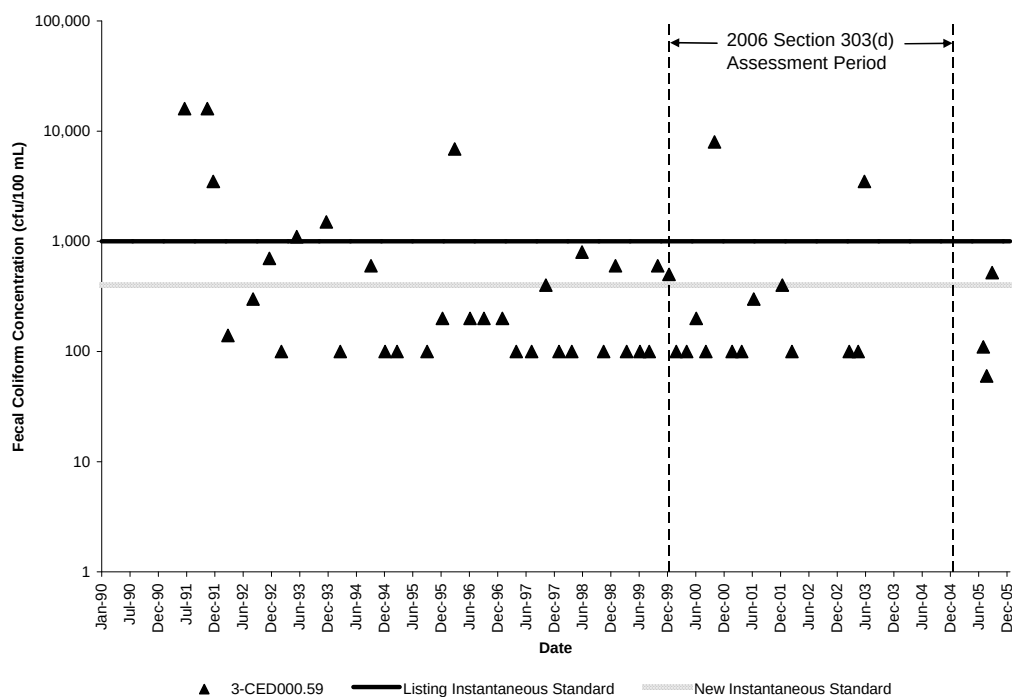


Figure 2.6. Fecal coliform concentrations (VADEQ station 3-CED000.59) in the Cedar Run (VAN-E16R-01) impairment.

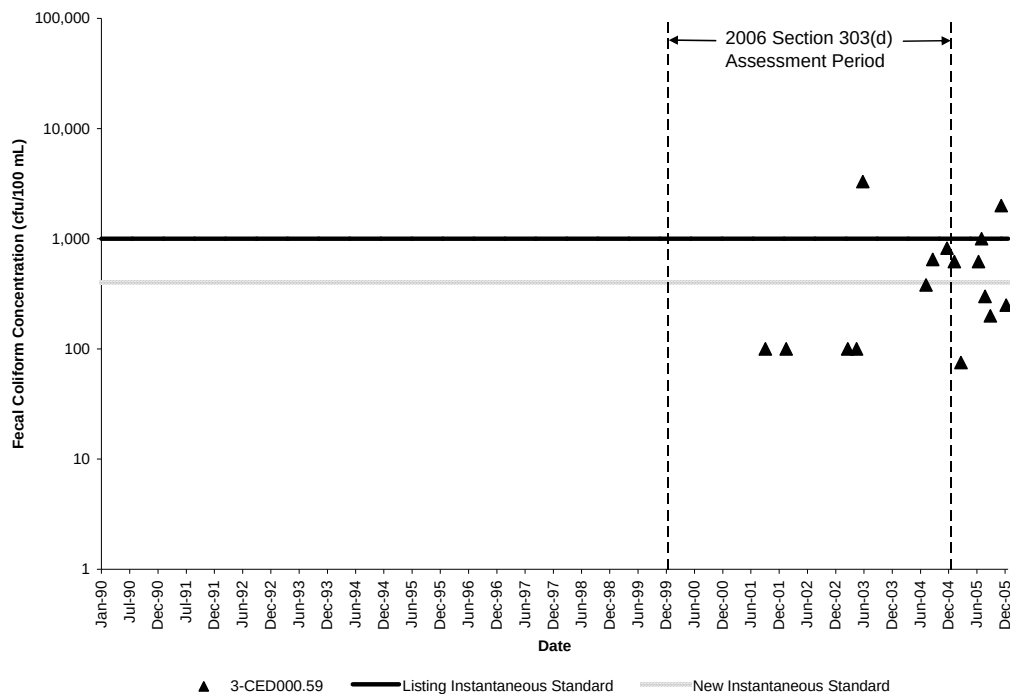


Figure 2.7. Fecal coliform concentrations (VADEQ station 3-CED003.52) in the Cedar Run (VAN-E16R-01) impairment.

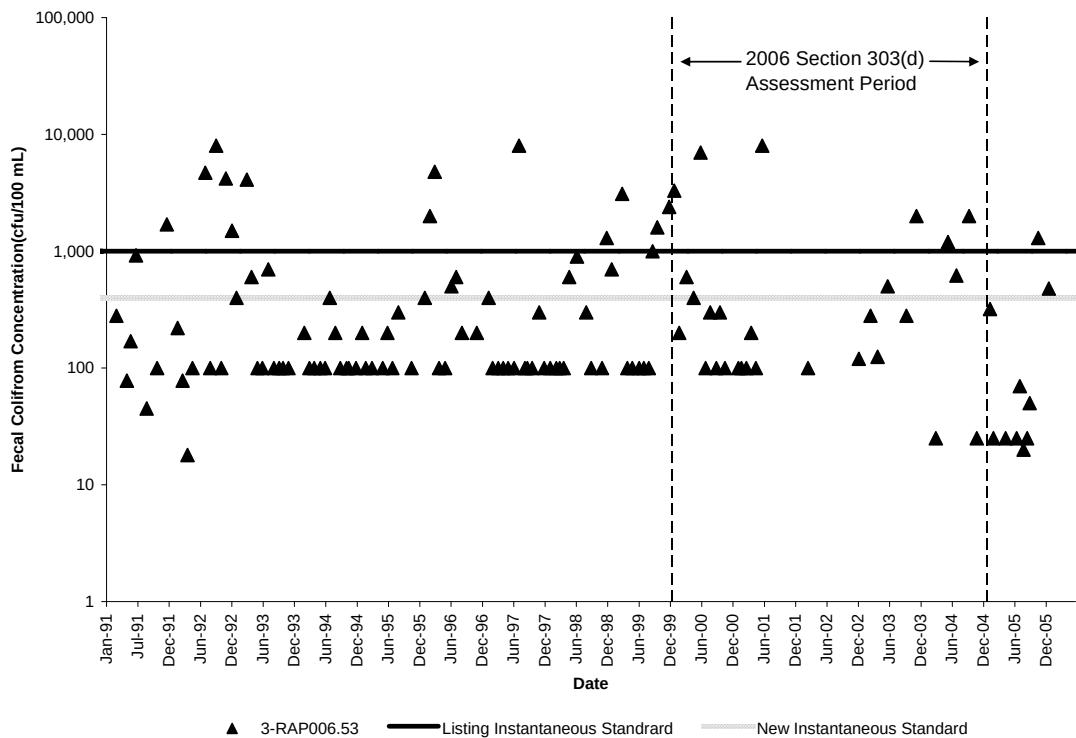


Figure 2.8. Fecal coliform concentrations (VADEQ station 3-RAP006.53) in the Rapidan River (VAN-E18R-01) impairment.

Seasonal variability of fecal coliform concentration 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 – 2.3). Mean monthly fecal coliform bacteria concentrations were plotted for stations 3-MAS001.55, 3-BLU002.60, 3-XEZ000.12, 3-RAP045.08, 3-CED000.59, 3-CED003.52, and 3-RAP006 (Figures 2.9 - 2.15).

April and September at station 3-MAS001.55 had the highest mean fecal coliform concentration (Figure 2.9). The lower concentrations occurred in the winter months with the remaining months having a uniform distribution. The mean fecal coliform concentration in the winter months tended to be higher with the highest mean fecal coliform bacteria concentration occurring in November and December followed by June and April at station 3-BLU002.60 (Figure 2.10). Sampling at station 3-XEZ000.12 was limited to 12 samples with no samples collected in January and December. Two samples were collected in August and October and the remaining months had one sample collected. Based on this dataset, seasonal difference could not be determined (Figure 2.11). At station 3-RAP045.08, mean fecal coliform bacteria concentrations fluctuated throughout the year and a noticeable seasonal difference was not detected (Figure 2.12). The highest average values were detected in December, June, April, and August. At station 3-CED000.59, the data indicate that higher in-stream fecal coliform concentrations occur during the fall months, particularly in November (Figure 2.13). November and June at station 3-CED003.52 had the highest mean fecal coliform concentration (Figure 2.14). The lower concentrations occurred in the winter months with the remaining months having a uniform distribution. Figure 2.15 shows a month with a higher mean fecal coliform concentration in the spring, summer, fall and winter seasons, particularly in March, July, September, and December, therefore seasonality was not distinguishable at station 3-RAP006.53.

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 2.9 – 2.15.

Table 2.2. Number of samples collected per month from 1/1/90 to 12/31/06 in the Marsh Run, Blue Run, UT to Rapidan River, and Rapidan River impairments.

Month	Samples Collected at			
	3-MAS001.55	3-BLU002.60	3-XEZ000.12	3-RAP045.08
	(#)	(#)	(#)	(#)
January	0	4	0	12
February	2	4	1	9
March	2	8	1	13
April	2	6	1	12
May	1	1	1	13
June	2	9	1	12
July	1	2	1	8
August	2	3	2	10
September	1	6	1	8
October	3	5	2	8
November	1	3	1	8
December	1	5	0	8
TOTAL	18	56	12	121

Table 2.3. Number of samples collected per month from 1/1/90 to 12/31/06 in the Cedar Run and Rapidan River impairments.

Month	Samples Collected at		
	3-CED000.59	3-CED003.52	3-RAP006.53
	(#)	(#)	(#)
January	4	3	9
February	3	1	12
March	7	3	11
April	5	2	11
May	0	0	12
June	8	2	12
July	2	2	10
August	3	1	12
September	5	3	10
October	3	0	8
November	2	1	10
December	6	2	8
TOTAL	48	20	125

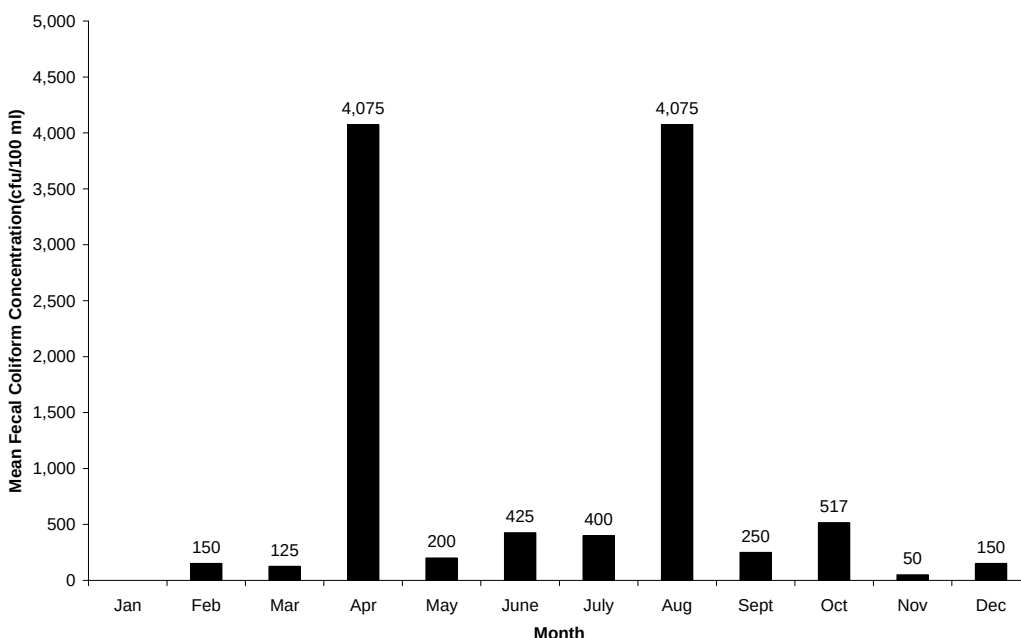


Figure 2.9. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-MAS001.55) in the Marsh Run (VAN-E13R-03) impairment from August 2001 through June 2005.

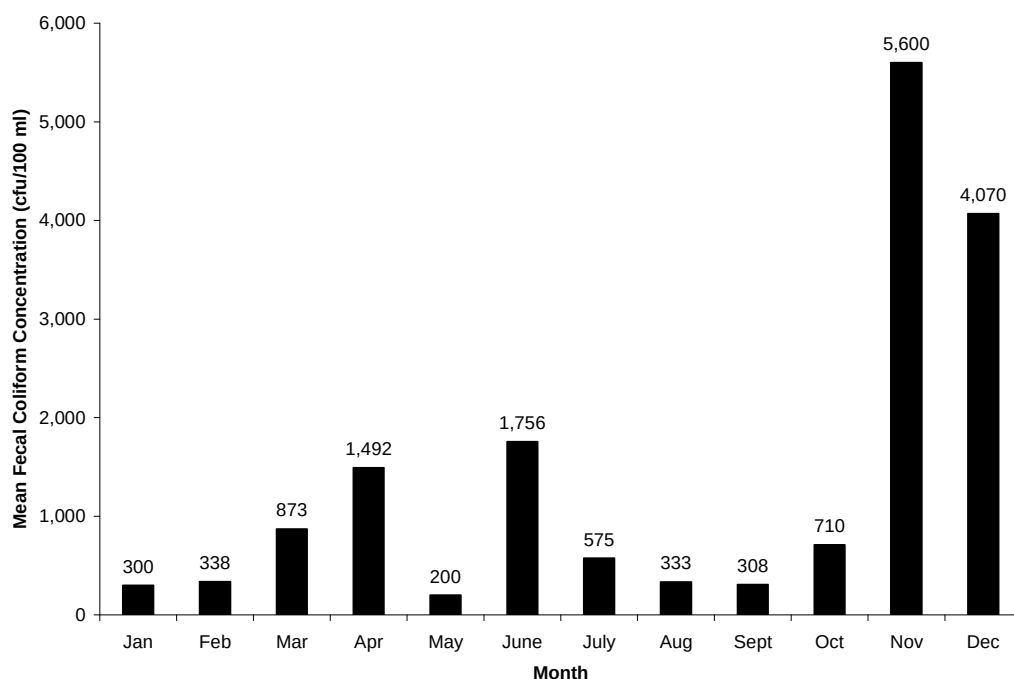


Figure 2.10. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-BLU002.60) in the Blue Run (VAN-E13R-01) impairment from June 1991 through June 2005.

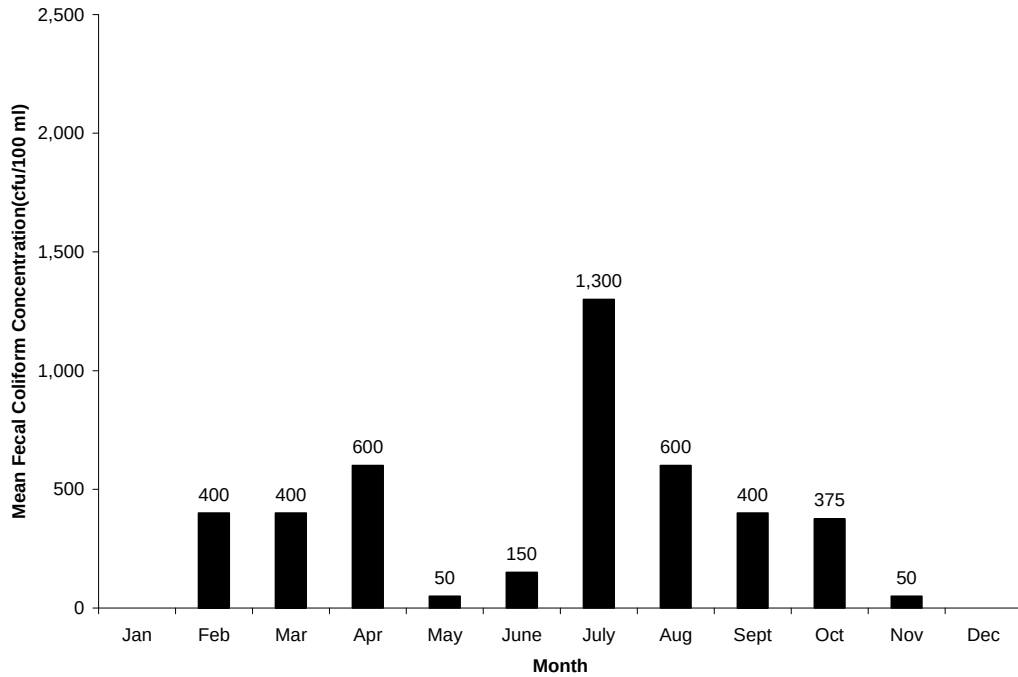


Figure 2.11. Impact of seasonality on fecal coliform (VADEQ station 3-XEZ000.12) in the Rapidan Tributary (VAN-E13R-04) impairment from August 2001 through June 2005.

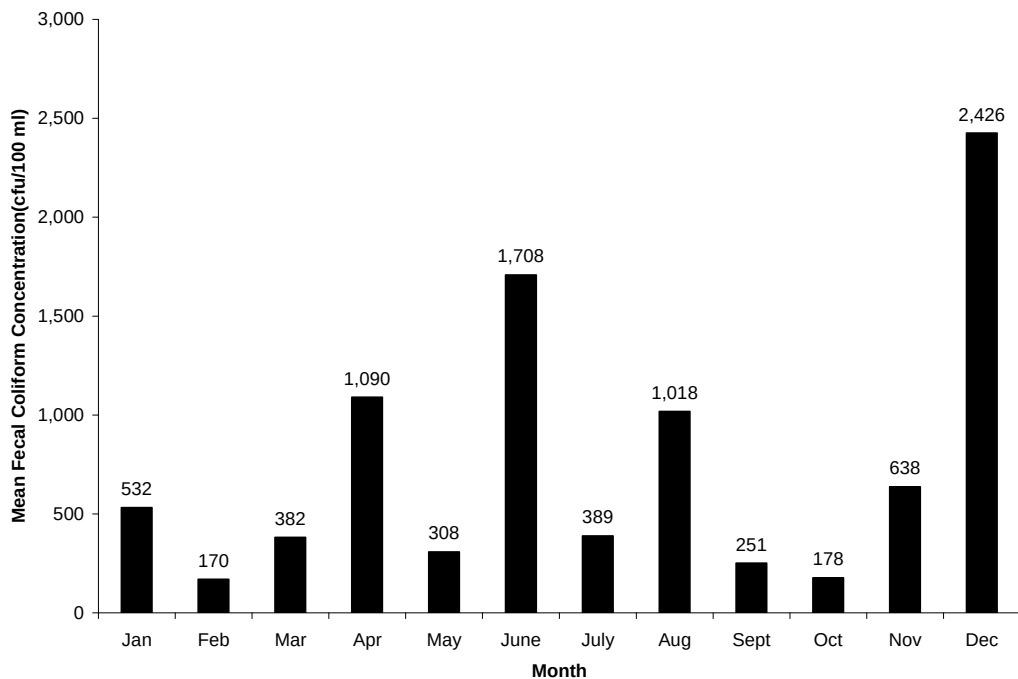


Figure 2.12. Impact of seasonality on fecal coliform (VADEQ station 3-RAP045.08) in the Rapidan River (VAN-E13R-02) impairment from April 1991 through January 2002.

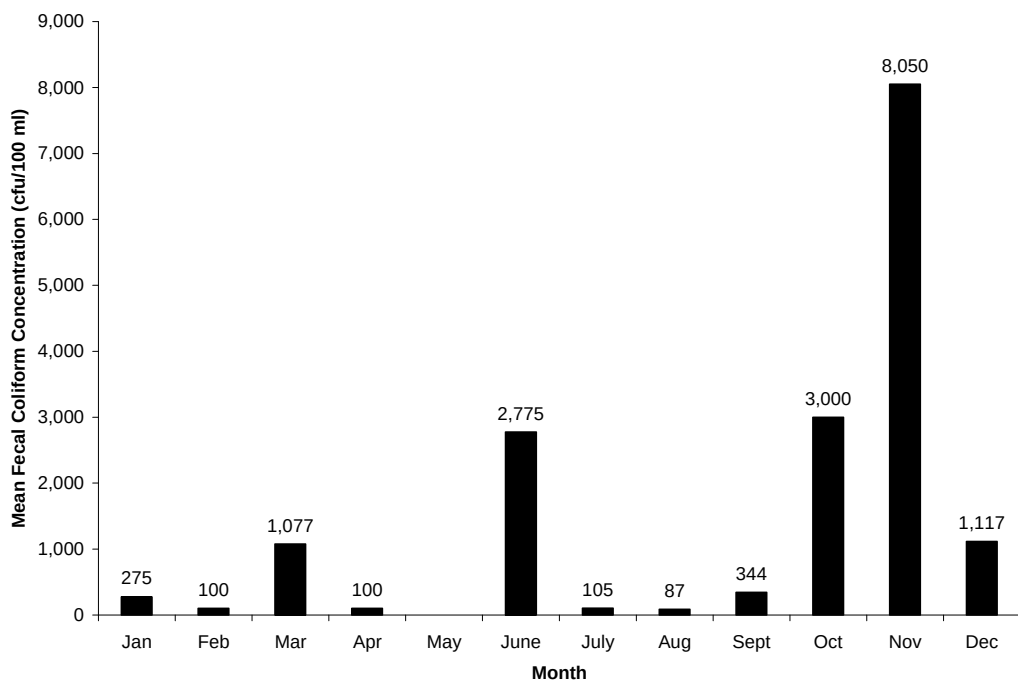


Figure 2.13. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-CED000.59) in the Cedar Run (VAN-E16R-01) impairment from June 1991 through September 2005.

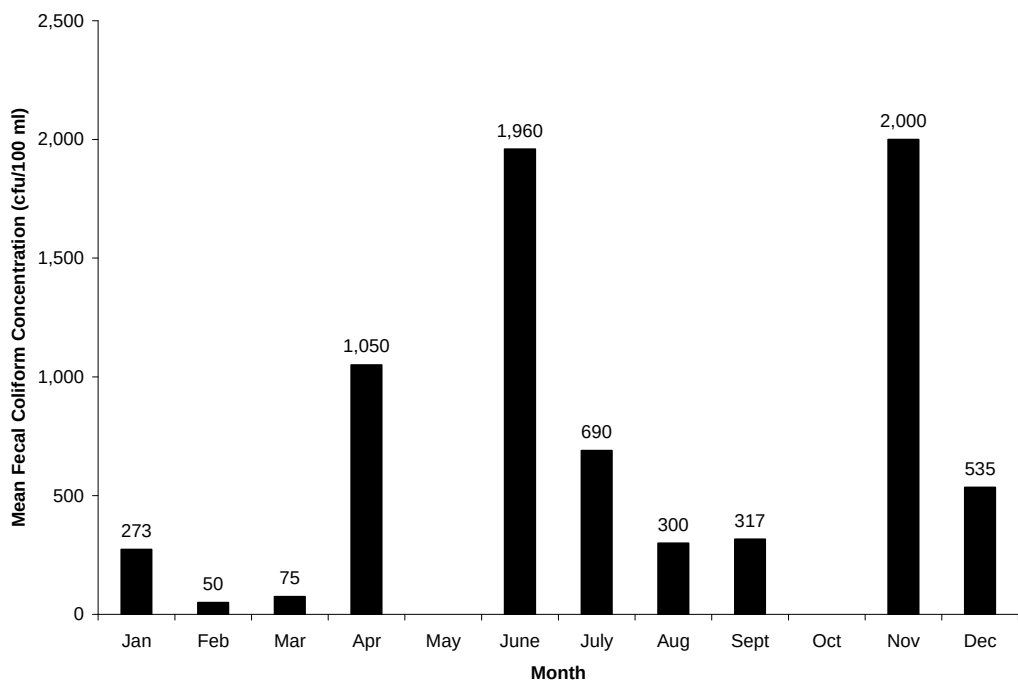


Figure 2.14. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-CED003.52) in the Cedar Run (VAN-E16R-01) impairment from June 1991 through September 2005.

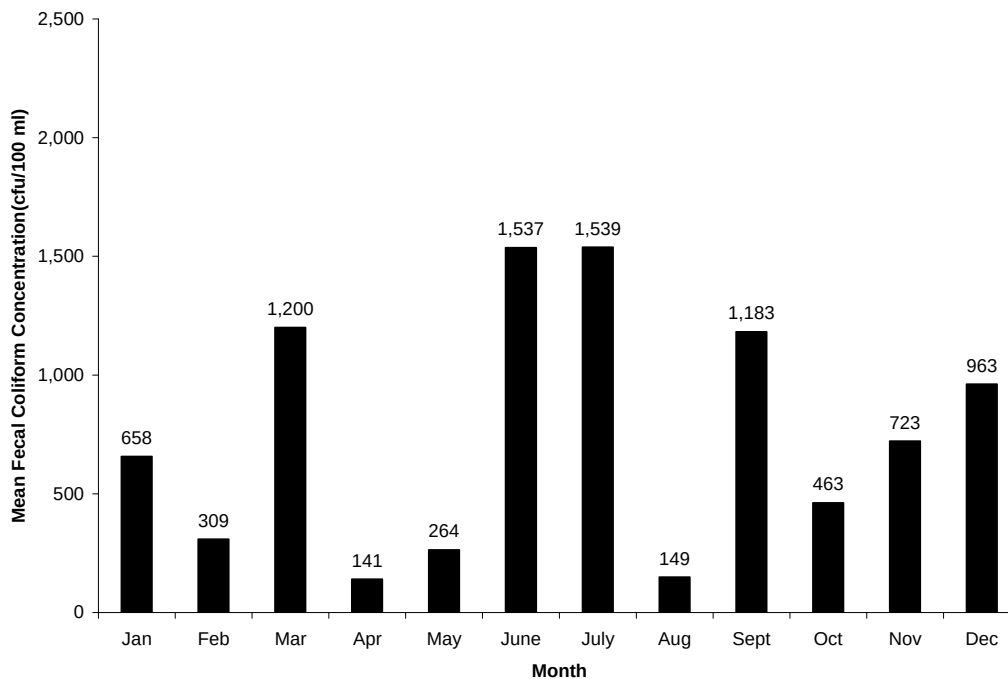


Figure 2.15. Impact of seasonality on fecal coliform concentrations (VADEQ station 3-RAP006.53) in the Rapidan River (VAN-E18R-01) impairment from February 1991 through June 2003.

2.5.2 Historic Data for *E. Coli*

VADEQ staff examined water samples collected at stations 3-MAS001.55, 3-BLU002.60, 3-XEZ000.12, 3-RAP045.08, 3-CED000.59, 3-CED003.52, and 3-RAP006.53 for their concentration of *E. coli* (Figures 2.16 through 2.22). This analysis was conducted concurrently with other monthly testing at the stations from December 2002 through April 2006. One of the 11 (9.1%) samples analyzed from station 3-MAS001.55 exceeded the instantaneous *E. coli* bacteria standard. Of the 11 water quality samples collected at station 3-BLU002.60, six (54.5%) of the samples exceeded the instantaneous *E. coli* bacteria standard of 235 cfu/100 mL. At station 3-XEZ000.12, six of 10 (60.0%) samples violated the instantaneous *E. coli* bacteria standard. Eight of the 23 (34.8%) samples analyzed from station 3-RAP045.08 exceeded the instantaneous *E. coli* bacteria standard. At station 3-CED000.59, zero of 5 (0.0%) samples violated the instantaneous *E. coli* bacteria standard. The instantaneous *E. coli* bacteria standard was exceeded in nine of 25 (36.0%) samples collected at station 3-RAP006.53.

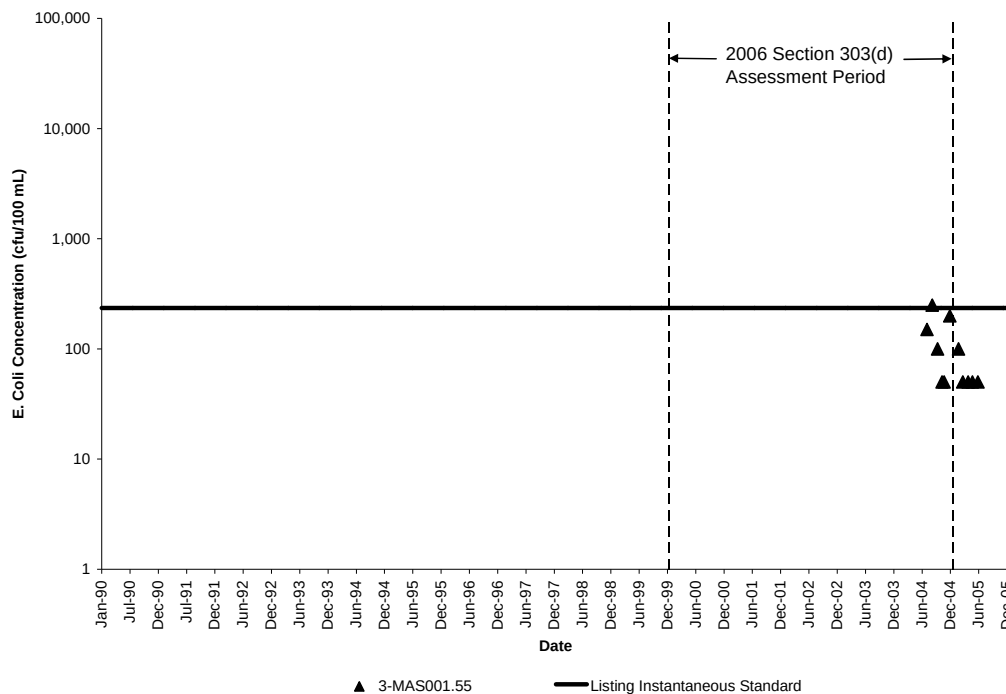


Figure 2.16. *E. coli* concentrations (VADEQ station 3-MAS001.55) in the Marsh Run (VAN-E13R-03) impairment.

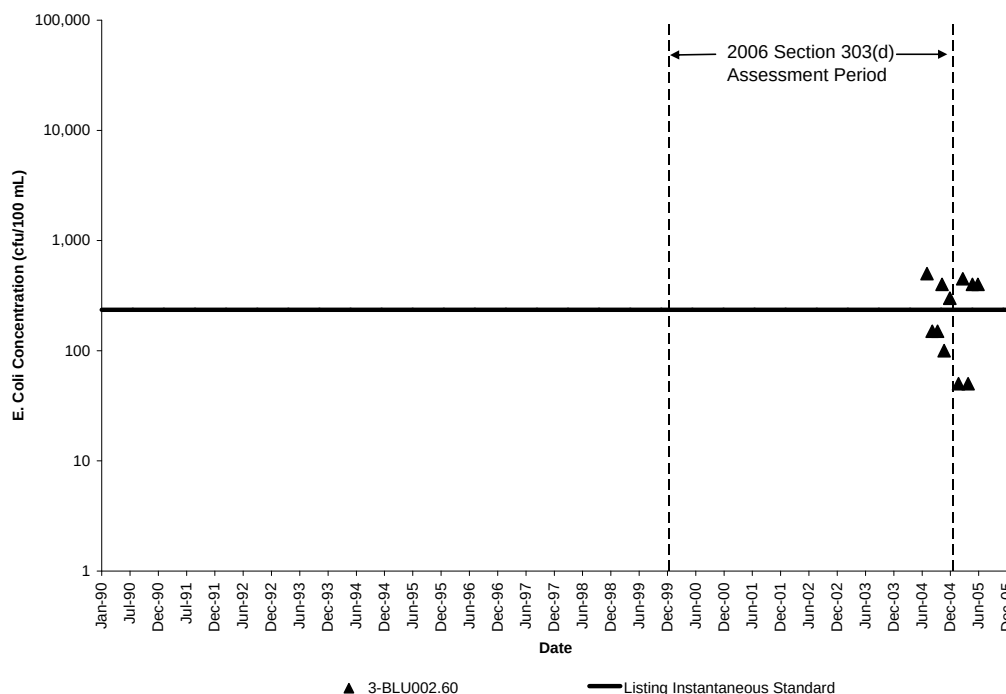


Figure 2.17. *E. coli* concentrations (VADEQ station 3-BLU002.60) in the Blue Run (VAN-E13R-01) impairment.

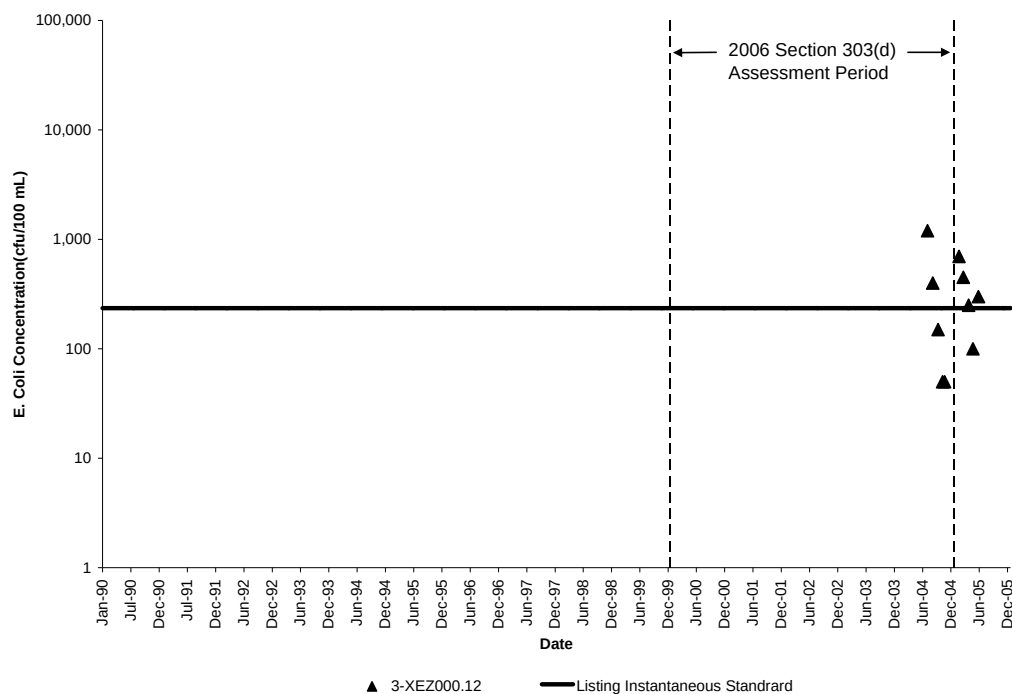


Figure 2.18. *E. coli* concentrations (VADEQ station 3-XEZ000.12) in the Rapidan Tributary (VAN-E13R-04) impairment.

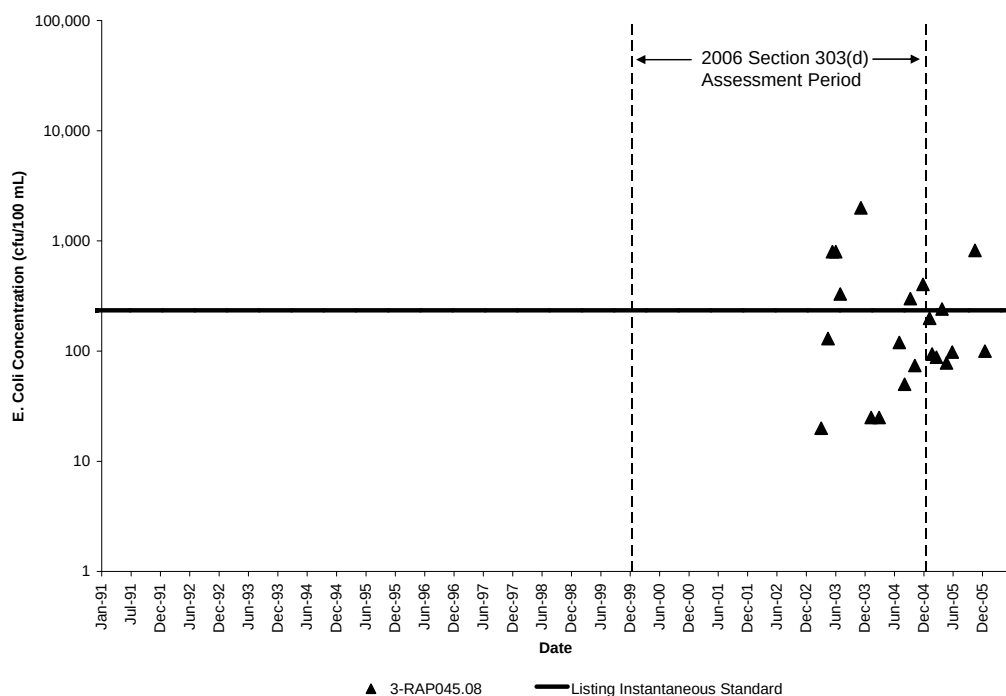


Figure 2.19. *E. coli* concentrations (VADEQ station 3-RAP045.08) in the Rapidan River (VAN-E13R-02) impairment.

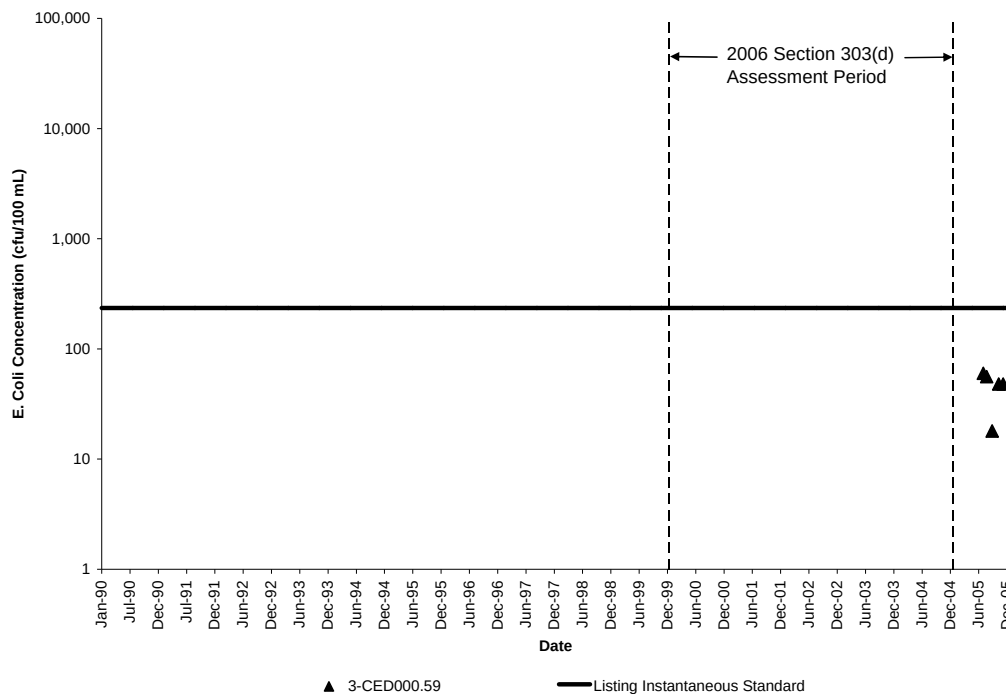


Figure 2.20. *E. coli* concentrations (VADEQ station 3-CED000.59) in the Cedar Run (VAN-E16R-01) impairment.

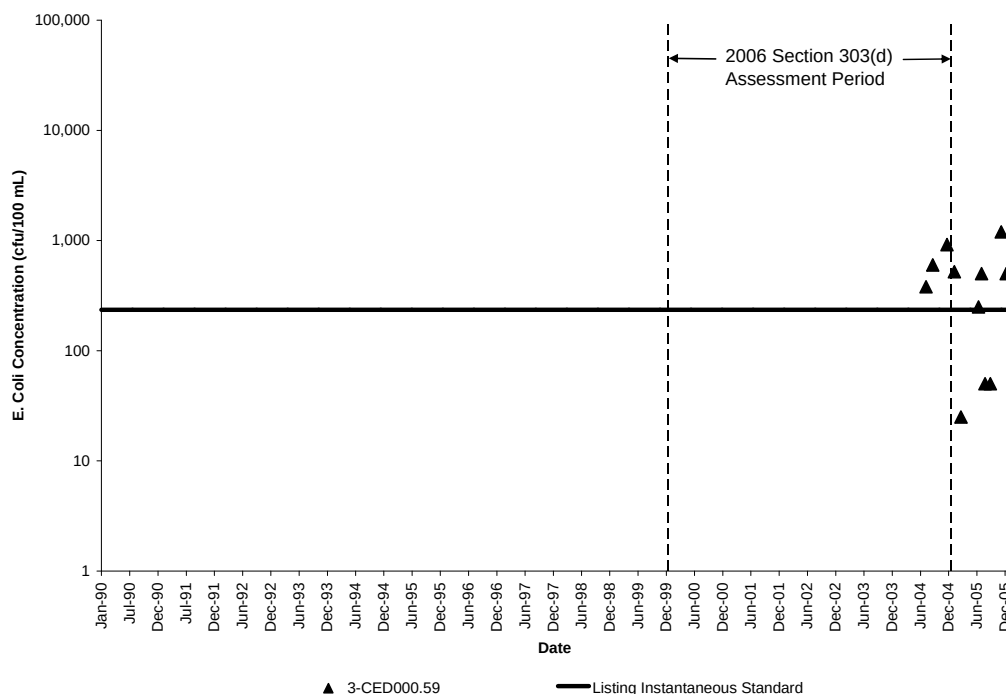


Figure 2.21. *E. coli* concentrations (VADEQ station 3-CED003.52) in the Cedar Run (VAN-E16R-01) impairment.

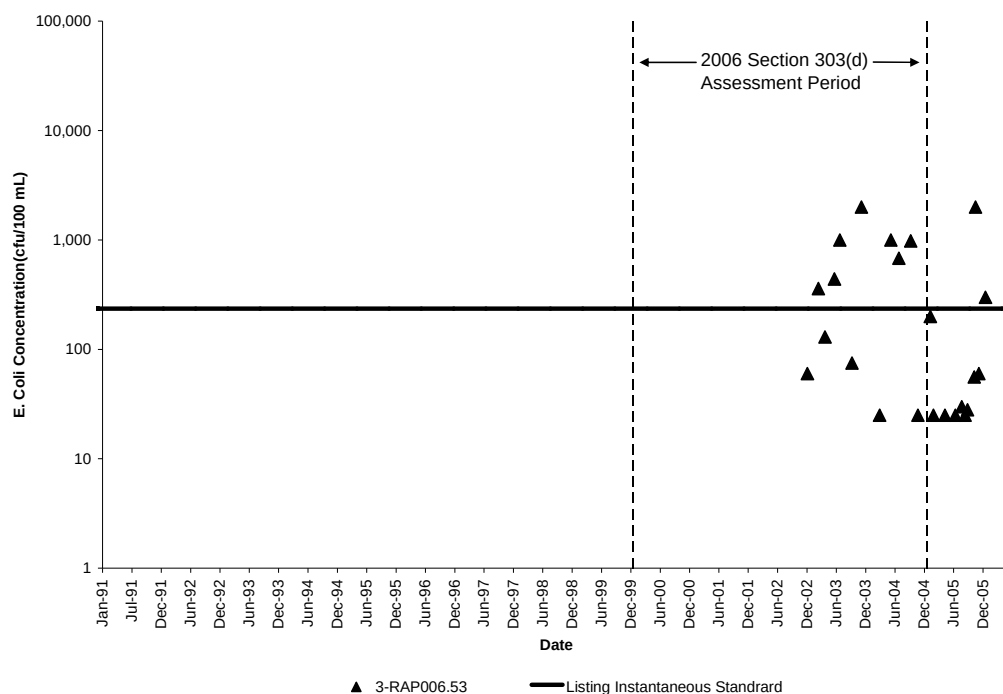


Figure 2.22. *E. coli* concentrations (VADEQ station 3-RAP006.53) in the Rapidan River (VAN-E18R-01) impairment.

2.5.3 Historic Data for Bacteria Source Tracking

The results from 12 monthly bacteria source tracking (BST) samples collected at stations 3-BLU000.80, 3-RAP045.08, 3-CED000.59, and 3-RAP006.53 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 Blue Run, Cedar Run, and Rapidan River 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 2.4 through 2.7 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 also referenced in Appendix B. At station 3-BLU000.80, 16.7% (two of 12) of the samples exceeded either the fecal coliform or *E. coli* bacteria instantaneous standard. The

exceedances occurred in March and April of 2005. Three of 12 (25.0%) samples exceeded either the fecal coliform or *E. coli* bacteria instantaneous standard at station 3-RAP045.08. The exceedances occurred in September and December of 2004 and April of 2005. The one exceedance (8.3%) of either the fecal coliform or *E. coli* bacteria instantaneous standard occurred in September of 2005 at station 3-CED000.59. At station 3-RAP006.53, 8.3% (1 of 12) of the samples exceeded either the fecal coliform or *E. coli* bacteria instantaneous standard. The exceedances occurred in April of 2006.

Table 2.4. Presence/absence analysis of bacteria sources at station 3-BLU000.80 in Blue Run (VAN-E13R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples¹ (%)	Frequency of Presence in Samples Exceeding Water Quality Standards² (%)
Wildlife	58	0
Human	25	50
Livestock	92	100
Pet	50	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 2.5. Presence/absence analysis of bacteria sources at station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Bacteria Source	Frequency of Presence in All Samples¹ (%)	Frequency of Presence in Samples Exceeding Water Quality Standards² (%)
Wildlife	67	67
Human	58	67
Livestock	92	100
Pet	50	33

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 2.6. Presence/absence analysis of bacteria sources at station 3-CED000.59 in Cedar Run (VAN-E16R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples¹ (%)	Frequency of Presence in Samples Exceeding Water Quality Standards² (%)
Wildlife	50	0
Human	33	0
Livestock	42	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 2.7. Presence/absence analysis of bacteria sources at station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples¹ (%)	Frequency of Presence in Samples Exceeding Water Quality Standards² (%)
Wildlife	75	100
Human	17	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.

Chapter 3. Bacteria Source Assessment

Potential bacteria sources in 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) 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); Albemarle, Madison, Greene, Culpeper, Orange, and Spotsylvania County Planning Departments; Natural Resources Conservation Service (NRCS); Virginia Department of Agricultural and Consumer Services (VDACS); Thomas Jefferson, Culpeper, 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 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) 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 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) 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 Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01), and Rapidan River (VAN-E18R-01) watersheds, there are no active permitted facilities discharging bacteria in the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), and Unnamed Tributary to the Rapidan River (VAN-E13R-04) 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 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) watersheds.

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

Impairment	Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	<i>E. coli</i> Load (cfu/yr)
Rapidan River (VAN-E13R-02)	VA0090948	Rapidan STP	URR-05	0.600	1.66E+12	1.04E+12
Rapidan River (VAN-E13R-02)	VA0051144	Greene County WTP	URR-05	0.026	0.00E+00	0.00E+00
Rapidan River (VAN-E13R-02)	VA0060879	Rapidan Baptist Camp and Conference	URR-09	0.020	5.51E+10	3.48E+10
Rapidan River (VAN-E13R-02)	VA0053121	Orange Town WTP	URR-15	0.266	0.00E+00	0.00E+00
Rapidan River (VAN-E13R-02)	VA0021385	Orange Town Waste Water	URR-16	3.000	8.29E+12	5.22E+12
Rapidan River (VAN-E13R-02)	VA0092053	Spicers Mill STP	URR-16	0.090	2.49E+11	1.57E+11
Rapidan River (VAN-E13R-02)	VA0027839	Woodberry Forest School	URR-19	0.039	1.08E+11	6.79E+10
Rapidan River (VAN-E18R-01)	VAG406382	Residence	LRR-01	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406306	Residence	LRR-01	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406213	Residence	LRR-01	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406266	Residence	LRR-01	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406337	Residence	LRR-03	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406186	Residence	LRR-03	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406214	Residence	LRR-03	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406414	Residence	LRR-03	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406381	Residence	LRR-04	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406362	Residence	LRR-04	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VA0087718	DOC - Coffeewood Correctional Center (Municipal)	LRR-04	0.200	5.51E+11	3.48E+11
Cedar Run (VAN-E16R-01)	VA0087718	DOC - Coffeewood Correctional Center (Industrial)	LRR-04	0.070	0.00E+00	0.00E+00
Cedar Run (VAN-E16R-01)	VAG406154	Residence	LRR-04	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406041	Residence	LRR-04	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406305	Residence	LRR-04	0.001	2.68E+09	1.69E+09
Cedar Run (VAN-E16R-01)	VAG406010	Residence	LRR-06	0.001	2.68E+09	1.69E+09

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

Impairment	Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	<i>E. coli</i> Load (cfu/yr)
Rapidan River (VAN-E18R-01)	VA0092011	Meadowbrook WWTF	LRR-08	0.200	5.51E+11	3.48E+11
Rapidan River (VAN-E18R-01)	VAG406287	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406294	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406318	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406407	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406335	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406336	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406349	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406290	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406286	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406309	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406268	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406021	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406112	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406127	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406140	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406182	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406200	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406167	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406070	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406117	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406261	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406081	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406163	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VAG406219	Residence	LRR-08	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VA0091961	Locust Grove Town Center	LRR-08	0.020	5.51E+10	3.48E+10
Rapidan River (VAN-E18R-01)	VA0083411	Wilderness Wastewater Treatment Plant	LRR-11	2.000	5.51E+12	3.48E+12
Rapidan River (VAN-E18R-01)	VAG406044	Residence	LRR-12	0.001	2.68E+09	1.69E+09
Rapidan River (VAN-E18R-01)	VA0081621	Lake Wilderness Public Water Systems	LRR-12	0.008	0.00E+00	0.00E+00
Rapidan River (VAN-E18R-01)	VA0074381	Camp Happyland	LRR-13	0.026	7.19E+10	4.53E+10

3.2 Marsh Run (VAN-E13R-03) Sources

3.2.1 Humans and Pets

There are 15 homes served by municipal sanitary sewer in the Marsh Run (VAN-E13R-03) watershed. Wastewater from 422 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Marsh Run (VAN-E13R-03) watershed has an estimated population of 1,165 people (448 households at an average of 2.60 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 2.27×10^{12} cfu/day (8.29×10^{14} cfu/year) in Marsh Run (VAN-E13R-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.

3.2.1.1 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 Marsh Run (VAN-E13R-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, 2000, and 2004 U.S. Census Bureau demographics data (UCSB; 1990, 2000, and 2004). 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 2.60 persons/household was 5.07×10^9 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 3.4.

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 age category. 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 11 houses that potentially could be classified as straight pipes in the Marsh Run (VAN-E13R-03) watershed (Table 3.4).

3.2.1.3 Biosolids

According to VDH records; 13,261; 18,198; 10,896; 5,608; 14,521; and 7,478 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Orange County. In Greene County; 5,520; 5158; and 3,367 dry tons of Class B biosolids were applied in 2003, 2004, and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Marsh Run (VAN-E13R-03) watershed were not available. To estimate biosolids applications within each Marsh Run (VAN-E13R-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. A sample collected by VDH and tested in 2006 The fecal coliform density of biosolids from Blue Plains from a sample collected by VDH and tested 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 Marsh Run (VAN-E13R-03) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
URR-07	122
URR-08	259
Total	381

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 237 dogs and 269 cats were projected to reside in the Marsh Run (VAN-E13R-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 448 for Marsh Run (VAN-E13R-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 Marsh Run (VAN-E13R-03) watershed is 2.0×10^{11} cfu/day (7.4×10^{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 sewerage 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-E13R-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 (#)			
URR-07	546	9	132	42	19	62	4	206
URR-08	619	6	155	54	20	74	7	242
Total	1,165	15	287	96	39	136	11	448

^aCalculated from average of 1.0 pet per household.

3.2.3 Livestock Sources

In the Marsh Run (VAN-E13R-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 Marsh Run (VAN-E13R-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.

3.2.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are no dairy operations presently operating in the Marsh Run (VAN-E13R-03) watershed. 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 Marsh Run (VAN-E13R-03) watershed (393 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 Marsh Run (VAN-E13R-03) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
URR-07	0	0	122
URR-08	0	0	271
Total	0	0	393

^aConsists 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 Marsh Run (VAN-E13R-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 3.7 for dairy cattle and in Tables 3.8 for beef cattle.

Table 3.7. Distribution of the dairy cattle^a population in the Marsh Run (VAN-E13R-03) 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

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.8. Distribution of the beef cattle population (pairs) in the Marsh Run (VAN-E13R-03) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	344.09	86.17	21.54	0.14	0.00
February	0.00	403.93	101.16	25.29	0.17	0.00
March	0.00	415.84	104.14	26.04	0.26	0.00
April	0.00	427.74	107.12	26.78	0.35	0.00
May	0.00	439.56	110.08	27.52	0.54	0.00
June	0.00	450.96	112.94	28.23	1.30	0.00
July	0.00	462.91	115.93	28.98	1.33	0.00
August	0.00	474.85	118.92	29.73	1.37	0.00
September	0.00	487.41	122.07	30.52	0.60	0.00
October	0.00	299.12	74.91	18.73	0.25	0.00
November	0.00	314.12	78.67	19.67	0.19	0.00
December	0.00	329.13	82.43	20.61	0.14	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 both dairy (Table 3.7) and 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 Marsh Run (VAN-E13R-03) watersheds is 12,154 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.83×10^{10} cfu/day (6.68×10^{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 cattle (Table 3.8) 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 Marsh Run (VAN-E13R-03) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,654; 33,375; and 1,663 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-E13R-03), averaged over the year, are 3.67×10^{12} , 1.85×10^{13} , and 9.27×10^{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 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.11. The total wildlife fecal coliform production each year in the Marsh Run (VAN-E13R-03) watershed, is 1.03×10^{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 3.9).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.9). 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 3.9, 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 3.10.

Table 3.9. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Marsh Run (VAN-E13R-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	0.042	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 3.10. Distribution of wildlife among sub-watersheds in Marsh Run (VAN-E13R-03) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
URR-07	170	196	204	22	28	10	23
URR-08	274	252	544	29	38	13	29
Total	444	448	748	51	66	23	52

3.2.5 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Marsh Run (VAN-E13R-03) watershed along with average fecal coliform production rates are shown in Table 3.11. The total fecal coliform production by all sources in the Marsh Run (VAN-E13R-03) watershed is 8.03×10^{15} cfu/yr.

Table 3.11. Potential fecal coliform sources and daily fecal coliform production by source in Marsh Run (VAN-E13R-03) 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			
<i>Milk and Dry Cows</i>	0	25,000	0
<i>Heifers</i>	0	8,800	0
Beef Cattle (pairs)	393	33,000	1,753,435
Horses	70	420	2,942
Humans	1165	1,950	76,342
Pets	448	450	20,174
Deer	444	350	15,551
Raccoon	448	50	2,242
Muskrat	748	25	1,871
Beaver	51	0.2	1
Wild Turkey	52	93	484
Duck	23	2,400	4,193
Goose	66	800	3,953

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 3.12. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.12.

From Table 3.12, it is clear in the Marsh Run (VAN-E13R-03) watershed that nonpoint source loadings to the land surface are more than 180 times as large as direct loadings to the streams, with pastures receiving about 93% 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 3.12. Annual fecal coliform loadings to the stream and the various land use categories in the Marsh Run (VAN-E13R-03) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	2,078	0.30
Cattle in Stream	668	0.10
Wildlife in Stream	1,055	0.15
<i>Loading to Land Surfaces</i>		
Cropland	106	0.02
Pasture 1	488,571	71.15
Pasture 2	122,773	17.88
Pasture 3	30,901	4.50
Forest	7,332	1.07
Residential*	33,150	4.83
Total	686,633	100.00

*Includes loads received from failed septic systems and pets.

3.3 Blue Run (VAN-E13R-01) Sources

3.3.1 Humans and Pets

There are 341 homes served by municipal sanitary sewer in the Blue Run (VAN-E13R-01) watershed. Wastewater from 782 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Blue Run (VAN-E13R-01) watershed has an estimated population of 2,747 people (1,123 households at an average of 2.45 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 5.36×10^{12} cfu/day (1.96×10^{15} cfu/year) in Blue Run (VAN-E13R-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 Blue Run (VAN-E13R-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 2.45 persons/household was 4.77×10^9 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 3.14.

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 38 houses that potentially could be classified as straight pipes in the Blue Run (VAN-E13R-01) watershed (Table 3.14).

3.3.1.3 Biosolids

According to VDH records; 13,261; 18,198; 10,896; 5,608; 14,521; and 7,478 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Orange County. In Albemarle County; 3,243; 3,001; 4,395; and 5,122 dry tons of Class B biosolids were applied in 2001, 2003, 2004, and 2005, respectively. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Blue Run (VAN-E13R-01) watershed were not available. To estimate biosolids applications within each Blue Run (VAN-E13R-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. A sample collected by VDH and tested in 2006 The fecal coliform density of biosolids from Blue Plains from a sample collected by VDH and tested 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 3.13 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.13. Estimated average annual biosolids application amount for each subwatershed in the Blue Run (VAN-E13R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
URR-11	241
URR-12	389
URR-13	363
URR-14	224
Total	1,214

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 595 dogs and 674 cats were projected to reside in the Blue Run (VAN-E13R-01) watershed. 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 1,123 for Blue Run (VAN-E13R-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 Blue Run (VAN-E13R-01) watershed is 5.1×10^{11} cfu/day (1.8×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.14. 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 3.14. Estimated human population, number of sewerred houses, number of unsewerred houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Blue Run (VAN-E13R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewerred Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population ^a
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
URR-11	748	45	142	44	21	66	27	279
URR-12	601	139	100	25	16	45	6	286
URR-13	452	60	92	27	15	43	4	198
URR-14	946	97	109	71	82	60	1	360
Total	2,747	341	443	167	134	214	38	1,123

^aCalculated from average of 1.0 pet per household.

3.3.3 Livestock Sources

In the Blue Run (VAN-E13R-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 Blue Run (VAN-E13R-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 are no dairy operations presently operating in the Blue Run (VAN-E13R-03) 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 3.18). Beef cattle in the Blue Run (VAN-E13R-01) watershed (1,353 pairs) included cow/calf and feeder operations (Table 3.15).

Table 3.15. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Blue Run (VAN-E13R-01) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
URR-11	0	0	336
URR-12	0	0	417
URR-13	0	0	363
URR-14	0	0	237
Total	0	0	1,353

^aConsists 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 3.16.
- 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 3.16). 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 3.16. Time spent by cattle in confinement and in the stream in Blue Run (VAN-E13R-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 3.17 for dairy cattle and in Table 3.18 for beef cattle.

Table 3.17. Distribution of the dairy cattle^a population in the Blue Run (VAN-E13R-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

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.18. Distribution of the beef cattle population (pairs) in the Blue Run (VAN-E13R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	1184.62	296.67	74.17	0.49	0.00
February	0.00	1390.64	348.27	87.07	0.57	0.00
March	0.00	1431.62	358.53	89.63	0.88	0.00
April	0.00	1472.59	368.79	92.20	1.21	0.00
May	0.00	1513.31	378.99	94.75	1.86	0.00
June	0.00	1552.54	388.82	97.20	4.47	0.00
July	0.00	1593.67	399.11	99.78	4.59	0.00
August	0.00	1634.80	409.41	102.35	4.71	0.00
September	0.00	1678.02	420.24	105.06	2.07	0.00
October	0.00	1029.78	257.90	64.47	0.85	0.00
November	0.00	1081.44	270.83	67.71	0.67	0.00
December	0.00	1133.12	283.78	70.94	0.47	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 and beef cattle (Table 3.18) 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 Blue Run (VAN-E13R-01) watersheds is 41,845 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 6.31×10^{10} cfu/day (2.30×10^{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 3.18) 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 Blue Run (VAN-E13R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,473; 3,237; and 1,617 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 Blue Run (VAN-E13R-01), averaged over the year, are 3.59×10^{12} , 1.81×10^{12} , and 9.04×10^{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 Blue Run (VAN-E13R-01) watershed is included in Table 3.19. 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 Blue Run (VAN-E13R-01) watershed is 1.26×10^{11} cfu/day (4.59×10^{13} cfu/year).

Table 3.19. Horse population by subwatershed in the Blue Run (VAN-E13R-01) watershed.

Subwatershed	Horses
URR-11	105
URR-12	80
URR-13	69
URR-14	45
Total	299

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 Blue Run (VAN-E13R-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 3.22. The total wildlife fecal coliform production each year in the Blue Run (VAN-E13R-01) watershed, is 2.25×10^{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 3.20).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.20). 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 3.20, 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 3.21.

Table 3.20. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Blue Run (VAN-E13R-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	0.042	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 3.21. Distribution of wildlife among sub-watersheds in Blue Run (VAN-E13R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
URR-11	268	328	1,480	37	46	17	32
URR-12	220	210	554	23	32	12	17
URR-13	144	158	325	18	25	9	9
URR-14	173	150	2,565	17	24	9	15
Total	805	846	4,921	95	127	47	73

3.3.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Blue Run (VAN-E13R-01) watershed along with average fecal coliform production rates are shown in Table 3.22. The total fecal coliform production by all sources in the Blue Run (VAN-E13R-01) watershed is 2.31×10^{16} cfu/yr.

Table 3.22. Potential fecal coliform sources and daily fecal coliform production by source in Blue Run (VAN-E13R-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			
<i>Milk and Dry Cows</i>	0	25,000	0
<i>Heifers</i>	0	8,800	0
Beef Cattle (pairs)	1353	33,000	6,036,637
Horses	299	420	12,567
Turkey			0
Humans	2747	1,950	124,932
Pets	1123	450	50,570
Deer	805	350	28,194
Raccoon	846	50	4,233
Muskrat	4921	25	12,318
Beaver	95	0.2	2
Wild Turkey	73	93	679
Duck	47	2,400	8,626
Goose	127	800	7,626

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 3.23. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.23.

From Table 3.23, it is clear in the Blue Run (VAN-E13R-01) watershed that nonpoint source loadings to the land surface are more than 188 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 3.23. Annual fecal coliform loadings to the stream and the various land use categories in the Blue Run (VAN-E13R-01) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	7,068	0.31
Cattle in Stream	2,301	0.10
Wildlife in Stream	2,867	0.12
<i>Loading to Land Surfaces</i>		
Cropland	359	0.02
Pasture 1	1,692,521	73.37
Pasture 2	426,396	18.48
Pasture 3	106,709	4.63
Forest	11,591	0.50
Residential*	56,990	2.47
Total	2,306,802	100.00

*Includes loads received from failed septic systems and pets.

3.4 UT to Rapidan River (VAN-E13R-04) Sources

3.4.1 Humans and Pets

There are 105 homes served by municipal sanitary sewer in the UT to Rapidan River (VAN-E13R-04) watershed. Wastewater from 44 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The UT to Rapidan River (VAN-E13R-04) watershed has an estimated population of 354 people (143 households at an average of 2.48 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 6.901×10^{11} cfu/day (2.52×10^{14} cfu/year) in UT to Rapidan River (VAN-E13R-04) 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.

3.4.1.1 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 UT to Rapidan River (VAN-E13R-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 2.48 persons/household was 4.83×10^9 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 4 houses that potentially could be classified as straight pipes in the UT to Rapidan River (VAN-E13R-04) watershed (Table 3.25).

3.4.1.3 Biosolids

According to VDH records; 13,261; 18,198; 10,896; 5,608; 14,521; and 7,478 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Orange County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the UT to Rapidan River (VAN-E13R-04) watershed were not available. To estimate biosolids applications within each UT to Rapidan River (VAN-E13R-04) 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. A sample collected by VDH and tested in 2006 The fecal coliform density of biosolids from Blue Plains from a sample collected by VDH and tested 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 3.24 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.24. Estimated average annual biosolids application amount for each subwatershed in the UT to Rapidan River (VAN-E13R-04) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
URR-18	120
Total	120

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 76 dogs and 86 cats were projected to reside in the UT to Rapidan River (VAN-E13R-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 153 for UT to Rapidan River (VAN-E13R-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 UT to Rapidan River (VAN-E13R-04) watershed is 6.4×10^{10} cfu/day (2.3×10^{13} 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 sewerred houses, number of unsewerred houses by age category, number of failing septic systems, number of straight pipes, and pet population in the UT to Rapidan River (VAN-E13R-04) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewerred Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population ^a
			Pre-1984	1985 - 1994	Post-1994			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
URR-18	354	105	44	0	0	17	4	153
Total	354	105	44	0	0	17	4	153

^aCalculated from average of 1.0 pet per household.

3.4.3 Livestock Sources

In the UT to Rapidan River (VAN-E13R-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 UT to Rapidan River (VAN-E13R-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.

3.4.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are no dairy operations presently operating in the UT to Rapidan River (VAN-E13R-04) 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 3.26). Beef cattle in the UT to Rapidan River (VAN-E13R-04) watershed (131 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 UT to Rapidan River (VAN-E13R-04) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
URR-18	0	0	131
Total	0	0	131

^aConsists 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 UT to Rapidan River (VAN-E13R-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 3.28 for dairy cattle and in Table 3.29 for beef cattle.

Table 3.28. Distribution of the dairy cattle^a population in the UT to Rapidan River (VAN-E13R-04) 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

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.29. Distribution of the beef cattle population (pairs) in the UT to Rapidan River (VAN-E13R-04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	114.70	28.72	7.18	0.05	0.00
February	0.00	134.64	33.72	8.43	0.06	0.00
March	0.00	138.61	34.71	8.68	0.09	0.00
April	0.00	142.58	35.71	8.93	0.12	0.00
May	0.00	146.52	36.69	9.17	0.18	0.00
June	0.00	150.32	37.65	9.41	0.43	0.00
July	0.00	154.30	38.64	9.66	0.44	0.00
August	0.00	158.28	39.64	9.91	0.46	0.00
September	0.00	162.47	40.69	10.17	0.20	0.00
October	0.00	99.71	24.97	6.24	0.08	0.00
November	0.00	104.71	26.22	6.56	0.06	0.00
December	0.00	109.71	27.48	6.87	0.05	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 UT to Rapidan River (VAN-E13R-04) watersheds is 4,051 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 6.10×10^9 cfu/day (2.23×10^{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.

3.4.3.3 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 UT to Rapidan River (VAN-E13R-04) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,585; 3,292; and 1,646 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 UT to Rapidan River (VAN-E13R-04), averaged over the year, are 3.64×10^{12} , 1.82×10^{12} , and 9.19×10^{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 UT to Rapidan River (VAN-E13R-04) 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 UT to Rapidan River (VAN-E13R-04) watershed is 1.05×10^{10} cfu/day (3.84×10^{12} cfu/year).

Table 3.30. Horse population by subwatershed in the UT to Rapidan River (VAN-E13R-04) watershed.

Subwatershed	Horses
UUR-18	25
Total	25

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 UT to Rapidan River (VAN-E13R-04) 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 UT to Rapidan River (VAN-E13R-04) watershed, is 1.72×10^{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 3.31).

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 UT to Rapidan River (VAN-E13R-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	0.045	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 3.32. Distribution of wildlife among sub-watersheds in UT to Rapidan River (VAN-E13R-04) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
URR-18	68	56	280	6	10	4	5
Total	68	56	280	6	10	4	5

3.4.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the UT to Rapidan River (VAN-E13R-04) watershed along with average fecal coliform production rates are shown in Table 3.33. The total fecal coliform production by all sources in the UT to Rapidan River (VAN-E13R-04) watershed is 2.22×10^{15} cfu/yr.

Table 3.33. Potential fecal coliform sources and daily fecal coliform production by source in UT to Rapidan River (VAN-E13R-04) 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			
<i>Milk and Dry Cows</i>	0	25,000	0
<i>Heifers</i>	0	8,800	0
Beef Cattle (pairs)	131	33,000	584,478
Horses	25	420	1,051
Chicken	0	89	0
Humans	354	1,950	10,875
Pets	153	450	6,890
Deer	68	350	2,382
Raccoon	56	50	280
Muskrat	280	25	700
Beaver	6	0.2	0
Wild Turkey	5	93	47
Duck	4	2,400	719
Goose	10	800	599

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 UT to Rapidan River (VAN-E13R-04) watershed that nonpoint source loadings to the land surface are more than 192 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 UT to Rapidan River (VAN-E13R-04) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	722	0.33
Cattle in Stream	223	0.10
Wildlife in Stream	203	0.09
<i>Loading to Land Surfaces</i>		
Cropland	8	0.00
Pasture 1	162,918	73.41
Pasture 2	40,955	18.45
Pasture 3	10,316	4.65
Forest	820	0.37
Residential*	5,763	2.60
Total	221,928	100.00

*Includes loads received from failed septic systems and pets.

3.5 Rapidan River (VAN-E13R-02) Sources

3.5.1 Humans and Pets

There are 1,199 homes served by municipal sanitary sewer in the Rapidan River (VAN-E13R-02) watershed. Wastewater from 3,572 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rapidan River (VAN-E13R-02) watershed has an estimated population of 13,127 people (4,846 households at an average of 2.71 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce 1.95×10^{13} cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of 2.56×10^{13} cfu/day (9.34×10^{15} cfu/year) in Rapidan River (VAN-E13R-02) 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.

3.5.1.1 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 Rapidan River (VAN-E13R-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 2.71 persons/household was 5.25×10^9 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 117 houses that potentially could be classified as straight pipes in the Rapidan River (VAN-E13R-02) watershed (Table 3.36).

3.5.1.3 Biosolids

According to VDH records; 1,3261;18,198; 10,896; 5,608; 14,521; and 7,478 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Orange County. In Greene County; 5,520; 5,158; and 3,367 dry tons of Class B biosolids were applied in 2003, 2004, and 2005, respectively. 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 Rapidan River (VAN-E13R-02) watershed were not available. To estimate biosolids applications within each Rapidan River (VAN-E13R-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 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 2.0×10^6 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. A sample collected by VDH and tested in 2006 The fecal coliform density of biosolids from Blue Plains from a sample collected by VDH and tested 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 Rapidan River (VAN-E13R-02) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
URR-01	42
URR-02	200
URR-03	405
URR-04	396
URR-05	1,791
URR-06	615
URR-09	726
URR-10	421
URR-15	1,731
URR-16	263
URR-17	99
URR-19	185
Total	6,874

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 2,568 dogs and 2,908 cats were projected to reside in the Rapidan River (VAN-E13R-02) watershed. 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 4,888 for Rapidan River (VAN-E13R-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 Rapidan River (VAN-E13R-02) watershed is 72.2×10^{12} cfu/day (8.0×10^{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 sewerred houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rapidan River (VAN-E13R-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 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
URR-1	311	9	48	36	38	28	8	139
URR-2	129	0	61	5	0	25	5	71
URR-3	437	4	169	23	0	72	22	218
URR-4	1,065	77	291	67	22	130	15	472
URR-5	3,648	347	631	207	130	298	9	1,324
URR-6	1,593	37	296	103	86	142	3	525
URR-9	888	6	241	40	18	105	12	317
URR-10	493	2	110	36	32	52	2	182
URR-15	3,561	560	559	92	13	242	38	1,262
URR-16	446	31	70	29	30	35	2	162
URR-17	216	64	26	0	0	10	1	91
URR-19	339	62	63	0	0	26	0	125
Total	13,126	1,199	2,565	638	369	1,165	117	4,888

^aCalculated from average of 1.0 pet per household.

3.5.3 Livestock Sources

In the Rapidan River (VAN-E13R-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 Rapidan River (VAN-E13R-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.

3.5.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the Rapidan River (VAN-E13R-02) watershed. Based on information provided, it was determined that there were 2,580 milk cows, 1,292 dry cows, and 1,292 heifers on the farm. 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 Rapidan River (VAN-E13R-02) watershed (7,069 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 Rapidan River (VAN-E13R-02) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
URR-01	0	0	44
URR-02	0	0	223
URR-03	0	0	460
URR-04	0	0	348
URR-05	120	1	1,756
URR-06	871	2	567
URR-09	2,671	2	765
URR-10	551	2	456
URR-15	700	3	1,887
URR-16	251	1	256
URR-17	0	0	104
URR-19	0	0	203
Total	5,164	11	7,069

^aConsists 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 Rapidan River (VAN-E13R-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 3.39 for dairy cattle and in Table 3.40 for beef cattle.

Table 3.39. Distribution of the dairy cattle^a population in the Rapidan River (VAN-E13R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream ^b	Loafing ^c
January	2451.80	2064.93	517.14	129.28	0.85	0.00
February	2451.80	2064.93	517.14	129.28	0.85	0.00
March	1032.00	3145.40	787.73	196.93	1.94	0.00
April	774.00	3341.28	836.78	209.20	2.74	0.00
May	774.00	3340.23	836.52	209.13	4.12	0.00
June	774.00	3336.05	835.47	208.87	9.60	0.00
July	774.00	3336.05	835.47	208.87	9.60	0.00
August	774.00	3336.05	835.47	208.87	9.60	0.00
September	774.00	3340.23	836.52	209.13	4.12	0.00
October	774.00	3341.28	836.78	209.20	2.74	0.00
November	1032.00	3145.40	787.73	196.93	1.94	0.00
December	2451.80	2064.93	517.14	129.28	0.85	0.00

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.40. Distribution of the beef cattle population (pairs) in the Rapidan River (VAN-E13R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	3251.74	3713.56	930.02	232.50	1.52	0.00
February	3817.26	4359.40	1091.76	272.94	1.79	0.00
March	0.00	7479.78	1873.22	468.30	4.61	0.00
April	0.00	7693.82	1926.82	481.71	6.32	0.00
May	0.00	7906.56	1980.10	495.03	9.74	0.00
June	0.00	8111.54	2031.44	507.86	23.35	0.00
July	0.00	8326.42	2085.25	521.31	23.97	0.00
August	0.00	8541.29	2139.06	534.77	24.59	0.00
September	0.00	8767.14	2195.62	548.91	10.80	0.00
October	0.00	5380.29	1347.43	336.86	4.42	0.00
November	0.00	5650.19	1415.02	353.76	3.48	0.00
December	3110.36	3552.11	889.58	222.40	1.46	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 both dairy (Table 3.39) and 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 Rapidan River (VAN-E13R-02) watersheds is 352,171 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 4.07×10^{11} cfu/day (1.49×10^{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

Dairy (Table 3.39) and 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 Rapidan River (VAN-E13R-02) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 11,059; 5,531; and 2,762 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 Rapidan River (VAN-E13R-02), averaged over the year, are 4.67×10^{12} , 2.35×10^{11} , and 1.16×10^{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.

3.5.3.4 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 Rapidan River (VAN-E13R-02) watershed is 68,853,941 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 1,038.6 acres of cropland and 0.0 acres of pasture 1 in the Rapidan River (VAN-E13R-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 3.41. Dry cows and heifers were assumed to produce only solid manure.

Table 3.41. Schedule of cattle waste application in Rapidan River (VAN-E13R-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.

3.5.3.5 Land Application of Poultry Litter

Poultry litter produced by chickens and turkeys during confinement is collected for land application. The main considerations for the poultry operations are the total number of birds produced in a given cycle, the number of cycles per year, and the amount of time between cycles during which the poultry house is empty. Based on these factors, the amount of poultry litter produced in each watershed was estimated along with the bacteria content of the litter (Table 3.46). Poultry litter is applied at the rate of 6,000 lb/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid and solid manure, poultry litter is only applied to cropland during February through May and the months of October and November.

Poultry litter can be applied to pasture during the whole year except during December and January. The application schedule for poultry litter is given in Table 3.41. Based on availability of land and poultry litter, as well as the assumptions regarding application rate, 571.3 acres of the cropland and 289.6 acres of the pasture 1 in Rapidan River (VAN-E13R-02) watershed received poultry litter application.

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3.5.3.6 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 3.42.

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 3.42). 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 3.42). 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 3.41. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 718.3 acres of the cropland and 123.4 acres of the pasture 1 in Rapidan River (VAN-E13R-02) received solid manure application.

Table 3.42. 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 Rapidan River (VAN-E13R-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	1,292	1,400	115.0	2.17	4.43
Heifer	1,292	640	40.7	2.17	
Beef (pairs)	7,069	1,000	60.0	5.50	

^aSource: BSE (2003)

3.5.4 Horses

The estimated number of horses in the Rapidan River (VAN-E13R-02) watershed is included in Table 3.43. 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 Rapidan River (VAN-E13R-02) watershed is 5.23×10^{11} cfu/day (1.91×10^{14} cfu/year).

Table 3.43. Horse population by subwatershed in the Rapidan River (VAN-E13R-02) watershed.

Subwatershed	Horses
URR-01	10
URR-02	51
URR-03	104
URR-04	43
URR-05	202
URR-06	47
URR-09	160
URR-10	98
URR-15	409
URR-16	56
URR-17	22
URR-19	42
Total	1,244

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 Rapidan River (VAN-E13R-02) 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 3.46. The total wildlife fecal coliform production each year in the Rapidan River (VAN-E13R-02) watershed, is 1.20×10^{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 3.44).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.44). 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 3.44, 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 3.45.

Table 3.44. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rapidan River (VAN-E13R-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 3.45. Distribution of wildlife among sub-watersheds in Rapidan River (VAN-E13R-02) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
URR-01	476	248	102	28	54	28	47
URR-02	194	155	2392	18	24	11	116
URR-03	560	409	857	47	58	35	33
URR-04	825	553	597	62	112	39	106
URR-05	1207	985	2551	110	152	70	86
URR-06	325	301	840	33	45	16	25
URR-09	375	407	1128	45	60	21	30
URR-10	143	166	566	20	27	10	9
URR-15	984	854	395	94	138	48	65
URR-16	123	112	118	13	17	6	6
URR-17	45	37	157	5	7	3	3
URR-19	103	99	0	12	14	5	7
Total	5360	4326	9703	487	708	292	533

3.5.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rapidan River (VAN-E13R-02) watershed along with average fecal coliform production rates are shown in Table 3.46. The total fecal coliform production by all sources in the Rapidan River (VAN-E13R-02) watershed is 1.64×10^{17} cfu/yr.

Table 3.46. Potential fecal coliform sources and daily fecal coliform production by source in Rapidan River (VAN-E13R-02) 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			
<i>Milk and Dry Cows</i>	3872	25,000	9,686,630
<i>Heifers</i>	1292	8,800	1,477,583
Beef Cattle (pairs)	7069	33,000	31,539,530
Horses	1244	420	52,284
Turkey	12,000	93	511,850
Humans	13126	1,950	686,466
Pets	4888	450	220,111
Deer	5360	350	187,728
Raccoon	4326	50	21,645
Muskrat	9703	25	19,271
Beaver	487	0.2	10
Wild Turkey	533	93	4,030
Duck	292	2,400	52,827
Goose	708	800	42,483

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 3.47. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.47.

From Table 3.47, it is clear in the Rapidan River (VAN-E13R-02) watershed that nonpoint source loadings to the land surface are more than 257 times as large as direct loadings to the streams, with pastures receiving about 84% 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 3.47. Annual fecal coliform loadings to the stream and the various land use categories in the Rapidan River (VAN-E13R-02) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	21,942	0.15
Cattle in Stream	14,851	0.10
Wildlife in Stream	11,947	0.08
<i>Loading to Land Surfaces</i>		
Cropland	85,598	0.60
Pasture 1	10,442,557	73.33
Pasture 2	2,627,936	18.45
Pasture 3	650,535	4.57
Forest	76,964	0.54
Residential*	308,958	2.17
Total	14,241,290	100.00

*Includes loads received from failed septic systems and pets.

3.6 Cedar Run (VAN-E16R-01) Sources

3.6.1 Humans and Pets

There are 77 homes served by municipal sanitary sewer in the Cedar Run (VAN-E16R-01) watershed. Wastewater from 398 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Cedar Run (VAN-E16R-01) watershed has an estimated population of 2,066 people (471 households at an average of 4.39 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 4.03×10^{12} cfu/day (1.47×10^{15} cfu/year) in Cedar Run (VAN-E16R-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.

3.6.1.1 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 Cedar Run (VAN-E16R-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 4.39 persons/household was 8.55×10^9 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 3.49.

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 6 houses that potentially could be classified as straight pipes in the Cedar Run (VAN-E16R-01) watershed (Table 3.49).

3.6.1.3 Biosolids

According to VDH records; 33,550; 16,332; 15,180; 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 Culpepper County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Cedar Run (VAN-E16R-01) watershed were not available. To estimate biosolids applications within each Cedar Run (VAN-E16R-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. A sample collected by VDH and tested in 2006 The fecal coliform density of biosolids from Blue Plains from a sample collected by VDH and tested 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 3.48 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 and 4.2 for location of subwatersheds).

Table 3.48. Estimated average annual biosolids application amount for each subwatershed in the Cedar Run (VAN-E16R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
LRR-01	1,333
LRR-02	37
LRR-07	110
LRR-08	2,262
LRR-09	1,364
LRR-10	790
LRR-11	707
LRR-12	263
LRR-13	36
LRR-14	59
LRR-15	147
Total	7,108

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 250 dogs and 283 cats were projected to reside in the Cedar Run (VAN-E16R-01) watershed. 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 480 for Cedar Run (VAN-E16R-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 Cedar Run (VAN-E16R-01) watershed is 2.1×10^{11} cfu/day (7.7×10^{13} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.49. 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 3.49. Estimated human population, number of sewerred houses, number of unsewerred houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Cedar Run (VAN-E16R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewerred Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population ^a
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
LRR-03	1,298	77	145	102	35	79	3	361
LRR-04	607	0	77	14	0	33	3	94
LRR-05	136	0	18	3	0	8	0	21
LRR-06	24	0	3	1	0	1	0	4
Total	2,065	77	243	120	35	121	6	480

^aCalculated from average of 1.0 pet per household.

3.6.3 Livestock Sources

In the Cedar Run (VAN-E16R-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 Cedar Run (VAN-E16R-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.

3.6.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are three dairy operations presently operating in the Cedar Run (VAN-E16R-01) watershed. Based on information provided, it was determined that there were 695 milk cows, 348 dry cows, and 348 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.50). Beef cattle in the Cedar Run (VAN-E16R-01) watershed (972 pairs) included cow/calf and feeder operations (Table 3.50).

Table 3.50. Distribution of beef cattle among subwatersheds in Cedar Run (VAN-E16R-01) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
LRR-03	1,391	3	490
LRR-04	0	0	440
LRR-05	0	0	39
LRR-06	0	0	3
Total	1,391	3	972

^aConsists 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 3.51.
- 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 3.51). 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 3.51. Time spent by cattle in confinement and in the stream in Cedar Run (VAN-E16R-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 3.52 for dairy cattle and in Table 3.52 for beef cattle.

Table 3.52. Distribution of the dairy cattle^a population in the Cedar Run (VAN-E16R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream ^b	Loafing ^c
January	799.65	450.22	112.75	28.19	0.18	0.00
February	799.65	450.22	112.75	28.19	0.18	0.00
March	278.00	847.25	212.18	53.05	0.52	0.00
April	208.50	900.01	225.40	56.35	0.74	0.00
May	208.50	899.73	225.33	56.33	1.11	0.00
June	208.50	898.61	225.05	56.26	2.59	0.00
July	208.50	898.61	225.05	56.26	2.59	0.00
August	208.50	898.61	225.05	56.26	2.59	0.00
September	208.50	899.73	225.33	56.33	1.11	0.00
October	208.50	900.01	225.40	56.35	0.74	0.00
November	278.00	847.25	212.18	53.05	0.52	0.00
December	799.65	450.22	112.75	28.19	0.18	0.00

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.53. Distribution of the beef cattle population (pairs) in the Cedar Run (VAN-E16R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	851.04	213.13	53.28	0.35	0.00
February	0.00	999.04	250.20	62.55	0.41	0.00
March	0.00	1028.48	257.57	64.39	0.63	0.00
April	0.00	1057.91	264.94	66.24	0.87	0.00
May	0.00	1087.17	272.27	68.07	1.34	0.00
June	0.00	1115.35	279.33	69.83	3.21	0.00
July	0.00	1144.90	286.73	71.68	3.30	0.00
August	0.00	1174.44	294.12	73.53	3.38	0.00
September	0.00	1205.50	301.90	75.48	1.49	0.00
October	0.00	739.80	185.27	46.32	0.61	0.00
November	0.00	776.91	194.57	48.64	0.48	0.00
December	0.00	814.03	203.87	50.97	0.33	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 both dairy (Table 3.52) and beef cattle (Table 3.53) 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 Cedar Run (VAN-E16R-01) watersheds is 67,123 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 6.82×10^{10} cfu/day (2.49×10^{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

Dairy (Table 3.52) and beef (Table 3.53) 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 Cedar Run (VAN-E16R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 9,262; 4,632; and 2,314 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 Cedar Run (VAN-E16R-01), averaged over the year, are 3.50×10^{12} , 1.76×10^{12} , and 8.76×10^{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.

3.6.3.4 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 Cedar Run (VAN-E16R-01) watershed is 18,547,865 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 279.8 acres of cropland and 0.0 acres of pasture 1 in the the Cedar Run (VAN-E16R-01) 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 3.54. Dry cows and heifers were assumed to produce only solid manure.

Table 3.54. Schedule of cattle waste application in the Cedar Run (VAN-E16R-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.

3.6.3.5 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 3.55.

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 3.55). 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 3.55). 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 3.54. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 81.5 acres of the cropland and 0.0 acres of the pasture 1 in the Cedar Run (VAN-E16R-01) received solid manure application.

Table 3.55. 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 the Cedar Run (VAN-E16R-01) watershed.

Type of Cattle	Population	Typical Weight (lb) ^a	Solid Manure Produced (lb/animal-day) ^a	Fecal Coliform Concentration in Fresh Manure ($\times 10^8$ cfu/lb) ^a	Weighted Average Fecal Coliform Concentration in Fresh Manure ($\times 10^8$ cfu/lb)
Dry Cow	348	1,400	115.0	2.17	3.90
Heifer	348	640	40.7	2.17	
Beef (pairs)	972	1,000	60.0	5.50	

^aSource: BSE (2003)

3.6.4 Horses

The estimated number of horses in the Cedar Run (VAN-E16R-01) watershed is included in Table 3.56. 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 Cedar Run (VAN-E16R-01) watershed is 1.26×10^{11} cfu/day (4.60×10^{13} cfu/year).

Table 3.56. Horse population by subwatershed in the Cedar Run (VAN-E16R-01) watershed.

Subwatershed	Horses (#)
LRR-03	151
LRR-04	136
LRR-05	12
LRR-06	1
Total	300

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 Cedar Run (VAN-E16R-01) 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 3.59. The total wildlife fecal coliform production each year in the Cedar Run (VAN-E16R-01) watershed, is 1.87×10^{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 3.57).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.57). 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 3.57, 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 foot 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 3.58.

Table 3.57. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Cedar Run (VAN-E16R-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	0.006 ^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 3.58. Distribution of wildlife among sub-watersheds in Cedar Run (VAN-E16R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
LRR-03	416	304	1,052	34	43	27	13
LRR-04	317	193	775	22	44	16	16
LRR-05	71	44	80	5	9	4	7
LRR-06	14	14	3	2	2	1	2
Total	818	555	1,910	63	98	48	38

3.6.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Cedar Run (VAN-E16R-01) watershed along with average fecal coliform production rates are shown in Table 3.59. The total fecal coliform production by all sources in the Cedar Run (VAN-E16R-01) watershed is 2.78×10^{16} cfu/yr.

Table 3.59. Potential fecal coliform sources and daily fecal coliform production by source in Cedar Run (VAN-E16R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^7$ cfu/AU-day) ^a	Fecal Coliform Produced ($\times 10^7$ cfu/ day) ^b
Dairy Cattle			
Milk and Dry Cows	1,043	25,000	2,609,286
Heifers	348	8,800	397,987
Beef Cattle (pairs)	972	33,000	4,336,741
Horses	300	420	12,609
Humans	2065	1,950	123,208
Pets	480	450	21,592
Deer	818	350	28,650
Raccoon	555	50	2,777
Muskrat	1910	25	4,778
Beaver	63	0.2	1
Wild Turkey	38	93	354
Duck	48	2,400	8,745
Goose	98	800	5,910

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 3.60. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.60.

From Table 3.60, it is clear in the Cedar Run (VAN-E16R-01) watershed that nonpoint source loadings to the land surface are more than 363 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 3.60. Annual fecal coliform loadings to the stream and the various land use categories in the Cedar Run (VAN-E16R-01) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	2,319	0.09
Cattle in Stream	2,490	0.10
Wildlife in Stream	1,981	0.08
<i>Loading to Land Surfaces</i>		
Cropland	10,159	0.41
Pasture 1	1,820,139	73.69
Pasture 2	458,761	18.57
Pasture 3	114,180	4.62
Forest	9,398	0.38
Residential*	50,533	2.05
Total	2,469,960	100.00

*Includes loads received from failed septic systems and pets.

3.7 Rapidan River (VAN-E18R-01) Sources

3.7.1 Humans and Pets

There are 2,942 homes served by municipal sanitary sewer in the Rapidan River (VAN-E18R-01) watershed. Wastewater from 4,036 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Rapidan River (VAN-E18R-01) watershed has an estimated population of 19,754 people (6,526 households at an average of 3.03 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 3.85×10^{13} cfu/day (1.41×10^{16} cfu/year) in Rapidan River (VAN-E18R-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.

3.7.1.1 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 Rapidan River (VAN-E18R-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 2.63 persons/household was 5.12×10^9 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 3.62.

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 47 houses that potentially could be classified as straight pipes in the Rapidan River (VAN-E18R-01) watershed (Table 3.62).

3.7.1.3 Biosolids

According to VDH records; 13,261; 18,198; 10,896; 5,608; 14,521; and 7,478 dry tons of Class B biosolids were applied in 2000, 2001, 2002, 2003, 2004, and 2005, respectively, in Orange County. In Culpepper County; 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 Spotsylvania County; 7,141 and 5,811 dry tons of Class B biosolids were applied in 2004 and 2005. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Rapidan River (VAN-E18R-01) watershed were not available. To estimate biosolids applications within each Rapidan River (VAN-E18R-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 biosolids from Blue Plains from a sample collected by VDH and tested 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 3.61 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.61. Estimated average annual biosolids application amount for each subwatershed in the Rapidan River (VAN-E18R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
LRR-03	782
LRR-04	646
LRR-05	60
LRR-06	4
Total	1,492

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 United States (AVMA, 1997). Based on these densities and number of households in each watershed, 3,459 dogs and 3,916 cats were projected to reside in the Rapidan River (VAN-E18R-01) watershed. 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 7,023 for Rapidan River (VAN-E18R-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 Rapidan River (VAN-E18R-01) watershed is 2.9×10^{12} cfu/day (1.1×10^{15} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.62. 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 3.62. Estimated human population, number of sewerred houses, number of unsewerred houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Rapidan River (VAN-E18R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewerred Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population ^a
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
LRR-01	1,827	232	319	10	0	129	9	570
LRR-02	24	0	5	1	0	2	0	6
LRR-07	145	0	33	7	4	15	2	46
LRR-08	1,746	27	359	101	80	166	11	578
LRR-09	1,480	0	386	69	19	169	6	481
LRR-10	1,943	1	423	122	67	196	6	618
LRR-11	6,286	1,760	282	254	125	167	9	2,430
LRR-12	5,689	858	228	362	215	170	0	1,663
LRR-13	137	2	22	9	7	11	0	39
LRR-14	478	10	42	33	21	24	1	106
LRR-15	2,289	52	178	159	94	106	3	486
Total	22,044	2,942	2,277	1,127	632	1,155	47	7,023

^aCalculated from average of 1.0 pet per household.

3.7.3 Livestock Sources

In the Rapidan River (VAN-E18R-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 Rapidan River (VAN-E18R-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.

3.7.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there are 11 dairy operations presently operating in the Rapidan River (VAN-E18R-01) watershed. Based on information provided, it was determined that there were 1,940 milk cows; 971 dry cows; and 971 heifers distributed between the farms. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.63). Beef cattle in the Rapidan River (VAN-E18R-01) watershed (6,039 pairs) included cow/calf and feeder operations (Table 3.63).

Table 3.63. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Rapidan River (VAN-E18R-01) watersheds.

Subwatershed	Dairy Cattle ^a	No. of Dairy Operations	Beef Cattle (pairs)
LRR-01	0	0	1,223
LRR-02	0	0	29
LRR-07	0	0	97
LRR-08	1,851	6	1,546
LRR-09	500	1	1,395
LRR-10	451	2	832
LRR-11	0	0	618
LRR-12	1,080	2	231
LRR-13	0	0	25
LRR-14	0	0	43
LRR-15	0	0	111
Total	3,882	11	6,150

^aConsists 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 3.64.
- 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 3.64). 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 3.64. Time spent by cattle in confinement and in the stream in Rapidan River (VAN-E18R-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 3.65 for dairy cattle and in Table 3.66 for beef cattle.

Table 3.65. Distribution of the dairy cattle^a population in the Rapidan River (VAN-E18R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream ^b	Loafing ^c
January	2231.80	1256.38	314.64	78.66	0.52	0.00
February	2231.80	1256.38	314.64	78.66	0.52	0.00
March	776.00	2364.38	592.13	148.03	1.46	0.00
April	582.00	2511.67	629.02	157.25	2.06	0.00
May	582.00	2510.88	628.82	157.20	3.09	0.00
June	582.00	2507.74	628.03	157.01	7.22	0.00
July	582.00	2507.74	628.03	157.01	7.22	0.00
August	582.00	2507.74	628.03	157.01	7.22	0.00
September	582.00	2510.88	628.82	157.20	3.09	0.00
October	582.00	2511.67	629.02	157.25	2.06	0.00
November	776.00	2364.38	592.13	148.03	1.46	0.00
December	2231.80	1256.38	314.64	78.66	0.52	0.00

^aIncludes milk cows, dry cows, and heifers.

^bNumber of dairy cattle defecating in stream.

^cMilk cows in loafing lot.

Table 3.66. Distribution of the beef cattle population (pairs) in the Rapidan River (VAN-E18R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	5287.46	1324.18	331.04	2.17	0.00
February	0.00	6207.01	1554.47	388.62	2.55	0.00
March	0.00	6389.93	1600.28	400.07	3.93	0.00
April	0.00	6572.78	1646.07	411.52	5.40	0.00
May	0.00	6754.52	1691.59	422.90	8.32	0.00
June	0.00	6929.64	1735.44	433.86	19.95	0.00
July	0.00	7113.21	1781.42	445.35	20.48	0.00
August	0.00	7296.77	1827.39	456.85	21.00	0.00
September	0.00	7489.71	1875.71	468.93	9.23	0.00
October	0.00	4596.35	1151.10	287.78	3.77	0.00
November	0.00	4826.92	1208.84	302.21	2.97	0.00
December	0.00	5057.57	1266.61	316.65	2.08	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 3.65) and beef cattle (Table 3.66) 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 Rapidan River (VAN-E18R-01) watersheds is 290,202 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 3.45×10^{11} cfu/day (1.26×10^{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.

3.7.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.65) and beef (Table 3.66) 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 Rapidan River (VAN-E18R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 8,616; 4,310; and 2.151 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 Rapidan River (VAN-E18R-01), averaged over the year, are 3.83×10^{12} , 1.93×10^{12} , and 9.51×10^{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 Rapidan River (VAN-E18R-01) watershed is 51,773,901 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 739.2 acres of cropland and 70.7 acres of pasture 1 in the Rapidan River (VAN-E18R-01) 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 3.67. Dry cows and heifers were assumed to produce only solid manure.

Table 3.67. Schedule of cattle waste application in Rapidan River (VAN-E18R-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.

3.7.3.5 Land Application of Poultry Litter

Poultry litter produced by chickens and turkeys during confinement is collected for land application. The main considerations for the poultry operations are the total number of birds produced in a given cycle, the number of cycles per year, and the amount of time between cycles during which the poultry house is empty. Based on these factors, the amount of poultry litter produced in each watershed was estimated along with the bacteria content of the litter (Table 3.72). Poultry litter is applied at the rate of 6,000 lb/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid and solid manure, poultry litter is only applied to cropland during February through May and the months of October and November.

Poultry litter can be applied to pasture during the whole year except during December and January. The application schedule for poultry litter is given in Table 3.67. Based on availability of land and poultry litter, as well as the assumptions regarding application rate, 837.5 acres of the cropland and 0.0 acres of the pasture 1 in Rapidan River (VAN-E13R-02) watershed received poultry litter application.

3.7.3.6 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 3.68.

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 3.68). 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 3.68). 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 3.67. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 164.2 acres of the cropland and 63.2 acres of the pasture in Rapidan River (VAN-E18R-01) received solid manure application.

Table 3.68. 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 Rapidan River (VAN-E18R-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	971	1,400	115.0	2.17	4.52
Heifer	971	640	40.7	2.17	
Beef (pairs)	6,039	1,000	60.0	5.50	

^aSource: BSE (2003)

3.7.4 Horses

The estimated number of horses in the Rapidan River (VAN-E18R-01) watershed is included in Table 3.69. 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 Rapidan River (VAN-E18R-01) watershed is 5.89×10^{11} cfu/day (2.15×10^{14} cfu/year).

Table 3.69. Horse population by subwatershed in the Rapidan River (VAN-E18R-01) watershed.

Subwatershed	Horses
LRR-01	267
LRR-02	8
LRR-07	19
LRR-08	438
LRR-09	267
LRR-10	159
LRR-11	141
LRR-12	76
LRR-13	8
LRR-14	18
LRR-15	51
Total	1,452

3.7.5 Other Livestock Sources

Other minor livestock-related sources of bacteria (e.g., goats) were present during watershed visits; however, a significant population was not identified within the Rapidan River (VAN-E18R-01) 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 3.72. The total wildlife fecal coliform production each year in the Rapidan River (VAN-E18R-01) watershed, is 1.26×10^{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 3.70).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.70). 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 3.70, 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 3.71.

Table 3.70. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Rapidan River (VAN-E18R-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	0.042	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 3.71. Distribution of wildlife among sub-watersheds in Rapidan River (VAN-E18R-01) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
LRR-01	798	584	1,925	64	92	46	38
LRR-02	14	9	33	1	2	1	1
LRR-07	81	101	155	12	13	5	9
LRR-08	1,344	1,028	2,979	115	182	64	95
LRR-09	795	814	1,911	91	125	44	73
LRR-10	779	1,009	1,198	115	144	50	111
LRR-11	911	1,011	859	108	156	55	122
LRR-12	436	460	420	51	64	23	51
LRR-13	75	86	50	10	13	5	12
LRR-14	118	108	70	12	16	6	15
LRR-15	407	403	270	45	56	20	51
Total	5,758	5,613	9,870	624	863	319	578

3.7.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Rapidan River (VAN-E18R-01) watershed along with average fecal coliform production rates are shown in Table 3.72. The total fecal coliform production by all sources in the Rapidan River (VAN-E18R-01) watershed is 1.38×10^{17} cfu/yr.

Table 3.72. Potential fecal coliform sources and daily fecal coliform production by source in Rapidan River (VAN-E18R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^7$ cfu/AU-day) ^a	Fecal Coliform Produced ($\times 10^7$ cfu/ day) ^b
Dairy Cattle			
<i>Milk and Dry Cows</i>	2,911	25,000	7,282,485
<i>Heifers</i>	971	8,800	1,110,474
Beef Cattle (pairs)	6,150	33,000	26,944,012
Horses	1,452	420	58,882
Turkey	53,500	93	497,891
Humans	22,044	1,950	683,272
Pets	7,023	450	294,448
Deer	5,758	350	187,413
Raccoon	5,613	50	26,068
Muskrat	9,870	25	24,016
Beaver	624	0.2	12
Wild Turkey	578	93	4,904
Duck	319	2,400	54,024
Goose	863	800	48,392

^aSource: Keeling (2003) - Production per animal unit per species.

^bFecal 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 3.73. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.73.

From Table 3.73, it is clear in the Rapidan River (VAN-E18R-01) watershed that nonpoint source loadings to the land surface are more than 357 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 3.73. Annual fecal coliform loadings to the stream and the various land use categories in the Rapidan River (VAN-E18R-01) watershed.

Source	Fecal Coliform Loading ($\times 10^{10}$ cfu/year)	Percent of Total Loading (%)
<i>Direct Loading to Streams</i>		
Straight Pipes	9,790	0.08
Cattle in Stream	12,607	0.10
Wildlife in Stream	13,193	0.10
<i>Loading to Land Surfaces</i>		
Cropland	38,102	0.30
Pasture 1	9,317,083	73.08
Pasture 2	2,351,836	18.45
Pasture 3	579,494	4.55
Forest	80,332	0.63
Residential*	347,078	2.72
Total	12,749,514	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 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) 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 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) 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 Upper Rapidan River watershed is 157,000 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 19 subwatersheds as shown in Figure 4.1. Impaired segments of Marsh Run (VAN-E13R-03) include URR-07 and URR-08. Impaired segments of Blue Run (VAN-E13R-01) include URR-11 through URR-14. Impaired segment of Unnamed Tributary to the Rapidan River (VAN-E13R-04) includes URR-18. Conway River (URR-04) and unimpaired segments URR-01, URR-02, URR-03, URR-05, URR-06, URR-09, URR-10, and URR-15 drain into impaired segments URR-16, URR-17, and URR-19 of Rapidan River (VAN-E13R-02).

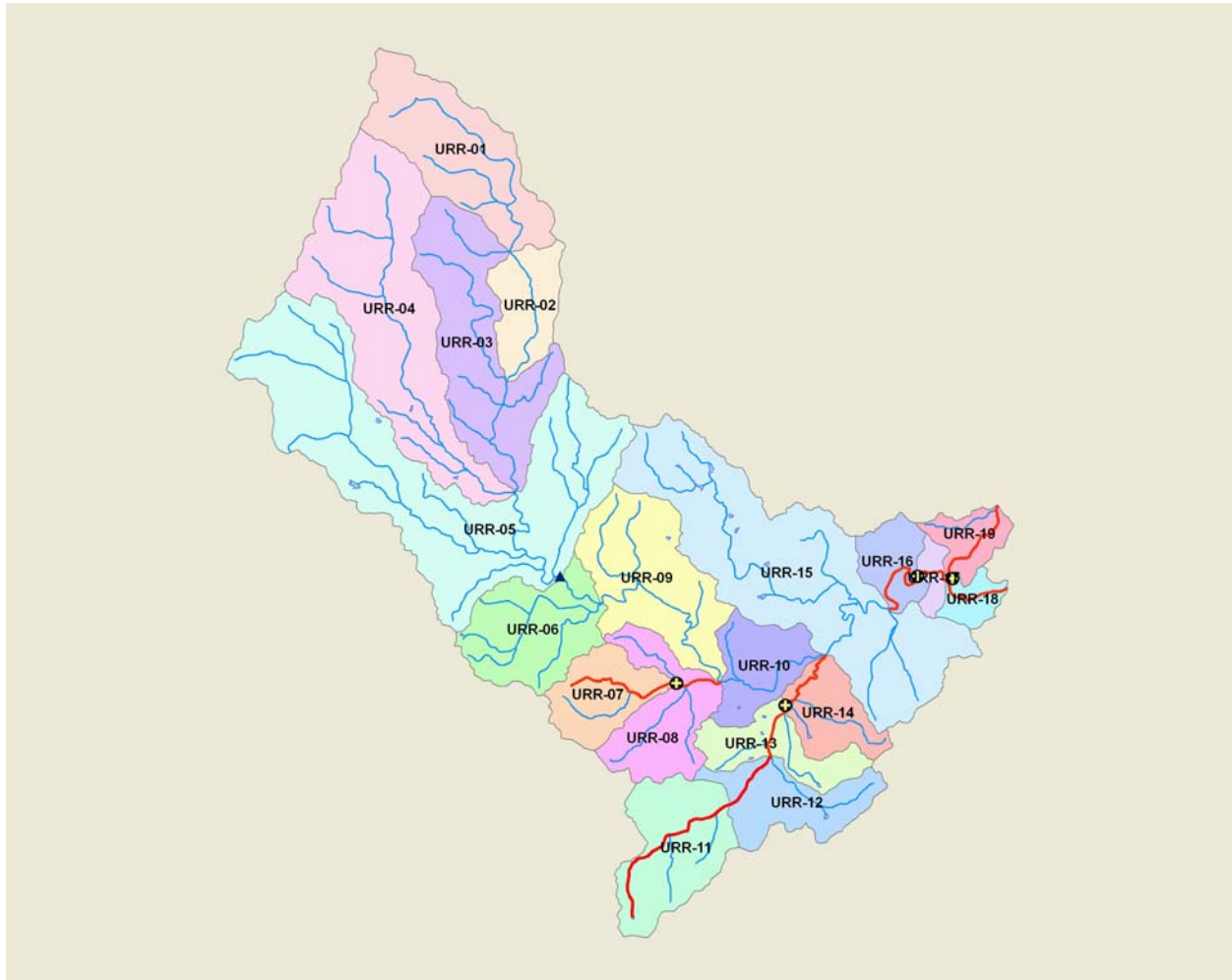


Figure 4.1. Upper Rapidan River subwatersheds.

The Lower Rapidan River watershed is 162,980 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 15 subwatersheds as shown in Figure 4.2. The unimpaired segment LRR-03 drains into the impaired segments LRR-04 through LRR-06 of Cedar Run (VAN-E16R-01). Mountain Run (LRR-09), Mine Run (LRR-10), and Wilderness Run (LRR-12) and unimpaired segments LRR-01, LRR-02, LRR-07, LRR-08, and LRR-11 drain into impaired segments LRR-13, and LRR-14 of Rapidan River (VAN-E18R-01).

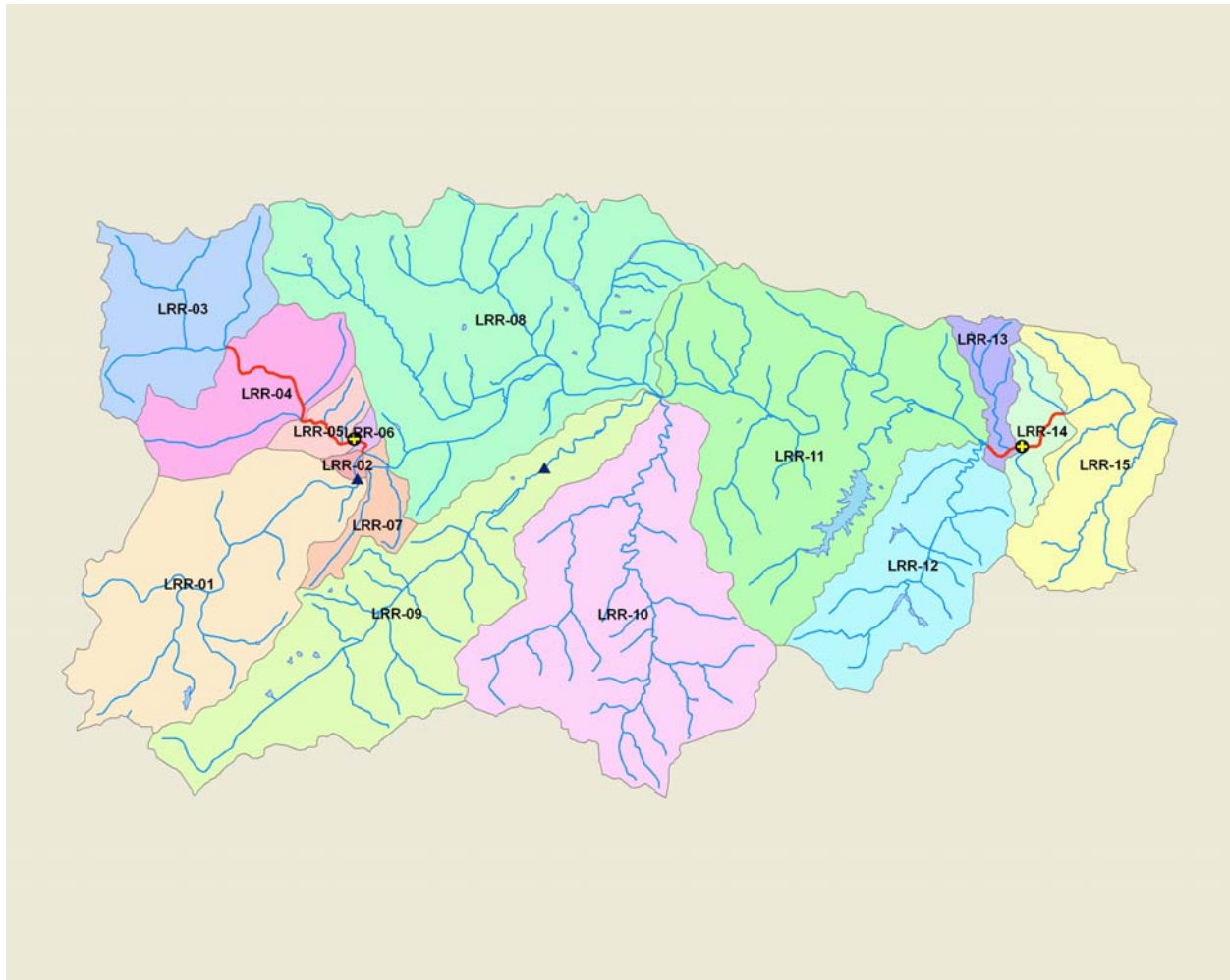


Figure 4.2. Lower Rapidan River subwatersheds.

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 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) 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 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) watersheds is presented in Tables 4.2 and 4.3.

Table 4.2. Land use distribution in Upper Rapidan River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
URR-1	52.8	137.4	68.8	34.4	139.0	1.0	9,916.4	10,349.9
URR-2	166.8	702.0	351.6	175.8	57.0	10.0	2,818.8	4,281.9
URR-3	292.0	1,450.2	726.3	363.2	196.0	26.5	9,064.4	12,118.6
URR-4	468.0	1,072.2	537.1	268.5	472.0	44.3	15,649.4	18,511.6
URR-5	999.8	5,404.8	2,707.1	1,353.6	1,324.0	203.4	15,939.6	27,932.4
URR-6	389.5	1,733.7	868.3	434.2	525.0	51.1	3,436.2	7,438.1
URR-7	57.2	404.4	202.5	101.3	206.0	39.2	3,548.0	4,558.5
URR-8	79.5	926.2	463.9	231.9	243.0	37.5	4,168.1	6,150.0
URR-9	654.8	2,433.3	1,218.8	609.4	318.0	145.8	4,491.3	9,871.2
URR-10	283.6	1,479.7	741.1	370.6	182.0	58.2	1,293.1	4,408.2
URR-11	78.7	1,235.4	618.8	309.4	279.0	43.2	5,061.2	7,625.6
URR-12	65.6	1,425.2	713.9	356.9	285.0	76.4	2,374.7	5,297.7
URR-13	222.9	1,240.3	621.2	310.6	198.0	111.7	1,425.5	4,130.2
URR-14	59.1	810.1	405.8	202.9	361.0	115.2	1,927.3	3,881.4
URR-15	1,188.4	6,100.3	3,055.5	1,527.8	1,262.0	194.8	9,407.1	22,735.9
URR-16	358.0	825.4	413.4	206.7	162.0	36.4	814.3	2,816.2
URR-17	68.7	342.5	171.6	85.8	81.0	13.4	265.8	1,028.7
URR-18	9.2	448.2	224.5	112.2	143.0	31.5	572.3	1,540.9
URR-19	82.1	668.3	334.7	167.4	128.0	15.3	924.8	2,320.7
Total	5,576.8	28,839.4	14,445.0	7,222.5	6,561.0	1,254.7	93,098.3	156,997.7

Table 4.3. Land use distribution in Lower Rapidan River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
LRR-1	546.4	4,727.4	2,367.8	1,183.9	559.0	283.1	7,938.3	17,606.0
LRR-2	10.4	135.5	67.8	33.9	4.0	0.0	42.9	294.5
LRR-3	630.0	2,623.5	1,314.1	657.0	361.0	96.8	3,354.4	9,036.9
LRR-4	186.4	2,358.7	1,181.4	590.7	87.0	119.5	2,635.7	7,159.3
LRR-5	37.0	207.1	103.7	51.9	19.0	2.5	1,183.8	1,605.1
LRR-6	0.6	14.6	7.3	3.7	4.0	0.0	269.4	299.6
LRR-7	135.7	336.5	168.5	84.3	46.0	0.0	1,375.5	2,146.5
LRR-8	1,703.1	7,642.8	3,828.1	1,914.0	578.0	17.7	14,467.3	30,150.9
LRR-9	637.5	4,771.7	2,390.0	1,195.0	482.0	36.7	11,078.6	20,591.6
LRR-10	220.7	2,846.4	1,425.7	712.8	619.0	8.8	17,943.3	23,776.7
LRR-11	326.3	2,488.5	1,246.4	623.2	2,429.0	600.9	18,085.2	25,799.4
LRR-12	175.6	1,008.7	505.3	252.6	1,663.0	108.2	6,873.4	10,586.8
LRR-13	6.5	136.8	68.5	34.2	39.0	19.2	1,803.8	2,108.0
LRR-14	16.6	238.3	119.3	59.7	106.0	22.3	2,073.3	2,635.4
LRR-15	38.9	623.4	312.2	156.1	486.0	106.5	7,463.8	9,187.0
Total	4,671.8	30,159.7	15,106.3	7,553.1	7,482.0	1,422.3	96,588.6	162,983.8

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 Upper Rapidan 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
URR-1	8.3	9	1	0.0435	2	0.038	0.110
URR-2	4.7	13	2	0.0077	2	0.038	0.110
URR-3	4.2	24	3	0.0042	3	0.038	0.110
URR-4	13.3	41	5	0.0276	3	0.038	0.110
URR-5	5.1	66	8	0.0012	4	0.038	0.110
URR-6	1.8	73	9	0.0017	4	0.038	0.110
URR-7	3.7	8	2	0.0052	2	0.038	0.110
URR-8	1.5	19	5	0.0004	2	0.038	0.110
URR-9	7.2	82	10	0.0024	4	0.038	0.110
URR-10	4.2	95	12	0.0003	4	0.038	0.110
URR-11	5.4	7	1	0.0208	2	0.038	0.110
URR-12	2.0	11	2	0.0041	4	0.038	0.110
URR-13	1.9	15	3	0.0017	6	0.038	0.110
URR-14	2.3	19	4	0.0008	6	0.038	0.110
URR-15	4.7	135	16	0.0020	3	0.038	0.110
URR-16	3.2	137	17	0.0008	3	0.038	0.110
URR-17	1.3	138	17	0.0014	3	0.038	0.110
URR-18	2.6	13	3	0.0127	5	0.038	0.110
URR-19	3.0	141	17	0.0018	3	0.038	0.110

^a Dimensionless.

Table 4.5. Stream channel characteristics used to calculate F-Tables in the Lower Rapidan 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
LRR-1	9.2	160	18	0.0037	3	0.038	0.110
LRR-2	0.7	165	19	0.0043	3	0.038	0.110
LRR-3	4.9	15	2	0.0077	6	0.038	0.110
LRR-4	3.2	27	4	0.0009	6	0.038	0.110
LRR-5	1.7	30	5	0.0008	3	0.038	0.110
LRR-6	0.6	30	5	0.0010	3	0.038	0.110
LRR-7	0.7	170	20	0.0008	5	0.038	0.110
LRR-8	8.4	185	22	0.0011	5	0.038	0.110
LRR-9	17.0	20	2	0.0048	3	0.038	0.110
LRR-10	13.7	25	3	0.0033	3	0.038	0.110
LRR-11	12.3	195	24	0.0006	5	0.038	0.110
LRR-12	9.0	15	3	0.0050	2	0.038	0.110
LRR-13	1.0	200	25	0.0014	5	0.038	0.110
LRR-14	1.5	205	26	0.0004	5	0.038	0.110
LRR-15	4.8	216	27	0.0021	5	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 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) 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), Big Meadows (440720), Madison (445150), Somerset (447904), Louisa (445050), 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 seven, 11, and 33 permitted point discharges located in the Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01), and Rapidan River (VAN-E18R-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 Upper Rapidan River and Lower Rapidan River 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 non-point source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint 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:

$$C_t = C_0 10^{-kt} \quad [4.1]$$

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 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) 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 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) 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 Upper Rapidan River

The Upper Rapidan River model was calibrated using observed flow values from USGS station #01665500 on Rapidan River near Ruckersville, VA for the period October 1, 1989 to September 30, 1994. The model was validated for the period October 1, 1994 to September 30, 1999. 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 (10/1/89 to 9/30/94) in Upper Rapidan River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	106.4	105.6	-0.8
Total of Highest 10% Flow Volume (in)	15	41.6	45.7	9.0
Total of Lowest 50% Flow Volume (in)	10	17.2	17.5	1.7
Total Winter Flow Volume (in)	20	37.9	38.4	1.3
Total Summer Flow Volume (in)	20	10.2	10.1	-1.0
Total Storm Volume (in)	20	98.1	100.8	2.7
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.77			

Table 4.8. Summary statistics for the validation period (10/1/94 to 9/30/99) in Upper Rapidan River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	20	71.2	79.8	10.8
Total of Highest 10% Flow Volume (in)	25	32.0	36.2	11.6
Total of Lowest 50% Flow Volume (in)	20	11.2	13.0	13.8
Total Winter Flow Volume (in)	30	18.7	18.8	0.5
Total Summer Flow Volume (in)	30	10.4	8.8	-18.2
Total Storm Volume (in)	30	65.5	76.3	14.2
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.66			

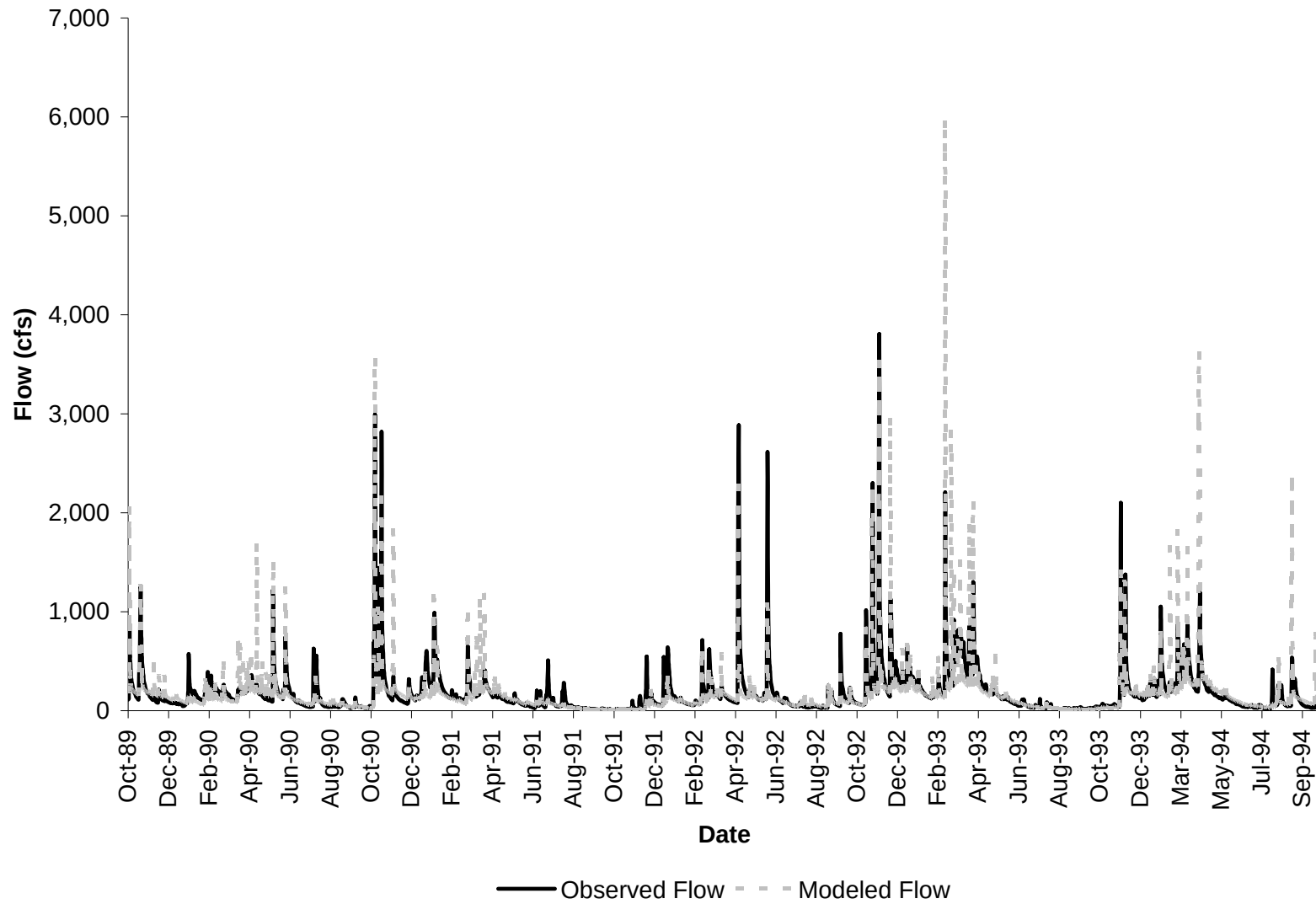


Figure 4.3. Observed and modeled flows for the calibration period 10/1/89 to 9/30/94 in Upper Rapidan River watershed.

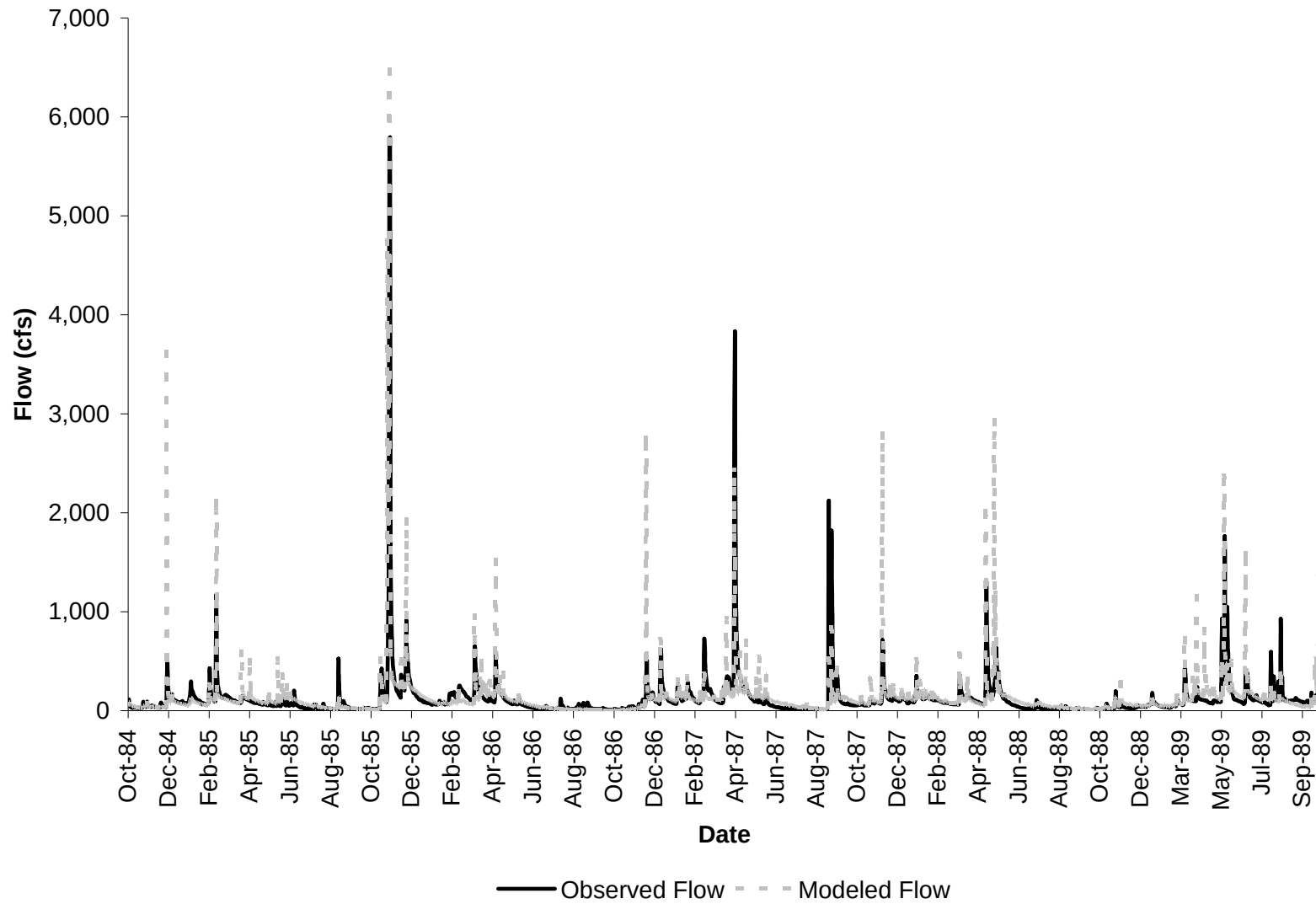


Figure 4.4. Observed and modeled flows for the validation period 10/1/94 to 9/30/99 in Upper Rapidan River watershed.

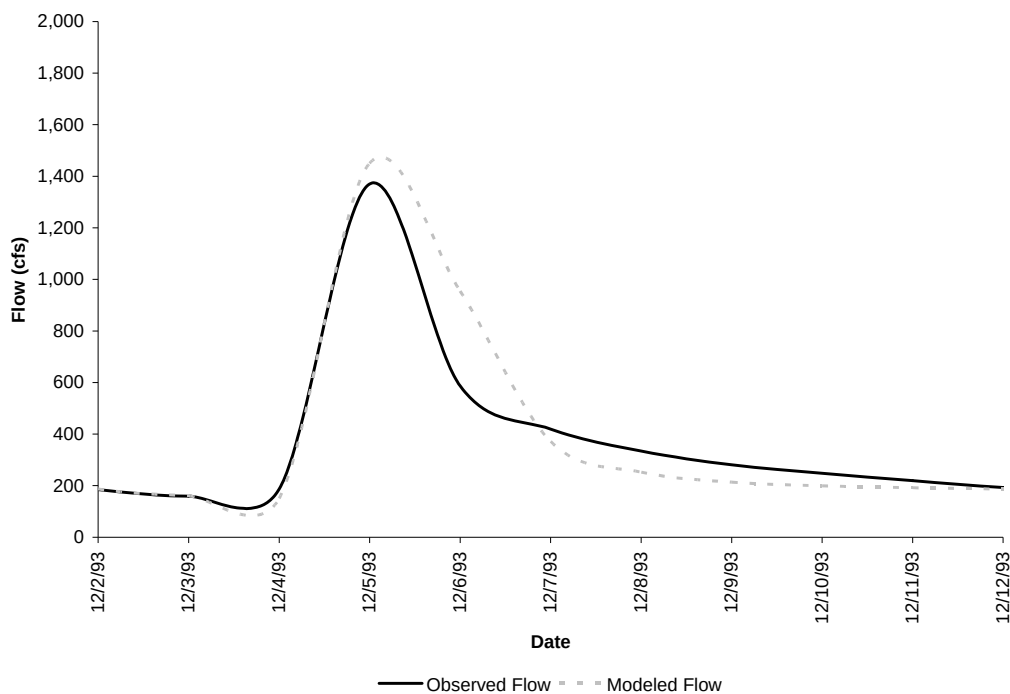


Figure 4.5. Observed and modeled flows for a representative storm (12/2/93-12/12/93) during the calibration period in Upper Rapidan River watershed.

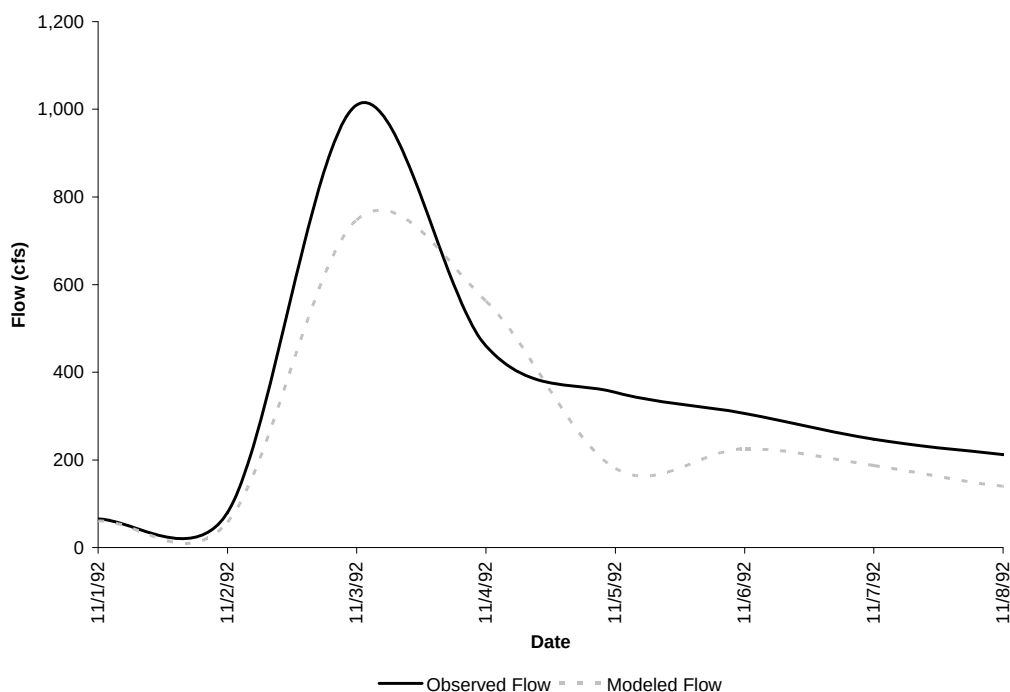


Figure 4.6. Observed and modeled flows for a representative storm (11/1/92-11/8/92) during the validation period in Upper Rapidan River watershed.

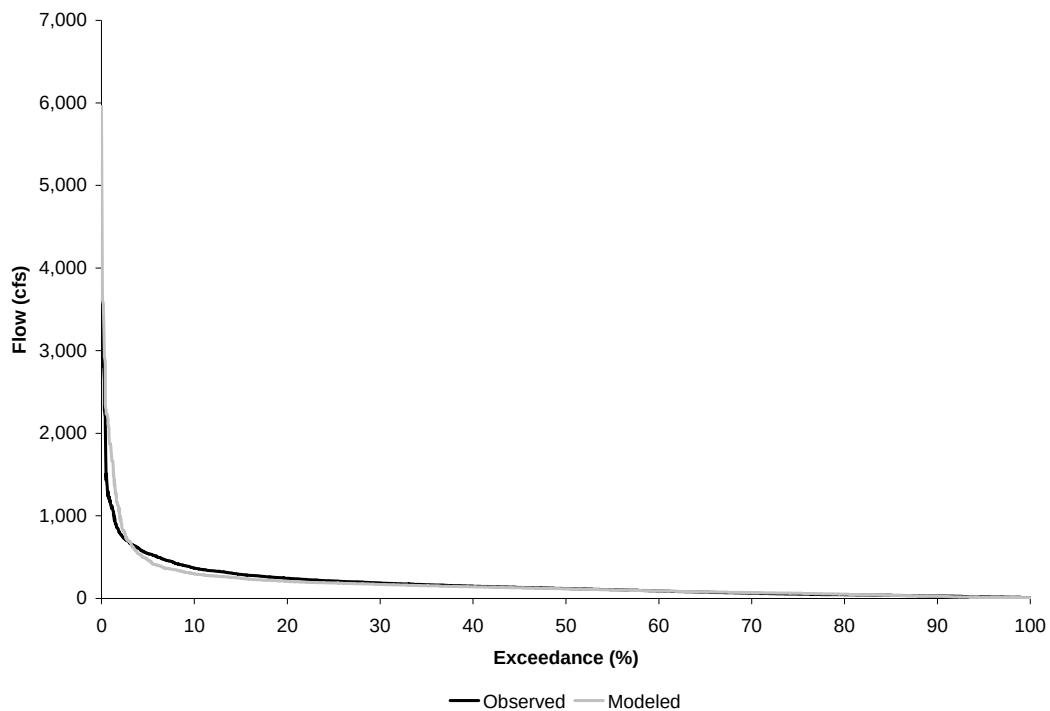


Figure 4.7. Cumulative frequency curves for the calibration period 10/1/89 to 9/30/94 in Upper Rapidan River watershed.

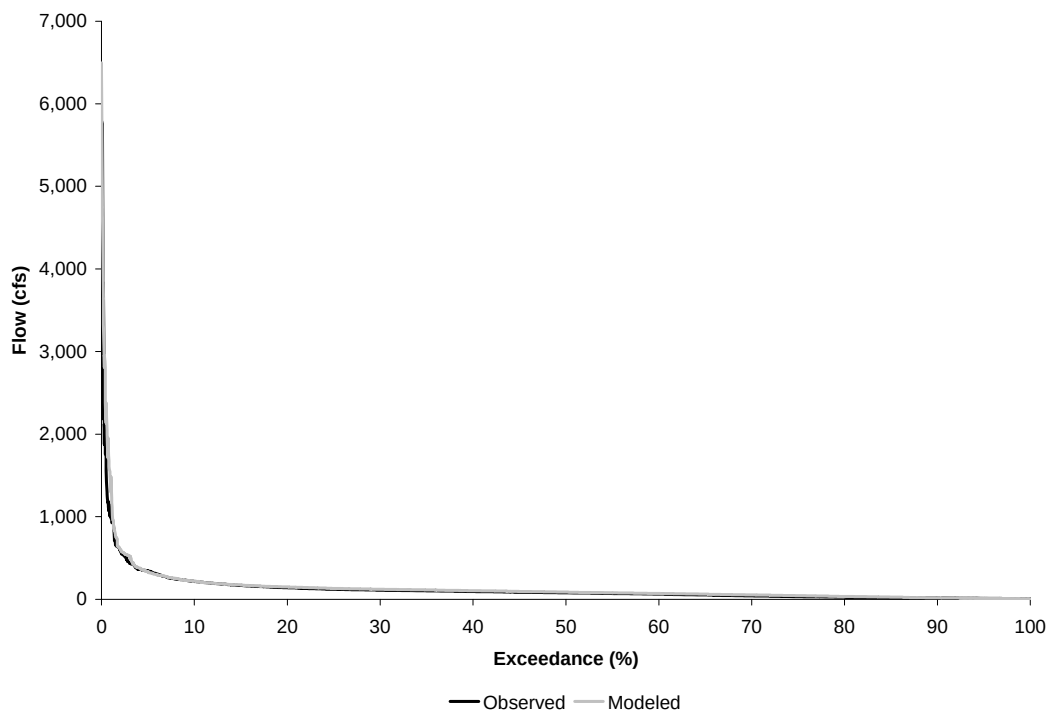


Figure 4.8. Cumulative frequency curves for the validation period 10/1/94 to 9/30/99 in Upper Rapidan River watershed.

Flow partitioning for Upper Rapidan River hydrologic model calibration and validation is shown in Table 4.9.

Table 4.9. Flow partitioning for the calibration and validation periods in Upper Rapidan River watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	66.5	50.2
Surface Runoff (in)	11.2 (16.9%)	9.9 (19.7%)
Interflow (in)	10.0 (15.1%)	6.8 (13.5%)
Baseflow (in)	45.3 (68.1%)	33.6 (66.8%)

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 Upper Rapidan 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 - 0.30	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	0.167-0.290	0.167-0.290	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
DEEPPFR	Fraction of groundwater inflow to deep recharge	none	0.0	0.2	0.0	0.5	0.0	0.0	Geology
BASETP	Fraction of remain ET from active baseflow	none	0.0	0.05	0.0	0.2	0.056	0.01	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	0.01 – 0.20	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 Upper Rapidan 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	0.00 1	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 Lower Rapidan River

The Lower Rapidan River model was calibrated using observed flow values from USGS station #01667500 on Rapidan River near Culpeper, Virginia for the period October 1, 1989 to September 30, 1994. The model was validated for the period October 1, 1994 to September 30, 1999. 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 (10/1/89 to 9/30/94) in Lower Rapidan River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	154.1	148.3	-3.9
Total of Highest 10% Flow Volume (in)	15	57.9	57.7	-0.3
Total of Lowest 50% Flow Volume (in)	10	25.9	27.5	5.8
Total Winter Flow Volume (in)	20	59.2	53.5	-10.7
Total Summer Flow Volume (in)	20	16.0	15.7	-1.9
Total Storm Volume (in)	20	139.2	137.9	-0.9
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.88			

Table 4.13. Summary statistics for the validation period (10/1/94 to 9/30/99) in Lower Rapidan River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	20	177.4	168.9	-5.0
Total of Highest 10% Flow Volume (in)	25	83.7	71.0	-17.9
Total of Lowest 50% Flow Volume (in)	20	23.3	27.9	16.5
Total Winter Flow Volume (in)	30	68.3	67.4	-1.3
Total Summer Flow Volume (in)	30	30.7	24.6	-24.8
Total Storm Volume (in)	30	168.6	160.6	-5.0
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.91			

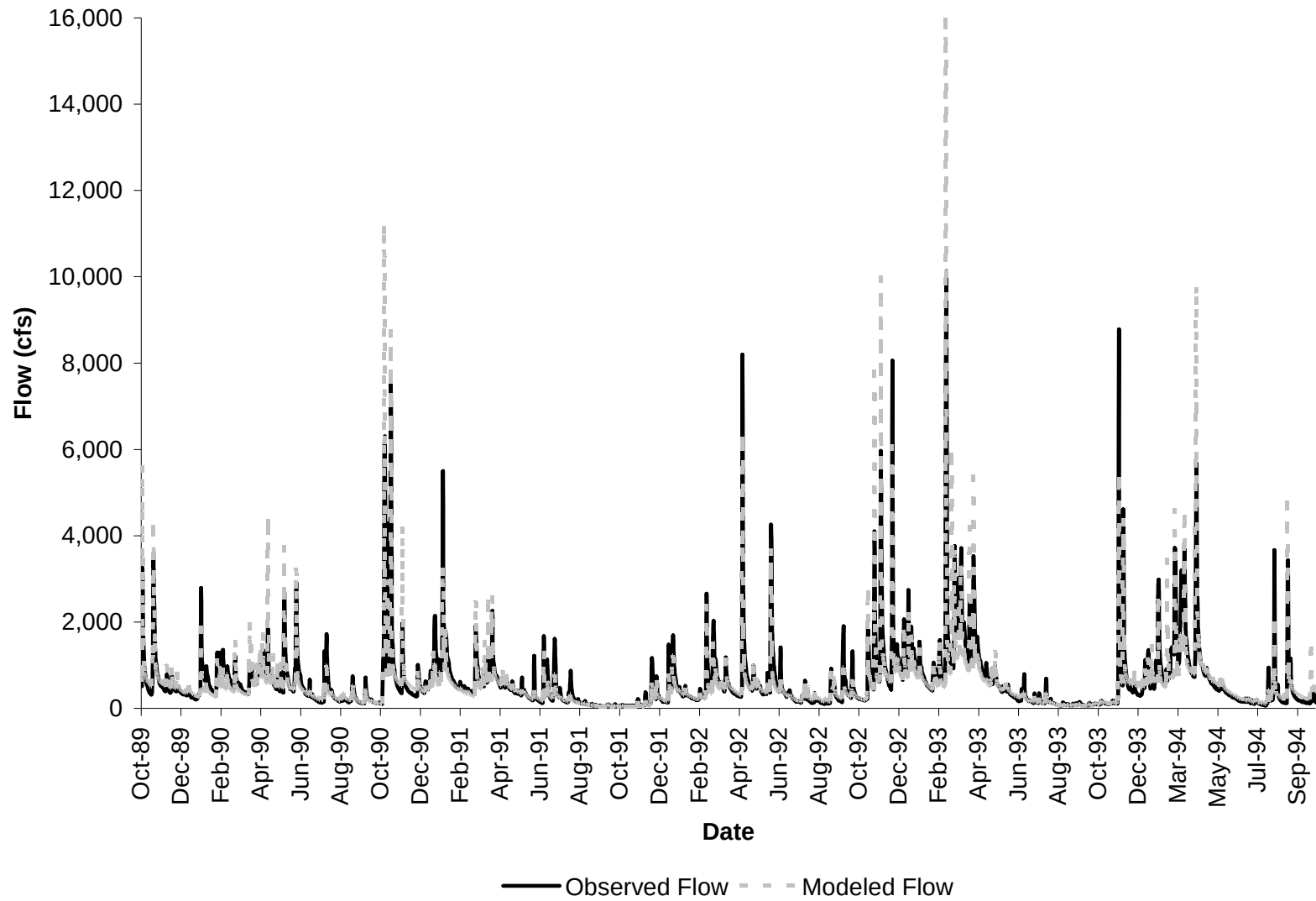


Figure 4.9. Observed and modeled flows for the calibration period 10/1/89 to 9/30/94 in Lower Rapidan River watershed.

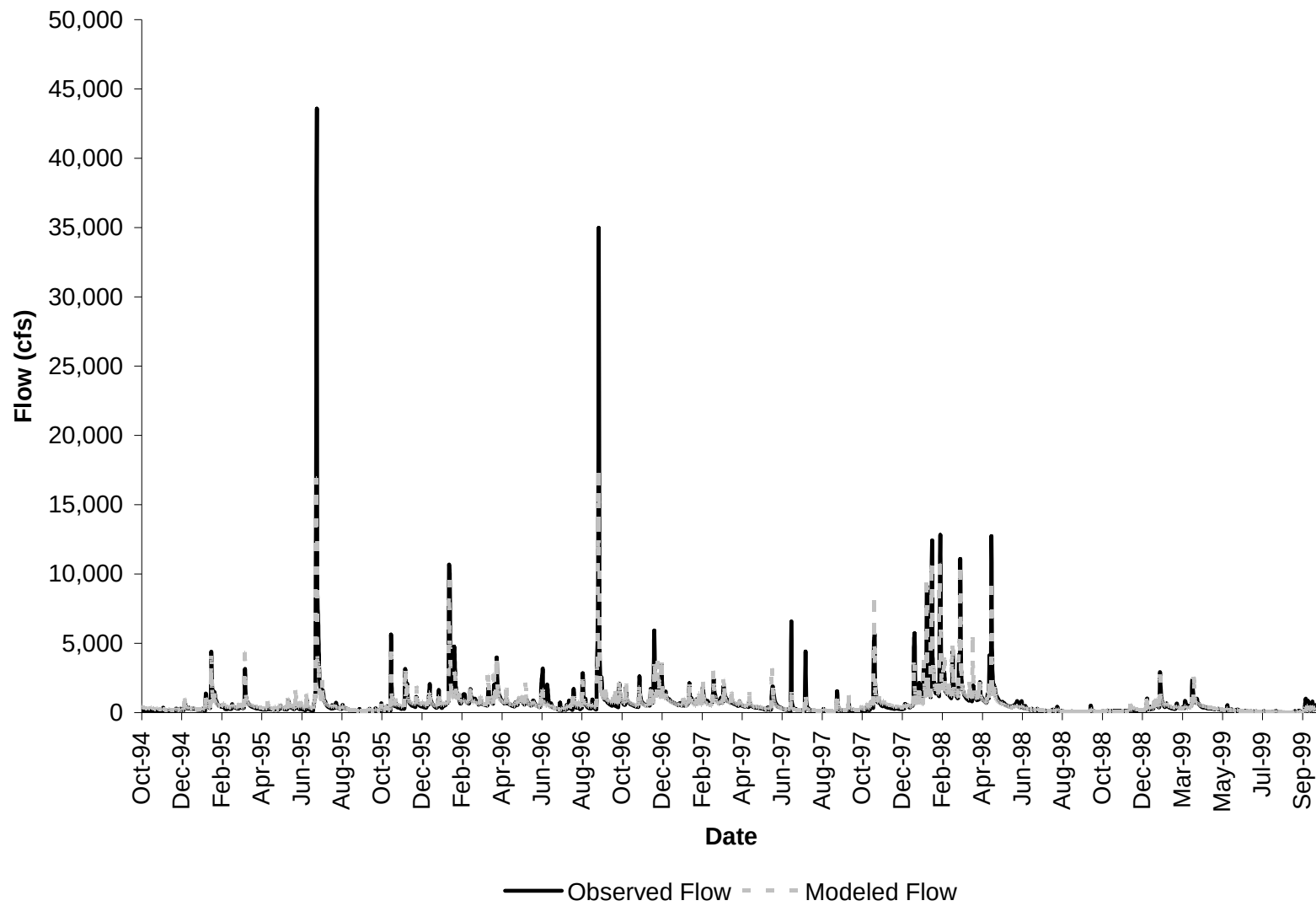


Figure 4.10. Observed and modeled flows for the validation period 10/1/94 to 9/30/99 in Lower Rapidan River watershed.

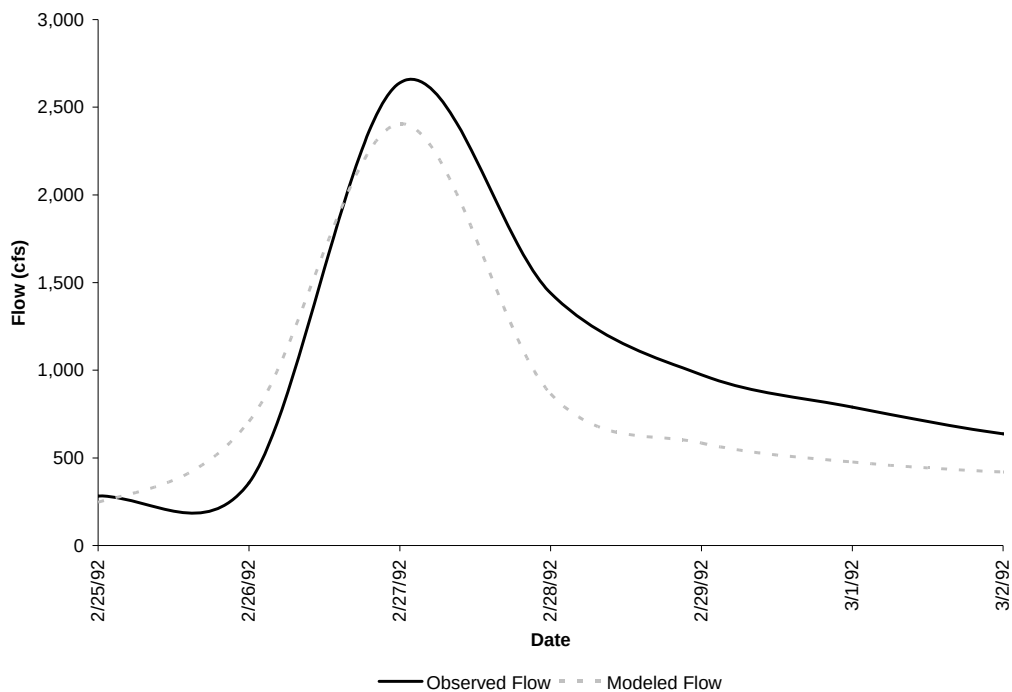


Figure 4.11. Observed and modeled flows for a representative storm (2/25/92-3/2/92) during the calibration period in Lower Rapidan River watershed.

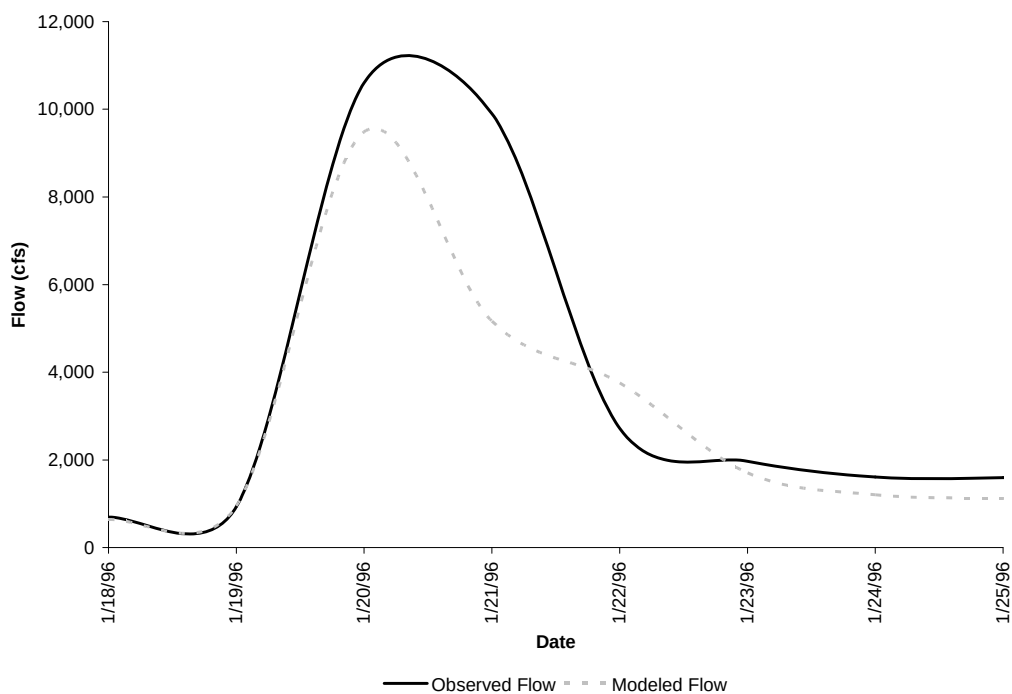


Figure 4.12. Observed and modeled flows for a representative storm (1/18/96-1/25/96) during the validation period in Lower Rapidan River watershed.

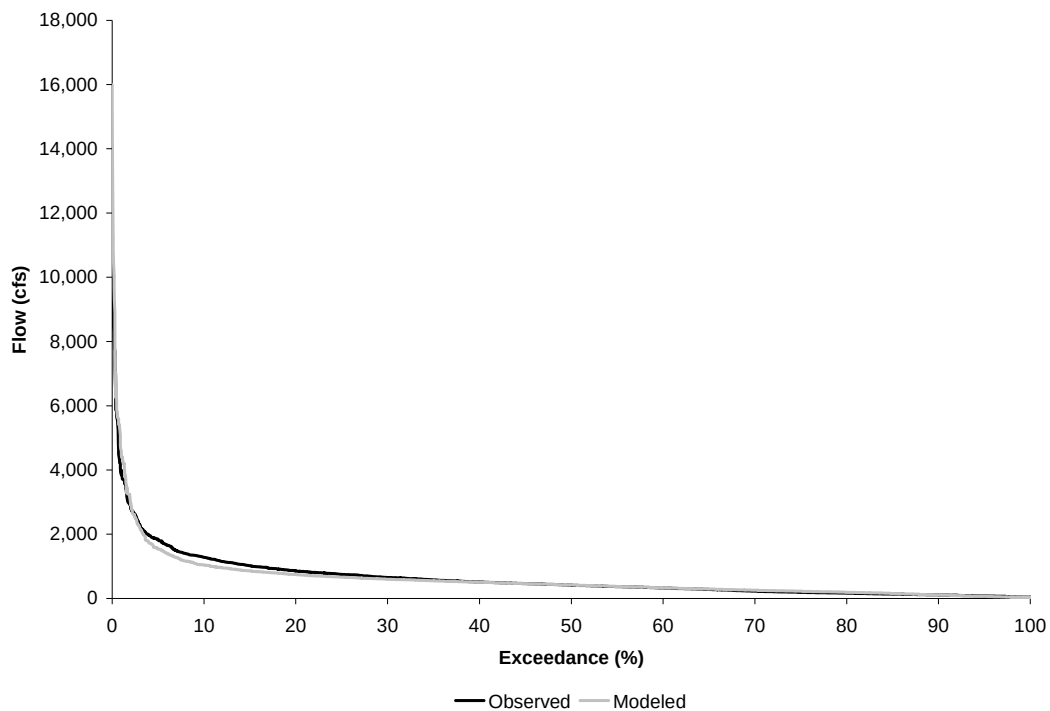


Figure 4.13. Cumulative frequency curves for the calibration period 10/1/89 to 9/30/94 in Lower Rapidan River watershed.

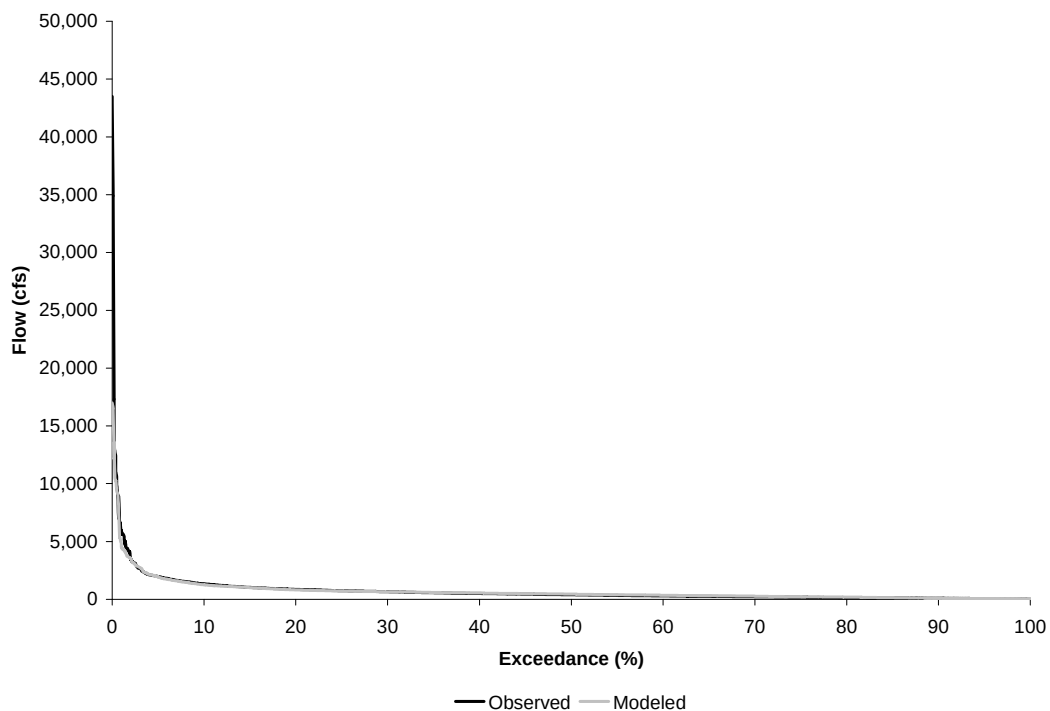


Figure 4.14. Cumulative frequency curves for the validation period 10/1/94 to 9/30/99 in Lower Rapidan River watershed.

Flow partitioning for Lower Rapidan River hydrologic model calibration and validation is shown in Table 4.14.

Table 4.14. Flow partitioning for the calibration and validation periods in Lower Rapidan River watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	65.8	64.0
Surface Runoff (in)	17.8 (27.1%)	18.0 (28.1%)
Interflow (in)	13.5 (20.5%)	13.7 (21.4%)
Baseflow (in)	34.5 (52.4%)	32.3 (50.5%)

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 Lower Rapidan 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	2.5 – 3.5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.21	0.03 - 0.15	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 - 0.207	0.033 - 0.207	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
DEEPR	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 Lower Rapidan 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	0.00 1	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 4.7.2.6).

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 laboratory 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 Marsh Run (VAN-E13R-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-MAS001.55 within the Marsh Run (VAN-E13R-03) 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-MAS001.55, were graphically compared to corresponding modeled concentrations at subwatershed URR-7 (Figure 4.15). 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. Table 4.18 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 4.18. A difference of one exceedance could result in a difference of exceedance rate of 33%. 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. Three observations were available for comparison during this period resulting in a 33% 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 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-E13R-03) watershed.

Table 4.17. Calibrated water quality HSPF parameters for Marsh Run (VAN-E13R-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	19E06-01E10	19E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-11E10	02E08-11E10	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	28E08-29E08	28E08-29E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	03E10-03E10	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	1.20	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	None	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

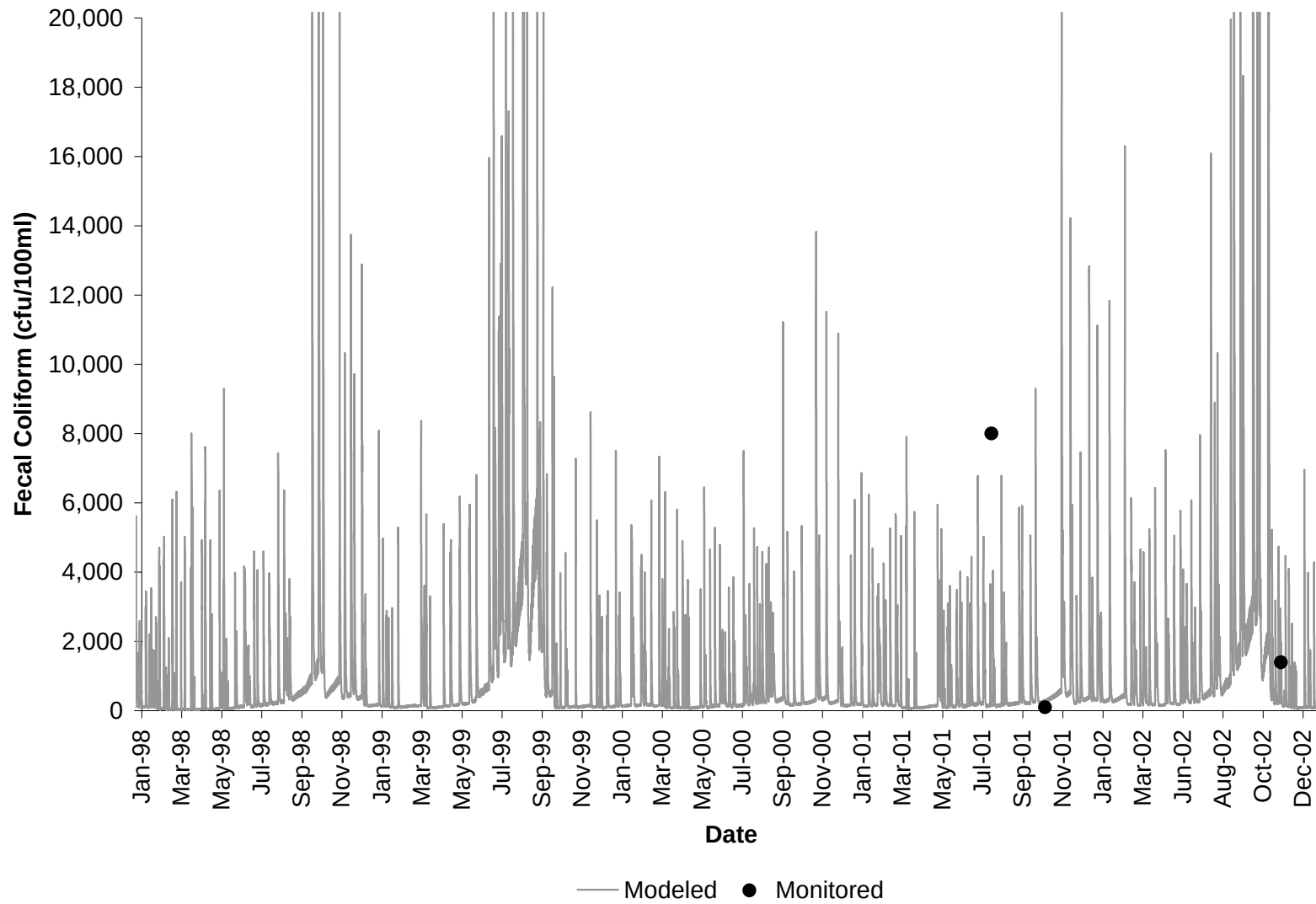


Figure 4.15. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed URR-7 in Marsh Run (VAN-E13R-03) impairment.

Table 4.18. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Marsh Run (VAN-E13R-03) watershed.

Parameter	Sub URR-7
Geometric Mean of Observed Values (cfu/100mL)	1038
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	1049
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	67
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	67
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	67
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	67

4.7.2.2 Blue Run (VAN-E13R-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-BLU002.60 within the Blue Run (VAN-E13R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.19. Observations from the VADEQ station, 3-BLU002.60, were graphically compared to corresponding modeled concentrations at subwatershed URR-13 (Figures 4.16 and 4.17). 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 4.20 and 4.21 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 4.20 and 4.21. A difference of one exceedance could result in a difference of exceedance rate of 5-7%. The highest difference (16%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (20%) 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 one model observation that was not above 1,000 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 Blue Run (VAN-E13R-01) watershed.

Table 4.19. Calibrated water quality HSPF parameters for Blue Run (VAN-E13R-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	16E06-01E10	16E06-01E10	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	13E08-24E08	13E08-24E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E10-02E10	01E10-02E10	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	1.65	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

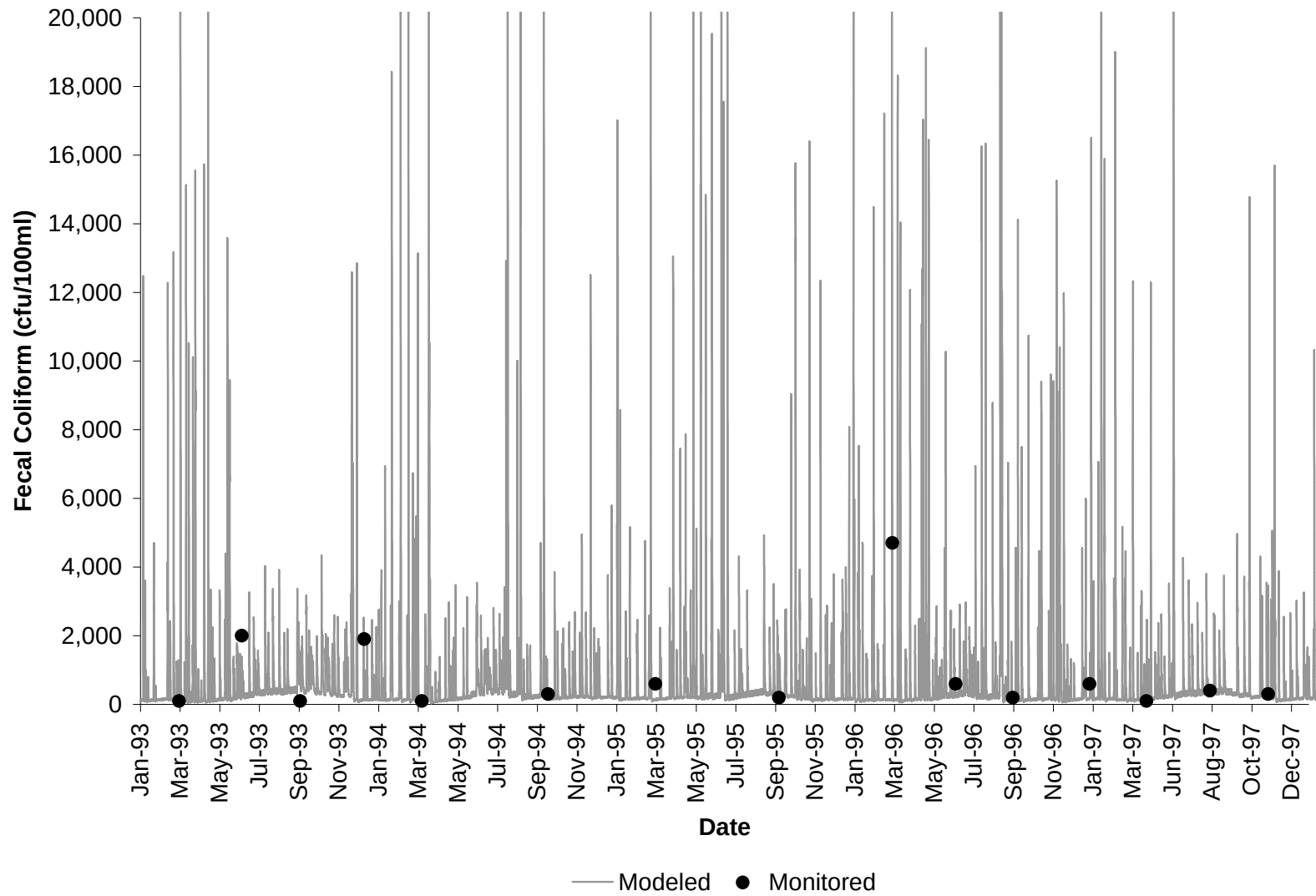


Figure 4.16. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed URR-13 in Blue Run (VAN-E13R-01) impairment.

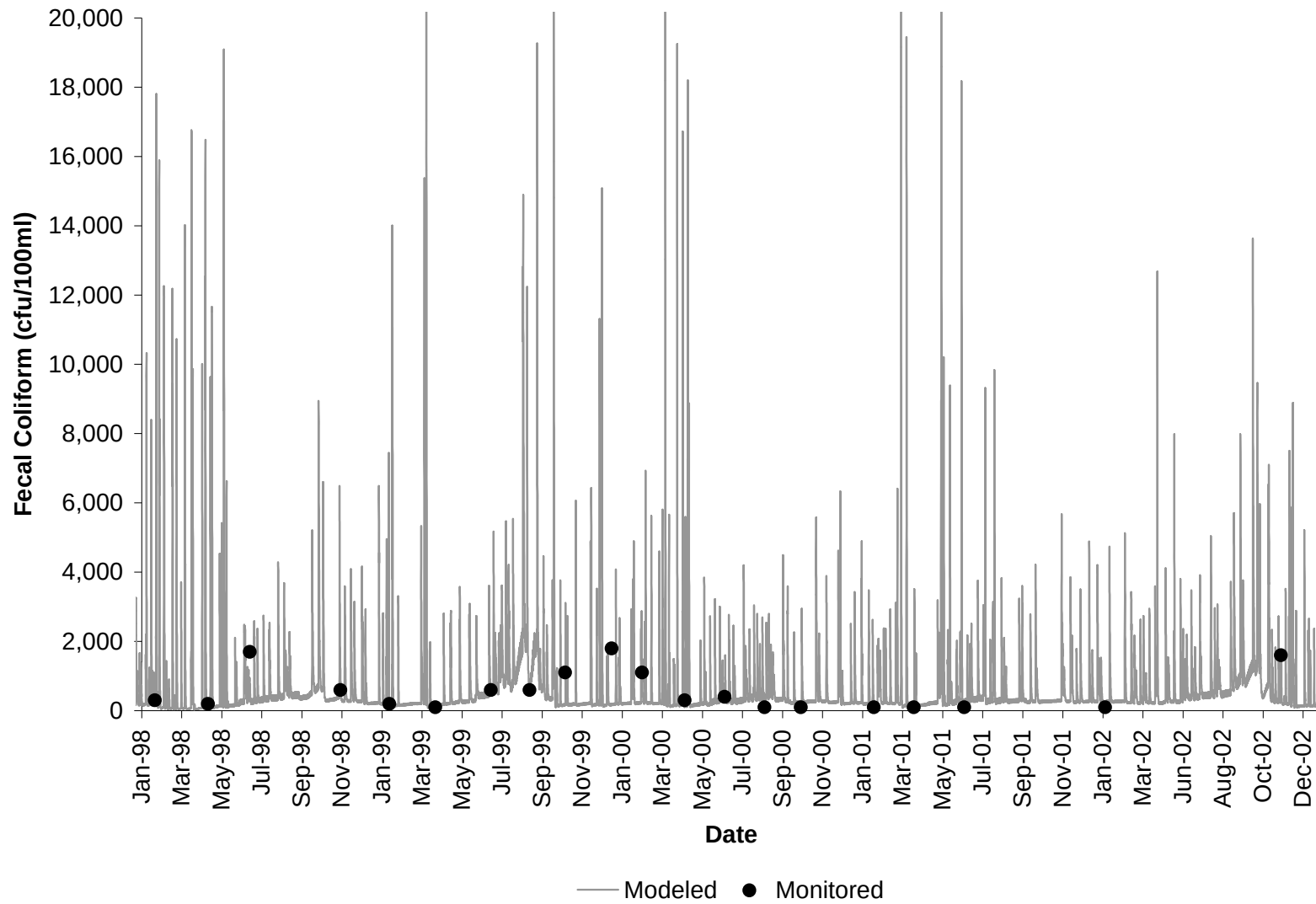


Figure 4.17. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed URR-13 in Blue Run (VAN-E13R-01) impairment.

Table 4.20. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Blue Run (VAN-E13R-01) watershed.

Parameter	Sub URR-13
Geometric Mean of Observed Values (cfu/100mL)	383
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	405
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	20
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	20
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	40
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	40

Table 4.21. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Blue Run (VAN-E13R-01) watershed.

Parameter	Sub URR-13
Geometric Mean of Observed Values (cfu/100mL)	326
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	281
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	25
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	20
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	40
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	35

4.7.2.3 UT to Rapidan River (VAN-E13R-04)

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-XEZ000.12 within the UT to Rapidan River (VAN-E13R-04) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.22. Observations from the VADEQ station, 3-XEZ000.12, were graphically compared to corresponding modeled concentrations at subwatershed URR-18 (Figure 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. Table 4.23 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 4.23. A difference of one exceedance could result in a difference of exceedance rate of 50%. 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 (0%) was recorded during the calibration period. Two observations were available for comparison during this period resulting in a 50% 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 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 UT to Rapidan River (VAN-E13R-04) watershed.

Table 4.22. Calibrated water quality HSPF parameters for UT to Rapidan River (VAN-E13R-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	76E05-13E09	24E06-01E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	76E06-13E10	02E08-11E10	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	11E08	11E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	99E08	99E08	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	1.05	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

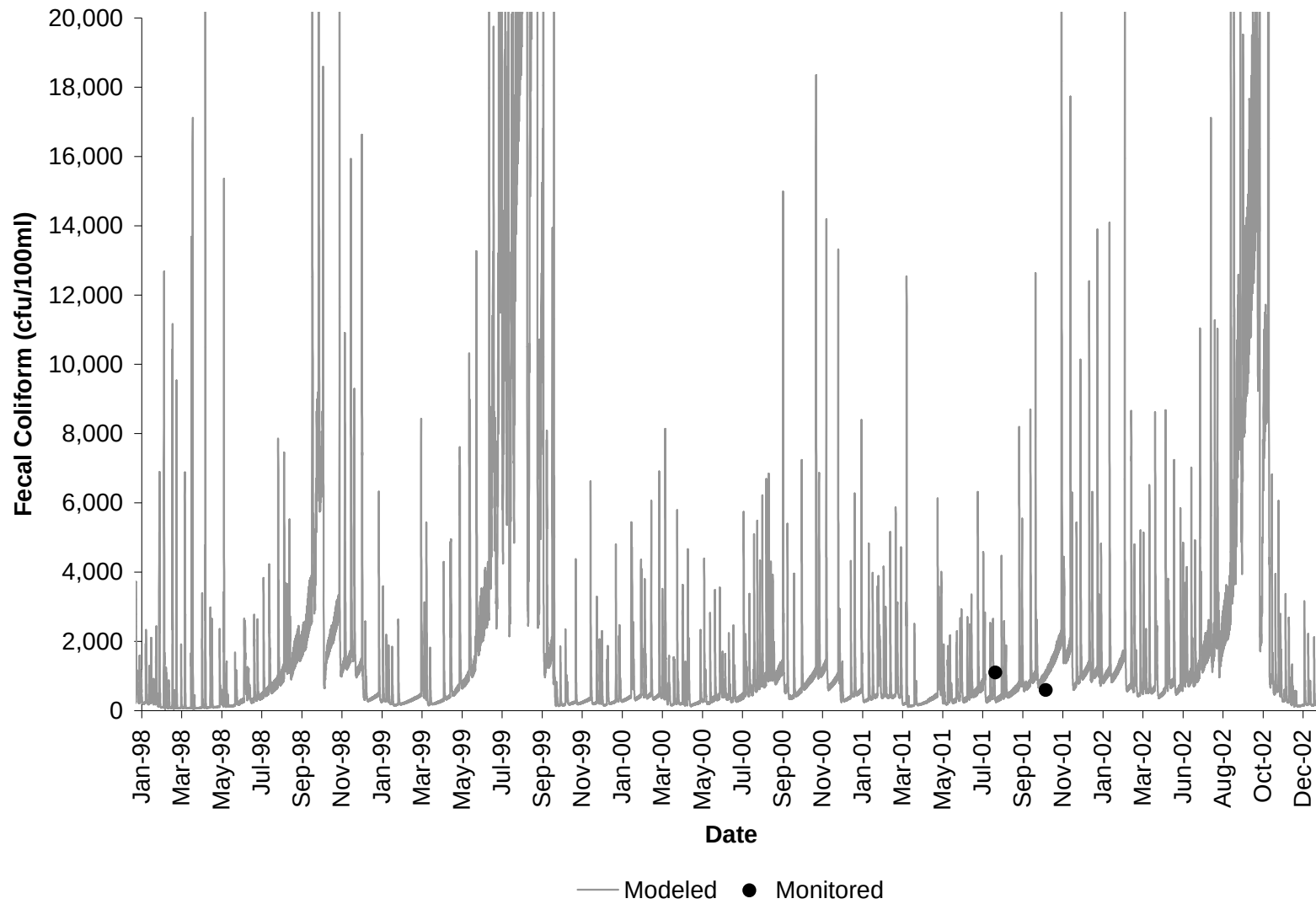


Figure 4.18. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed URR-18 in UT to Rapidan River (VAN-E13R-04) impairment.

Table 4.23. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in UT to Rapidan River (VAN-E13R-04) watershed.

Parameter	Sub URR-18
Geometric Mean of Observed Values (cfu/100mL)	812
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	930
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	50
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	50
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	100
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	100

4.7.2.4 Rapidan River (VAN-E13R-02)

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-RAP045.08 within the Rapidan River (VAN-E13R-02) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.24. Observations from the VADEQ station, 3-RAP045.08, were graphically compared to corresponding modeled concentrations at subwatershed URR-16 (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 4.25 and 4.26 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 4.25 and 4.26. A difference of one exceedance could result in a difference of exceedance rate of 2-3%. The highest difference (26%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (57%) was recorded during the validation period. Thirty-five observations were available for comparison during this period resulting in a 3% weighting when comparing the water quality standard exceedance rate. This translates into three model observations that were below 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 Rapidan River (VAN-E13R-02) watershed.

Table 4.24. Calibrated water quality HSPF parameters for Rapidan River (VAN-E13R-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	16E06-03E10	16E06-03E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E08-25E10	01E08-25E10	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	12E08-36E08	12E08-36E08	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	1.40	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

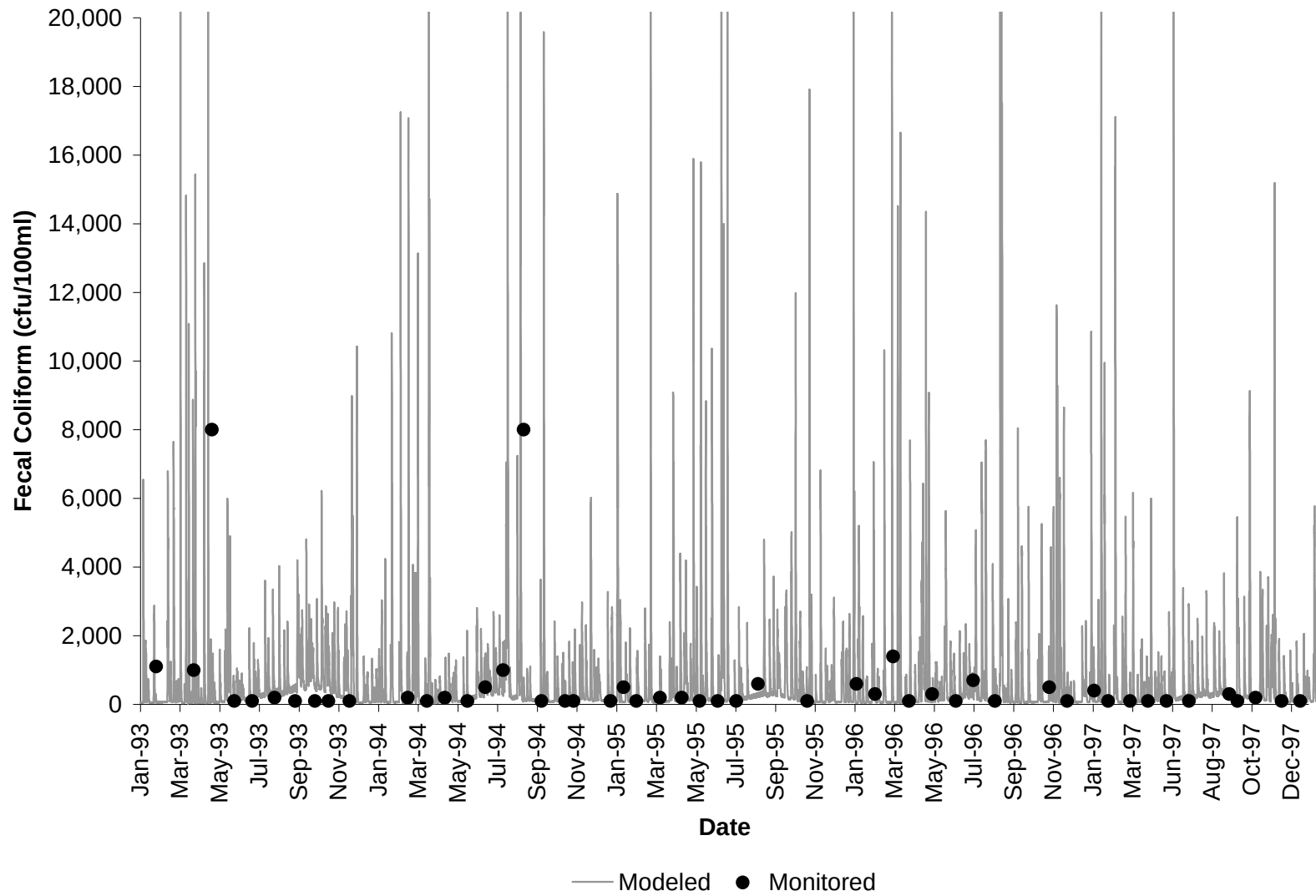


Figure 4.19. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed URR-16 in Rapidan River (VAN-E13R-02) impairment.

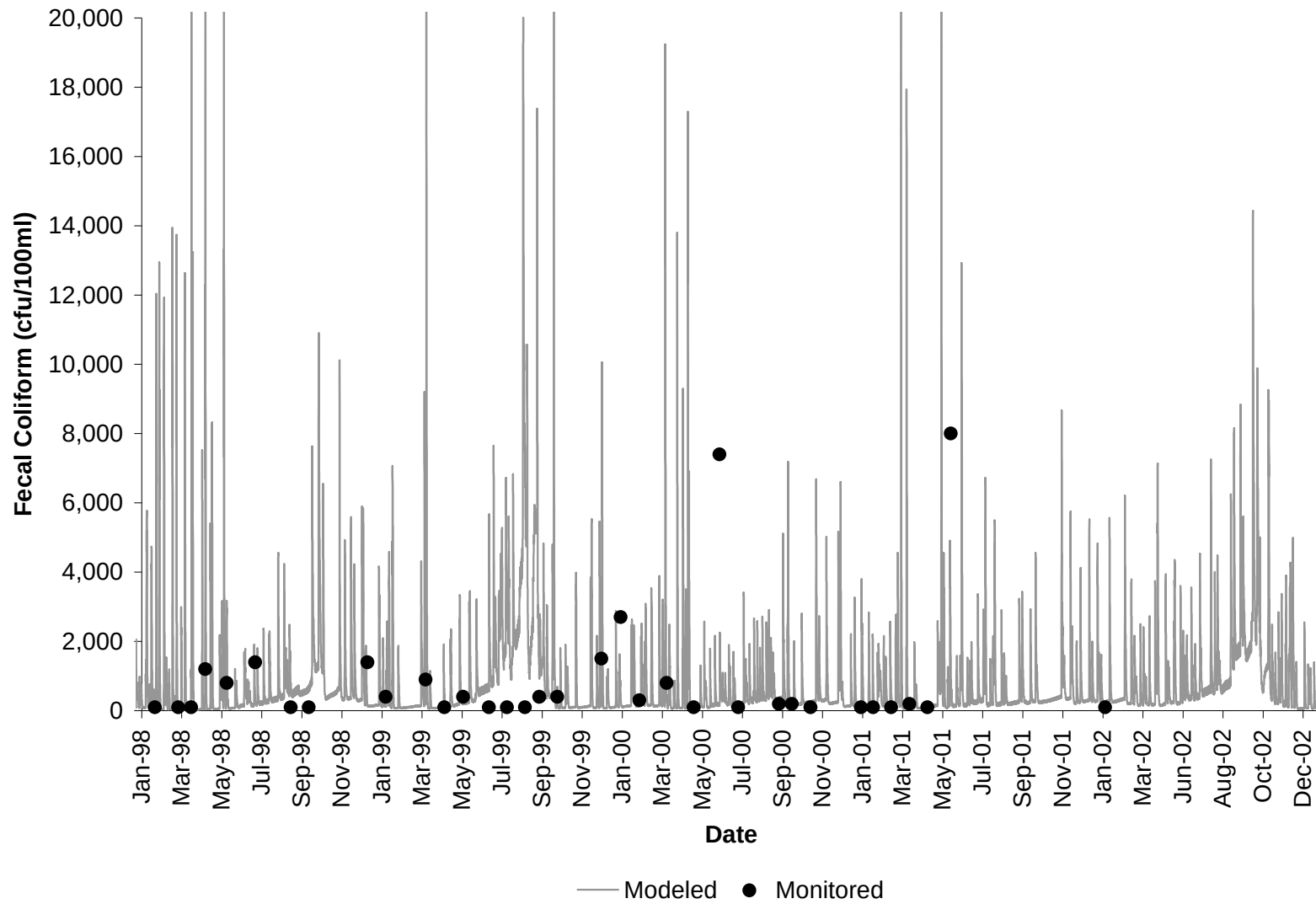


Figure 4.20. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed URR-16 in Rapidan River (VAN-E13R-02) impairment.

Table 4.25. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Rapidan River (VAN-E13R-02) watershed.

Parameter	Sub URR-16
Geometric Mean of Observed Values (cfu/100mL)	209
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	202
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	8
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	8
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	24
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	20

Table 4.26. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Rapidan River (VAN-E13R-02) watershed.

Parameter	Sub URR-16
Geometric Mean of Observed Values (cfu/100mL)	292
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	393
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	6
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	3
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	14
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	6

4.7.2.5 Cedar Run (VAN-E16R-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-CED000.59 within the Cedar Run (VAN-E16R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.27. Observations from the VADEQ station, 3-CED000.59, were graphically compared to corresponding modeled concentrations at subwatershed LRR-5 (Figures 4.21 and 4.22). 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 4.28 and 4.29 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 4.28 and 4.29. A difference of one exceedance could result in a difference of exceedance rate of 5-6%. The highest difference (10%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (100%) 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 one model observation that was above 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 Cedar Run (VAN-E16R-01) watershed.

Table 4.27. Calibrated water quality HSPF parameters for Cedar Run (VAN-E16R-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	19E06-02E10	19E06-02E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E08-14E10	02E08-14E10	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	28E08-92E08	28E08-92E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	03E10-08E10	03E10-08E10	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	2.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

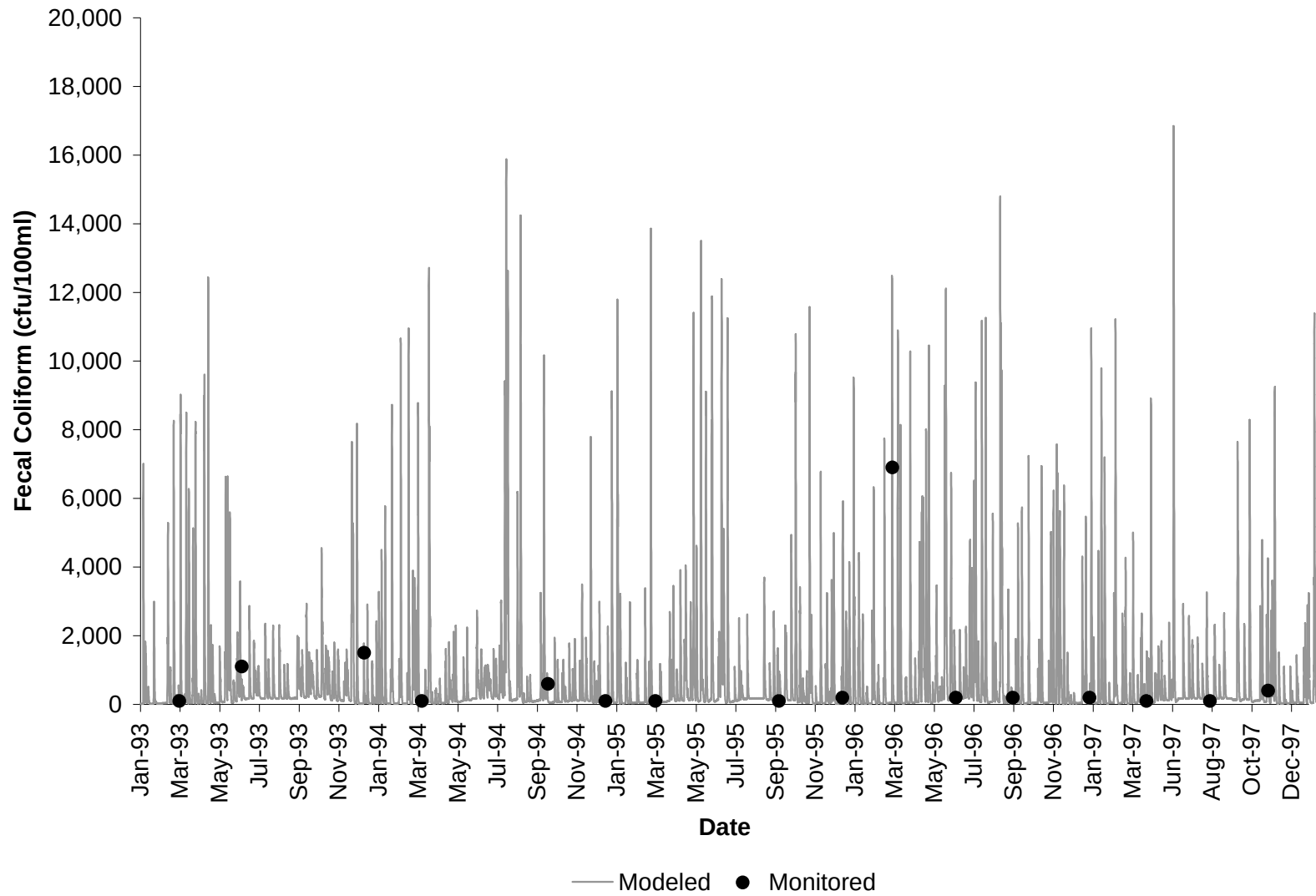


Figure 4.21. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed LRR-5 in Cedar Run (VAN-E16R-01) impairment.

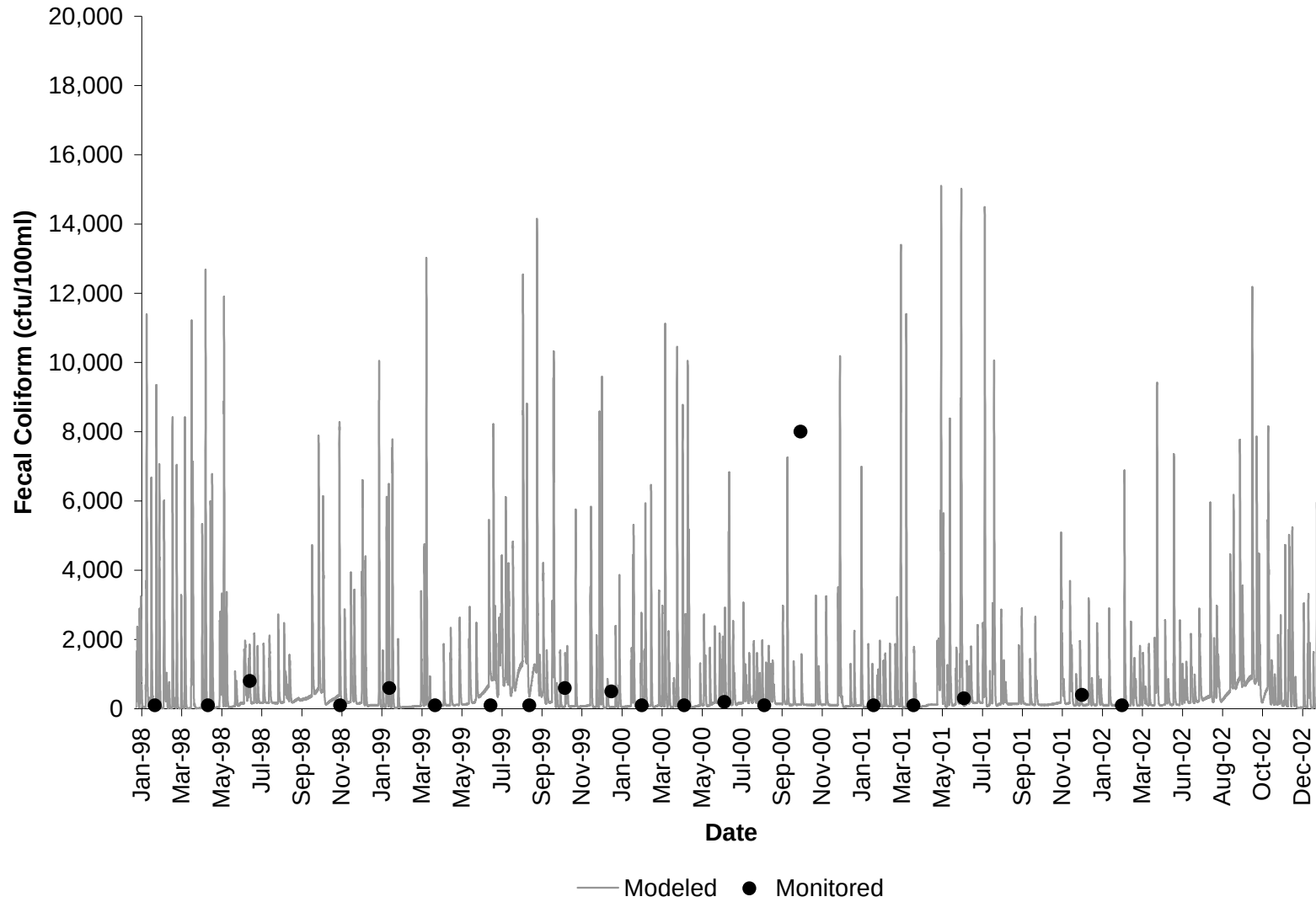


Figure 4.22. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed LRR-5 in Cedar Run (VAN-E16R-01) impairment.

Table 4.28. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Cedar Run (VAN-E16R-01) watershed.

Parameter	Sub LRR-05
Geometric Mean of Observed Values (cfu/100mL)	260
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	246
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	19
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	19
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	25
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	38

Table 4.29. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Cedar Run (VAN-E16R-01) watershed.

Parameter	Sub LRR-05
Geometric Mean of Observed Values (cfu/100mL)	210
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	233
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	5
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	10
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	25
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	35

4.7.2.6 Rapidan River (VAN-E18R-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-RAP006.53 within the Rapidan River (VAN-E18R-01) impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.30. Observations from the VADEQ station, 3-RAP006.53, were graphically compared to corresponding modeled concentrations at subwatershed LRR-13 (Figures 4.23 and 4.24). 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 4.31 and 4.32 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 4.31 and 4.32. A difference of one exceedance could result in a difference of exceedance rate of 2-3%. The highest difference (3%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard exceedance rates (17%) was recorded during the validation period. Thirty-eight observations were available for comparison during this period resulting in a 3% weighting when comparing the water quality standard exceedance rate. This translates into one model observation that was above 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 Rapidan River (VAN-E18R-01) watershed.

Table 4.30. Calibrated water quality HSPF parameters for Rapidan River (VAN-E18R-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	16E06-02E10	16E06-02E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	01E08-22E10	01E08-22E10	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	07E08-90E08	07E08-90E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	62E08-08E10	62E08-08E10	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	1.5	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

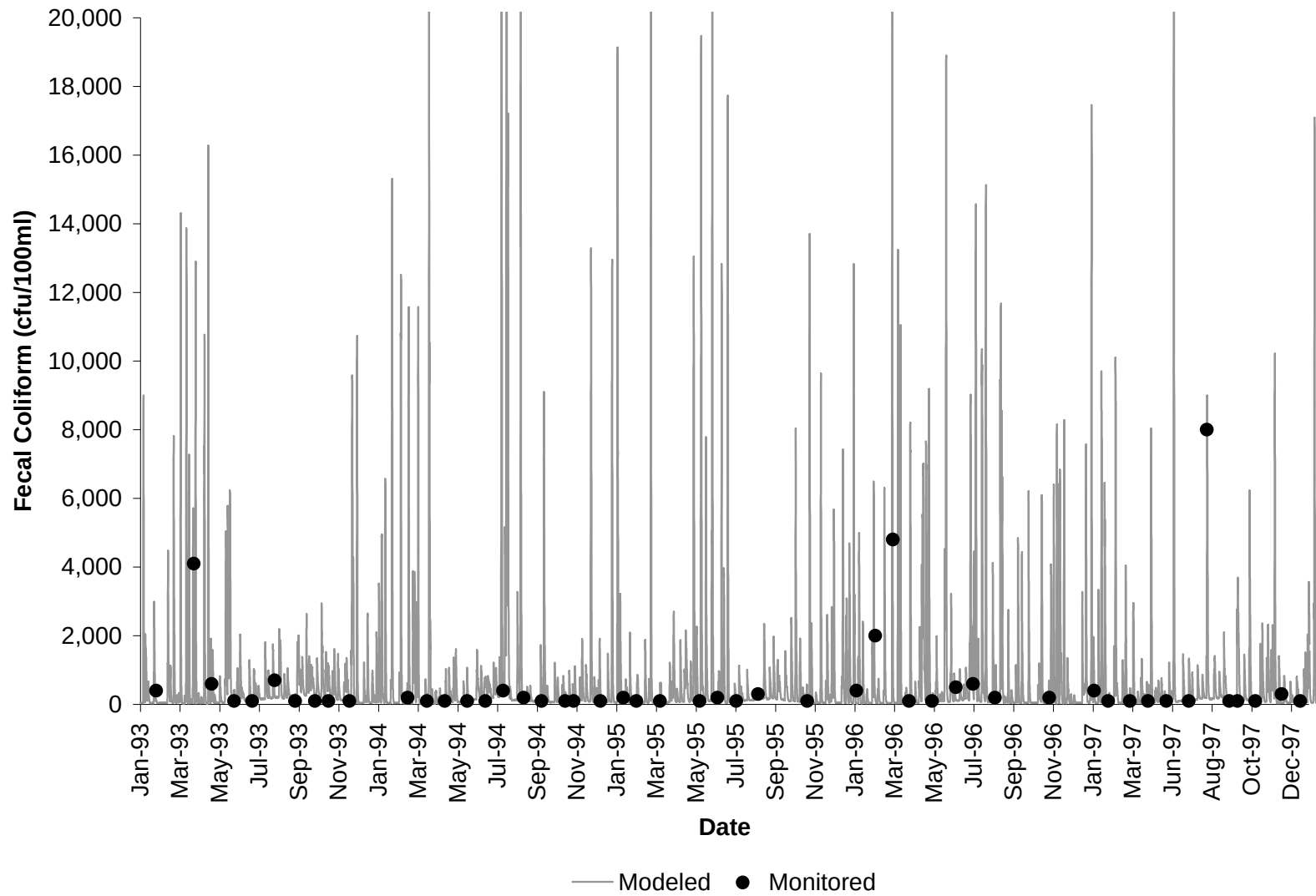


Figure 4.23. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed LRR-13 in Rapidan River (VAN-E18R-01) impairment.

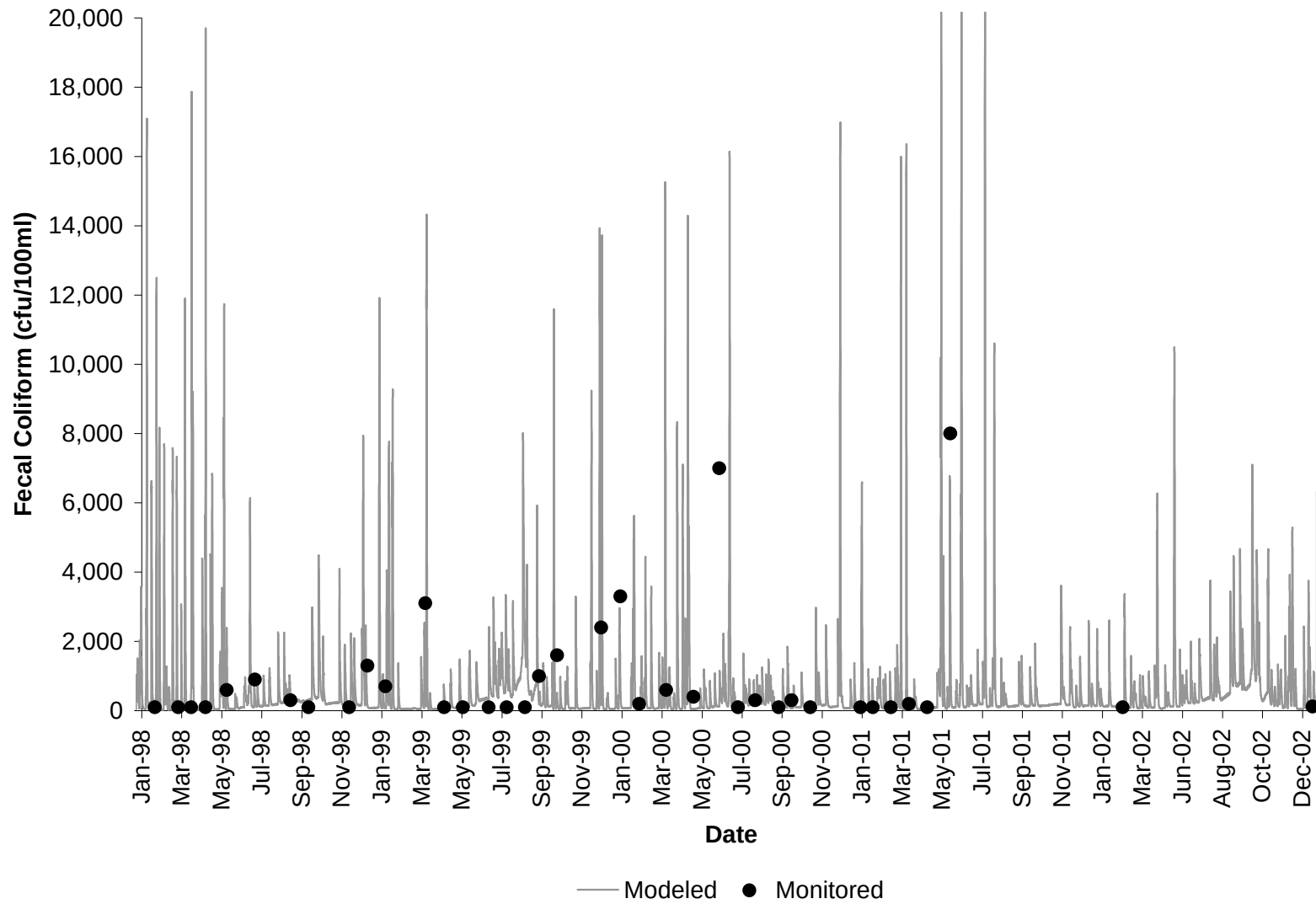


Figure 4.24. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed LRR-13 in Rapidan River (VAN-E18R-01) impairment.

Table 4.31. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Rapidan River (VAN-E18R-01) watershed.

Parameter	Sub LRR-13
Geometric Mean of Observed Values (cfu/100mL)	197
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	194
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	8
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	8
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	16
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	18

Table 4.32. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Rapidan River (VAN-E18R-01) watershed.

Parameter	Sub LRR-13
Geometric Mean of Observed Values (cfu/100mL)	289
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	282
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	18
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Exceedance Rate (%)	21
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	32
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	37

Chapter 5. Load Allocations

1.1 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 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 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 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). 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:

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{MOS} \quad [5.1]$$

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:

$$\log_2(\text{EC}) = -0.0172 + 0.91905 \cdot \log_2(\text{FC}) \quad [5.2]$$

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.

5.1 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 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) impairments. Appendix C contains tables with monthly land-based and direct bacteria loadings for existing conditions.

5.1.1 Marsh Run (VAN-E13R-03)

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 instantaneous standard of 235 cfu/100 mL (Figure 5.2). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Marsh Run (VAN-E13R-03) impairment was subwatershed URR-08.

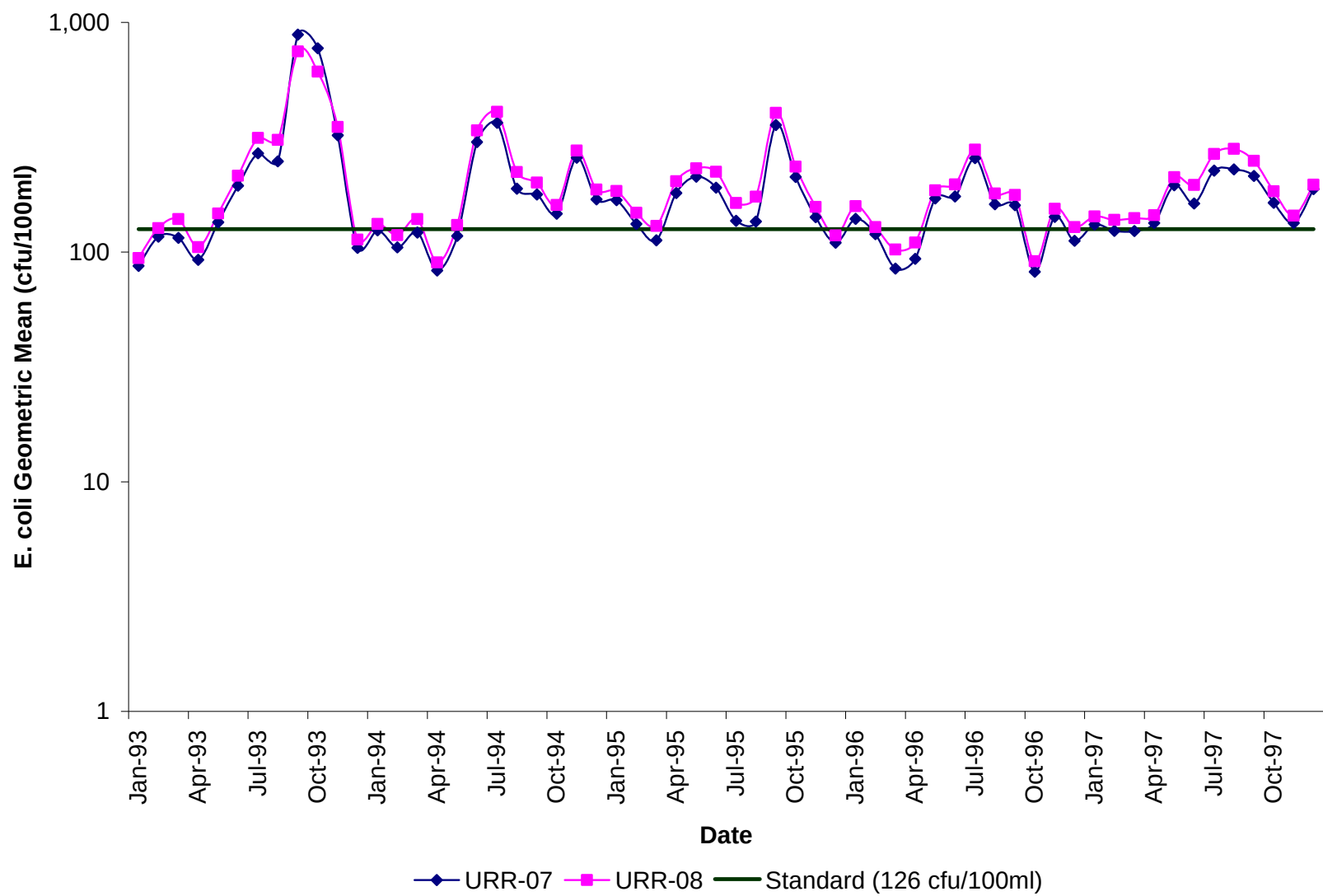


Figure 5.1. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds URR-07 to URR-08 in Marsh Run (VAN-E13R-03) watershed.

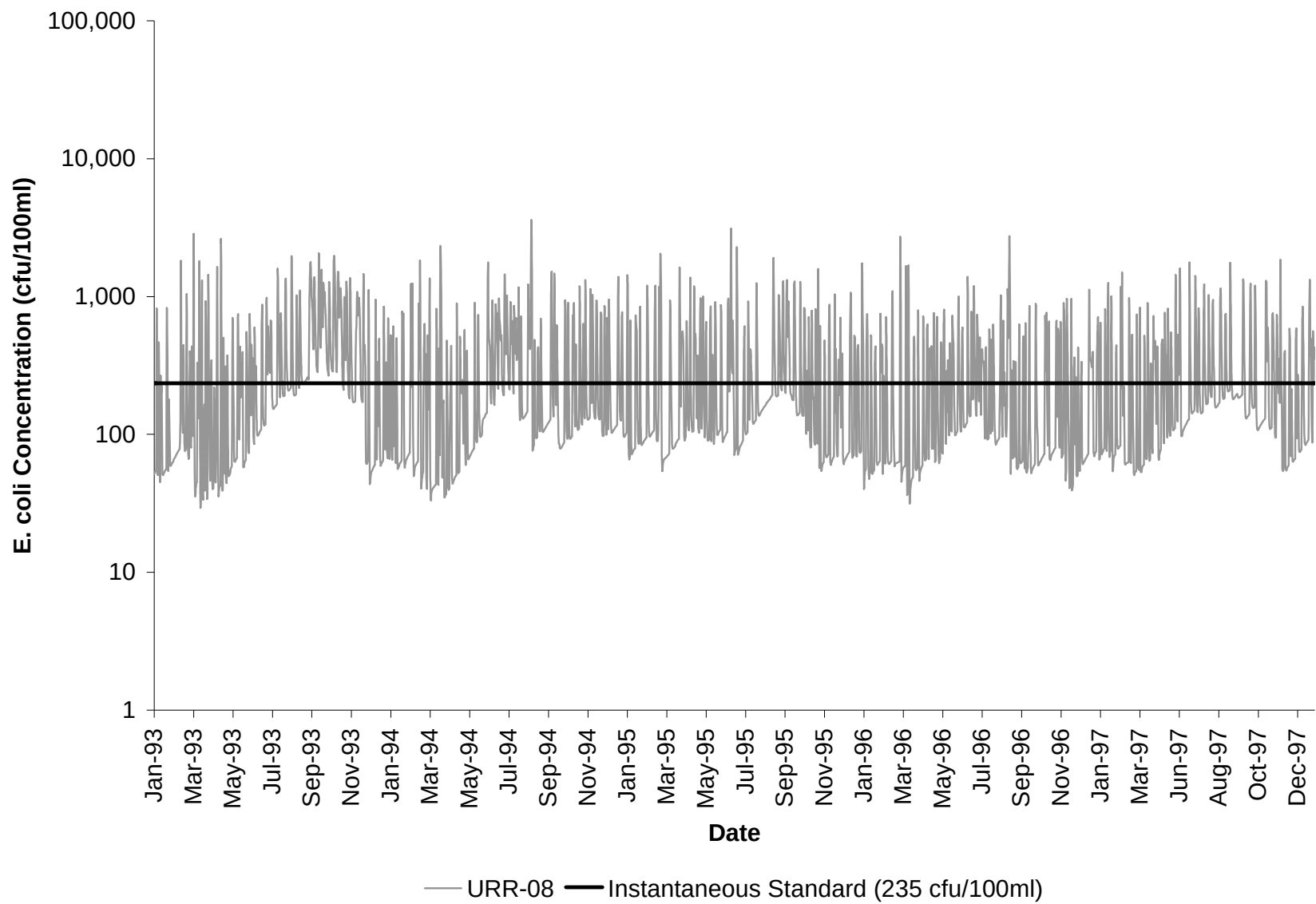


Figure 5.2. Daily average *E. coli* concentrations for subwatershed URR-08 in Marsh Run (VAN-E13R-03) watershed.

5.1.2 Blue Run (VAN-E13R-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 instantaneous standard of 235 cfu/100 mL (Figure 5.4). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Blue Run (VAN-E13R-01) impairment was subwatershed URR-14.

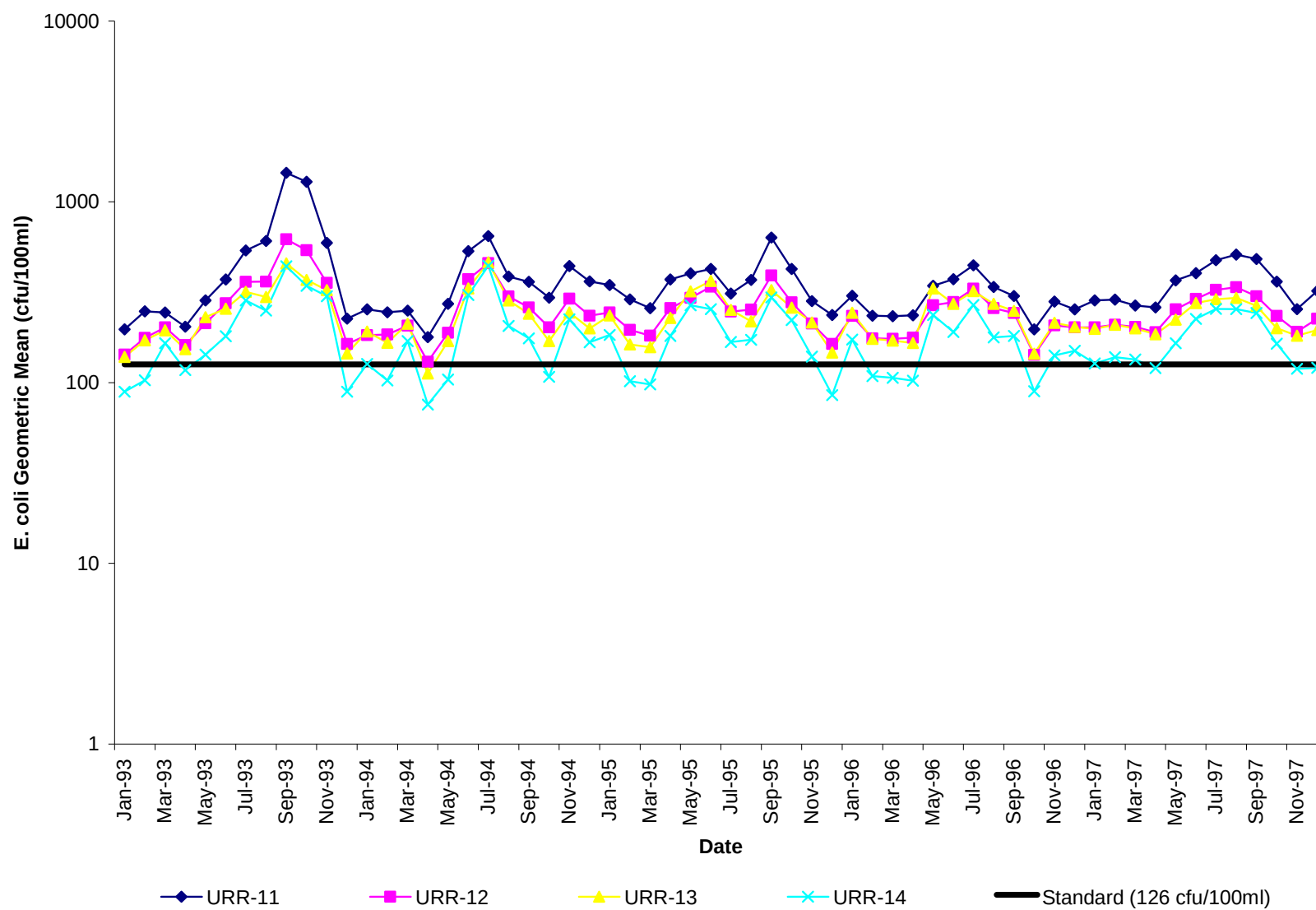


Figure 5.3. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds URR-11 to URR-14 in Blue Run (VAN-E13R-01) watershed.

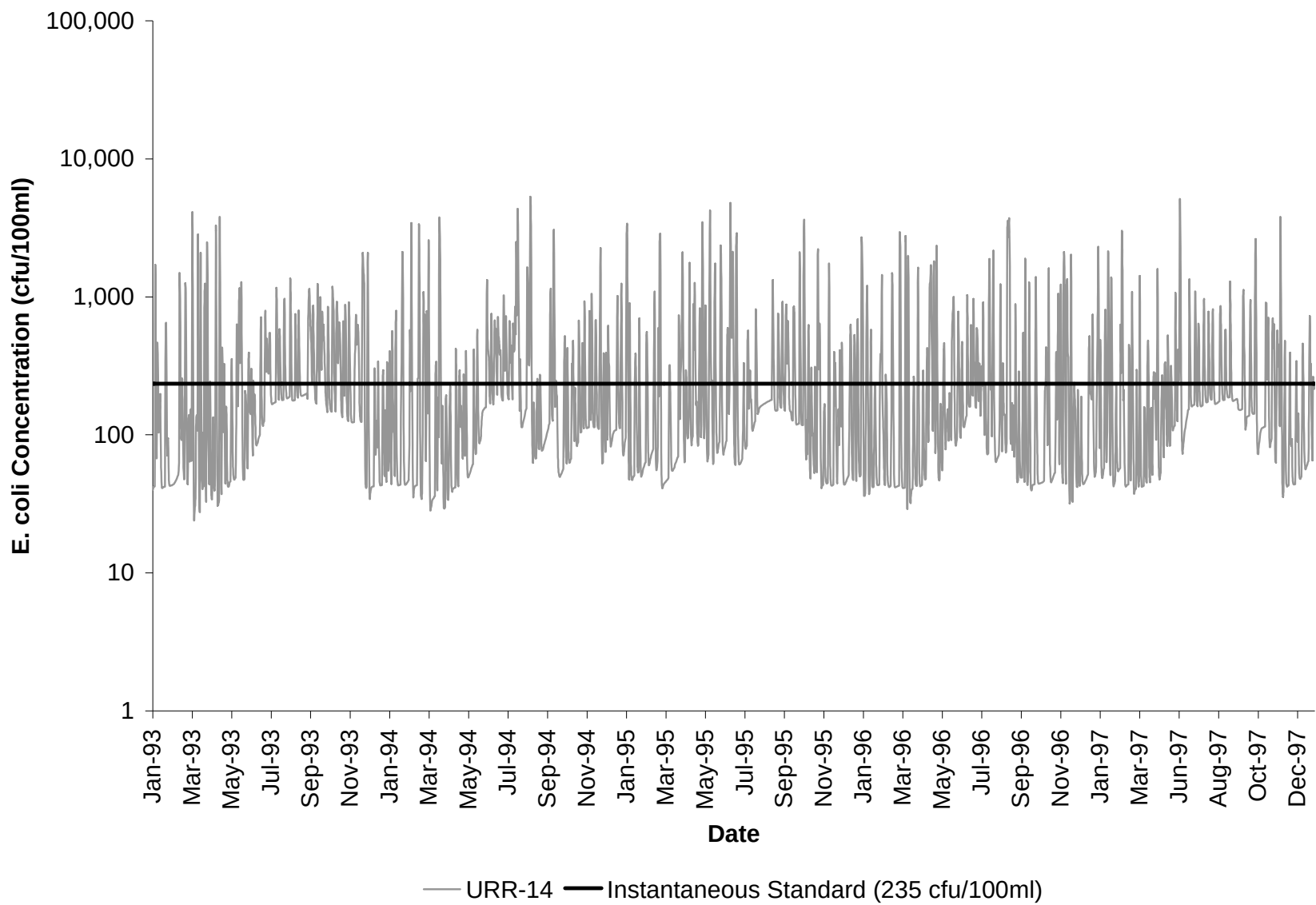


Figure 5.4. Daily average *E. coli* concentrations for subwatershed URR-14 in Blue Run (VAN-E13R-01) watershed.

5.1.3 UT to Rapidan River (VAN-E13R-04)

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 instantaneous standard of 235 cfu/100 mL (Figure 5.6). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the UT to Rapidan River (VAN-E13R-04) impairment was subwatershed URR-18.

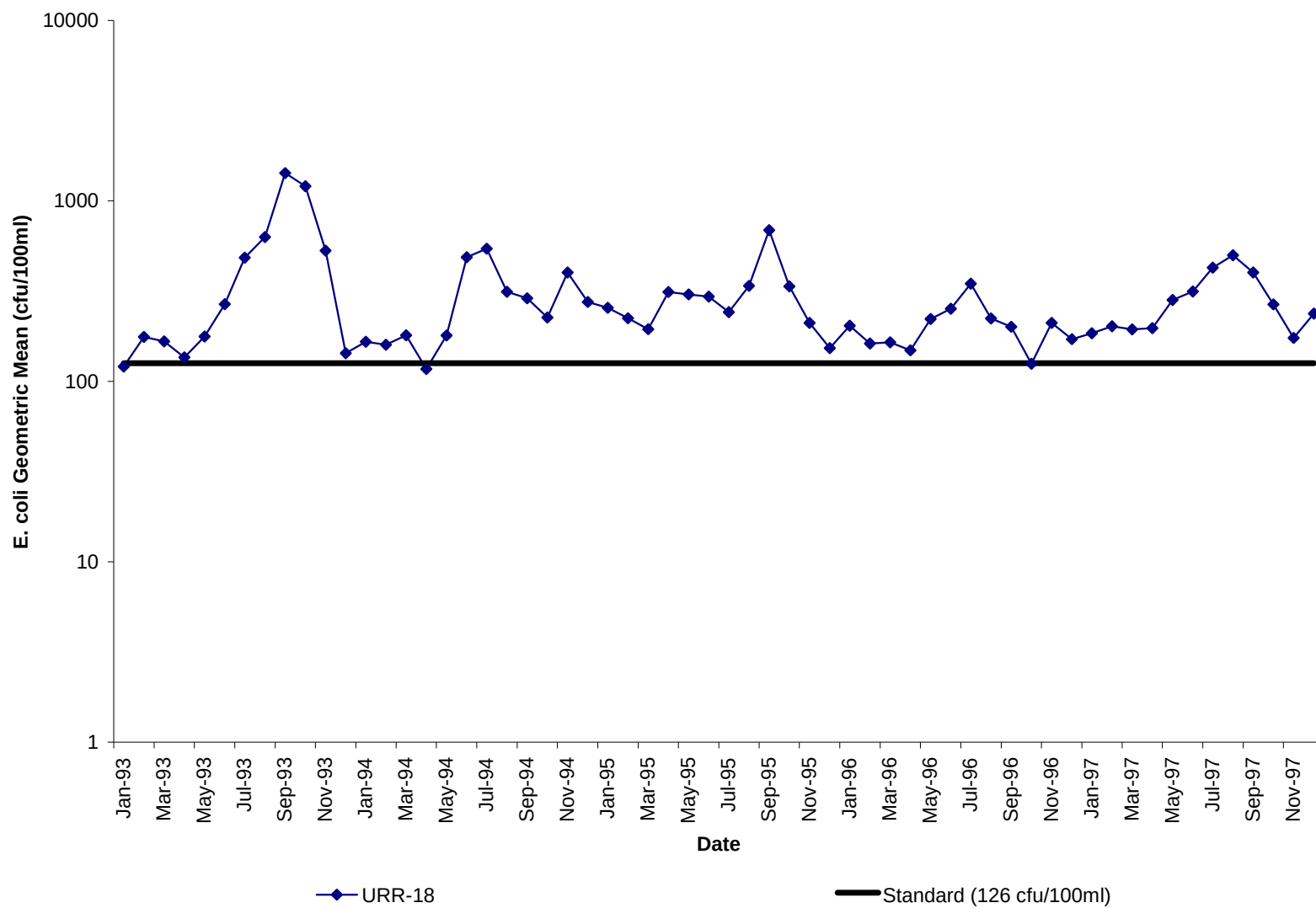


Figure 5.5. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatershed URR-18 in UT to Rapidan River (VAN-E13R-04) watershed.

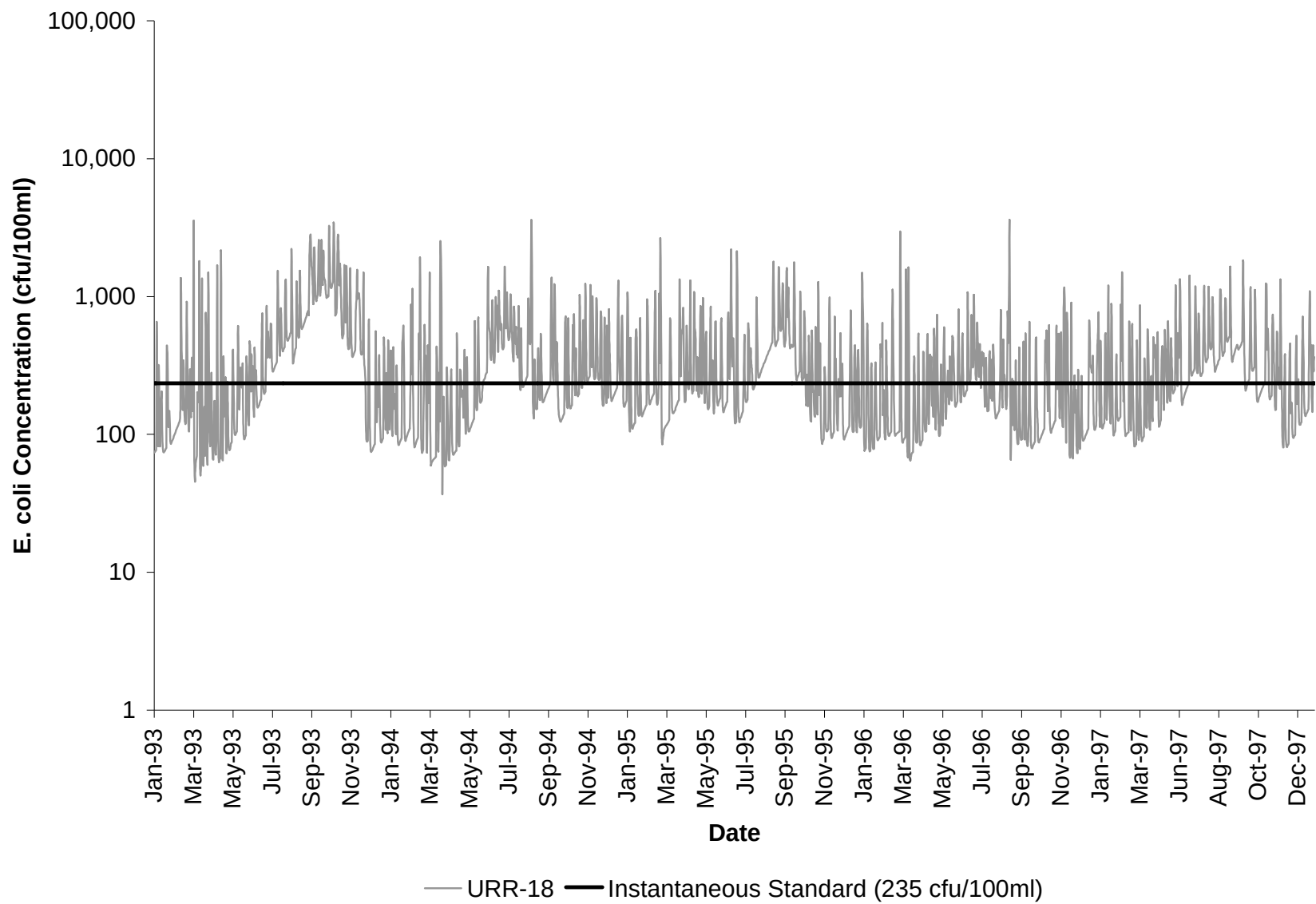


Figure 5.6. Daily average *E. coli* concentrations for subwatershed URR-18 in UT to Rapidan River (VAN-E13R-04) watershed.

5.1.4 Rapidan River (VAN-E13R-02)

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 instantaneous standard of 235 cfu/100 mL (Figure 5.8). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rapidan River (VAN-E13R-02) impairment was subwatershed URR-19.

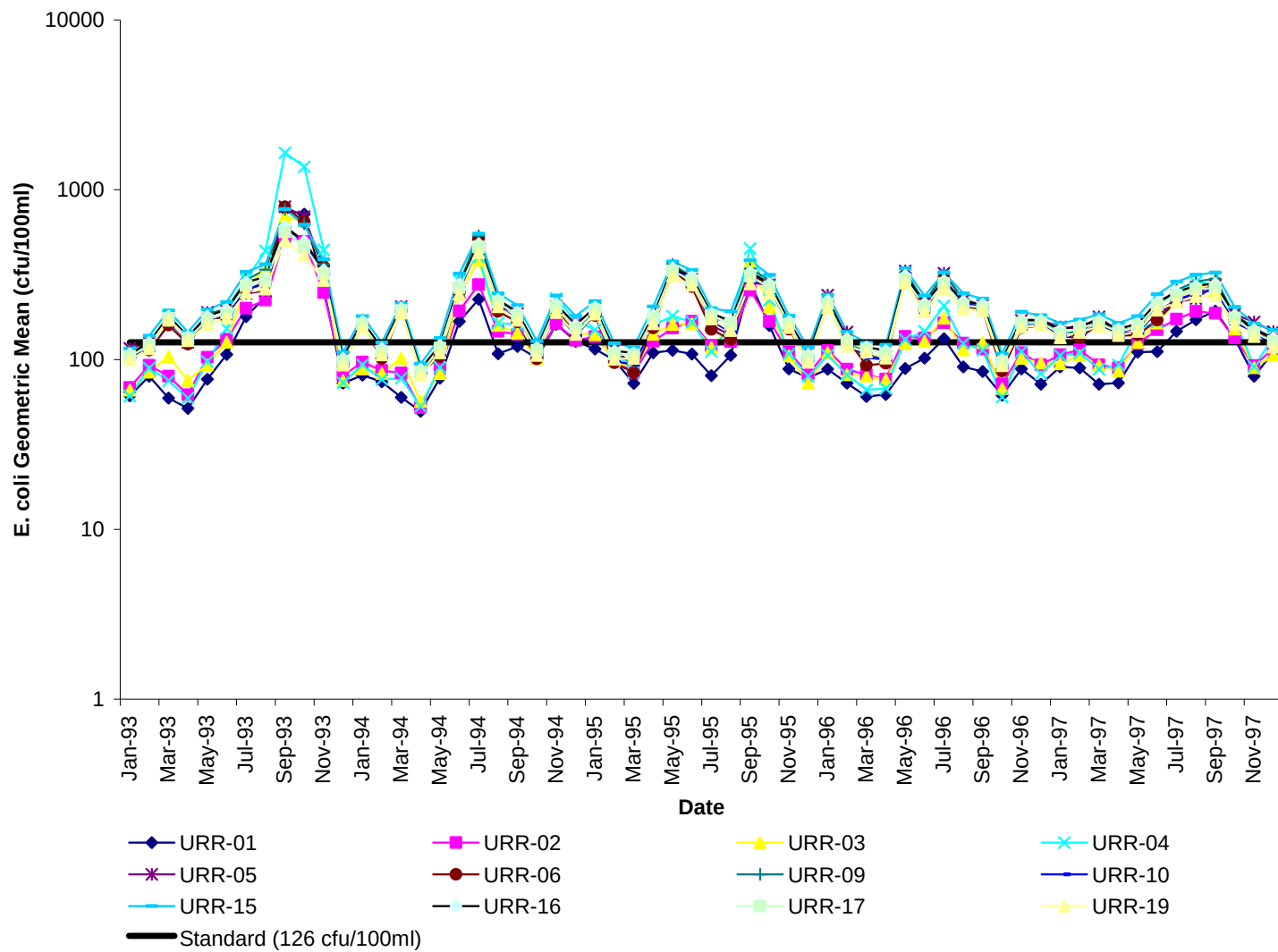


Figure 5.7. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds URR-01 to URR-06; URR-09 to URR-10; URR-15 to URR-17; URR-19 in Rapidan River (VAN-E13R-02) watershed.

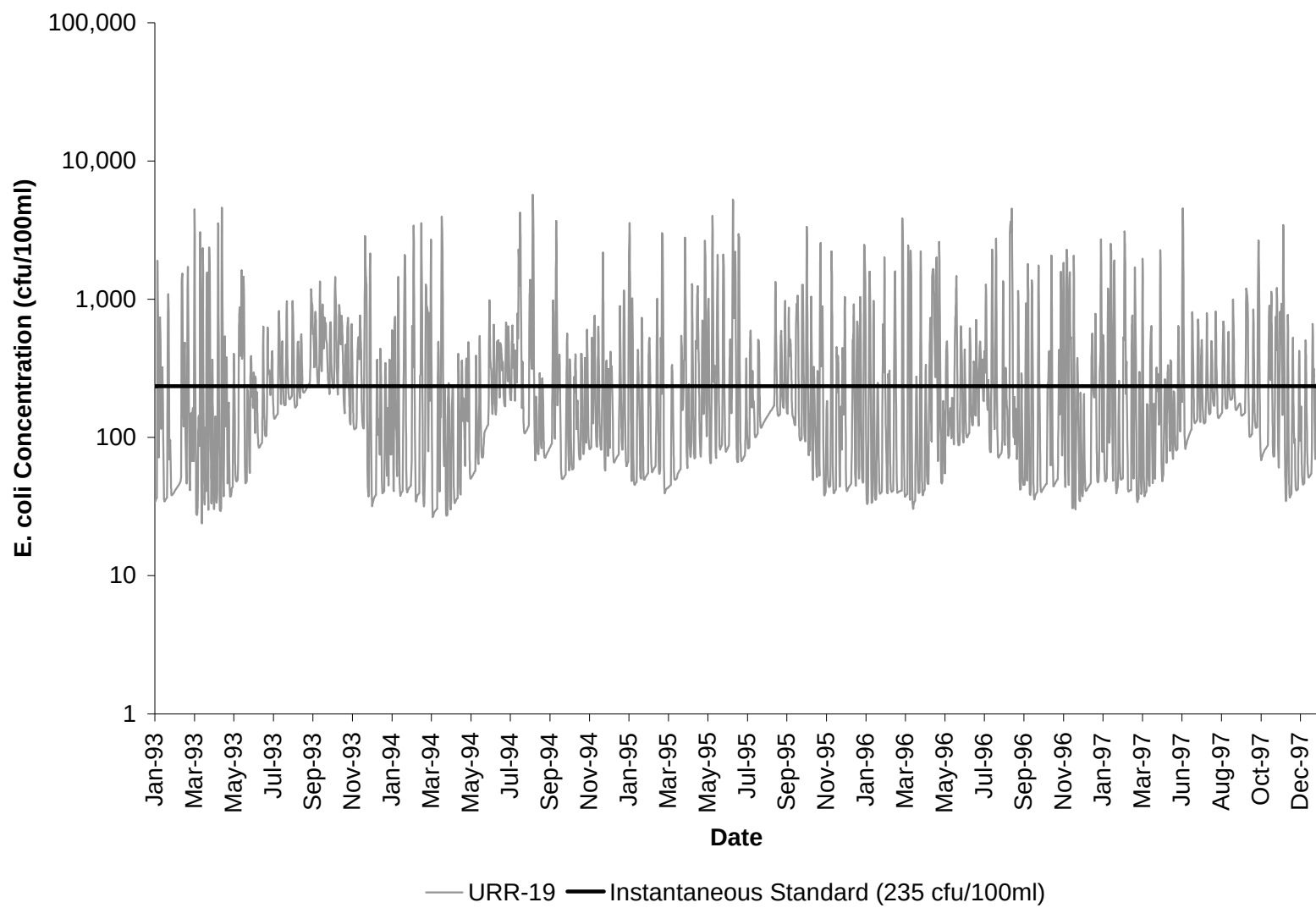


Figure 5.8. Daily average *E. coli* concentrations for subwatershed URR-19 in Rapidan River (VAN-E13R-02) watershed.

5.1.5 Cedar Run (VAN-E16R-01)

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 instantaneous standard of 235 cfu/100 mL (Figure 5.10). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Cedar Run (VAN-E16R-01) impairment was subwatershed LRR-06.

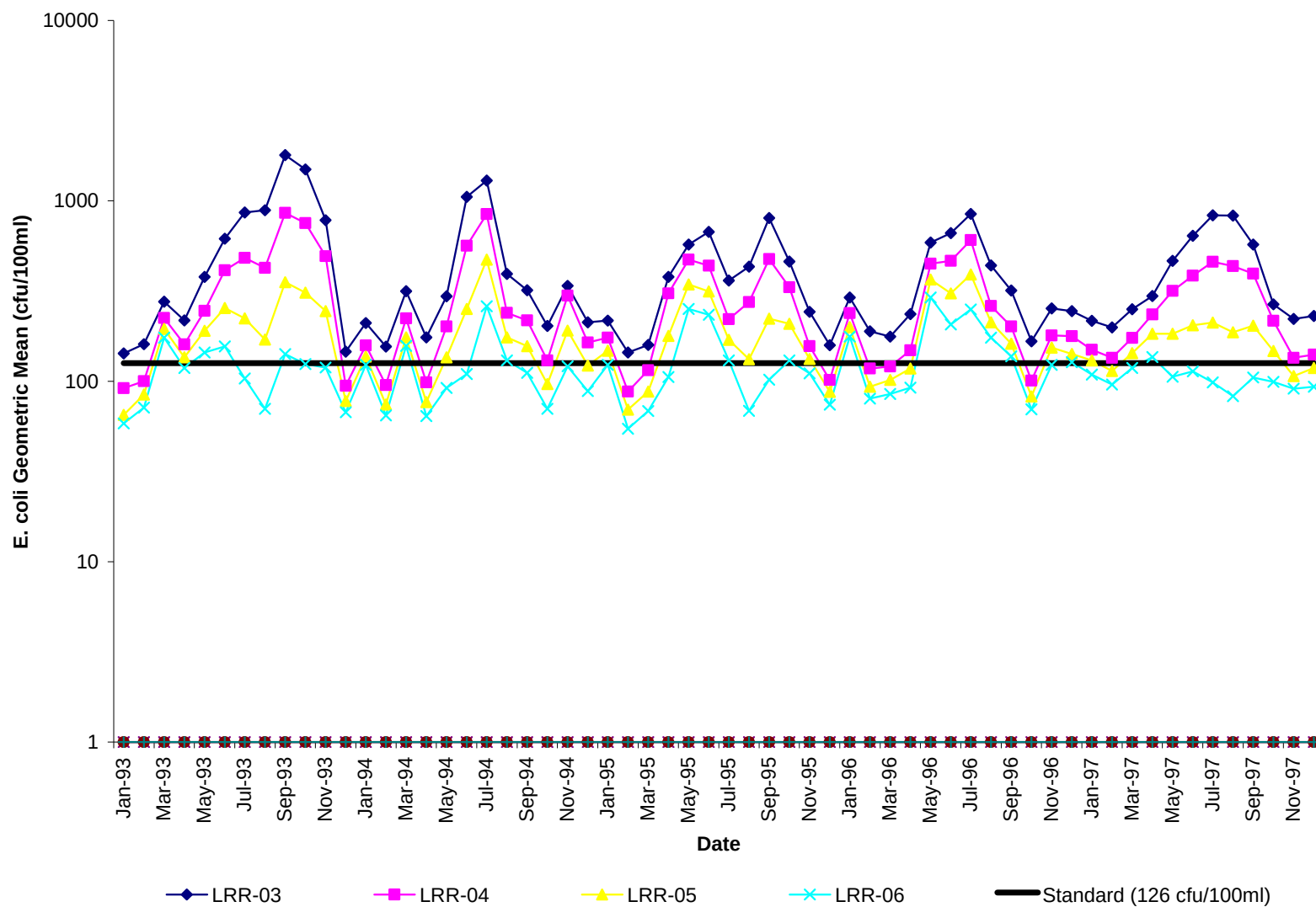


Figure 5.9. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds LRR-03 to LRR-06 in Cedar Run (VAN-E16R-01) watershed.

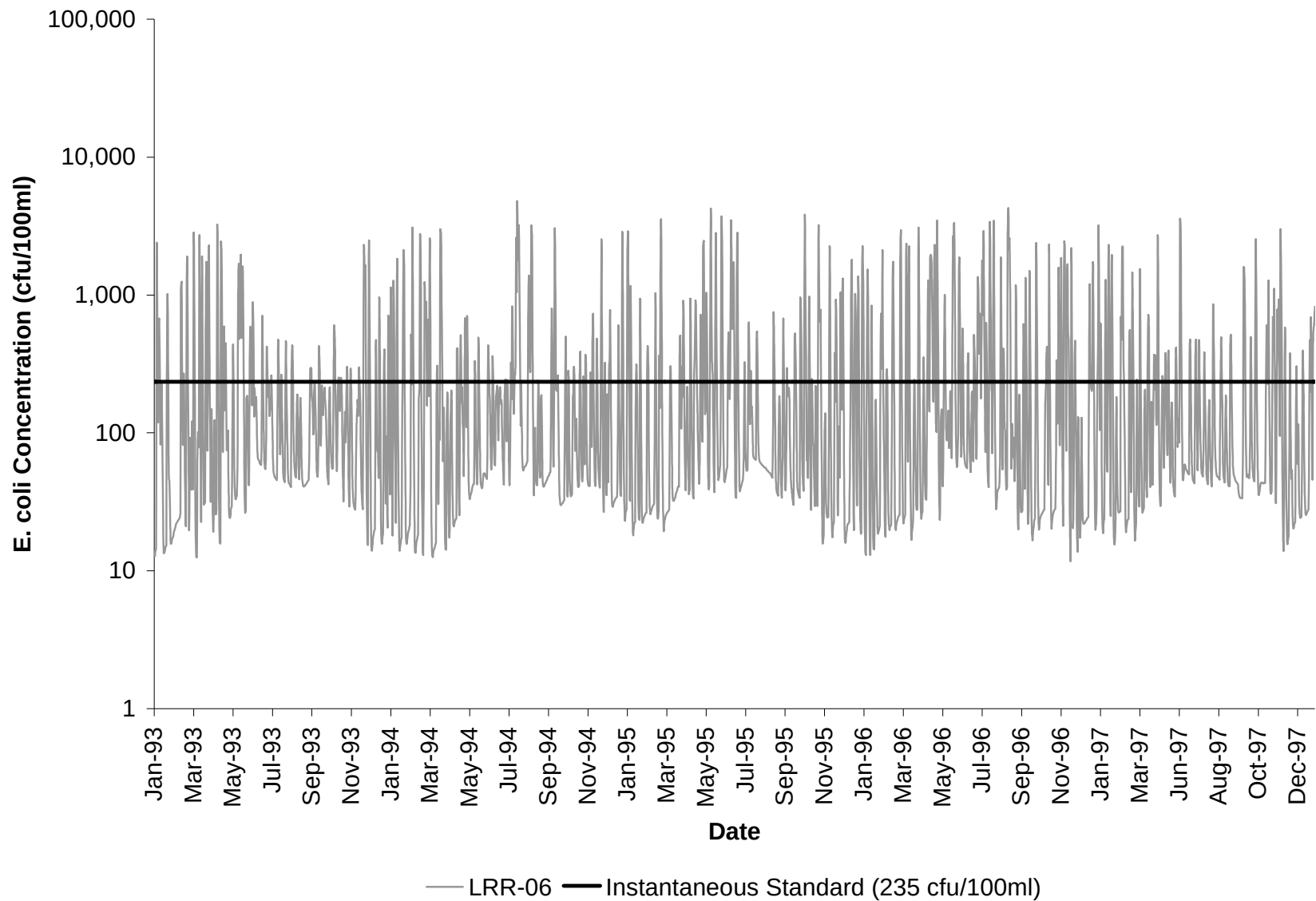


Figure 5.10. Daily average *E. coli* concentrations for subwatershed LRR-06 in Cedar Run (VAN-E16R-01) watershed.

5.1.6 Rapidan River (VAN-E18R-01)

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 instantaneous standard of 235 cfu/100 mL (Figure 5.12). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Rapidan River (VAN-E18R-01) impairment was subwatershed LRR-14.

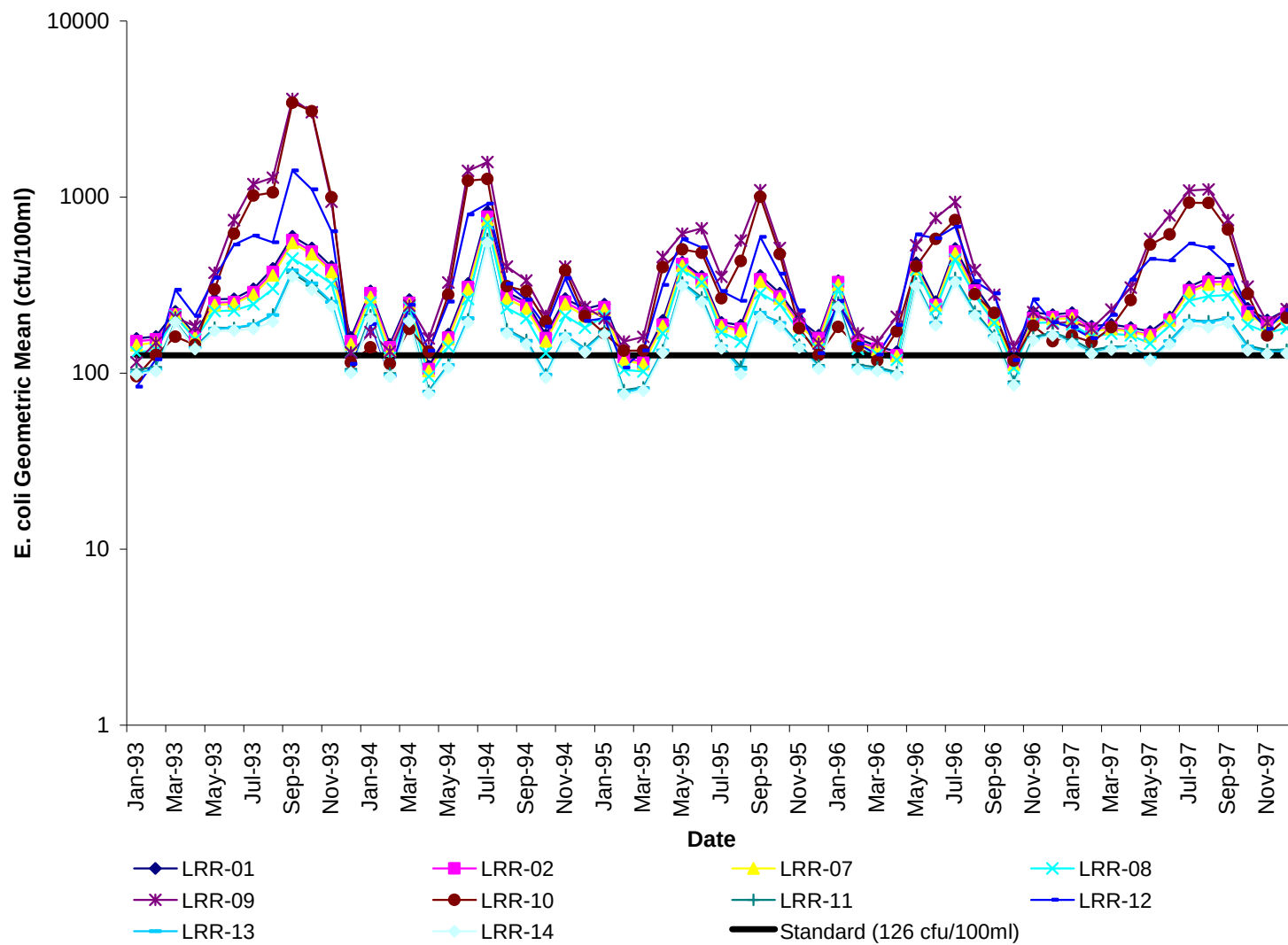


Figure 5.11. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds LRR-01 to LRR-02; LRR-07 to LRR-14 in Rapidan River (VAN-E18R-01) watershed.

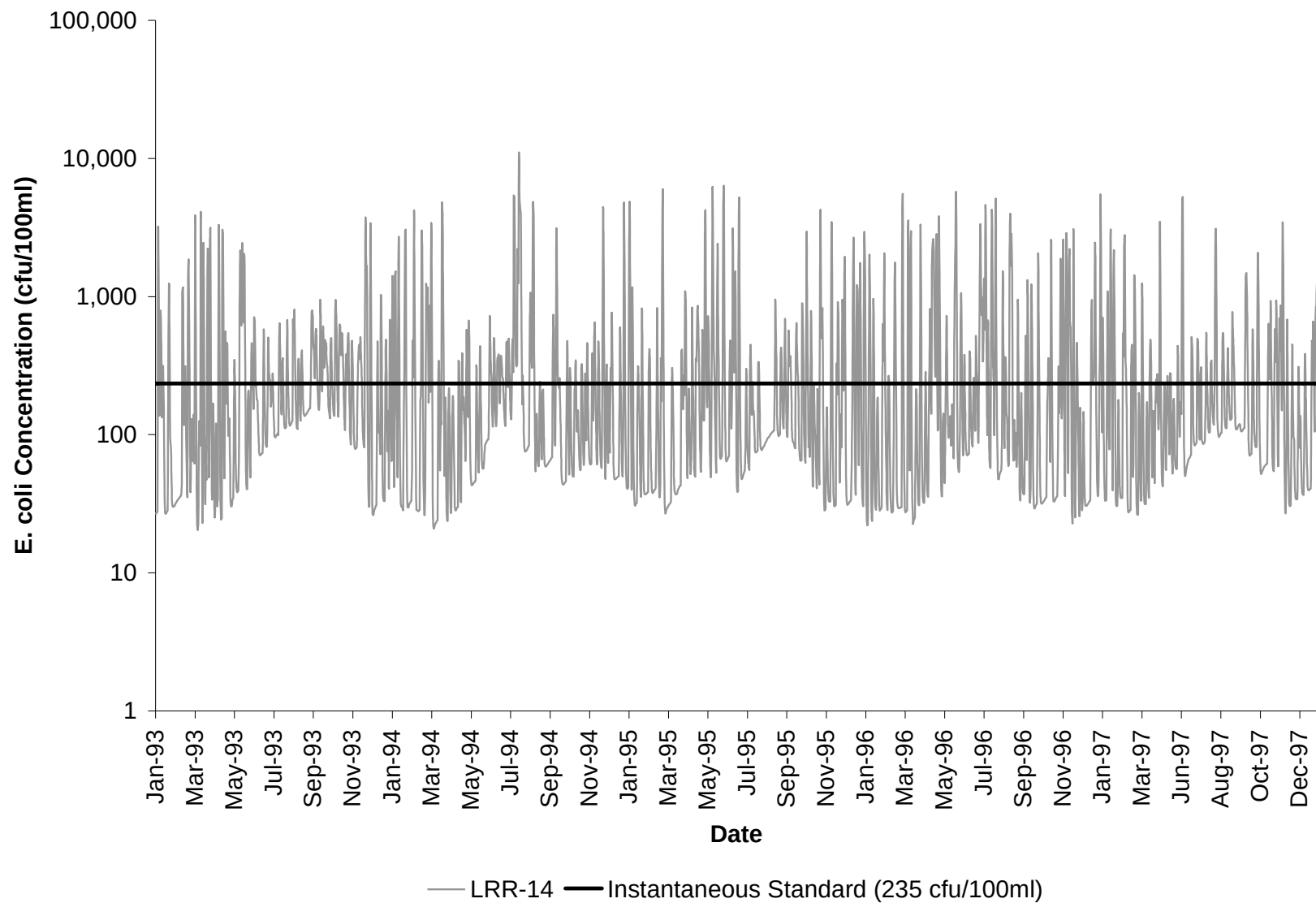


Figure 5.12. Daily average *E. coli* concentrations for subwatershed LRR-14 in Rapidan River (VAN-E18R-01) watershed.

5.2 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.

5.2.1 Marsh Run (VAN-E13R-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 5.13 and 5.14, respectively. Figures 5.15 and 5.16, 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 5.13 with Figure 5.14 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.15 to Figure 5.16 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.

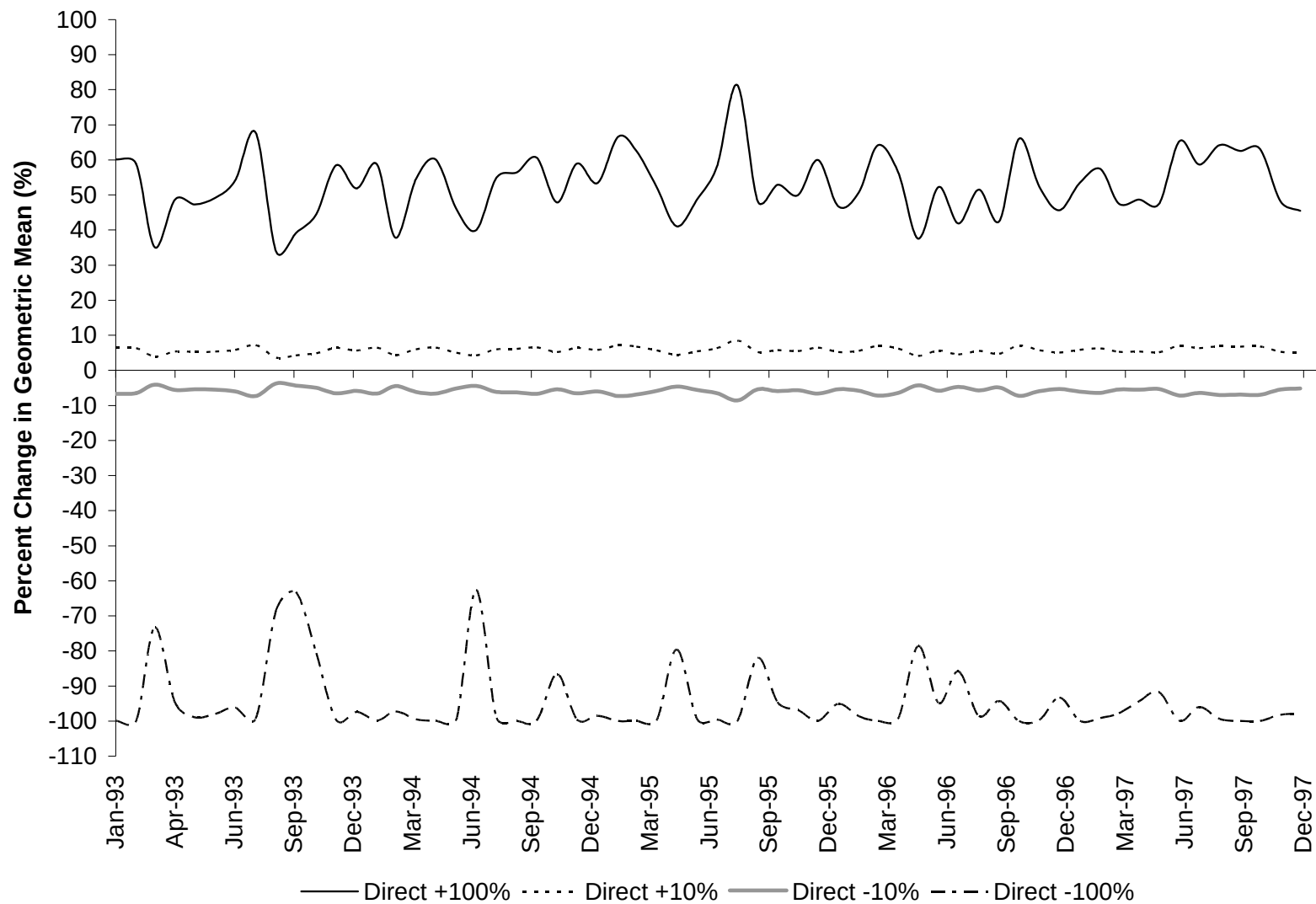


Figure 5.13. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-8) of Marsh Run (VAN-E13R-03) watershed, as affected by direct load changes.

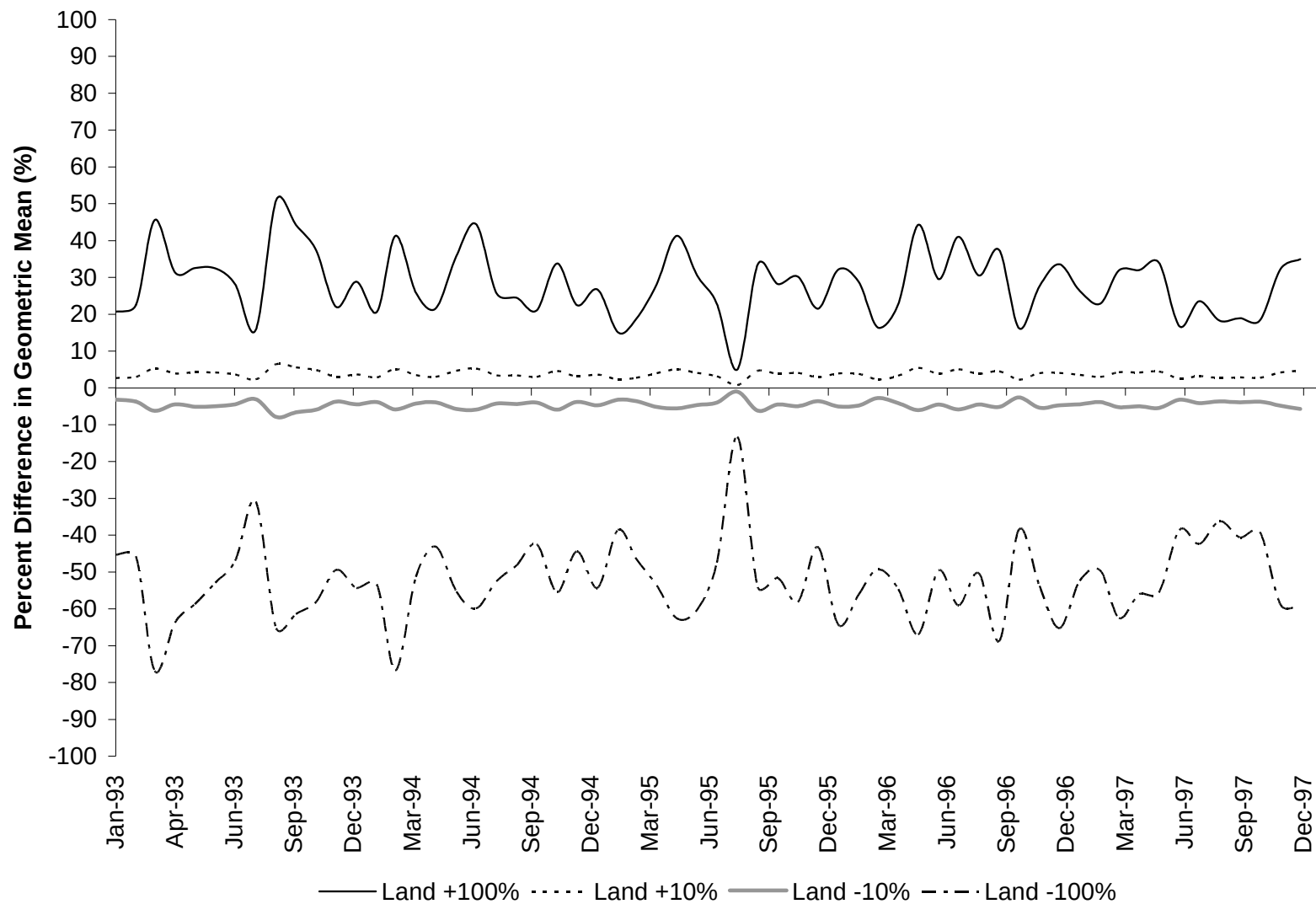


Figure 5.14. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-8) of Marsh Run (VAN-E13R-03) watershed, as affected by land-based load changes.

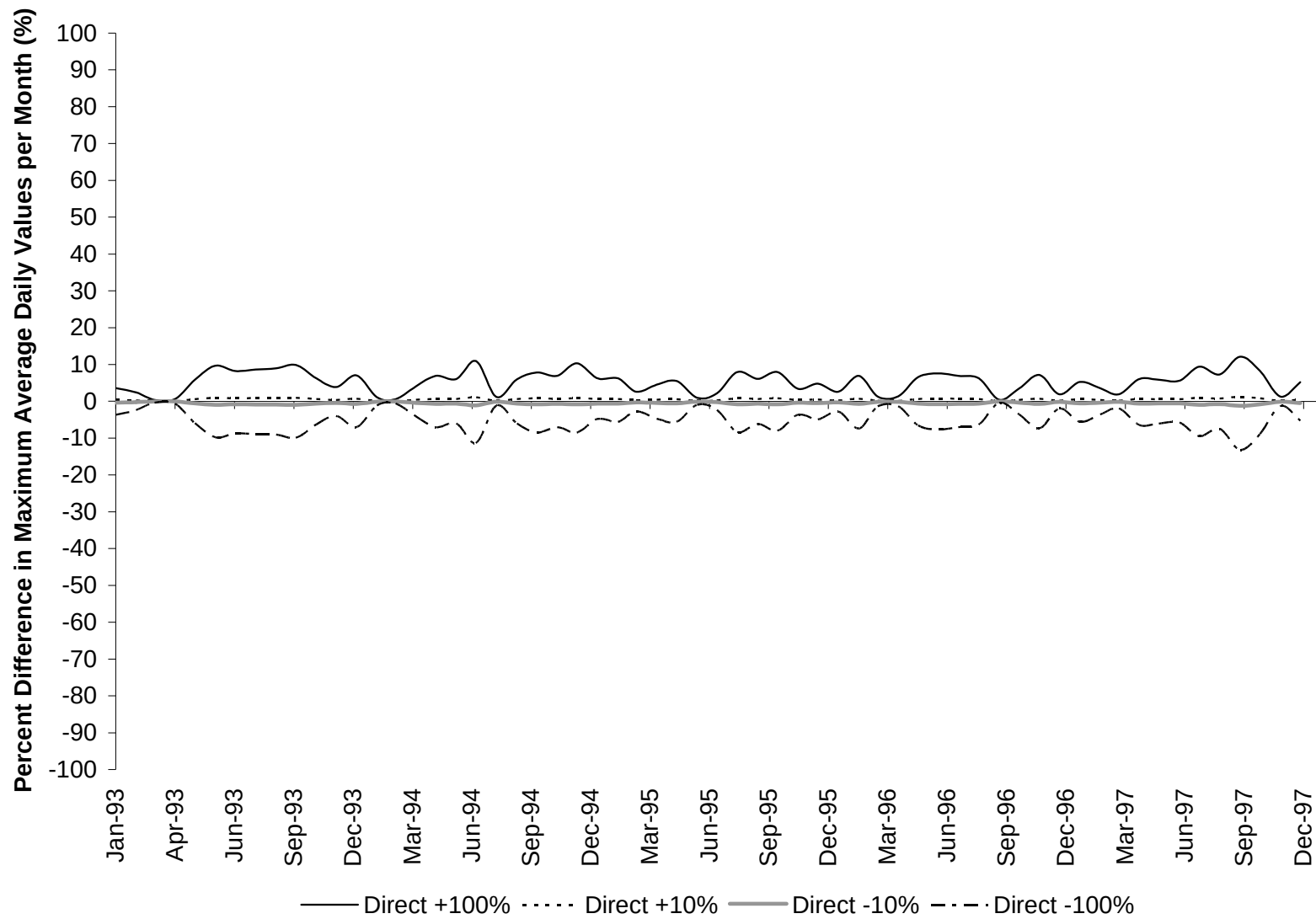


Figure 5.15. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-8) of Marsh Run (VAN-E13R-03) watershed, as affected by direct load changes.

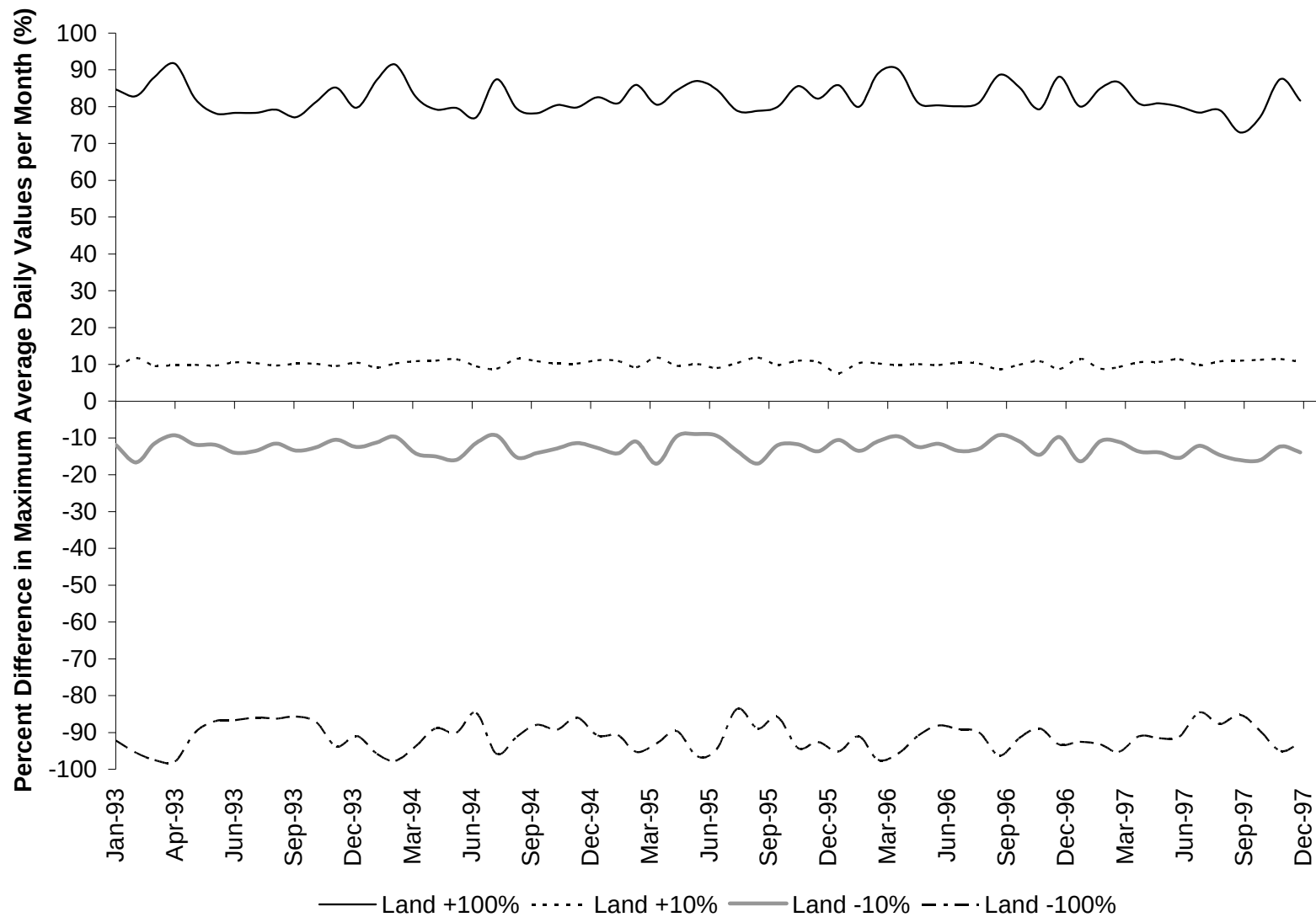


Figure 5.16. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-8) of Marsh Run (VAN-E13R-03) watershed, as affected by land-based load changes.

5.2.2 Blue Run (VAN-E13R-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 5.17 and 5.18, respectively. Figures 5.19 and 5.20, 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 5.17 with Figure 5.18 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.19 to Figure 5.20 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.

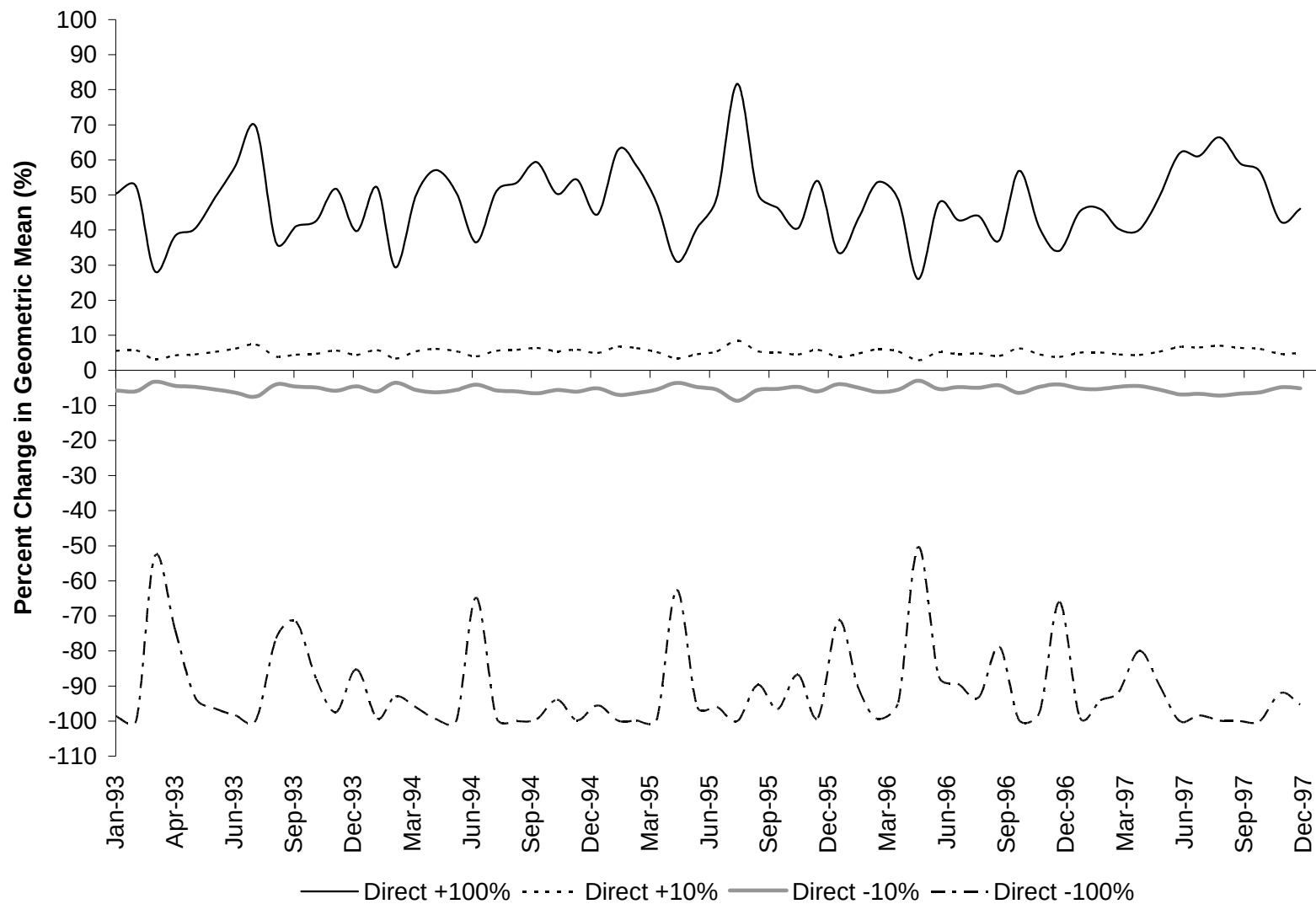


Figure 5.17. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-14) of Blue Run (VAN-E13R-01) watershed, as affected by direct load changes.

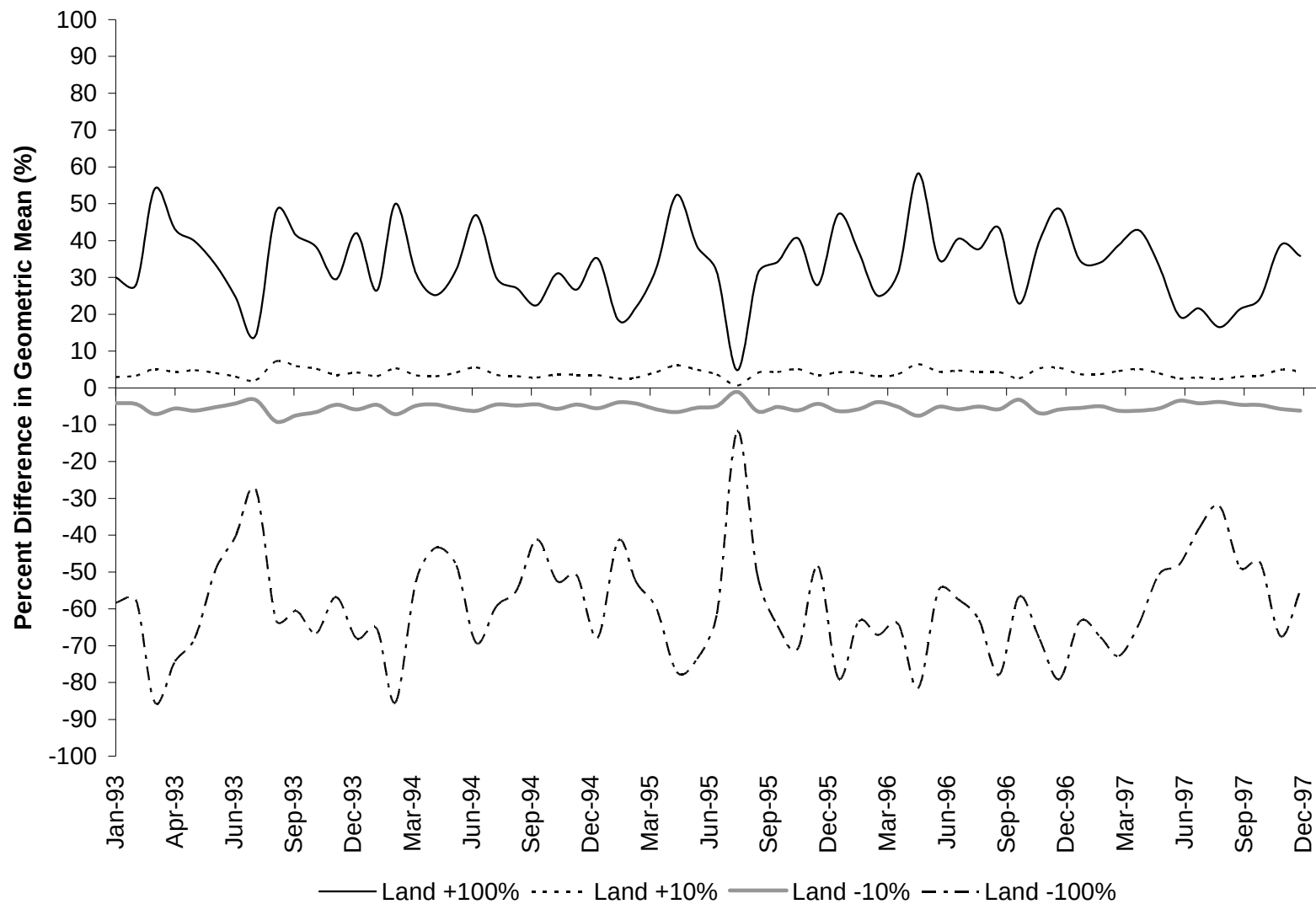


Figure 5.18. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-14) of Blue Run (VAN-E13R-01) watershed, as affected by land-based load changes.

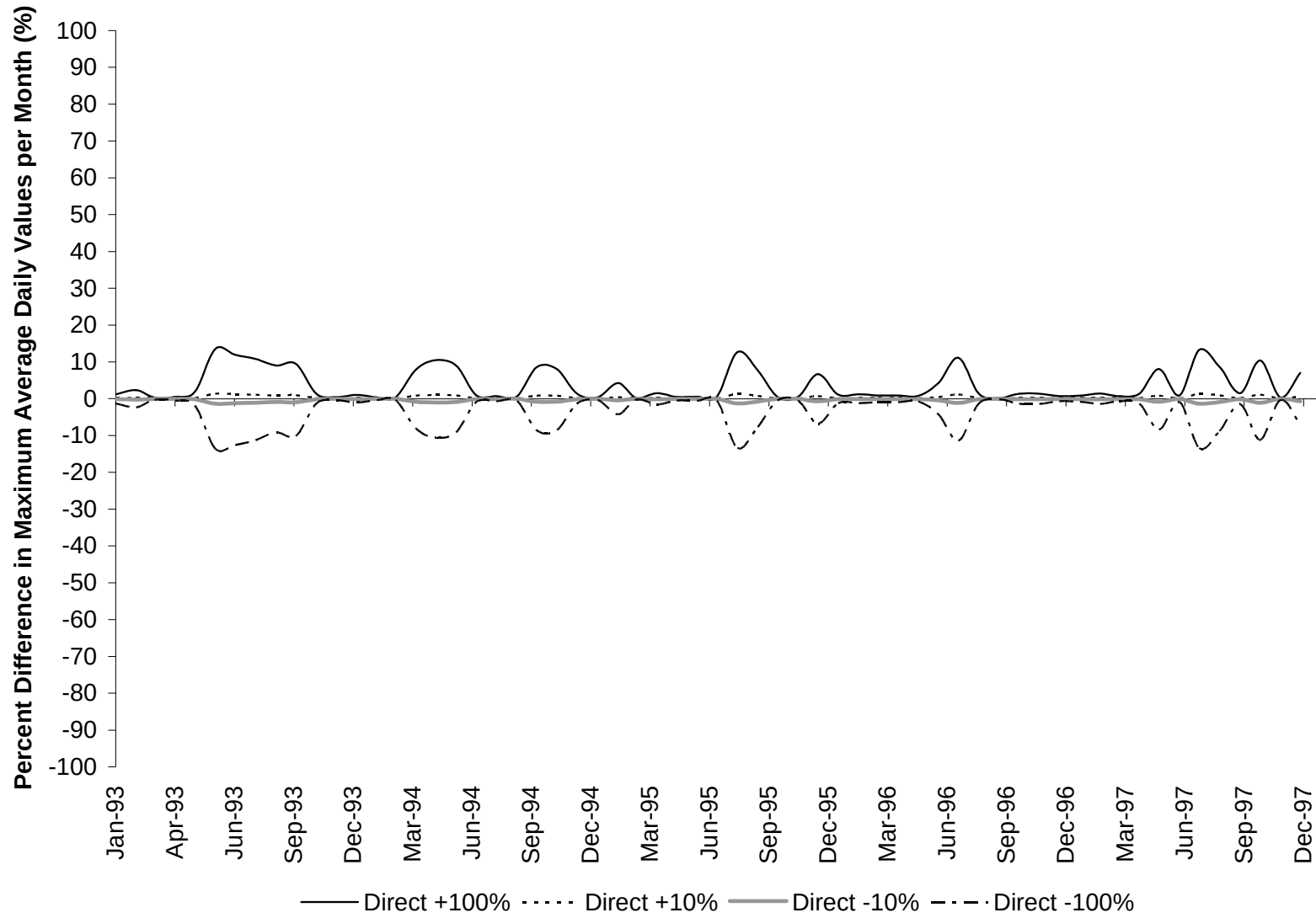


Figure 5.19. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-14) of Blue Run (VAN-E13R-01) watershed, as affected by direct load changes.

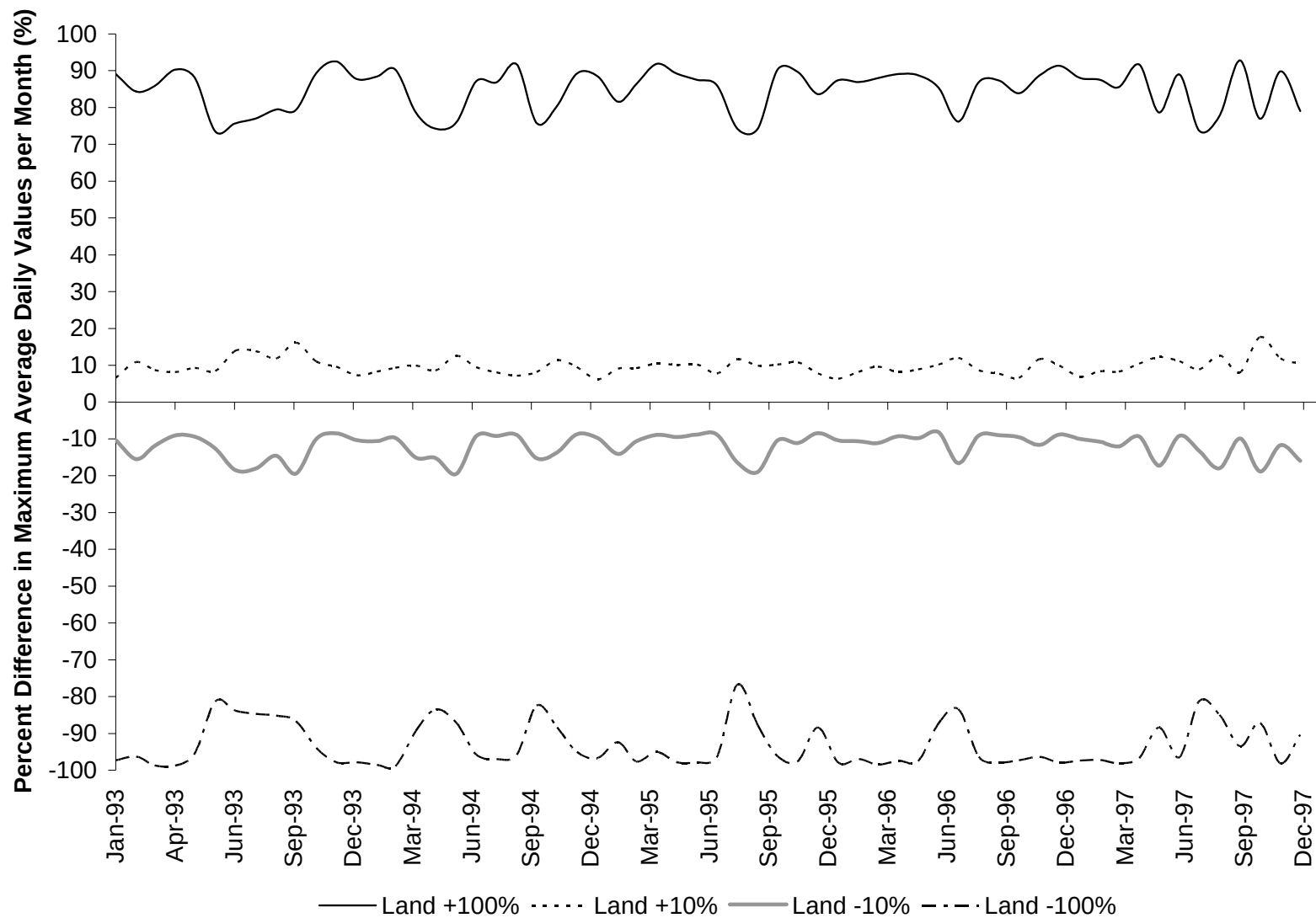


Figure 5.20. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-14) of Blue Run (VAN-E13R-01) watershed, as affected by land-based load changes.

5.2.3 UT to Rapidan River (VAN-E13R-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 5.21 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.

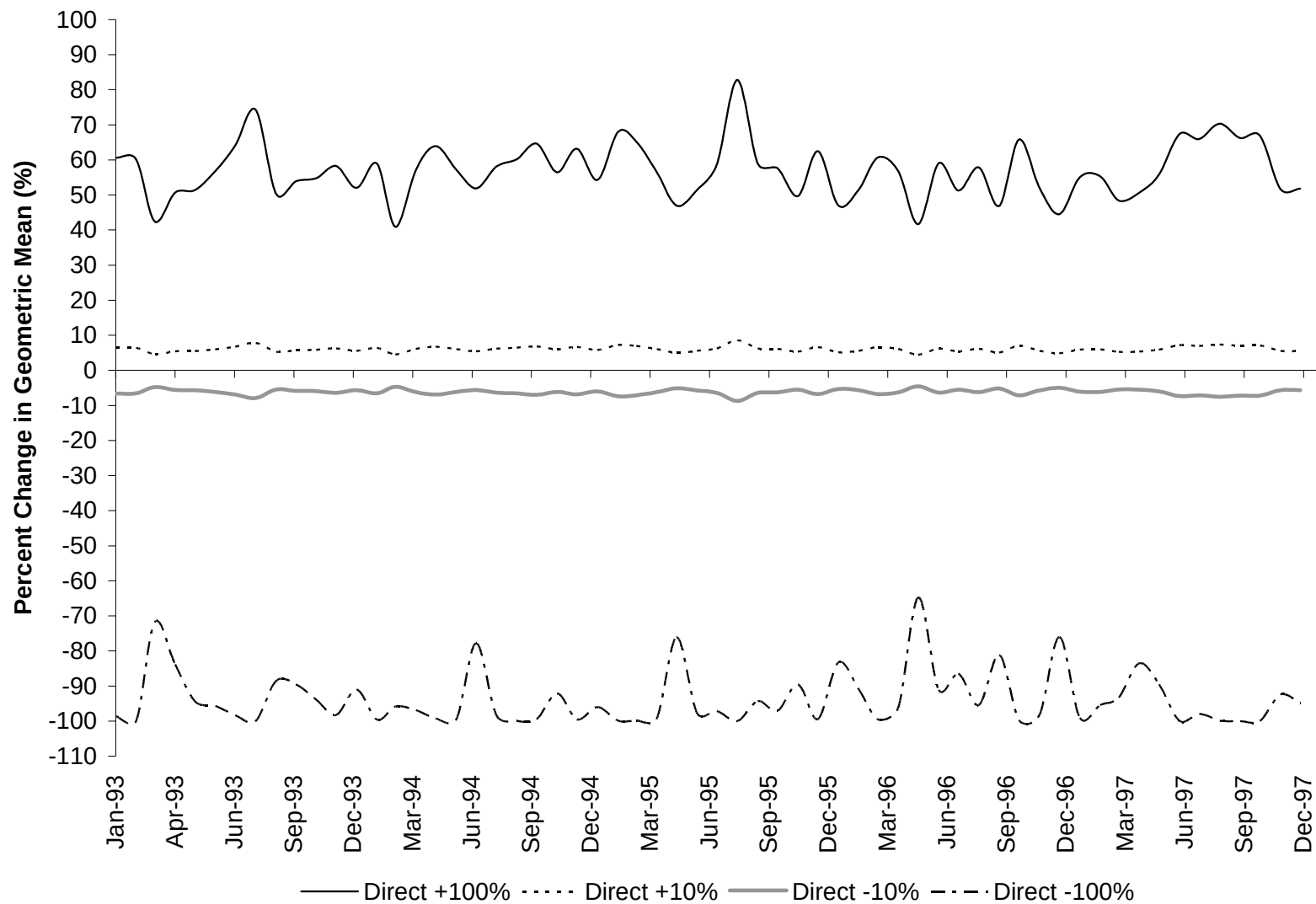


Figure 5.21. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-18) of UT to Rapidan River (VAN-E13R-04) watershed, as affected by direct load changes.

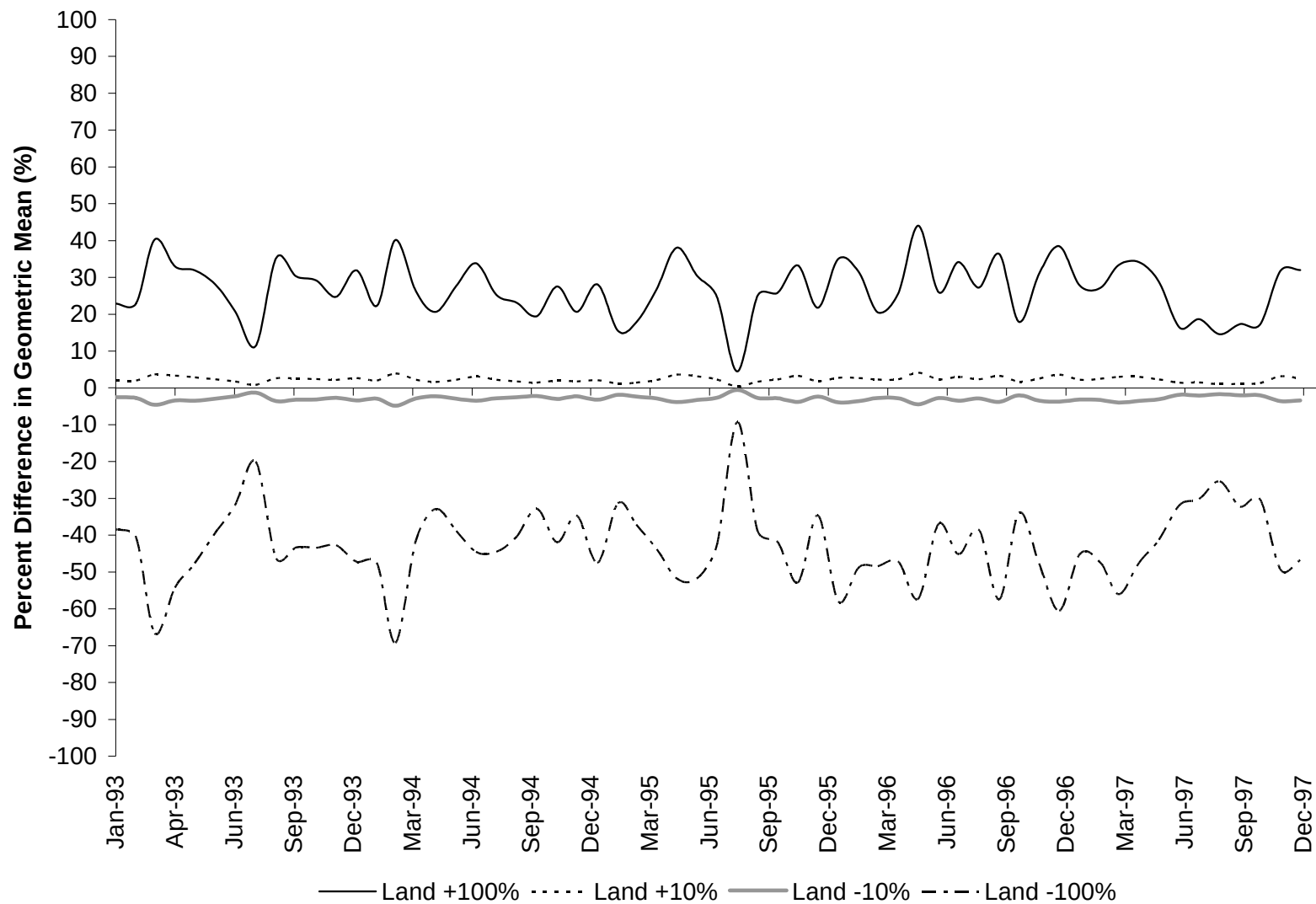


Figure 5.22. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-18) of UT to Rapidan River (VAN-E13R-04) watershed, as affected by land-based load changes.

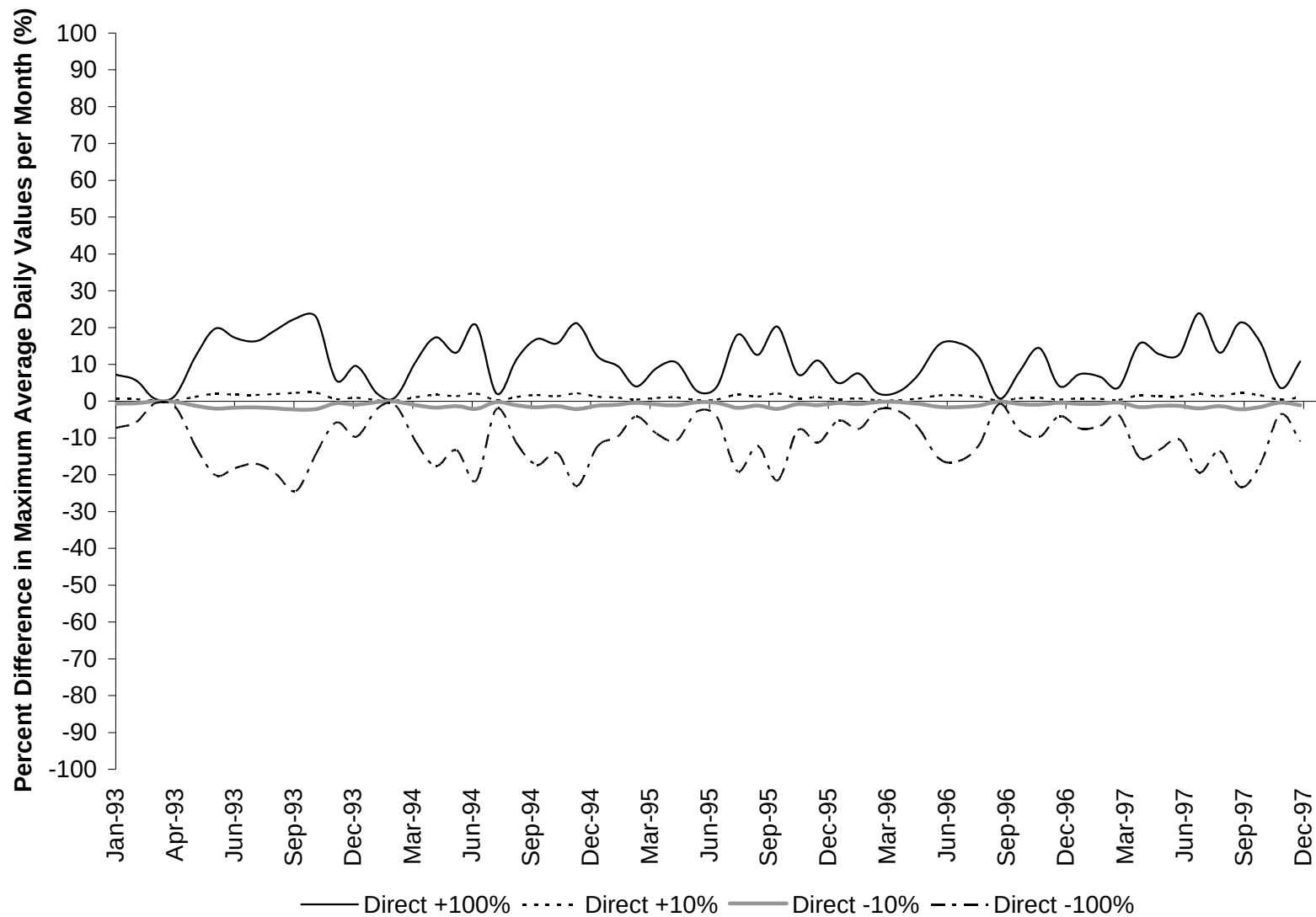


Figure 5.23. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-18) of UT to Rapidan River (VAN-E13R-04) watershed, as affected by direct load changes.

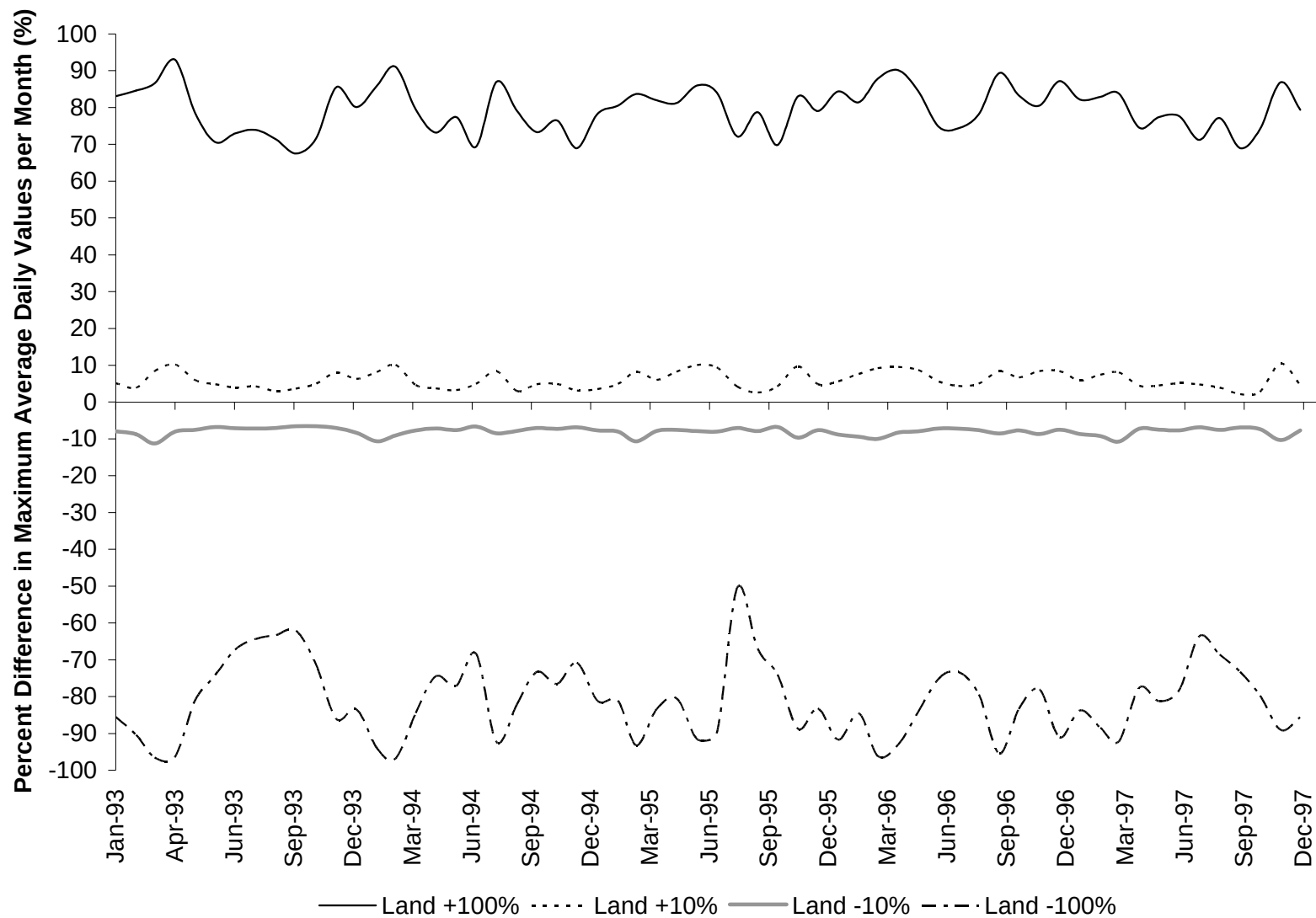


Figure 5.24. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-18) of UT to Rapidan River (VAN-E13R-04) watershed, as affected by land-based load changes.

5.2.4 Rapidan River (VAN-E13R-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 5.25 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.

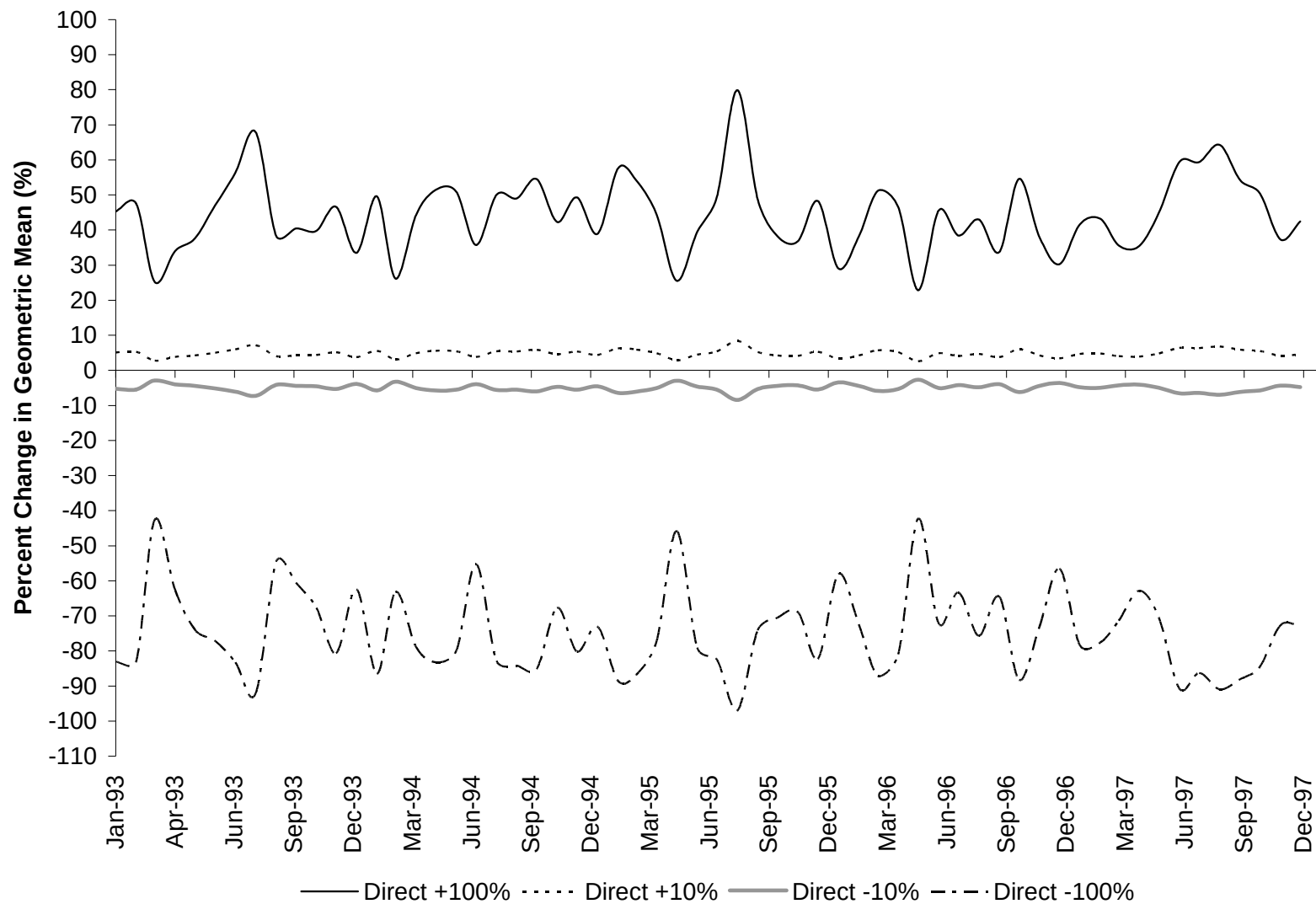


Figure 5.25. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-19) of Rapidan River (VAN-E13R-02) watershed, as affected by direct load changes.

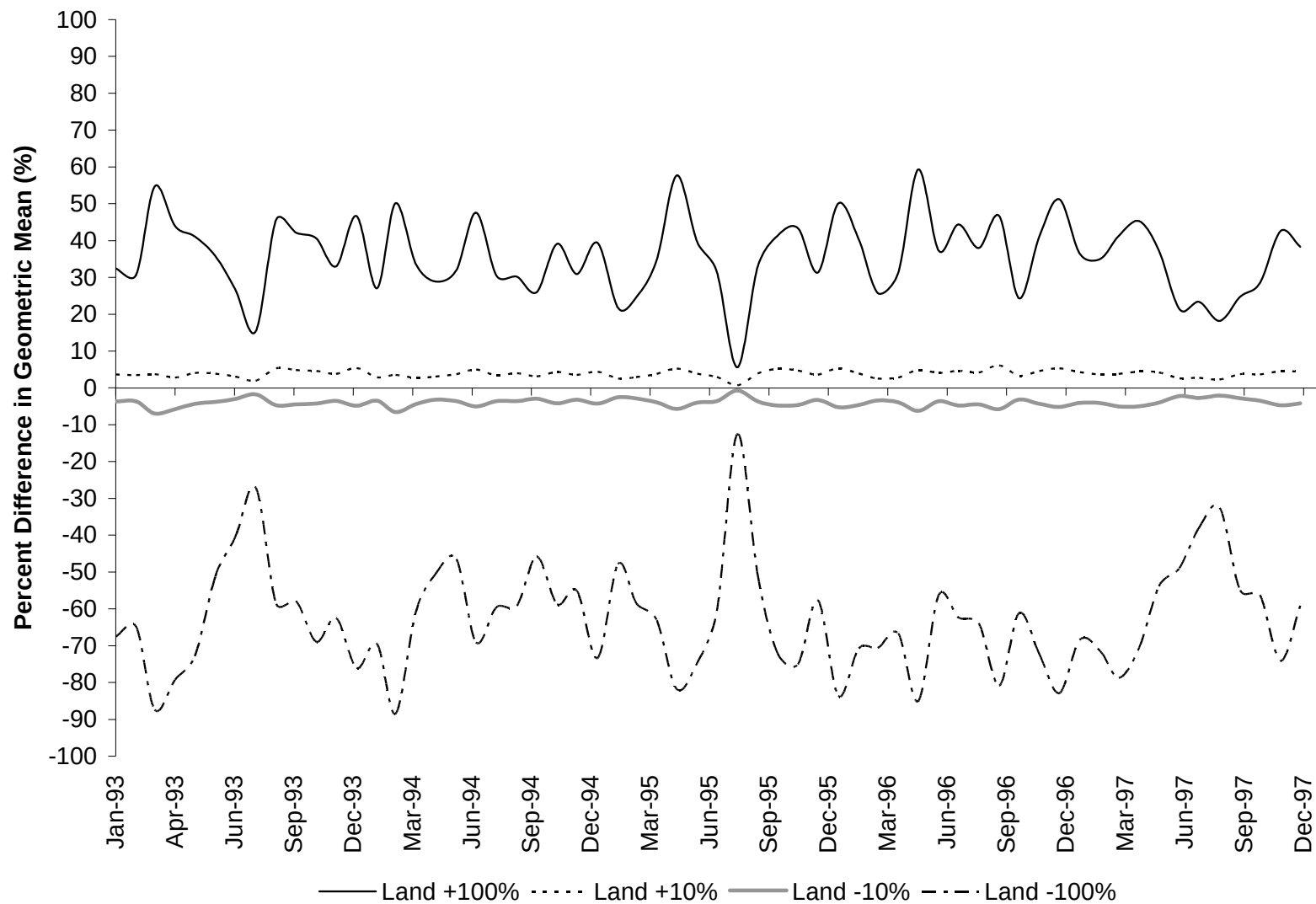


Figure 5.26. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed URR-19) of Rapidan River (VAN-E13R-02) watershed, as affected by land-based load changes.

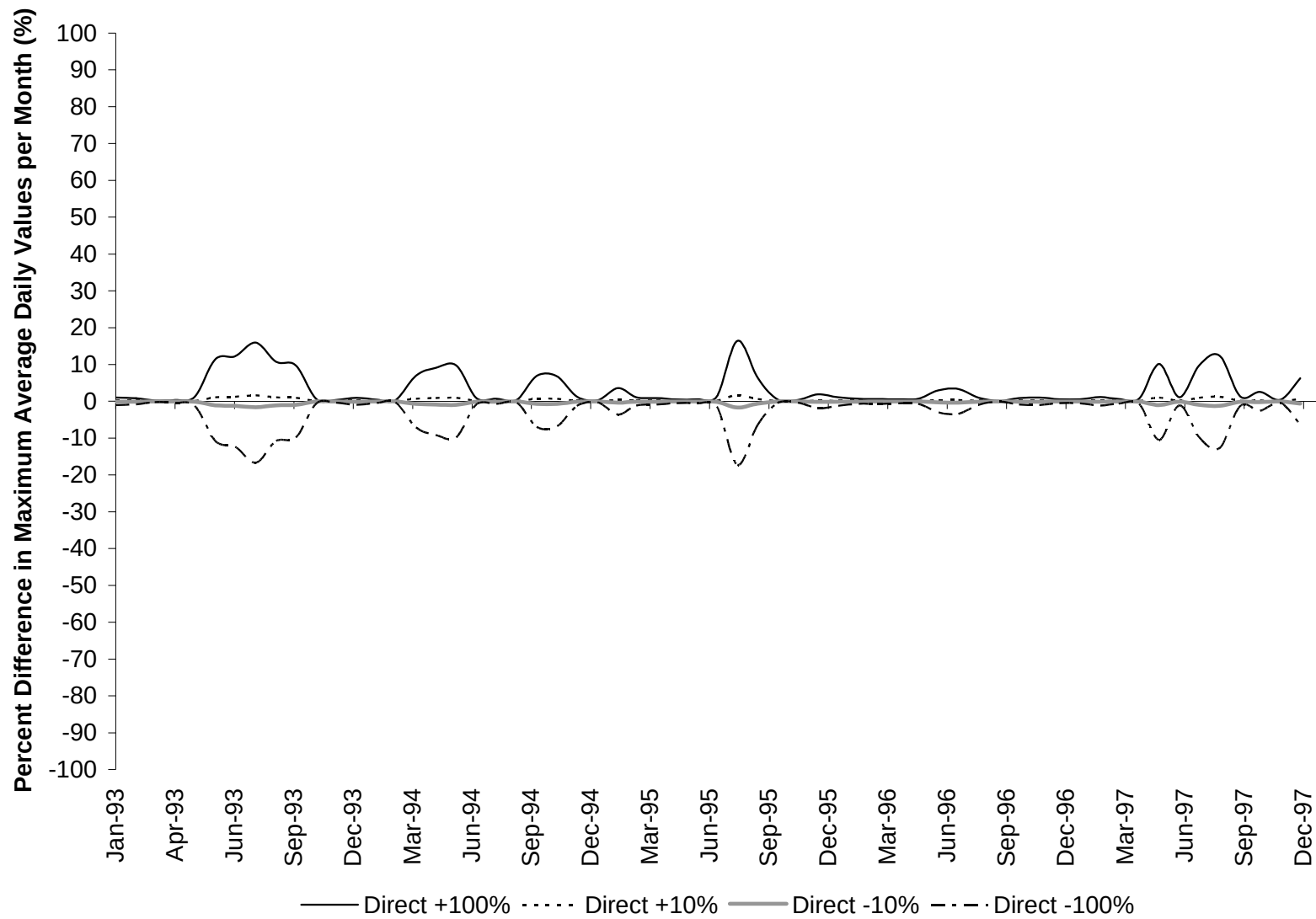


Figure 5.27. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-19) of Rapidan River (VAN-E13R-02) watershed, as affected by direct load changes.

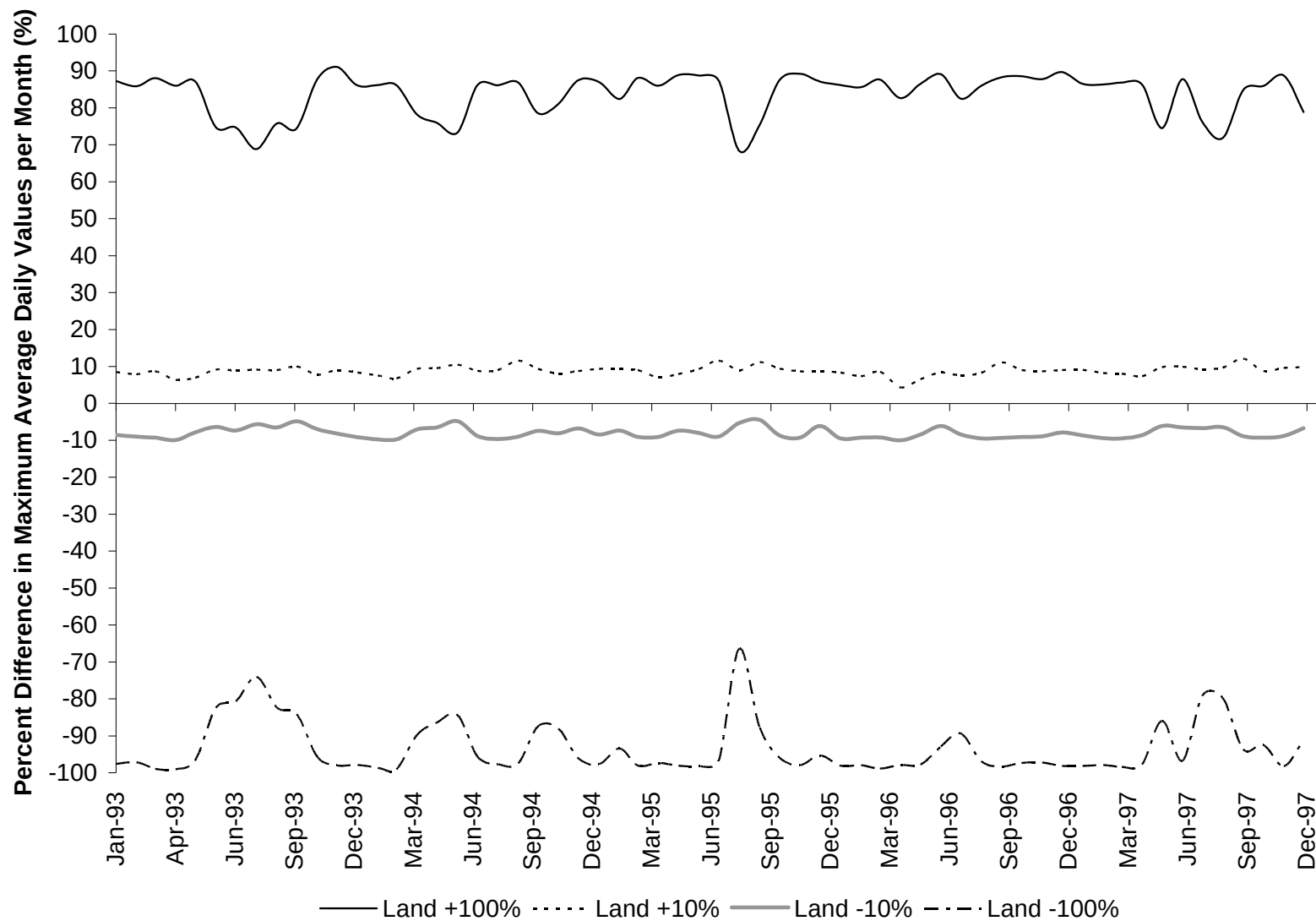


Figure 5.28. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed URR-19) of Rapidan River (VAN-E13R-02) watershed, as affected by land-based load changes.

5.2.5 Cedar Run (VAN-E16R-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.

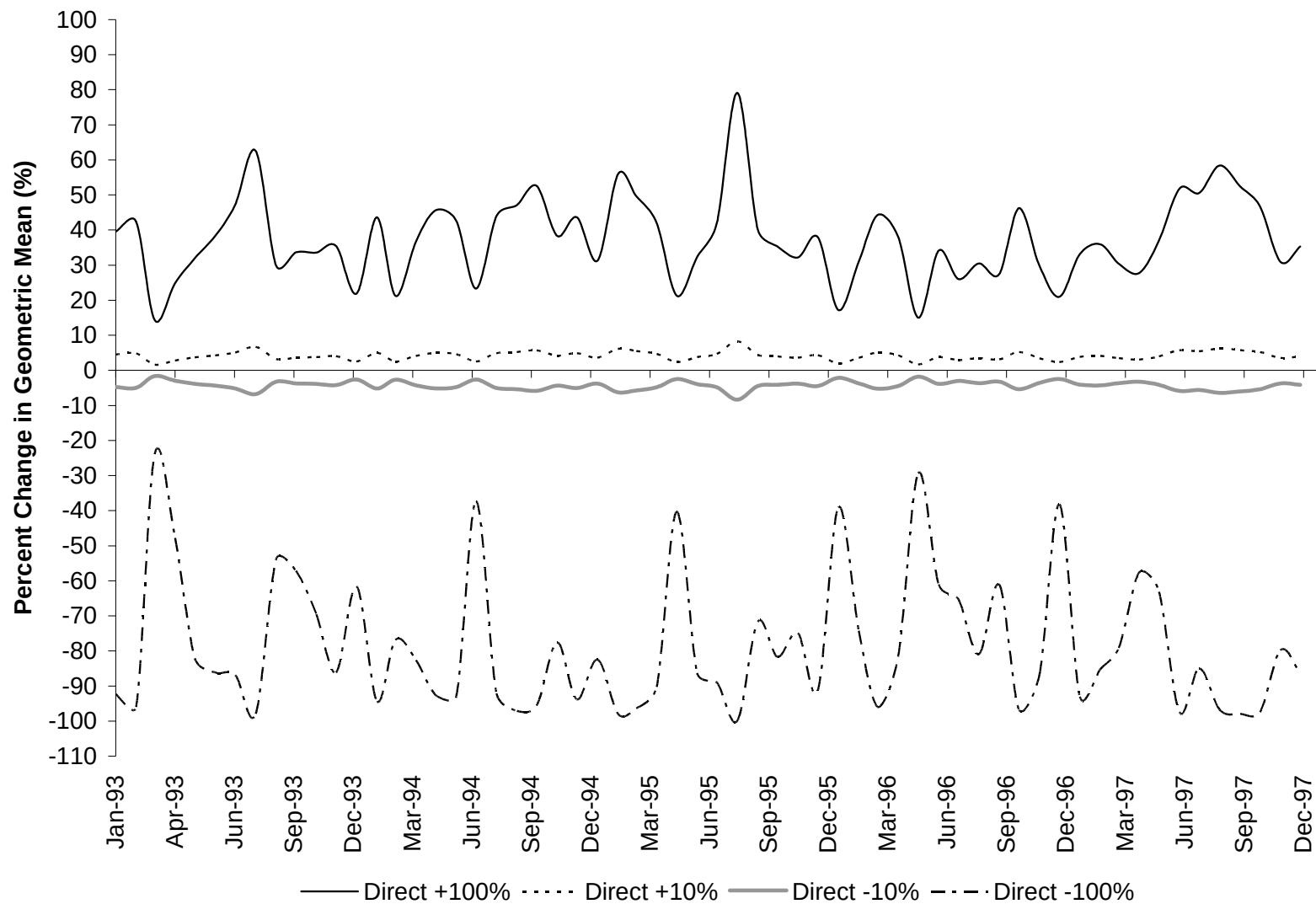


Figure 5.29. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed LRR-6) of Cedar Run (VAN-E16R-01) watershed, as affected by direct load changes.

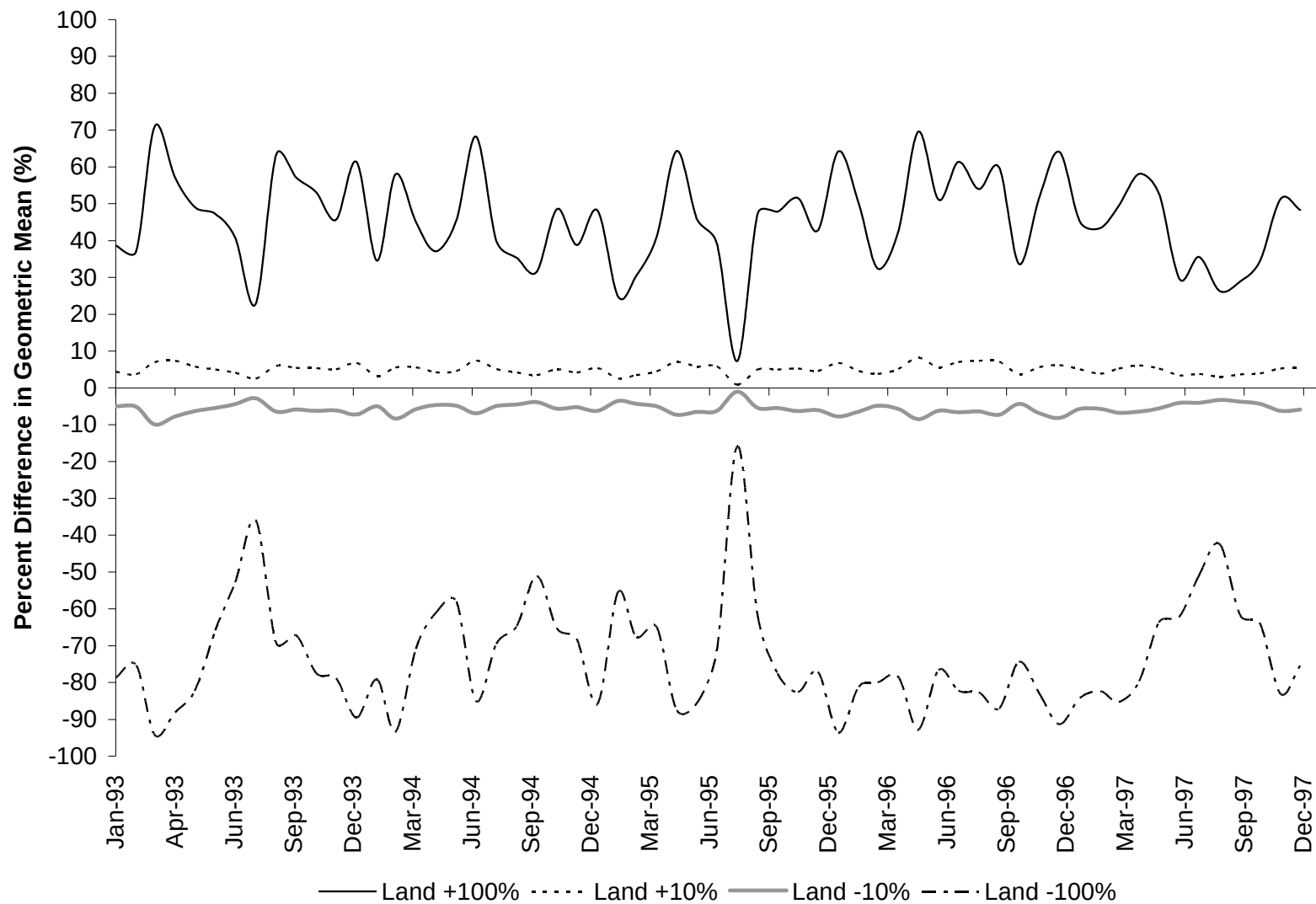


Figure 5.30. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed LRR-6) of Cedar Run (VAN-E16R-01) watershed, as affected by land-based load changes.

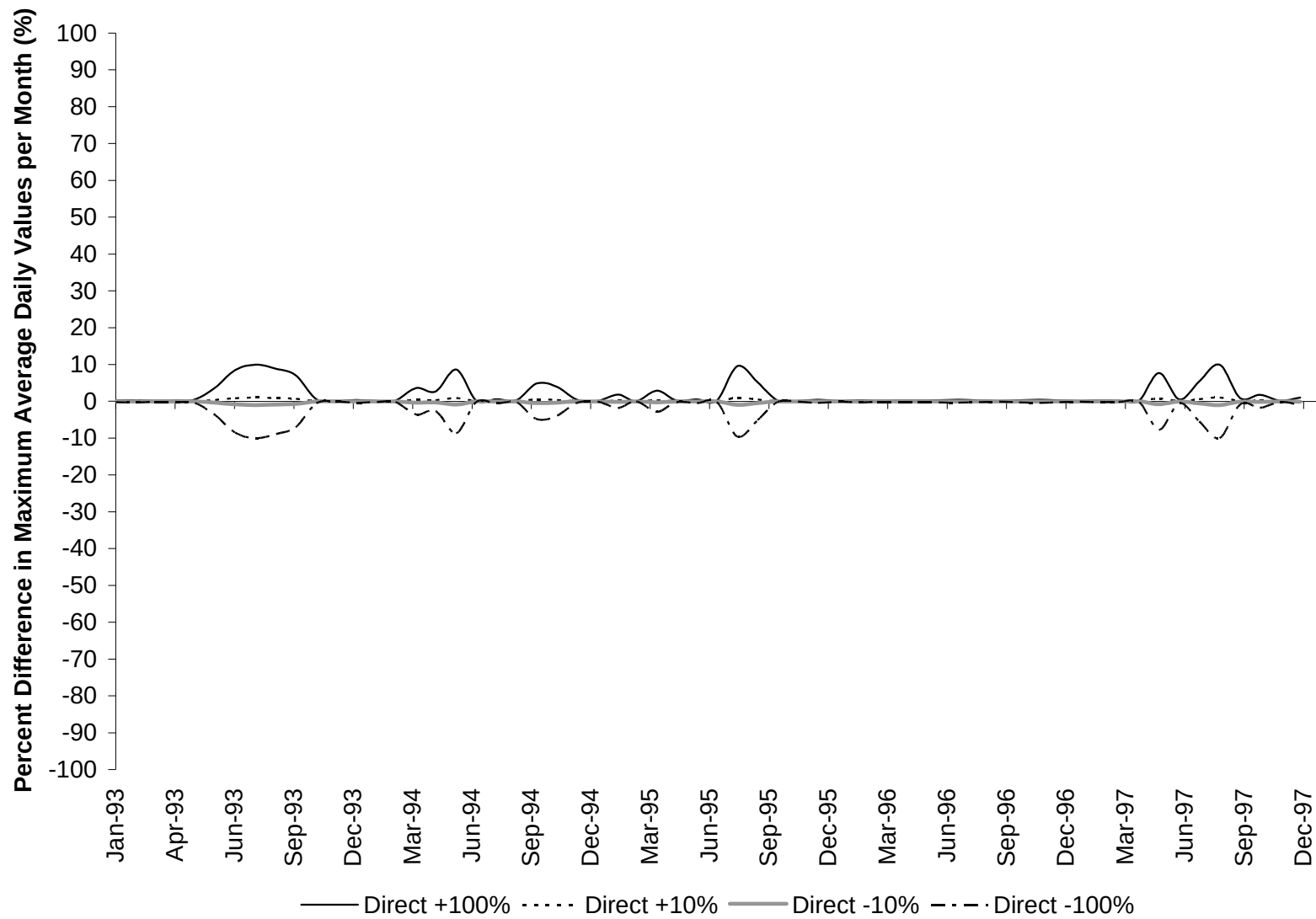


Figure 5.31. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed LRR-6) of Cedar Run (VAN-E16R-01) watershed, as affected by direct load changes.

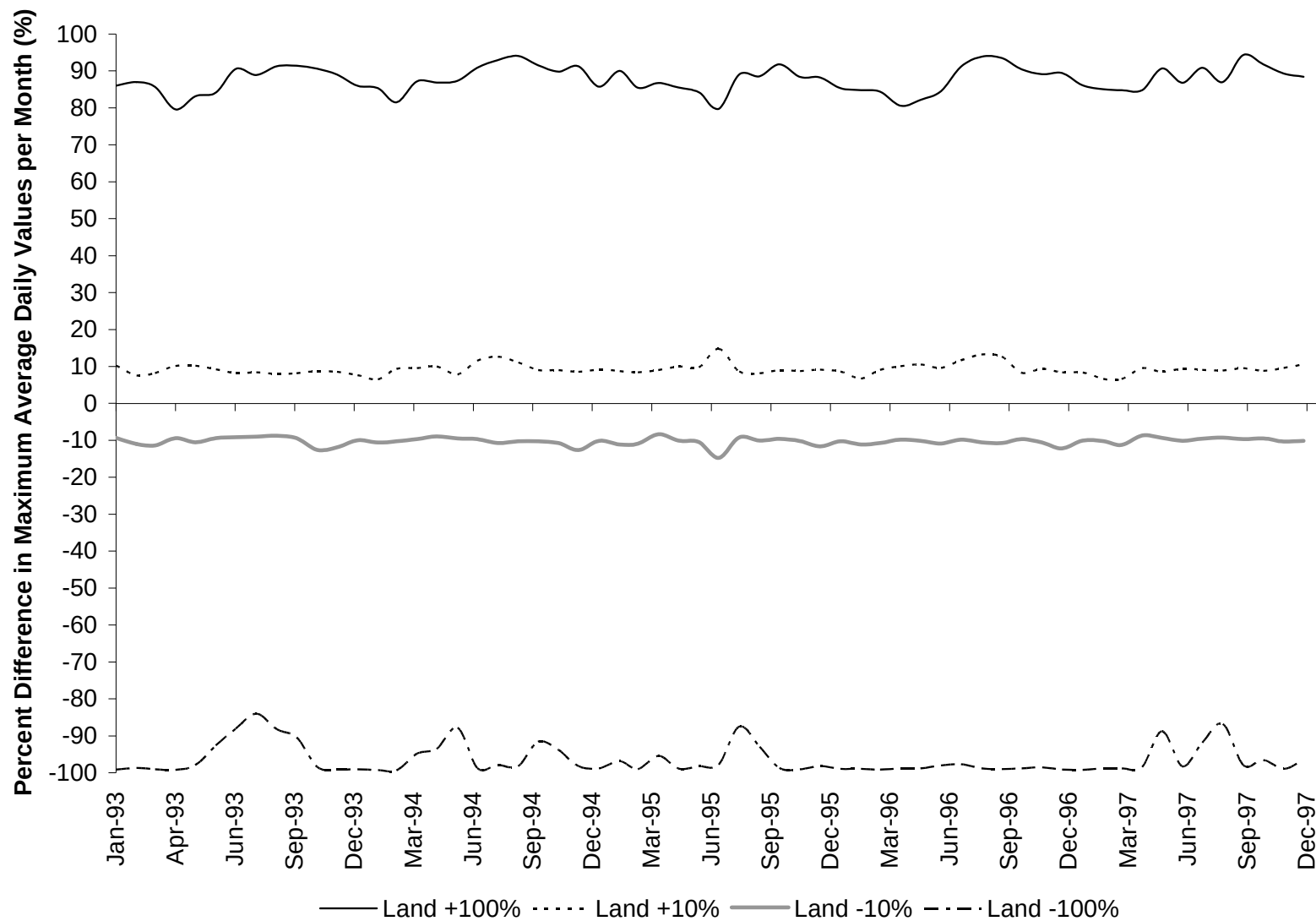


Figure 5.32. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed LRR-6) of Cedar Run (VAN-E16R-01) watershed, as affected by land-based load changes.

5.2.6 Rapidan River (VAN-E18R-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 5.33 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.

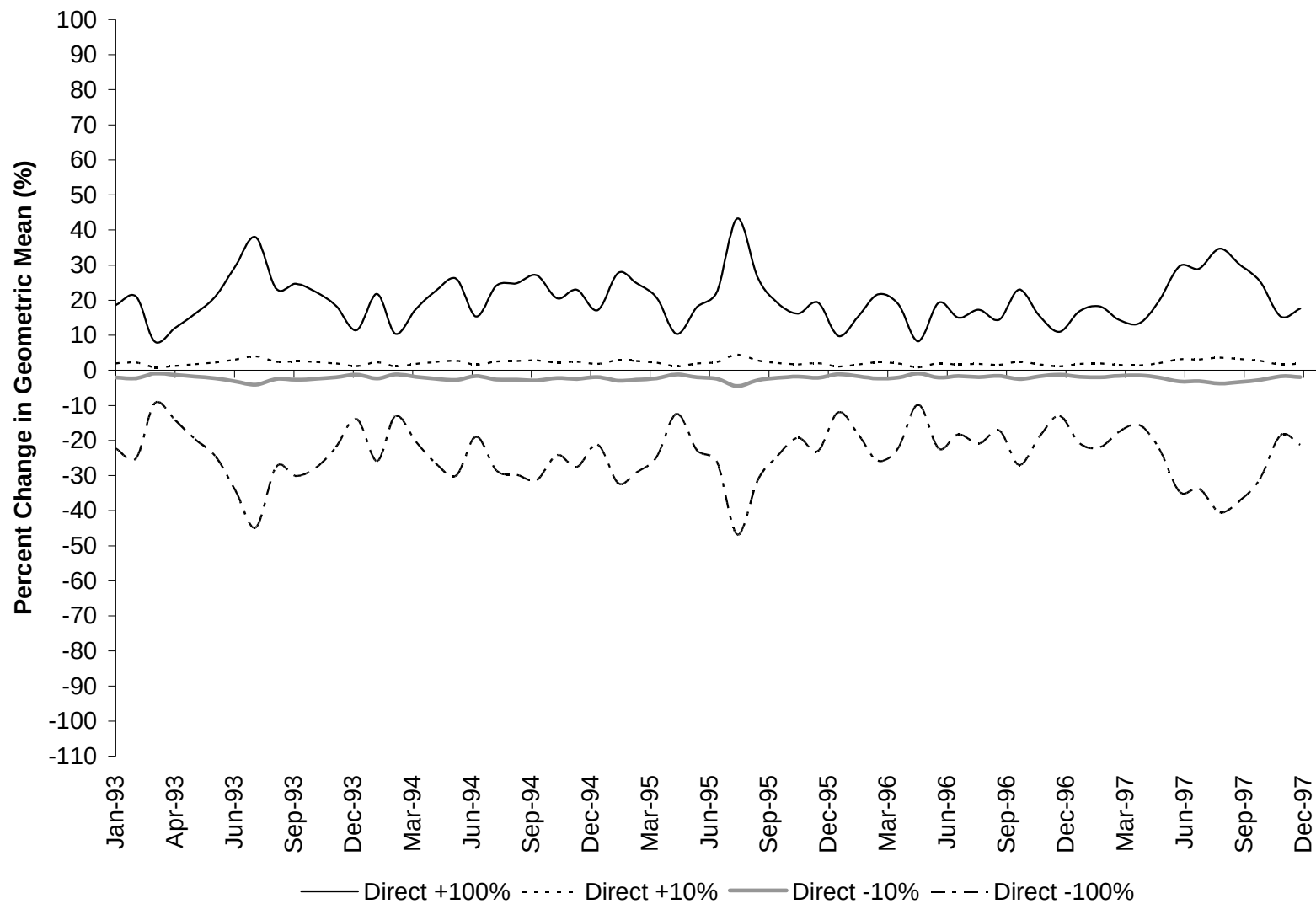


Figure 5.33. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed LRR-14) of Rapidan River (VAN-E18R-01) watershed, as affected by direct load changes.

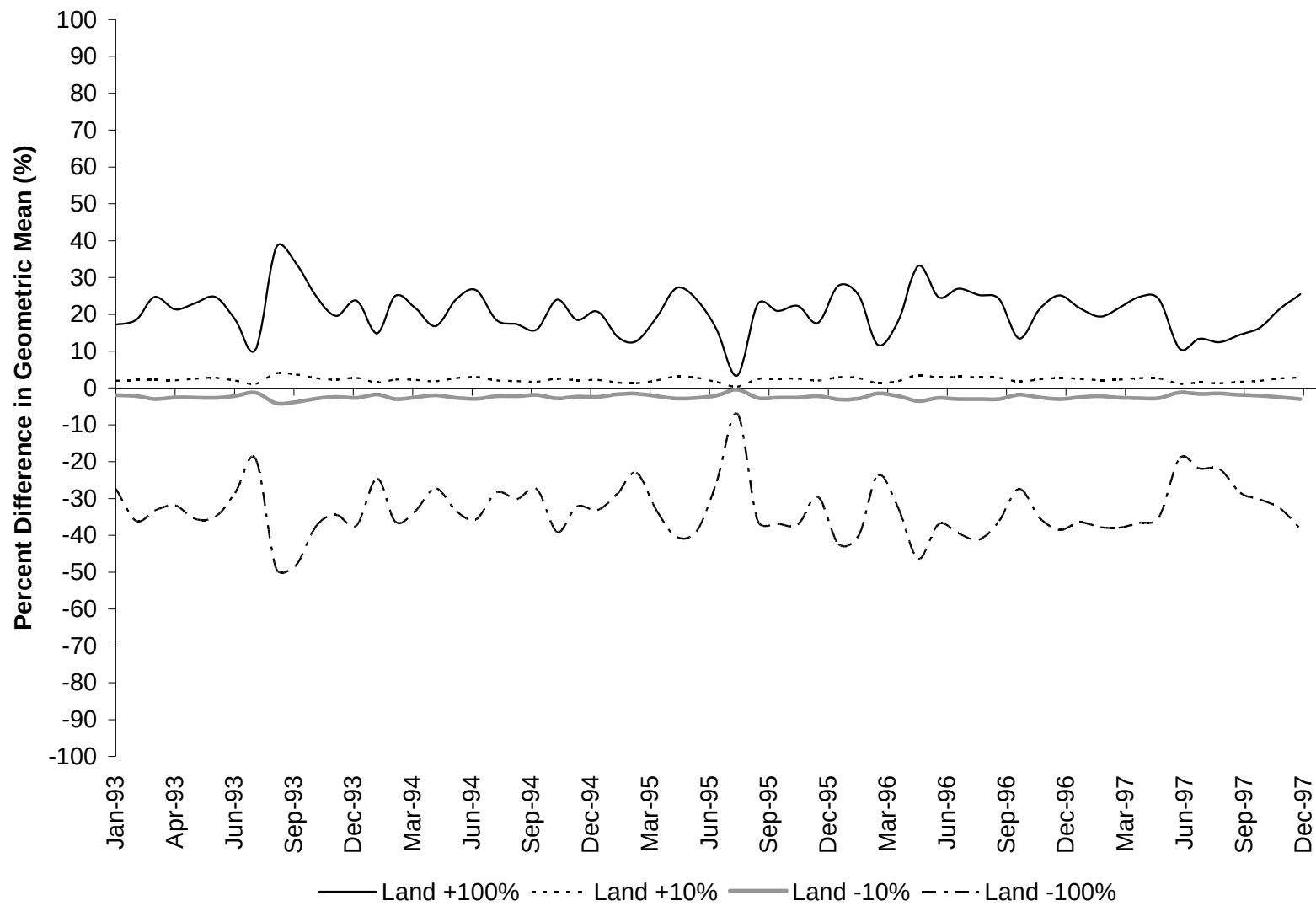


Figure 5.34. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed LRR-14) of Rapidan River (VAN-E18R-01) watershed, as affected by land-based load changes.

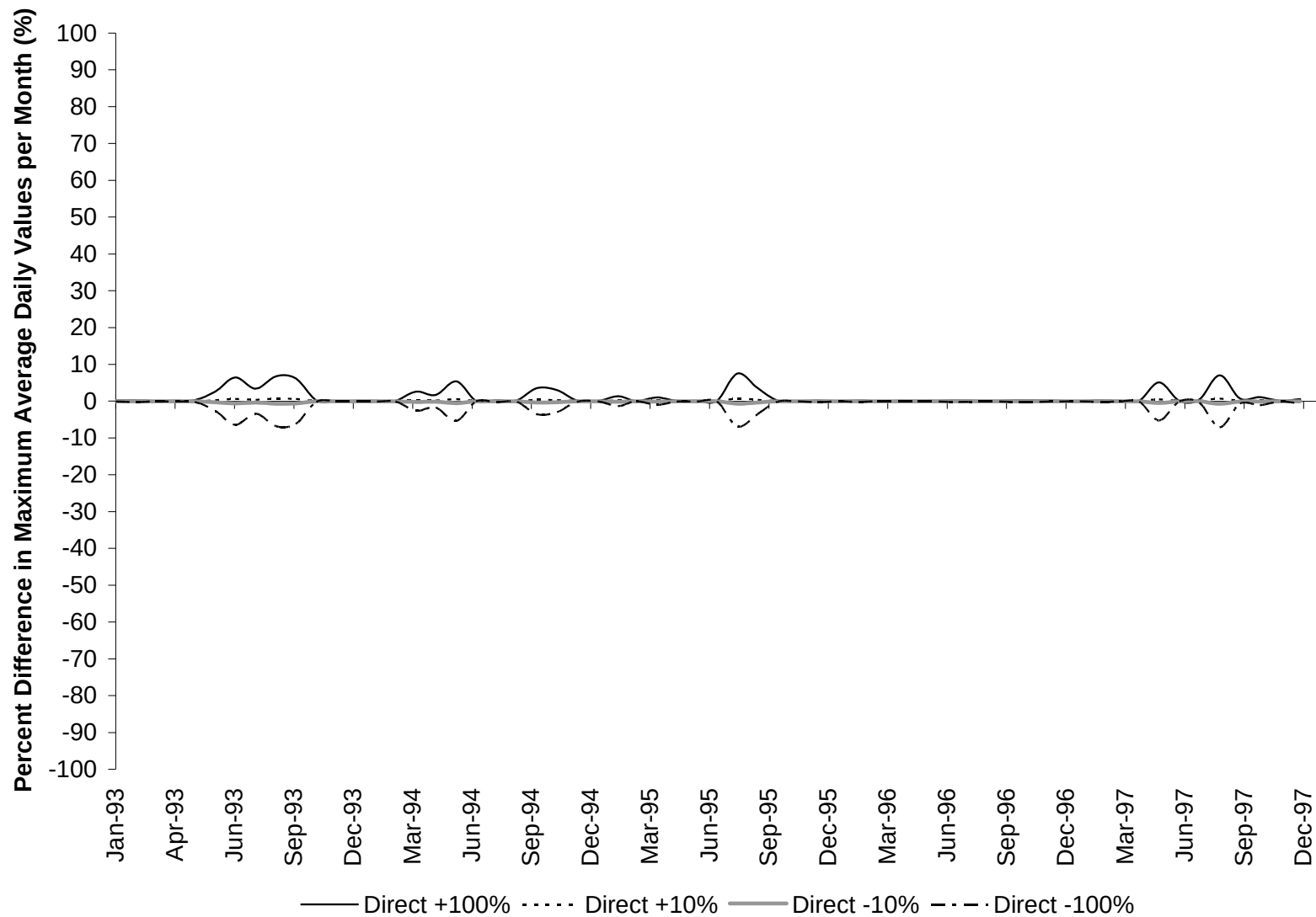


Figure 5.35. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed LRR-14) of Rapidan River (VAN-E18R-01) watershed, as affected by direct load changes.

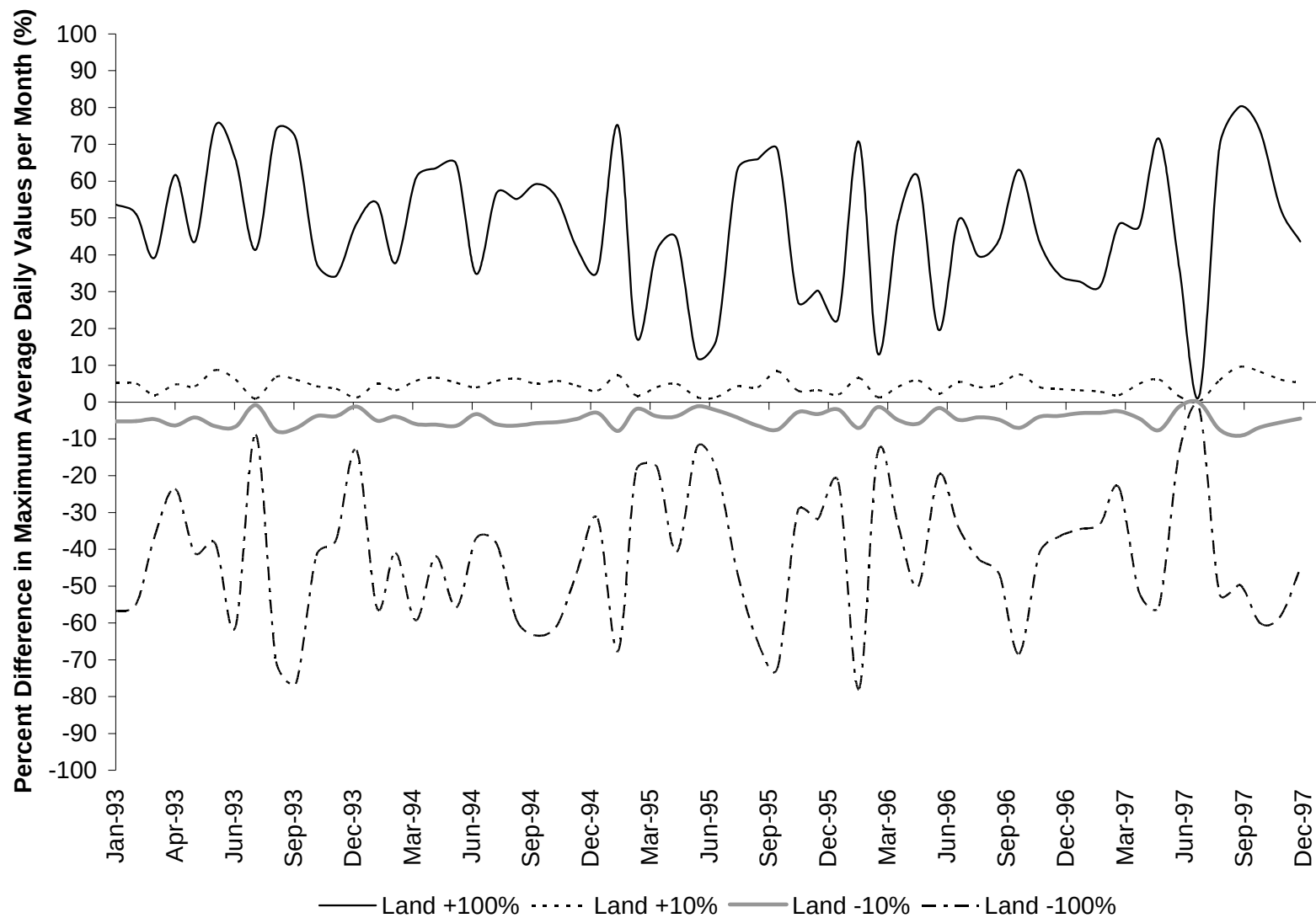


Figure 5.36. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed LRR-14) of Rapidan River (VAN-E18R-01) watershed, as affected by land-based load changes.

5.3 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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 six impairments, the final allocation scenarios for the six segments were similar.

Currently, there are seven, 11, and 34 active point discharges with a VPDES permit within the Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) watersheds, respectively. No municipalities with MS4 permits were identified within the Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) impairments and their results are summarized in Sections 5.4.1 through 5.4.6.

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 tested 100% reduction in straight pipes and livestock directly deposited loads. 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 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. (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 Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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 5.4.4, 5.4.5, and 5.4.6, 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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), and UT to Rapidan River (VAN-E13R-04) watersheds was accounted for by developing WLAs at <1% of the TMDL. 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 Rapidan 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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-01) impairments that meets both the calendar-month geometric mean and single sample water quality goals addresses the following issues:

- The TMDL was developed to meet the calendar-month geometric mean and single sample maximum 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 Marsh Run (VAN-E13R-03), Blue Run (VAN-E13R-01), UT to Rapidan River (VAN-E13R-04), Rapidan River (VAN-E13R-02), Cedar Run (VAN-E16R-01) and Rapidan River (VAN-E18R-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.

5.3.1 Marsh Run (VAN-E13R-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 5.1. Scenarios 5 through 8 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-E13R-03) watershed. Scenario 5 tested the land-based load reductions at 95%. Table 5.1 shows that exceedances are present when the anthropogenic land-based loads are tested at a 95% reduction rate. Scenario 6 tested the land-based load reductions at 97% 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 98% 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 5.37 for the final TMDL allocation (Scenario 8), along with the geometric mean and single sample maximum 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 Marsh Run (VAN-E13R-03) impairment. Table 5.4 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.1. TMDL allocation scenarios for Marsh Run (VAN-E13R-03) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance 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	85.0	36.6
1	100	0	100	0	0	0	0	18.3	31.9
2	100	50	100	50	50	0	0	8.3	19.9
3	100	75	100	75	75	0	0	3.3	9.3
4	100	100	100	100	100	0	0	0.0	0.0
5	100	95	100	95	95	0	0	3.3	0.1
6	100	97	100	97	97	0	0	1.7	0.1
7	100	98	100	98	98	0	0	0.0	0.0
8	100	98	98	98	98	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 Marsh Run (VAN-E13R-03) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.08E+13	0.00E+00	100
Livestock	6.68E+12	1.34E+11	98
Wildlife	1.05E+13	1.05E+13	0
<i>Total</i>	<i>3.80E+13</i>	<i>1.07E+13</i>	<i>72</i>
Land-based			
Residential	3.32E+14	6.63E+12	98
Cropland	1.06E+12	2.11E+10	98
Pasture	6.42E+15	1.28E+14	98
Forest	7.33E+13	7.33E+13	0
<i>Total</i>	<i>6.83E+15</i>	<i>2.08E+14</i>	<i>97</i>

Table 5.3. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Marsh Run (VAN-E13R-03) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	6.72E+10	6.65E+12	N/A	6.72E+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 5.4. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Marsh Run (VAN-E13R-03) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	7.61E+09	7.53E+11	N/A	7.61E+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.

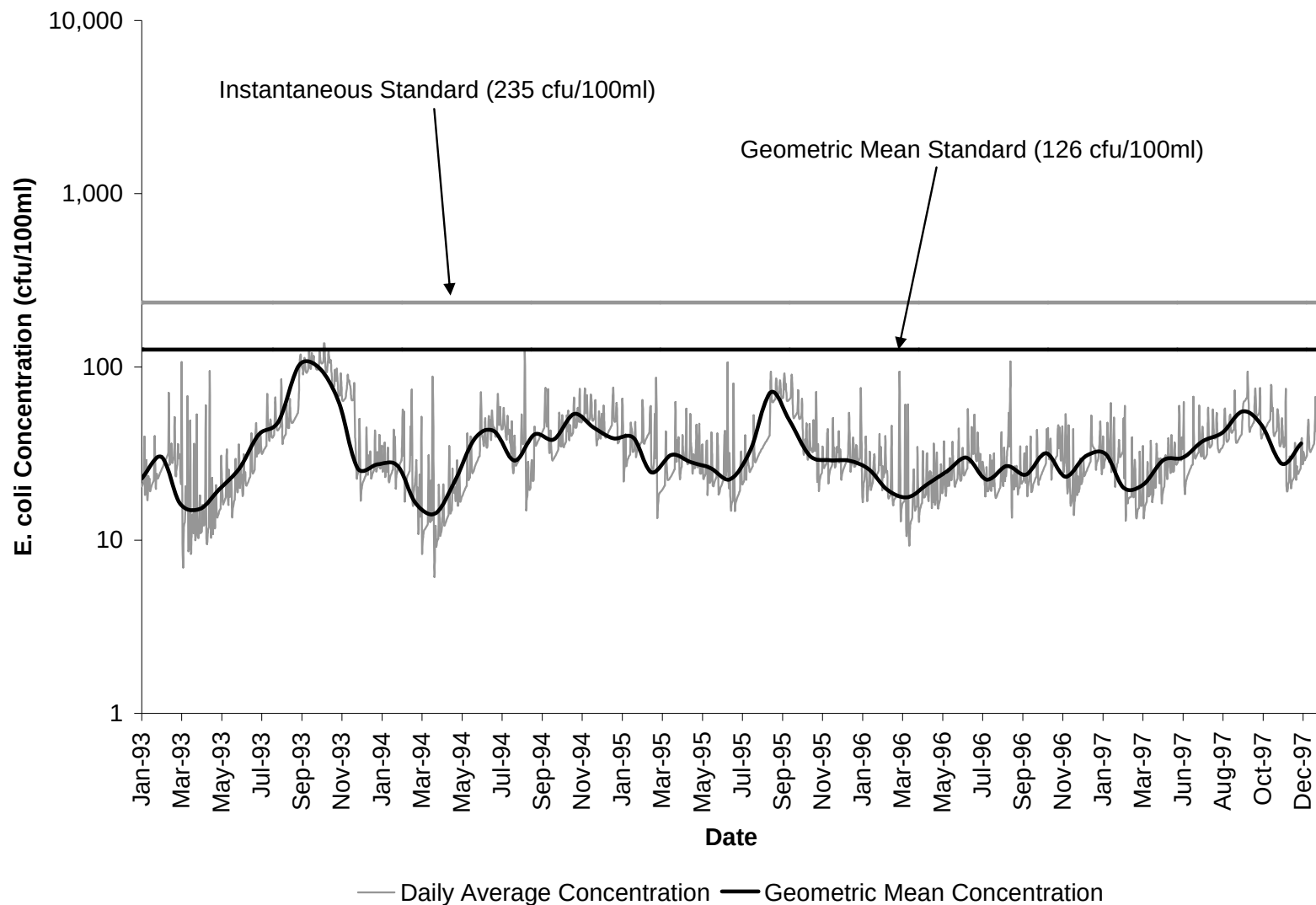


Figure 5.37. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.1) in Marsh Run (VAN-E13R-03) impairment.

5.3.2 Blue Run (VAN-E13R-01)

Formulations of Scenarios 1 through 4 are discussed in Section 5.5. The results of those scenarios, and additional scenarios, are displayed in Table 5.5. 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 Blue Run (VAN-E13R-01) watershed. The anthropogenic land-based and livestock directly deposited loads were all tested at a 99% reduction rate and there was no reduction in forest land based loads for Scenario 5 through 7. Scenario 5 represents a 25% reduction of wildlife directly deposited load. This scenario had a 3.3% exceedance of the geometric mean, but no exceedance for the instantaneous condition. Scenario 6 represents a 29% reduction of wildlife directly deposited load resulting in a 1.7% exceedance of the geometric mean standard, but no exceedance for the instantaneous condition. Scenario 7 represents a 30% 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 5.38 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.6 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 5.7 presents the final allocated in-stream *E. coli* loads for the Blue Run (VAN-E13R-01) impairment. Table 5.8 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.5. TMDL allocation scenarios for Blue Run (VAN-E13R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance of <i>E. coli</i> Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	100.0	63.1
1	100	0	100	0	0	0	0	21.7	30.6
2	100	50	100	50	50	0	0	8.8	21.0
3	100	75	100	75	75	0	0	6.7	11.2
4	100	100	100	100	100	0	0	3.3	0.3
5	100	99	99	99	99	25	0	3.3	0.0
6	100	99	99	99	99	29	0	1.7	0.0
7	100	99	99	99	99	30	0	0.0	0.0

Table 5.6. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Blue Run (VAN-E13R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	7.07E+13	0.00E+00	100
Livestock	2.30E+13	2.30E+11	99
Wildlife	2.87E+13	2.01E+13	30
<i>Total</i>	<i>1.22E+14</i>	<i>2.03E+13</i>	83
Land-based			
Residential	5.70E+14	5.70E+12	99
Cropland	3.59E+12	3.59E+10	99
Pasture	2.23E+16	2.23E+14	99
Forest	1.16E+14	1.16E+14	0
<i>Total</i>	<i>2.29E+16</i>	<i>3.44E+14</i>	98

Table 5.7. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Blue Run (VAN-E13R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	8.75E+10	8.66E+12	N/A	8.75E+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 5.8. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Blue Run (VAN-E13R-01) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	1.74E+10	1.72E+12	N/A	1.74E+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.

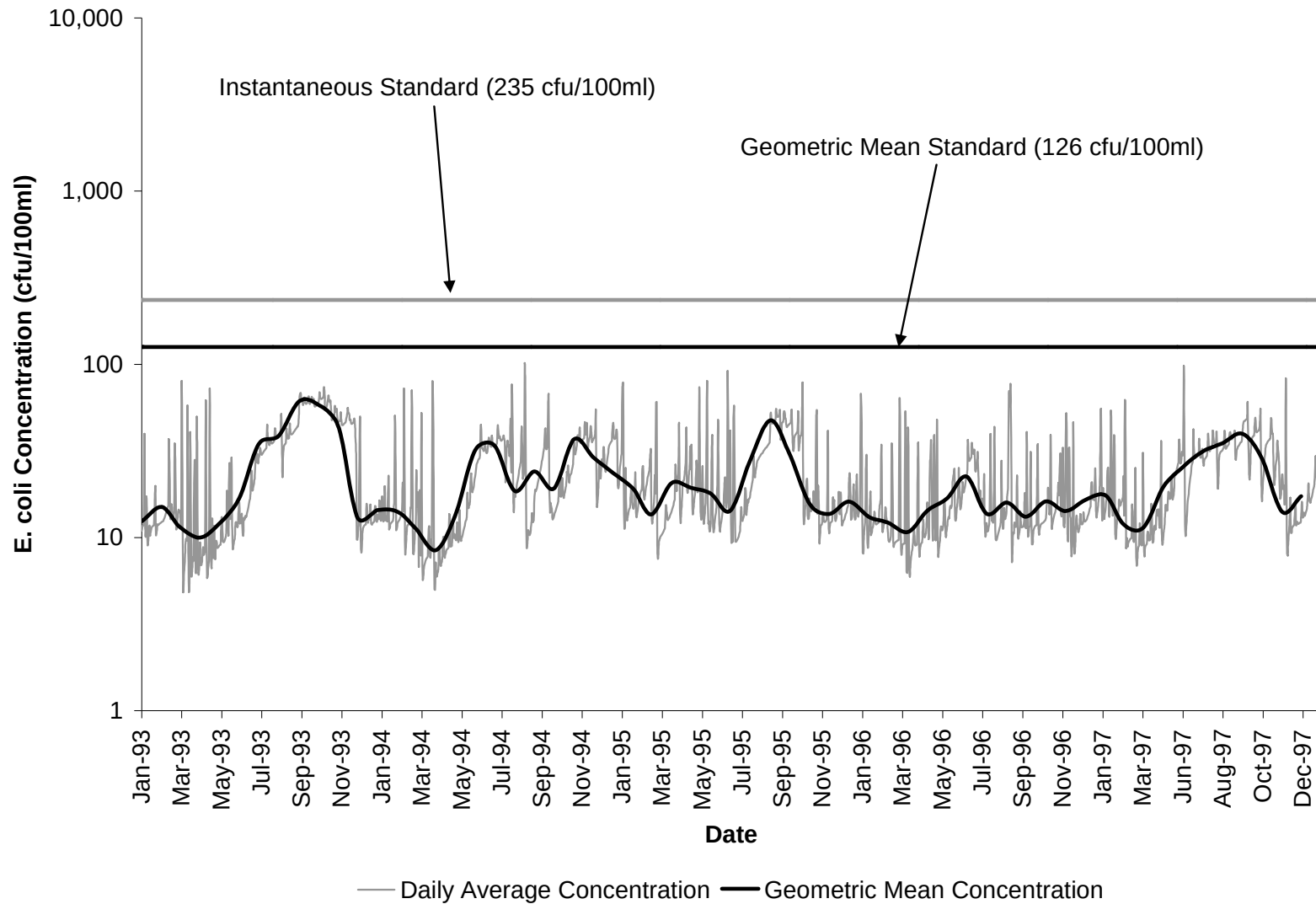


Figure 5.38. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.4) in Blue Run (VAN-E13R-01) impairment.

5.3.3 UT to Rapidan River (VAN-E13R-04)

Formulations of Scenario 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.9. 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 UT to Rapidan River (VAN-E13R-04) watershed. The anthropogenic land-based and livestock directly deposited loads were all tested at a 99% reduction rate and there was no reduction in forest land-based loads for Scenario 5 through 7. Scenario 5 represents a 25% reduction of wildlife directly deposited load. This scenario had a 3.3% exceedance in the geometric mean standard and a 0.1% exceedance of the instantaneous standard. Scenario 6 represents a 37% reduction of wildlife directly deposited load resulting in a 1.7% exceedance of the geometric mean standard, but no exceedance for the instantaneous standard. Scenario 7 represents a 38% 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 5.39 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.10 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 5.11 presents the final allocated in-stream *E. coli* loads for the UT to Rapidan River (VAN-E13R-04) impairment. Table 5.12 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.9. TMDL allocation scenarios for UT to Rapidan River (VAN-E13R-04) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance of <i>E. coli</i> Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean	Instantaneous
Existing Conditions	0	0	0	0	0	0	0	95.0	50.6
1	100	0	100	0	0	0	0	21.7	29.6
2	100	50	100	50	50	0	0	10.0	18.7
3	100	75	100	75	75	0	0	6.7	8.8
4	100	100	100	100	100	0	0	3.3	0.6
5	100	99	99	99	99	25	0	3.3	0.1
6	100	99	99	99	99	37	0	1.7	0.0
7	100	99	99	99	99	38	0	0.0	0.0

Table 5.10. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in UT to Rapidan River (VAN-E13R-04) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	7.22E+12	0.00E+00	100
Livestock	2.23E+12	2.23E+10	99
Wildlife	2.03E+12	1.26E+12	38
<i>Total</i>	<i>1.15E+13</i>	<i>1.28E+12</i>	89
Land-based			
Residential	5.76E+13	5.76E+11	99
Cropland	8.15E+10	8.15E+08	99
Pasture	2.14E+15	2.14E+13	99
Forest	8.20E+12	8.20E+12	0
<i>Total</i>	<i>2.21E+15</i>	<i>3.02E+13</i>	99

Table 5.11. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in UT to Rapidan River (VAN-E13R-04) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	6.99E+09	6.92E+11	N/A	6.99E+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.

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 5.12. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in UT to Rapidan River (VAN-E13R-04) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	9.67E+08	9.57E+10	N/A	9.67E+10

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.

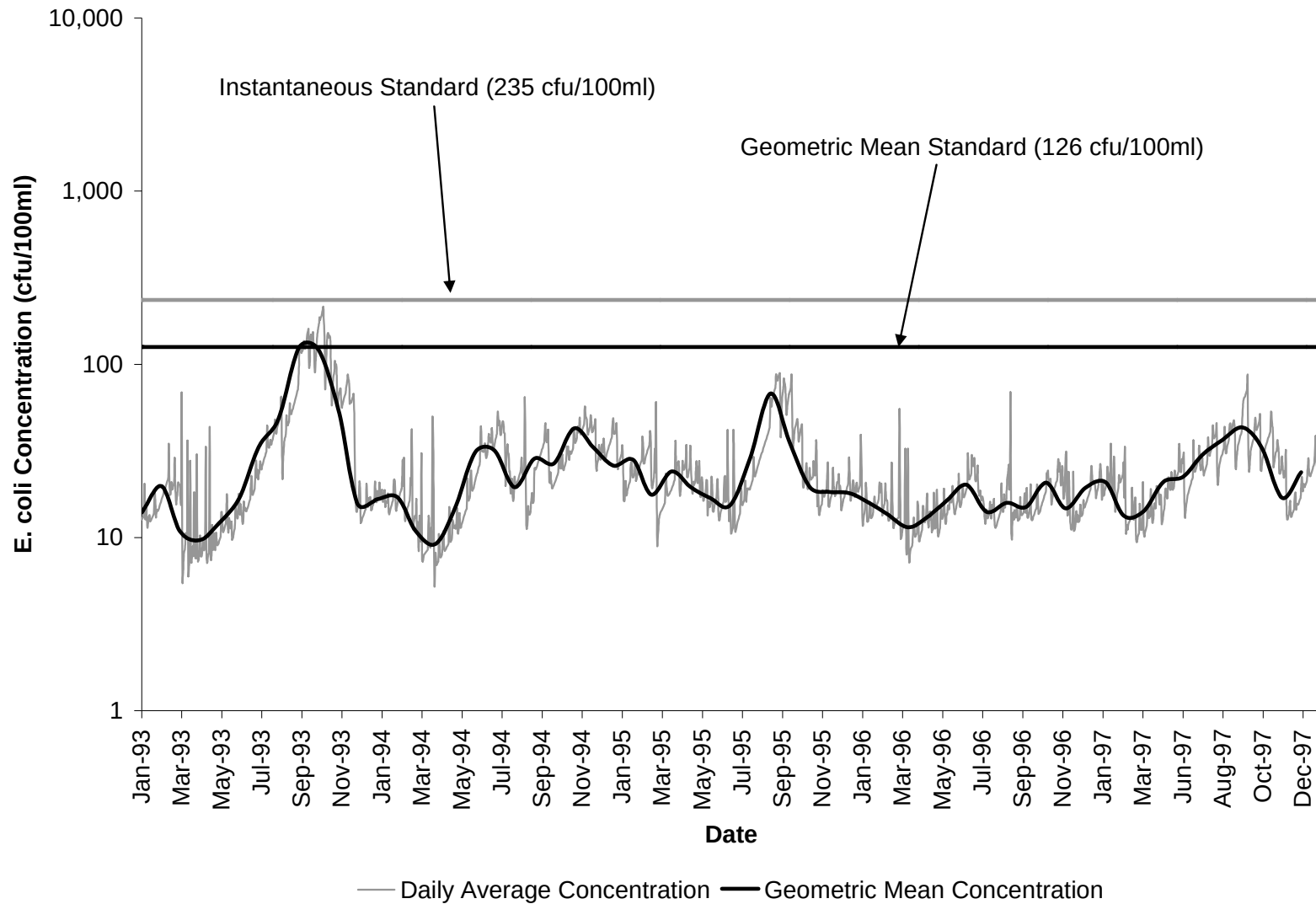


Figure 5.39. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.7) in UT to Rapidan River (VAN-E13R-04) impairment.

5.3.4 Rapidan River (VAN-E13R-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 5.13. Scenarios 5 through 8 are further reductions to the anthropogenic sources. It was determined (Scenario 4) that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Rapidan River (VAN-E13R-02) watershed. Scenario 5 tested the land-based load reductions at 95%. Table 5.10 shows that exceedances are present when the anthropogenic land-based loads are tested at a 95% reduction rate. Scenario 6 tested the land-based load reductions at 97% 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 98% 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 5.40 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.14 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 5.15 presents the final allocated in-stream *E. coli* loads for the Rapidan River (VAN-E13R-02) impairment. Table 5.16 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 Rapidan River (VAN-E13R-02) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.17). 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 5.13. TMDL allocation scenarios for Rapidan River (VAN-E13R-02) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance 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	80.0	39.8
1	100	0	100	0	0	0	0	26.7	33.6
2	100	50	100	50	50	0	0	10.0	20.7
3	100	75	100	75	75	0	0	3.3	11.2
4	100	100	100	100	100	0	0	0.0	0.0
5	100	95	100	95	95	0	0	0.0	0.6
6	100	97	100	97	97	0	0	0.0	0.1
7	100	98	100	98	98	0	0	0.0	0.0
8	100	98	98	98	98	0	0	0.0	0.0

Table 5.14. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rapidan River (VAN-E13R-02) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.19E+14	0.00E+00	100
Livestock	1.49E+14	2.97E+12	98
Wildlife	1.19E+14	1.19E+14	0
<i>Total</i>	<i>4.87E+14</i>	<i>1.22E+14</i>	<i>75</i>
Land-based			
Residential	3.09E+15	6.18E+13	98
Cropland	8.56E+14	1.71E+13	98
Pasture	1.37E+17	2.74E+15	98
Forest	7.70E+14	7.70E+14	0
<i>Total</i>	<i>1.42E+17</i>	<i>3.59E+15</i>	<i>97</i>

Table 5.15. Expansion matrix for WLA in the Rapidan River (VAN-E13R-02) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0090948	URR-05	0.6000	126	1.04E+12
VA0051144	URR-05	0.0256	126	0.00E+00
VA0060879	URR-09	0.0200	126	3.48E+10
VA0053121	URR-15	0.2660	126	0.00E+00
VA0021385	URR-16	3.0000	126	5.22E+12
VA0092053	URR-16	0.0900	126	1.57E+11
VA0027839	URR-19	0.0390	126	6.78E+10
Existing WLA		4.0406	126	6.53E+12
Expansion Scenario: 2 x Existing WLA		8.0812	126	1.31E+13
Expansion Scenario: 5 x Existing WLA		20.2030	126	3.26E+13 ^a

^a Future growth WLA

Table 5.16. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rapidan River (VAN-E13R-02) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	3.26E+13	5.59E+13	N/A	8.85E+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 5.17. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rapidan River (VAN-E13R-02) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	8.94E+10	1.42E+13	N/A	1.43E+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.

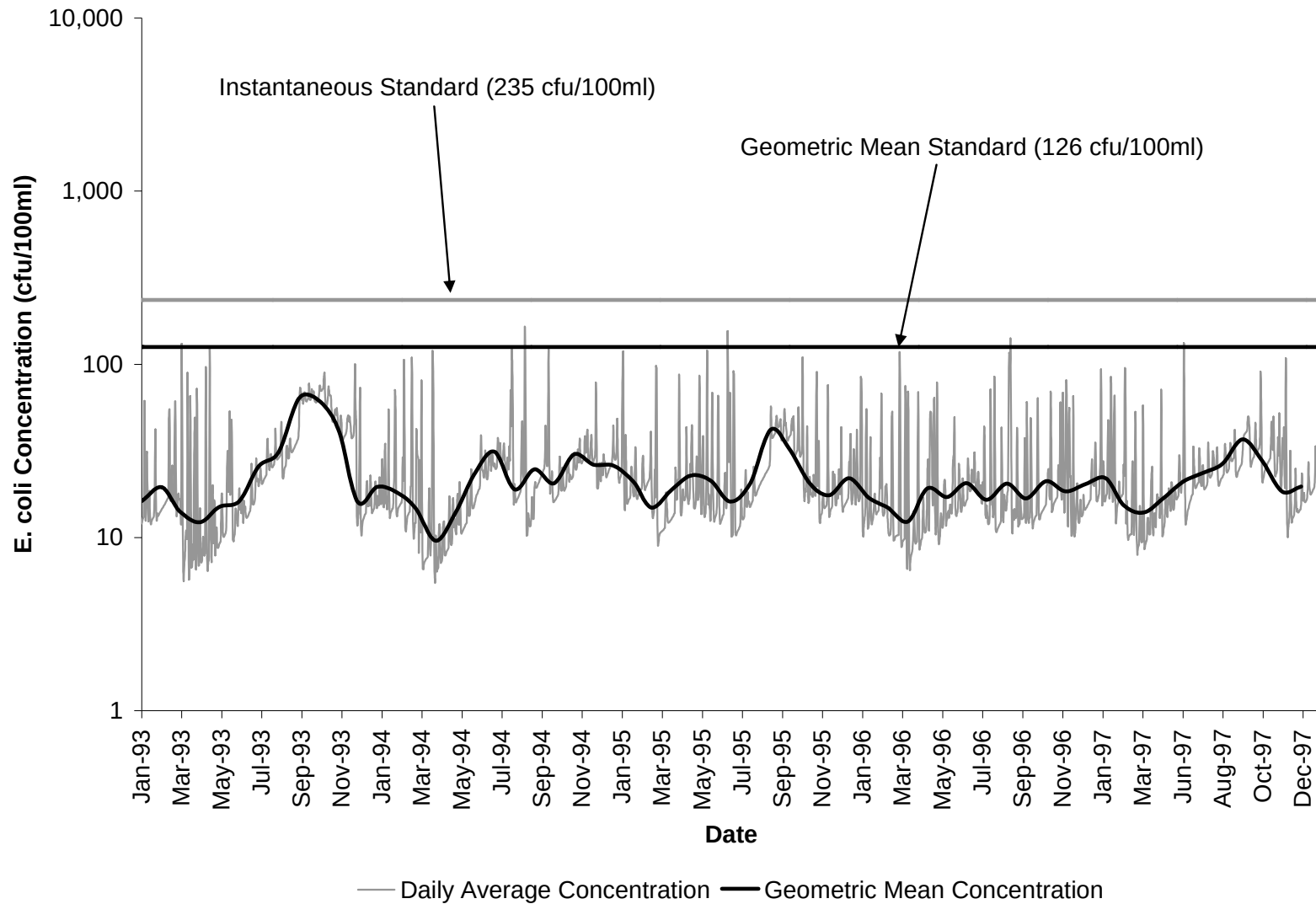


Figure 5.40. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.10) in Rapidan River (VAN-E13R-02) impairment.

5.3.5 Cedar Run (VAN-E16R-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 5.18. Scenarios 5 through 8 are further reductions to the anthropogenic sources. It was determined (Scenario 4) that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Cedar Run (VAN-E16R-01) watershed. Scenario 5 tested the land-based load reductions at 90%. Table 5.14 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 97% 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 98% 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 5.41 for the final TMDL allocation (Scenario 8), along with the geometric mean and instantaneous standards. Table 5.19 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 5.20 presents the final allocated in-stream *E. coli* loads for the Cedar Run (VAN-E16R-01) impairment. Table 5.21 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 Cedar Run (VAN-E16R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.22). 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 5.18. TMDL allocation scenarios for Cedar Run (VAN-E16R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance 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	81.7	50.9
1	100	0	100	0	0	0	0	45.0	37.0
2	100	50	100	50	50	0	0	21.7	27.8
3	100	75	100	75	75	0	0	10.0	18.4
4	100	100	100	100	100	0	0	0.0	0.0
5	100	90	100	90	90	0	0	3.3	8.0
6	100	97	100	97	97	0	0	1.7	0.4
7	100	98	100	98	98	0	0	0.0	0.0
8	100	98	98	98	98	0	0	0.0	0.0

Table 5.19. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Cedar Run (VAN-E16R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.32E+13	0.00E+00	100
Livestock	1.14E+13	2.28E+11	98
Wildlife	2.49E+13	2.49E+13	0
<i>Total</i>	<i>5.95E+13</i>	<i>2.51E+13</i>	58
Land-based			
Residential	5.05E+14	1.01E+13	98
Cropland	1.02E+14	2.03E+12	98
Pasture	2.39E+16	4.79E+14	98
Forest	9.40E+13	9.40E+13	0
<i>Total</i>	<i>2.46E+16</i>	<i>5.85E+14</i>	98

Table 5.20. Expansion matrix for WLA in the Cedar Run (VAN-E16R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VAG406337	LRR-03	0.0010	126	1.69E+09
VAG406186	LRR-03	0.0010	126	1.69E+09
VAG406214	LRR-03	0.0010	126	1.69E+09
VAG406414	LRR-03	0.0010	126	1.69E+09
VAG406381	LRR-04	0.0010	126	1.69E+09
VAG406362	LRR-04	0.0010	126	1.69E+09
VA0087718	LRR-04	0.2000	126	3.48E+11
VAG406154	LRR-04	0.0010	126	1.69E+09
VAG406041	LRR-04	0.0010	126	1.69E+09
VAG406305	LRR-04	0.0010	126	1.69E+09
VAG406010	LRR-06	0.0010	126	1.69E+09
Existing WLA		0.2100	126	3.65E+11
Expansion Scenario: 2 x Existing WLA		0.4200	126	7.30E+11
Expansion Scenario: 5 x Existing WLA		1.0500	126	1.82E+12 ^a

^a Future growth WLA

Table 5.21. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cedar Run (VAN-E16R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	1.82E+12	8.13E+12	N/A	9.95E+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 5.22. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cedar Run (VAN-E16R-01) impairment.

Pollutant	WLA¹ (cfu/d)	LA² (cfu/d)	MOS	TMDL³ (cfu/d)
<i>E. coli</i>	4.99+09	2.15E+12	N/A	2.15E+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.

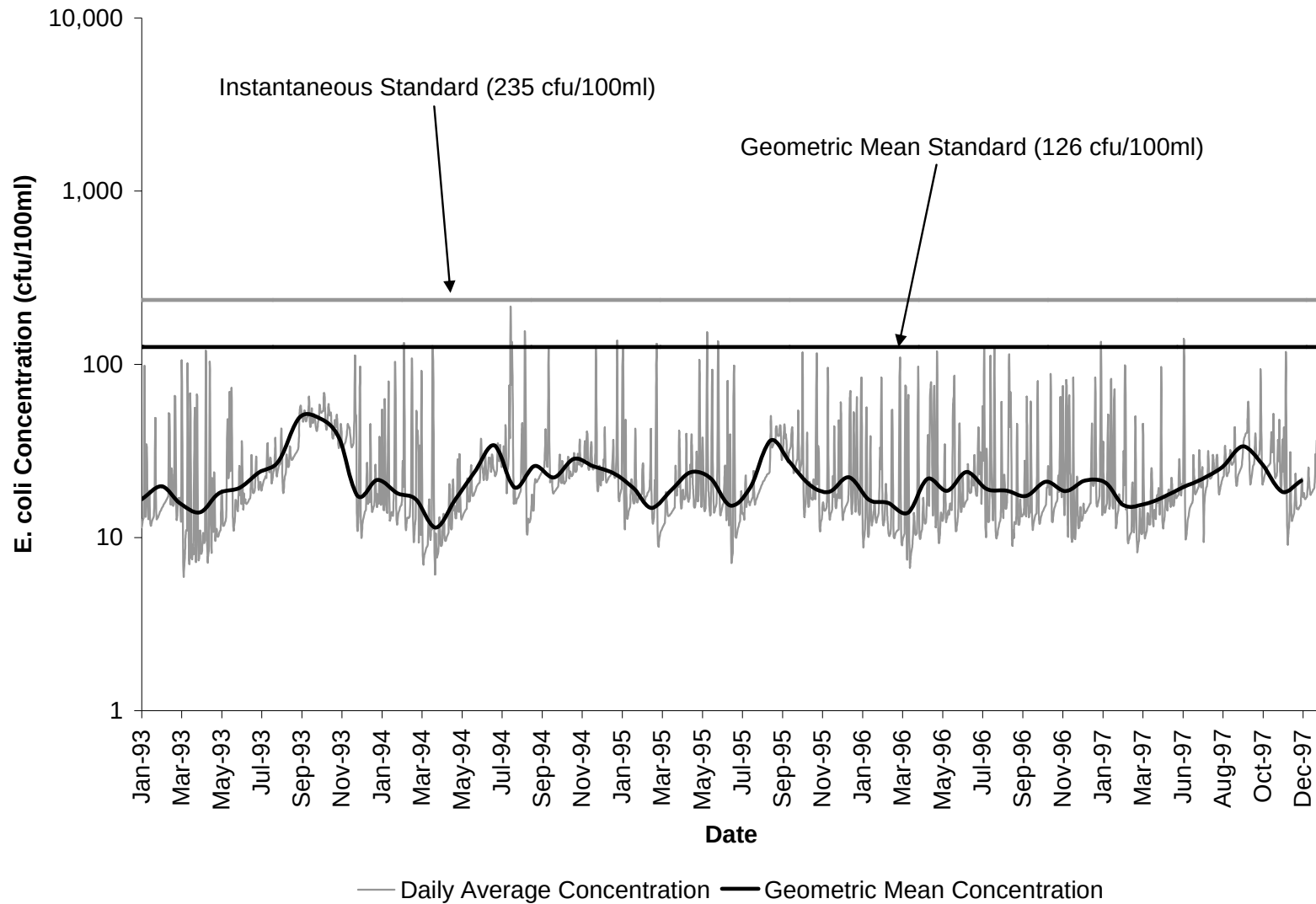


Figure 5.41. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 8 from Table 5.14) in Cedar Run (VAN-E16R-01) impairment.

5.3.6 Rapidan River (VAN-E18R-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 5.23. Scenarios 5 through 7 are further reductions to the anthropogenic sources. It was determined (Scenario 4) that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Rapidan River (VAN-E18R-01) watershed. Scenario 5 tested the land-based load reductions at 95%. Table 5.18 shows that exceedances are present when the anthropogenic land-based loads are tested at a 95% 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 anthropogenic land-based load reductions. Scenario 7 tested the land-based and livestock directly deposited loads at a 96% 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 5.42 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.24 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 5.25 presents the final allocated in-stream *E. coli* loads for the Rapidan River (VAN-E18R-01) impairment. Table 5.26 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 Rapidan River (VAN-E18R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.27). 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 5.23. TMDL allocation scenarios for Rapidan River (VAN-E18R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Exceedance 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	73.3	35.5
1	100	0	100	0	0	0	0	5.0	16.4
2	100	50	100	50	50	0	0	0.0	9.3
3	100	75	100	75	75	0	0	0.0	5.0
4	100	100	100	100	100	0	0	0.0	0.0
5	100	95	100	95	95	0	0	0.0	0.1
6	100	96	100	96	96	0	0	0.0	0.0
7	100	96	96	96	96	0	0	0.0	0.0

Table 5.24. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Rapidan River (VAN-E18R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.79E+13	0.00E+00	100
Livestock	1.26E+14	5.04E+12	96
Wildlife	1.32E+14	1.32E+14	0
<i>Total</i>	<i>3.56E+14</i>	<i>1.37E+14</i>	62
Land-based			
Residential	3.47E+15	1.39E+14	96
Cropland	3.81E+14	1.52E+13	96
Pasture	1.22E+17	4.90E+15	96
Forest	8.03E+14	8.03E+14	0
<i>Total</i>	<i>1.27E+17</i>	<i>5.86E+15</i>	95

Table 5.25. Expansion matrix for WLA in the Rapidan River (VAN-E18R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VAG406382	LRR-01	0.0010	126	1.69E+09
VAG406306	LRR-01	0.0010	126	1.69E+09
VAG406213	LRR-01	0.0010	126	1.69E+09
VAG406266	LRR-01	0.0010	126	1.69E+09
VA0092011	LRR-08	0.2000	126	3.48E+11
VA0091961	LRR-08	0.0200	126	3.48E+10
VAG406287	LRR-08	0.0010	126	1.69E+09
VAG406294	LRR-08	0.0010	126	1.69E+09
VAG406318	LRR-08	0.0010	126	1.69E+09
VAG406407	LRR-08	0.0010	126	1.69E+09
VAG406335	LRR-08	0.0010	126	1.69E+09
VAG406336	LRR-08	0.0010	126	1.69E+09
VAG406349	LRR-08	0.0010	126	1.69E+09
VAG406290	LRR-08	0.0010	126	1.69E+09
VAG406286	LRR-08	0.0010	126	1.69E+09
VAG406309	LRR-08	0.0010	126	1.69E+09
VAG406268	LRR-08	0.0010	126	1.69E+09
VAG406021	LRR-08	0.0010	126	1.69E+09
VAG406112	LRR-08	0.0010	126	1.69E+09
VAG406127	LRR-08	0.0010	126	1.69E+09
VAG406140	LRR-08	0.0010	126	1.69E+09
VAG406182	LRR-08	0.0010	126	1.69E+09
VAG406200	LRR-08	0.0010	126	1.69E+09
VAG406167	LRR-08	0.0010	126	1.69E+09
VAG406070	LRR-08	0.0010	126	1.69E+09
VAG406117	LRR-08	0.0010	126	1.69E+09
VAG406261	LRR-08	0.0010	126	1.69E+09
VAG406081	LRR-08	0.0010	126	1.69E+09
VAG406163	LRR-08	0.0010	126	1.69E+09
VAG406219	LRR-08	0.0010	126	1.69E+09
VA0083411	LRR-11	2.0000	126	3.48E+12
VAG406044	LRR-12	0.0010	126	1.69E+09
VA0081621	LRR-12	0.0080	126	0.00E+00
VA0074381	LRR-13	0.0260	126	4.52E+10
Existing WLA		2.2830	126	3.96E+12
Expansion Scenario: 2 x Existing WLA		4.5660	126	7.92E+12
Expansion Scenario: 5 x Existing WLA		11.4150	126	1.98E+13 ^a

^a Future growth WLA

Table 5.26. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Rapidan River (VAN-E18R-01) impairment.

Pollutant	WLA ¹ (cfu/yr)	LA ² (cfu/yr)	MOS	TMDL ³ (cfu/yr)
<i>E. coli</i>	1.98E+13	2.18E+14	N/A	2.38E+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 5.27. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Rapidan River (VAN-E18R-01) impairment.

Pollutant	WLA ¹ (cfu/d)	LA ² (cfu/d)	MOS	TMDL ³ (cfu/d)
<i>E. coli</i>	5.42E+10	4.23E+13	N/A	4.24E+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.

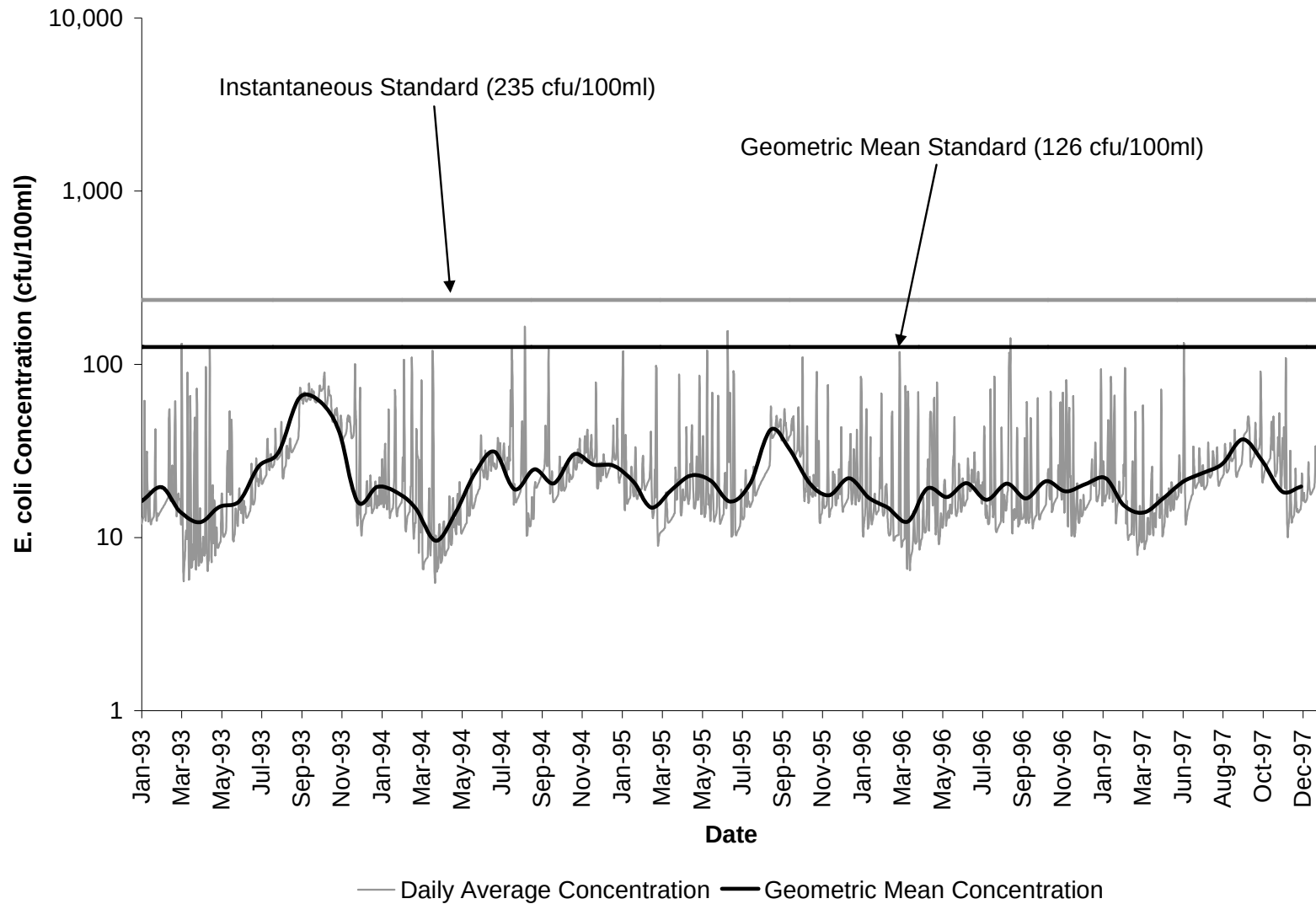


Figure 5.42. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.18) in Rapidan River (VAN-E18R-01) impairment.

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 nonpoint 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 non point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ 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 6.2.6.

6.2.1 Marsh Run (VAN-E13R-03)

The Stage 1 allocation for the Marsh Run (VAN-E13R-03) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 75% reduction in nonpoint source loadings to residential land use, a 75% reduction in nonpoint source loadings to pasture land use, a 75% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.64% 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 Marsh Run (VAN-E13R-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 6.1.

Table 6.1. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Marsh Run (VAN-E13R-03) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.08E+13	0.00E+00	100
Livestock	6.68E+12	1.67E+12	75
Wildlife	1.05E+13	1.05E+13	0
<i>Total</i>	<i>3.80E+13</i>	<i>1.22E+13</i>	68%
Land-based			
Residential	3.32E+14	8.29E+13	75
Cropland	1.06E+12	2.64E+11	75
Pasture	6.42E+15	1.61E+15	75
Forest	7.33E+13	7.33E+13	0
<i>Total</i>	<i>6.83E+15</i>	<i>1.76E+15</i>	74%

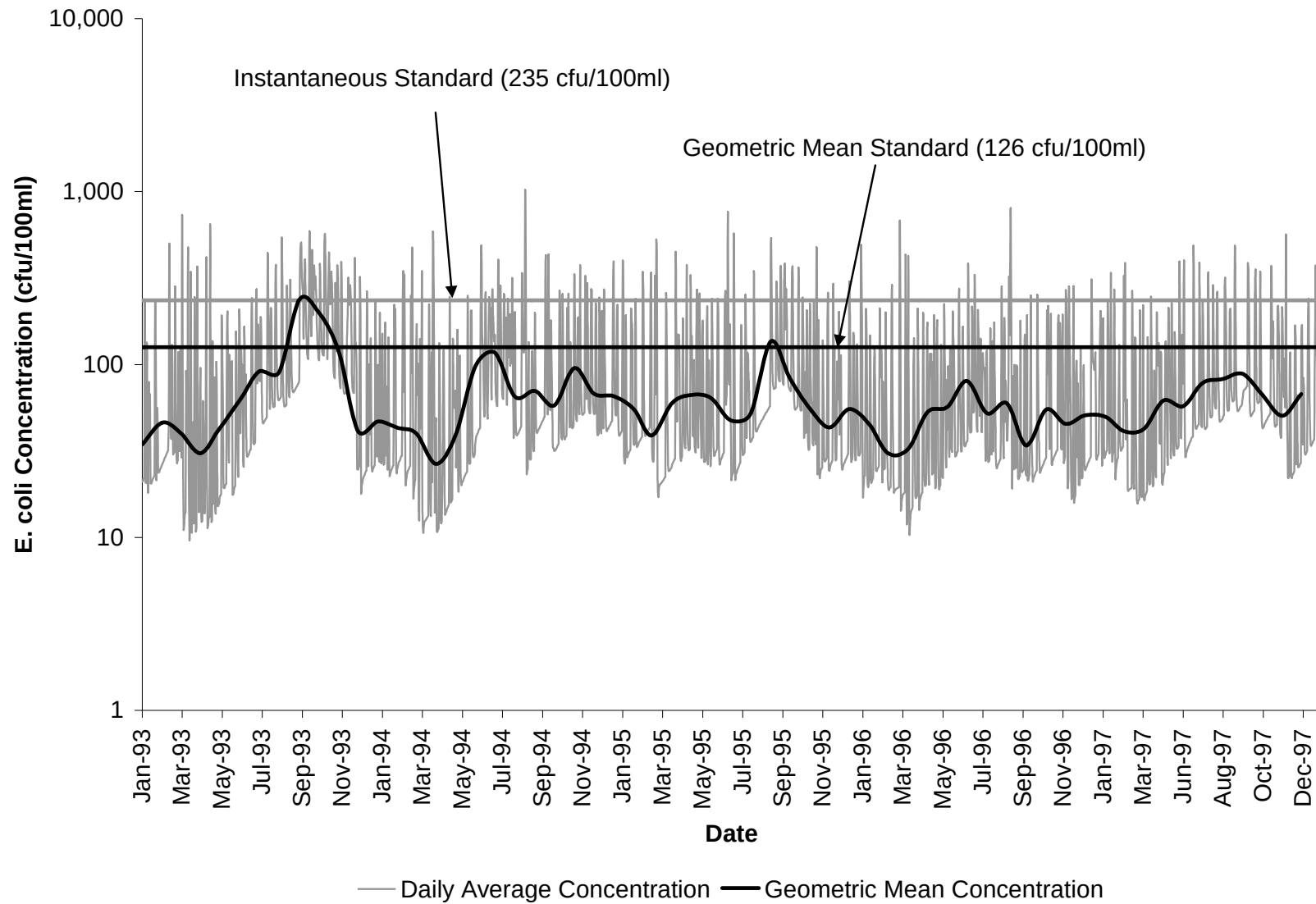


Figure 6.1. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Marsh Run (VAN-E13R-03) impairment.

6.2.2 Blue Run (VAN-E13R-01)

The Stage 1 allocation for the Blue Run (VAN-E13R-01) impairment requires a 100% reduction in straight pipes, 90% reduction in livestock direct deposition, a 0% reduction in wildlife direct deposition, a 78% 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 9.91% 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 6.2 for the Blue Run (VAN-E13R-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 Blue Run (VAN-E13R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	7.07E+13	0.00E+00	100
Livestock	2.30E+13	2.30E+12	90
Wildlife	2.87E+13	2.87E+13	0
<i>Total</i>	<i>1.22E+14</i>	<i>3.10E+13</i>	<i>75</i>
Land-based			
Residential	5.70E+14	1.25E+14	78
Cropland	3.59E+12	7.89E+11	78
Pasture	2.23E+16	4.90E+15	78
Forest	1.16E+14	1.16E+14	0
<i>Total</i>	<i>2.29E+16</i>	<i>5.14E+15</i>	<i>78</i>

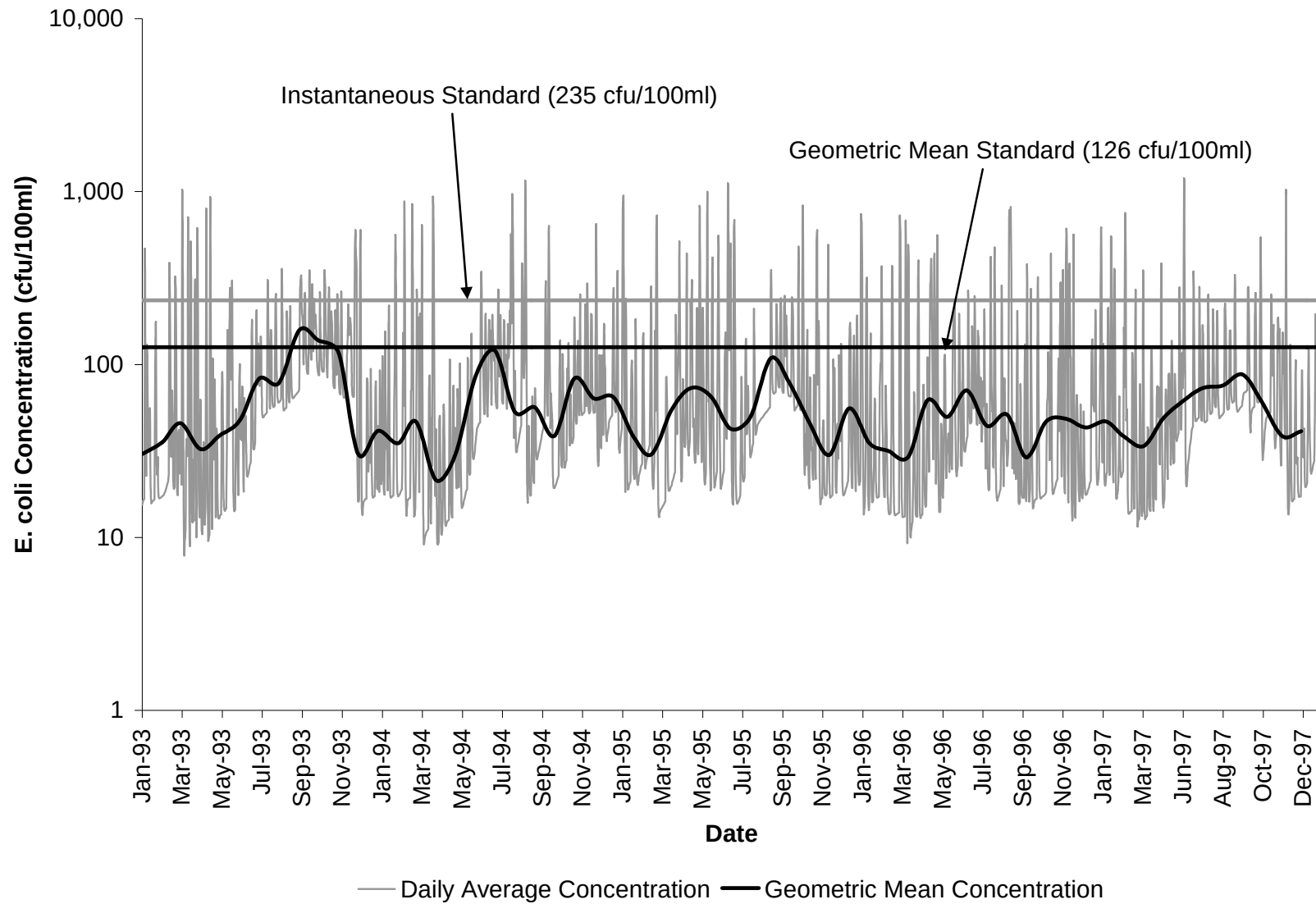


Figure 6.2. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Blue Run (VAN-E13R-01) impairment.

6.2.3 UT to Rapidan River (VAN-E13R-04)

The Stage 1 allocation for the UT to Rapidan River (VAN-E13R-04) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 75% reduction in nonpoint source loadings to residential land use, a 75% reduction in nonpoint source loadings to pasture land use, a 75% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.64% 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 UT to Rapidan River (VAN-E13R-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 6.3.

Table 6.3. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in UT to Rapidan River (VAN-E13R-04) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	7.22E+12	0.00E+00	100
Livestock	2.23E+12	5.57E+11	75
Wildlife	2.03E+12	2.03E+12	0
<i>Total</i>	<i>1.15E+13</i>	<i>2.59E+12</i>	<i>77</i>
Land-based			
Residential	5.76E+13	1.44E+13	75
Cropland	8.15E+10	2.04E+10	75
Pasture	2.14E+15	5.35E+14	75
Forest	8.20E+12	8.20E+12	0
<i>Total</i>	<i>2.21E+15</i>	<i>5.58E+14</i>	<i>75</i>

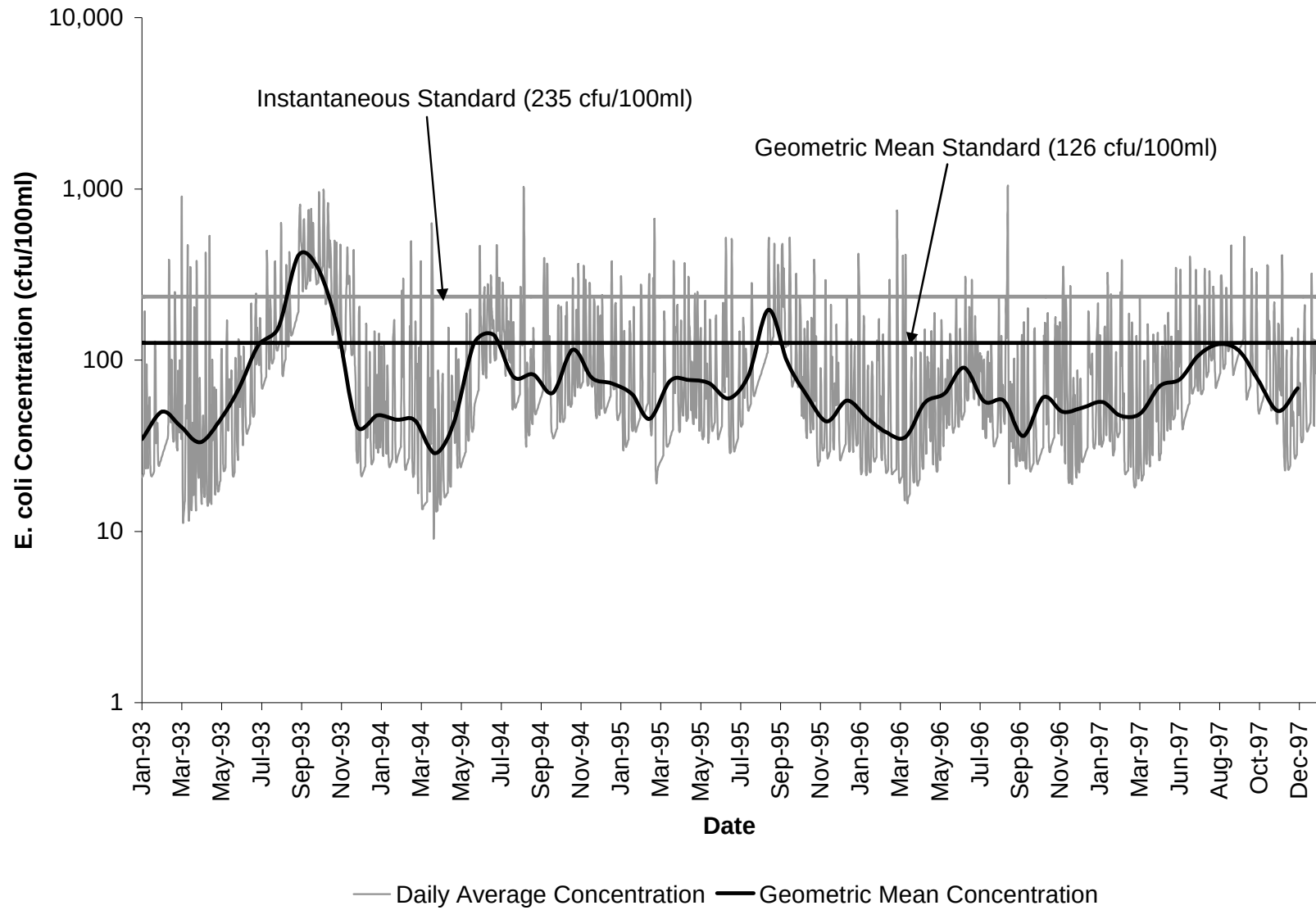


Figure 6.3. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in UT to Rapidan River (VAN-E13R-04) impairment.

6.2.4 Rapidan River (VAN-E13R-02)

The Stage 1 allocation for the Rapidan River (VAN-E13R-02) impairment requires a 100% reduction in straight pipes, 95% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 78% reduction in nonpoint source loadings to residential land use, a 78% reduction in nonpoint source loadings to pasture land use, a 78% 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 6.4 for the Rapidan River (VAN-E13R-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 6.4.

Table 6.4. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rapidan River (VAN-E13R-02) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.19E+14	0.00E+00	100
Livestock	1.49E+14	7.43E+12	95
Wildlife	1.19E+14	1.19E+14	0
<i>Total</i>	<i>4.87E+14</i>	<i>1.27E+14</i>	<i>74</i>
Land-based			
Residential	3.09E+15	6.80E+14	78
Cropland	8.56E+14	1.88E+14	78
Pasture	1.37E+17	3.02E+16	78
Forest	7.70E+14	7.70E+14	0
<i>Total</i>	<i>1.42E+17</i>	<i>3.18E+16</i>	<i>78</i>

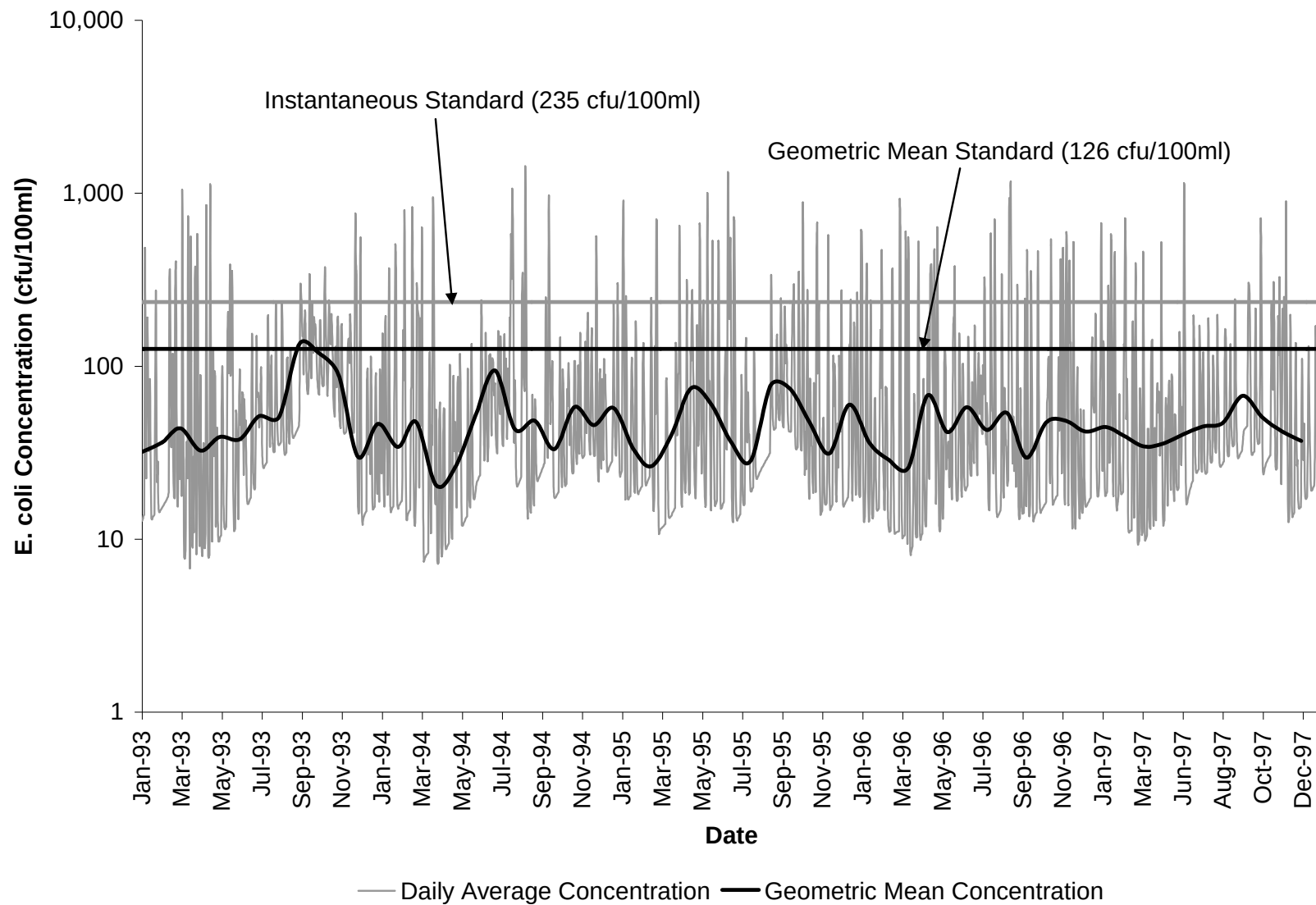


Figure 6.4. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rapidan River (VAN-E13R-02) impairment.

6.2.5 Cedar Run (VAN-E16R-01)

The Stage 1 allocation for the Cedar Run (VAN-E16R-01) impairment requires a 100% reduction in straight pipes, 89% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 89% reduction in nonpoint source loadings to residential and pasture land uses, a 89% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in an 8.65% 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 Cedar Run (VAN-E16R-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 6.5.

Table 6.5. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Cedar Run (VAN-E16R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.32E+13	0.00E+00	100
Livestock	1.14E+13	1.25E+12	89
Wildlife	2.49E+13	2.49E+13	0
<i>Total</i>	<i>5.95E+13</i>	<i>2.62E+13</i>	<i>56</i>
Land-based			
Residential	5.05E+14	5.56E+13	89
Cropland	1.02E+14	1.12E+13	89
Pasture	2.39E+16	2.63E+15	89
Forest	9.40E+13	9.40E+13	0
<i>Total</i>	<i>2.46E+16</i>	<i>2.79E+15</i>	<i>89</i>

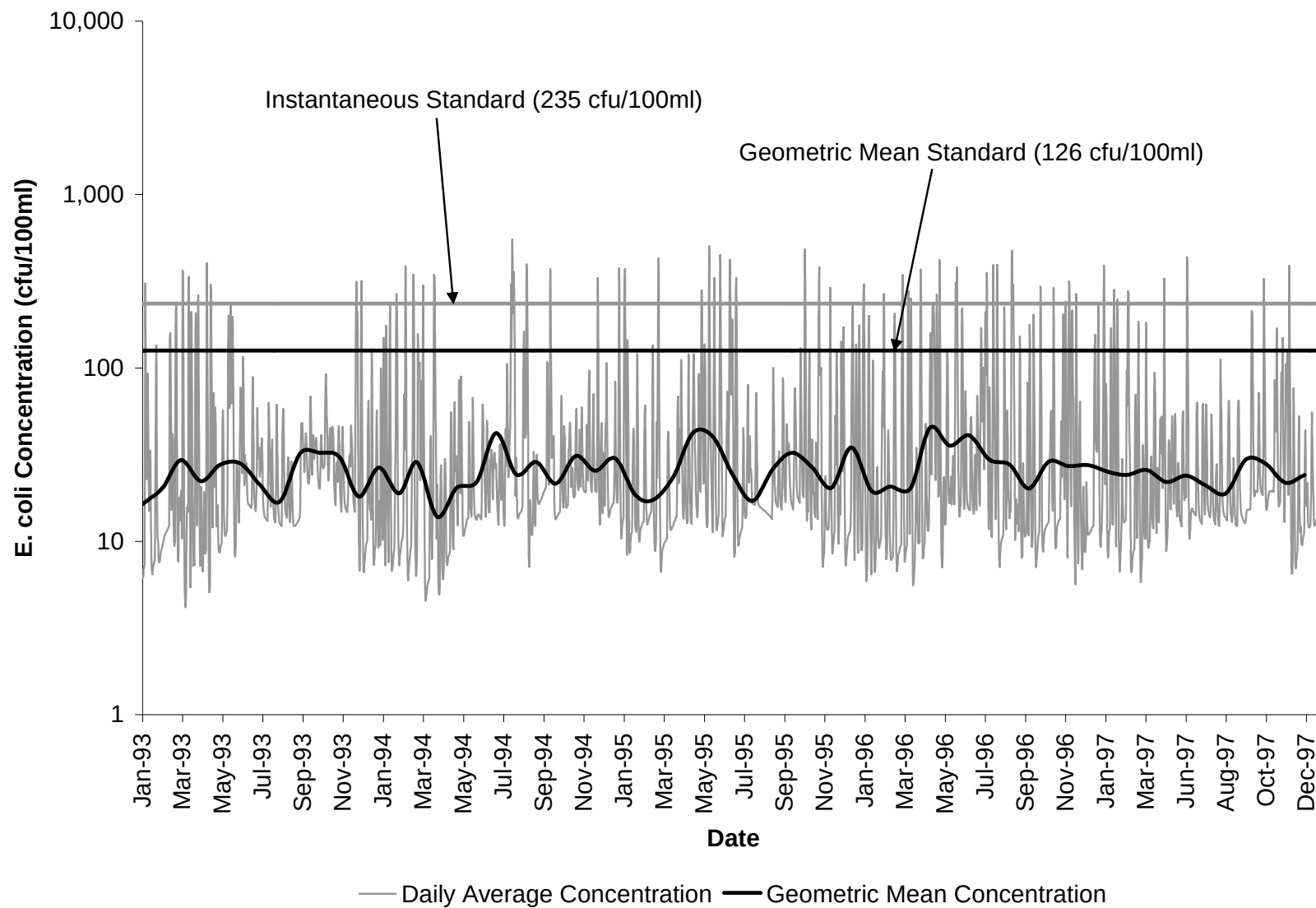


Figure 6.5. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Cedar Run (VAN-E16R-01) impairment.

6.2.6 Rapidan River (VAN-E18R-01)

The Stage 1 allocation for the Rapidan River (VAN-E18R-01) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 46% 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 6.6 for the Rapidan River (VAN-E18R-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 6.6.

Table 6.6. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Rapidan River (VAN-E18R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.79E+13	0.00E+00	100
Livestock	1.26E+14	3.15E+13	75
Wildlife	1.32E+14	1.32E+14	0
<i>Total</i>	<i>3.56E+14</i>	<i>1.63E+14</i>	<i>54</i>
Land-based			
Residential	3.47E+15	1.87E+15	46
Cropland	3.81E+14	2.06E+14	46
Pasture	1.22E+17	6.61E+16	46
Forest	8.03E+14	8.03E+14	0
<i>Total</i>	<i>1.27E+17</i>	<i>6.90E+16</i>	<i>46</i>

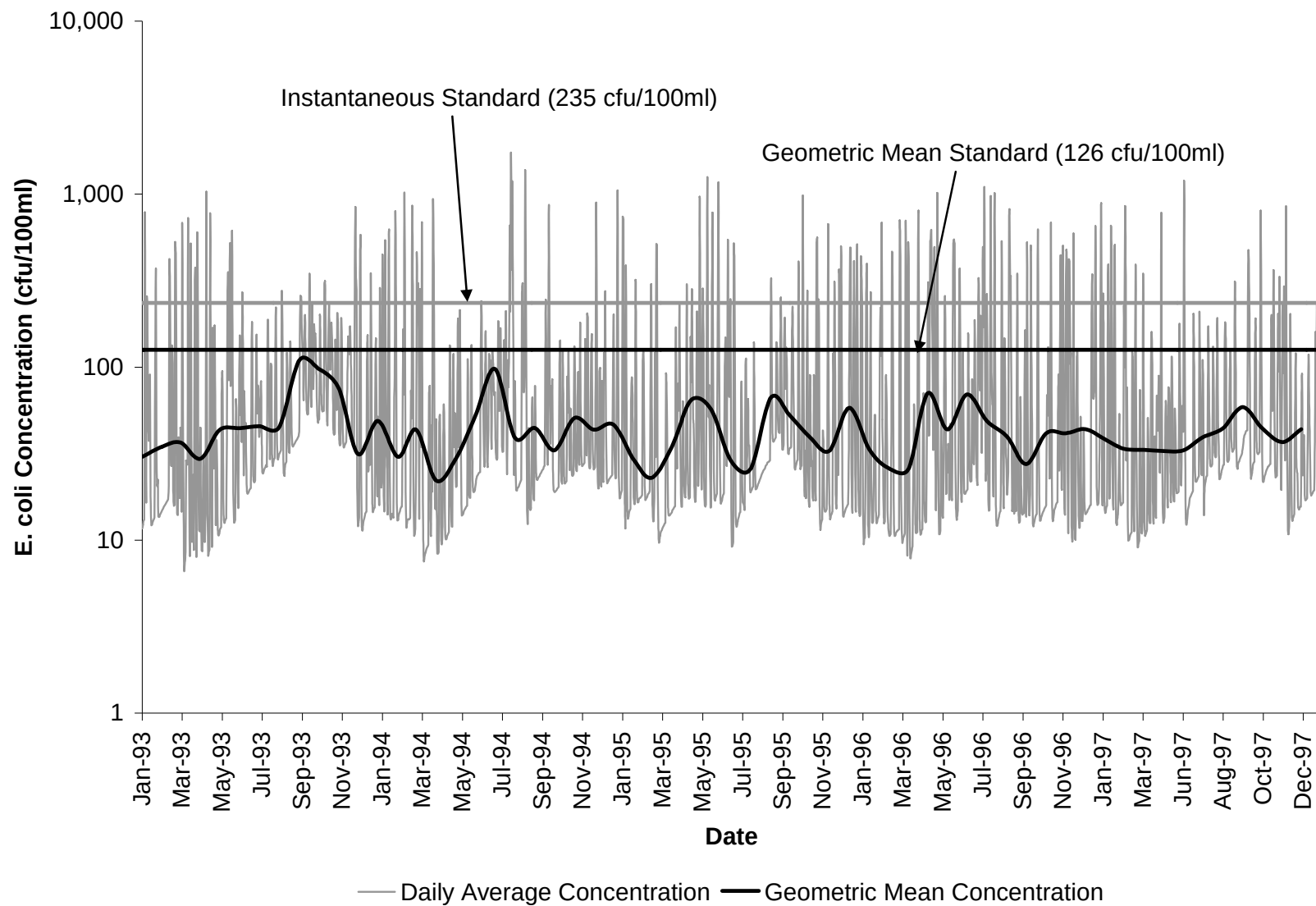


Figure 6.6. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Rapidan River (VAN-E18R-01) impairment.

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) (<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 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) 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 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) 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 at a “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 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 would not have been possible without public participation.

The first public meetings were held at the Mt. Nebo Church in Rochelle, Virginia and Germanna Community College in Locust Grove, Virginia on October 4, 2006 and October 18, 2006, respectively, to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. Twenty people attended the Mt. Nebo meeting and 0 people attended the Locust Grove 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 Mt. Nebo Church in Rochelle Virginia on March 19, 2007 and March 27, 2007, respectively, to discuss the source allocations and reductions required to meet the TMDL. Eleven people attended the Culpeper meeting and 22 people attended the Rochelle 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 meetings 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 extended from March 19, 2007 to April 18, 2007. One written comment was received.

In addition to keeping the public apprised of progress in the development of 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, 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
- Greene County Government
- Rural Madison
- Spotsylvania County Utilities
- Piedmont Environmental Council
- Rapidan Service Authority
- U.S. Department of Agriculture – Natural Resources Conservation Service
- Artery Development

Eighteen, nineteen, and eleven 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: $\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \cdots x_n}$ 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-MAS001.55 in Marsh Run (VAN-E13R-03) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-MAS001.55	06/18/91	9200		2.54
3-MAS001.55	11/12/91	16000		0
3-MAS001.55	12/19/91	16000		0.34
3-MAS001.55	03/23/92	230		0.11
3-MAS001.55	09/01/92	700		5.2
3-MAS001.55	12/14/92	400		0.03
3-MAS001.55	03/02/93	100		1.76
3-MAS001.55	06/08/93	2000		0.52
3-MAS001.55	09/07/93	100		1.68
3-MAS001.55	12/16/93	1900		0.82
3-MAS001.55	03/16/94	100		1.35
3-MAS001.55	09/29/94	300		0
3-MAS001.55	03/16/95	600		1.24
3-MAS001.55	09/25/95	200		0.89
3-MAS001.55	03/20/96	4700		0.25
3-MAS001.55	06/27/96	600		0.65
3-MAS001.55	09/24/96	200		3.93
3-MAS001.55	01/22/97	600		1.5

N/A – Data not available

Table A.2. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-BLU002.60 in Blue Run (VAN-E13R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-BLU002.60	06/18/91	9200		2.54
3-BLU002.60	11/12/91	16000		0
3-BLU002.60	12/19/91	16000		0.34
3-BLU002.60	03/23/92	230		0.11
3-BLU002.60	09/01/92	700		5.2
3-BLU002.60	12/14/92	400		0.03
3-BLU002.60	03/02/93	100		1.76
3-BLU002.60	06/08/93	2000		0.52
3-BLU002.60	09/07/93	100		1.68
3-BLU002.60	12/16/93	1900		0.82
3-BLU002.60	03/16/94	100		1.35
3-BLU002.60	09/29/94	300		0
3-BLU002.60	03/16/95	600		1.24
3-BLU002.60	09/25/95	200		0.89
3-BLU002.60	03/20/96	4700		0.25
3-BLU002.60	06/27/96	600		0.65
3-BLU002.60	09/24/96	200		3.93
3-BLU002.60	01/22/97	600		1.5
3-BLU002.60	04/21/97	100		#N/A
3-BLU002.60	07/29/97	400		0.09
3-BLU002.60	10/28/97	300		0.29
3-BLU002.60	01/21/98	300		0.04
3-BLU002.60	04/13/98	200		0.11
3-BLU002.60	06/17/98	1700		0.23
3-BLU002.60	11/04/98	600		1.13
3-BLU002.60	01/19/99	200		0.13
3-BLU002.60	03/31/99	100		2.66
3-BLU002.60	06/25/99	600		1.27

N/A – Data not available

Table A.3. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-BLU002.60 in Blue Run (VAN-E13R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-BLU002.60	08/24/99	600		2.48
3-BLU002.60	10/18/99	1100		0.64
3-BLU002.60	12/29/99	1800		1.15
3-BLU002.60	02/14/00	1100		0.2
3-BLU002.60	04/20/00	300		0.75
3-BLU002.60	06/21/00	400		1.11
3-BLU002.60	08/22/00	100		2.45
3-BLU002.60	10/17/00	100		1.34
3-BLU002.60	02/07/01	100		0.19
3-BLU002.60	04/10/01	100		0.95
3-BLU002.60	06/27/01	100		0.9
3-BLU002.60	01/31/02	100		0.9
3-BLU002.60	10/30/02	1600		1.63
3-BLU002.60	02/24/03	100		5.61
3-BLU002.60	03/25/03	500		0.67
3-BLU002.60	04/09/03	8000		3.05
3-BLU002.60	06/17/03	900		1.33
3-BLU002.60	07/15/04	750	500	0.52
3-BLU002.60	08/17/04	300	150	0.72
3-BLU002.60	09/21/04	350	150	2.25
3-BLU002.60	10/19/04	450	400	0.15
3-BLU002.60	11/02/04	200	100	0.09
3-BLU002.60	12/08/04	250	300	0.42
3-BLU002.60	02/03/05	50	50	0.39
3-BLU002.60	03/02/05	650	450	0.74
3-BLU002.60	04/06/05	250	50	2.17
3-BLU002.60	05/03/05	200	400	0.96
3-BLU002.60	06/08/05	300	400	0.75

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	11/26/1970	200		0.45
3-RAP045.08	12/09/1970	700		0.4
3-RAP045.08	01/14/1971	6200		0.3
3-RAP045.08	02/10/1971	1100		2.1
3-RAP045.08	03/18/1971	200		1.65
3-RAP045.08	04/25/1971	100		0.85
3-RAP045.08	05/04/1971	100		0
3-RAP045.08	06/01/1971	100		0.4
3-RAP045.08	07/15/1971	2900		2.05
3-RAP045.08	08/28/1971	8000		0
3-RAP045.08	09/27/1971	100		0.55
3-RAP045.08	10/03/1971	2600		0.13
3-RAP045.08	11/10/1971	200		0
3-RAP045.08	12/14/1971	2000		0.36
3-RAP045.08	01/23/1972	600		0.07
3-RAP045.08	02/21/1972	100		1.7
3-RAP045.08	03/02/1972	100		0.15
3-RAP045.08	04/05/1972	100		0.56
3-RAP045.08	05/04/1972	6000		0.65
3-RAP045.08	06/03/1972	5100		0.8
3-RAP045.08	07/15/1972	100		1.55
3-RAP045.08	08/10/1972	400		0.75
3-RAP045.08	09/21/1972	300		0.15
3-RAP045.08	10/05/1972	6000		1.17
3-RAP045.08	11/15/1972	2300		0.07
3-RAP045.08	12/08/1972	100		0.83
3-RAP045.08	01/23/1973	400		3.05
3-RAP045.08	02/26/1973	400		0.1

Table A.5. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	03/14/1973	200		0
3-RAP045.08	04/09/1973	1100		1.63
3-RAP045.08	05/11/1973	700		0.49
3-RAP045.08	06/22/1973	600		0.07
3-RAP045.08	07/12/1973	6000		0.39
3-RAP045.08	08/06/1973	900		2.9
3-RAP045.08	09/17/1973	1100		0.12
3-RAP045.08	10/09/1973	1800		0.2
3-RAP045.08	11/01/1973	1000		0.15
3-RAP045.08	01/02/1974	500		1.58
3-RAP045.08	01/24/1974	500		0.1
3-RAP045.08	02/27/1974	100		0.05
3-RAP045.08	03/18/1974	100		0
3-RAP045.08	04/09/1974	5300		1.41
3-RAP045.08	05/16/1974	500		0.5
3-RAP045.08	06/05/1974	400		0.61
3-RAP045.08	07/07/1974	100		0.77
3-RAP045.08	08/21/1974	1200		0.3
3-RAP045.08	09/09/1974	500		0
3-RAP045.08	11/01/1974	100		1.32
3-RAP045.08	01/08/1975	900		1.7
3-RAP045.08	03/20/1975	200		0
3-RAP045.08	05/05/1975	600		1.54
3-RAP045.08	06/30/1975	200		0.49
3-RAP045.08	09/16/1975	100		1.38
3-RAP045.08	11/20/1975	400		0.1
3-RAP045.08	01/12/1976	100		0.02
3-RAP045.08	03/10/1976	1600		0

Table A.6. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	09/03/1987	100		0.73
3-RAP045.08	10/01/1987	100		0.69
3-RAP045.08	11/04/1987	100		0.39
3-RAP045.08	12/02/1987	800		3.92
3-RAP045.08	02/11/1988	100		2.07
3-RAP045.08	03/07/1988	100		0.23
3-RAP045.08	04/07/1988	8000		0
3-RAP045.08	10/05/1988	100		0.54
3-RAP045.08	12/01/1988	2800		0.37
3-RAP045.08	04/29/1991	2400		1.01
3-RAP045.08	05/21/1991	330		0.87
3-RAP045.08	06/20/1991	1700		1.91
3-RAP045.08	08/21/1991	700		0.16
3-RAP045.08	12/17/1991	16000		0
3-RAP045.08	02/18/1992	220		0.3
3-RAP045.08	03/18/1992	170		0.1
3-RAP045.08	04/15/1992	330		2.43
3-RAP045.08	05/14/1992	200		0
3-RAP045.08	07/28/1992	700		1.5
3-RAP045.08	08/25/1992	100		0.54
3-RAP045.08	09/29/1992	700		1.97
3-RAP045.08	10/28/1992	100		0
3-RAP045.08	11/24/1992	2100		0.04
3-RAP045.08	12/29/1992	200		4.53
3-RAP045.08	01/25/1993	1100		0.34
3-RAP045.08	03/25/1993	1000		0.8
3-RAP045.08	04/22/1993	8000		2.45
3-RAP045.08	05/27/1993	100		0.42

Table A.7. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	06/24/1993	100		0.06
3-RAP045.08	07/29/1993	200		2.3
3-RAP045.08	08/30/1993	100		0.3
3-RAP045.08	09/30/1993	100		1.15
3-RAP045.08	10/21/1993	100		0.48
3-RAP045.08	11/23/1993	100		1.49
3-RAP045.08	02/22/1994	200		0.12
3-RAP045.08	03/24/1994	100		0.85
3-RAP045.08	04/21/1994	200		0
3-RAP045.08	05/26/1994	100		0.11
3-RAP045.08	06/23/1994	500		3.26
3-RAP045.08	07/21/1994	1000		2.65
3-RAP045.08	08/22/1994	8000		4.7
3-RAP045.08	09/19/1994	100		0.05
3-RAP045.08	10/26/1994	100		0.32
3-RAP045.08	11/08/1994	100		0.05
3-RAP045.08	01/05/1995	100		0.27
3-RAP045.08	01/25/1995	500		4.06
3-RAP045.08	02/14/1995	100		2.72
3-RAP045.08	03/23/1995	200		0.32
3-RAP045.08	04/26/1995	200		2.71
3-RAP045.08	05/24/1995	100		1.55
3-RAP045.08	06/21/1995	100		0.71
3-RAP045.08	07/20/1995	100		0
3-RAP045.08	08/23/1995	600		0.37
3-RAP045.08	11/08/1995	100		1.03
3-RAP045.08	01/24/1996	600		0.99
3-RAP045.08	02/22/1996	300		0.41

Table A.8. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP045.08	03/21/1996	1400		0.25
3-RAP045.08	04/15/1996	100		3.44
3-RAP045.08	05/21/1996	300		0.16
3-RAP045.08	06/27/1996	100		0.65
3-RAP045.08	07/24/1996	700		1.12
3-RAP045.08	08/27/1996	100		0.01
3-RAP045.08	11/20/1996	500		0
3-RAP045.08	12/18/1996	100		0.18
3-RAP045.08	01/29/1997	400		1.29
3-RAP045.08	02/20/1997	100		0.03
3-RAP045.08	03/26/1997	100		0.66
3-RAP045.08	04/23/1997	100		#N/A
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

Table A.9. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> 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

Table A.10. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP045.08 in Rapidan River (VAN-E13R-02) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> 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

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-XEZ000.12 in UT to Rapidan River (VAN-E13R-04) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-XEZ000.12	08/14/01	1100		5.7
3-XEZ000.12	10/31/01	600		1.97
3-XEZ000.12	07/15/04	1300	1200	0.52
3-XEZ000.12	08/17/04	100	400	0.72
3-XEZ000.12	09/21/04	400	150	2.25
3-XEZ000.12	10/19/04	150	50	0.15
3-XEZ000.12	11/02/04	50	50	0.09
3-XEZ000.12	02/03/05	400	700	0.39
3-XEZ000.12	03/02/05	400	450	0.74
3-XEZ000.12	04/06/05	600	250	2.17
3-XEZ000.12	05/03/05	50	100	0.96
3-XEZ000.12	06/08/05	150	300	0.75

Table A.12. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-CED000.59 in Cedar Run (VAN-E16R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-CED000.59	06/18/1991	16000		2.54
3-CED000.59	11/12/1991	16000		0
3-CED000.59	12/19/1991	3500		0.34
3-CED000.59	03/23/1992	140		0.11
3-CED000.59	09/01/1992	300		5.2
3-CED000.59	12/14/1992	700		0.03
3-CED000.59	03/02/1993	100		1.76
3-CED000.59	06/08/1993	1100		0.52
3-CED000.59	12/16/1993	1500		0.82
3-CED000.59	03/16/1994	100		1.35
3-CED000.59	09/29/1994	600		0
3-CED000.59	12/28/1994	100		0.34
3-CED000.59	03/16/1995	100		1.24
3-CED000.59	09/25/1995	100		0.89
3-CED000.59	01/02/1996	200		0.58
3-CED000.59	03/20/1996	6900		0.25
3-CED000.59	06/27/1996	200		0.65
3-CED000.59	09/24/1996	200		3.93
3-CED000.59	01/22/1997	200		1.5
3-CED000.59	04/21/1997	100		#N/A
3-CED000.59	07/29/1997	100		0.09
3-CED000.59	10/28/1997	400		0.29
3-CED000.59	01/21/1998	100		0.04
3-CED000.59	04/13/1998	100		0.11
3-CED000.59	06/17/1998	800		0.23
3-CED000.59	11/04/1998	100		1.13
3-CED000.59	01/19/1999	600		0.13
3-CED000.59	03/31/1999	100		2.66

Table A.13. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-CED000.59 in Cedar Run (VAN-E16R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-CED000.59	06/25/1999	100		1.27
3-CED000.59	08/24/1999	100		2.48
3-CED000.59	10/18/1999	600		0.64
3-CED000.59	12/29/1999	500		1.15
3-CED000.59	02/14/2000	100		0.2
3-CED000.59	04/20/2000	100		0.75
3-CED000.59	06/21/2000	200		1.11
3-CED000.59	08/22/2000	100		2.45
3-CED000.59	10/17/2000	8000		1.34
3-CED000.59	02/07/2001	100		0.19
3-CED000.59	04/10/2001	100		0.95
3-CED000.59	06/27/2001	300		0.9
3-CED000.59	12/27/2001	400		0.41
3-CED000.59	02/27/2002	100		0.79
3-CED000.59	03/03/2003	100		0.2
3-CED000.59	04/29/2003	100		0.01
3-CED000.59	06/09/2003	3500		0.25
3-CED000.59	07/12/2005	110	60	1.75
3-CED000.59	08/03/2005	60	56	0.06
3-CED000.59	09/07/2005	520	18	0
3-CED000.59	10/19/2005		48	0
3-CED000.59	11/16/2005		48	0

Table A.14. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	09/16/1974	400	NULL	0.71
3-RAP006.53	10/15/1974	100	NULL	0.1
3-RAP006.53	11/06/1974	100	NULL	1.02
3-RAP006.53	01/15/1975	200	NULL	0
3-RAP006.53	02/20/1975	100	NULL	0
3-RAP006.53	03/03/1975	100	NULL	1.1
3-RAP006.53	04/28/1975	100	NULL	0.7
3-RAP006.53	05/27/1975	400	NULL	0.72
3-RAP006.53	06/19/1975	100	NULL	0.9
3-RAP006.53	07/22/1975	100	NULL	0.41
3-RAP006.53	07/31/1975	100	NULL	0.49
3-RAP006.53	09/15/1975	100	NULL	1.22
3-RAP006.53	10/22/1975	100	NULL	0.74
3-RAP006.53	12/04/1975	100	NULL	0.65
3-RAP006.53	01/21/1976	100	NULL	1.77
3-RAP006.53	02/04/1976	1300	NULL	2.59
3-RAP006.53	03/18/1976	1200	NULL	0
3-RAP006.53	05/10/1976	100	NULL	0.38
3-RAP006.53	06/03/1976	800	NULL	0.17
3-RAP006.53	07/21/1976	100	NULL	0.74
3-RAP006.53	08/26/1976	100	NULL	0.74
3-RAP006.53	10/27/1976	3400	NULL	0.15
3-RAP006.53	11/17/1976	100	NULL	0.08
3-RAP006.53	12/14/1976	1800	NULL	0
3-RAP006.53	03/17/1977	100	NULL	0.35
3-RAP006.53	03/31/1977	100	NULL	0.3
3-RAP006.53	05/16/1977	100	NULL	0
3-RAP006.53	06/27/1977	100	NULL	0.75

Table A.15. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	07/25/1977	100	NULL	0.3
3-RAP006.53	08/23/1977	100	NULL	1.34
3-RAP006.53	09/02/1977	200	NULL	1.62
3-RAP006.53	10/25/1977	100	NULL	0
3-RAP006.53	11/09/1977	1200	NULL	1.44
3-RAP006.53	12/01/1977	6000	NULL	1.79
3-RAP006.53	02/27/1978	100	NULL	0
3-RAP006.53	03/07/1978	100	NULL	1.85
3-RAP006.53	04/14/1978	100	NULL	1.43
3-RAP006.53	05/25/1978	400	NULL	0.1
3-RAP006.53	06/20/1978	2000	NULL	0.51
3-RAP006.53	07/19/1978	100	NULL	0.82
3-RAP006.53	08/01/1978	8000	NULL	0
3-RAP006.53	09/05/1978	100	NULL	1.6
3-RAP006.53	10/16/1978	100	NULL	0
3-RAP006.53	11/13/1978	100	NULL	2.36
3-RAP006.53	12/14/1978	100	NULL	0.08
3-RAP006.53	01/25/1979	2400	NULL	0.4
3-RAP006.53	03/13/1979	100	NULL	0
3-RAP006.53	04/10/1979	100	NULL	0.05
3-RAP006.53	05/01/1979	100	NULL	1.7
3-RAP006.53	06/04/1979	8000	NULL	0.49
3-RAP006.53	07/30/1979	2500	NULL	0
3-RAP006.53	08/23/1979	100	NULL	0.14
3-RAP006.53	09/27/1979	600	NULL	5.43
3-RAP006.53	10/29/1979	200	NULL	0.4
3-RAP006.53	11/28/1979	4500	NULL	1.14
3-RAP006.53	12/12/1979	100	NULL	1.11

Table A.16. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	01/28/1980	100	NULL	0
3-RAP006.53	02/21/1980	100	NULL	3.6
3-RAP006.53	04/29/1980	8000	NULL	0.16
3-RAP006.53	05/14/1980	200	NULL	0
3-RAP006.53	06/16/1980	100	NULL	0
3-RAP006.53	07/01/1980	100	NULL	0.65
3-RAP006.53	10/15/1980	100	NULL	1.89
3-RAP006.53	11/25/1980	100	NULL	1.36
3-RAP006.53	12/22/1980	100	NULL	1.26
3-RAP006.53	01/29/1981	100	NULL	0
3-RAP006.53	02/19/1981	100	NULL	0
3-RAP006.53	03/30/1981	100	NULL	0
3-RAP006.53	04/29/1981	100	NULL	1
3-RAP006.53	05/27/1981	100	NULL	0.13
3-RAP006.53	06/30/1981	100	NULL	0
3-RAP006.53	07/08/1981	300	NULL	0.31
3-RAP006.53	08/12/1981	100	NULL	0
3-RAP006.53	09/23/1981	100	NULL	0.28
3-RAP006.53	10/20/1981	100	NULL	0.09
3-RAP006.53	11/23/1981	100	NULL	2.05
3-RAP006.53	12/17/1981	8000	NULL	0.41
3-RAP006.53	01/25/1982	500	NULL	0.05
3-RAP006.53	02/22/1982	100	NULL	3.06
3-RAP006.53	05/25/1982	2600	NULL	0.25
3-RAP006.53	07/28/1982	100	NULL	0.16
3-RAP006.53	08/30/1982	100	NULL	0.02
3-RAP006.53	09/20/1982	100	NULL	2.44
3-RAP006.53	10/13/1982	100	NULL	1.06

Table A.17. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	11/29/1982	1500	NULL	1.87
3-RAP006.53	12/15/1982	300	NULL	1.33
3-RAP006.53	01/26/1983	100	NULL	0.58
3-RAP006.53	02/23/1983	500	NULL	5.72
3-RAP006.53	03/28/1983	8000	NULL	1.79
3-RAP006.53	04/19/1983	700	NULL	0.11
3-RAP006.53	05/16/1983	1500	NULL	0.3
3-RAP006.53	06/16/1983	100	NULL	2.86
3-RAP006.53	08/29/1983	100	NULL	0.19
3-RAP006.53	09/27/1983	100	NULL	3.6
3-RAP006.53	10/26/1983	2300	NULL	0.05
3-RAP006.53	11/21/1983	8000	NULL	0.62
3-RAP006.53	12/12/1983	300	NULL	0.1
3-RAP006.53	01/04/1984	100	NULL	2.25
3-RAP006.53	02/09/1984	100	NULL	2.11
3-RAP006.53	03/08/1984	100	NULL	0.47
3-RAP006.53	04/11/1984	100	NULL	0.52
3-RAP006.53	05/03/1984	300	NULL	0.87
3-RAP006.53	06/06/1984	100	NULL	1.03
3-RAP006.53	07/19/1984	2200	NULL	0.69
3-RAP006.53	08/21/1984	200	NULL	1.32
3-RAP006.53	09/13/1984	100	NULL	1.83
3-RAP006.53	10/30/1984	8000	NULL	0
3-RAP006.53	11/15/1984	100	NULL	2.35
3-RAP006.53	03/28/1985	100	NULL	0.78
3-RAP006.53	04/29/1985	200	NULL	0.27
3-RAP006.53	05/08/1985	300	NULL	0.27
3-RAP006.53	06/24/1985	100	NULL	0.5

Table A.18. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	07/10/1985	100	NULL	0.7
3-RAP006.53	08/25/1985	100	NULL	0.94
3-RAP006.53	09/10/1985	200	NULL	0.4
3-RAP006.53	12/04/1985	1600	NULL	0
3-RAP006.53	01/28/1986	100	NULL	0.05
3-RAP006.53	02/26/1986	100	NULL	0.04
3-RAP006.53	03/19/1986	800	NULL	0.44
3-RAP006.53	04/09/1986	100	NULL	0.92
3-RAP006.53	05/01/1986	100	NULL	0
3-RAP006.53	06/11/1986	100	NULL	0
3-RAP006.53	07/09/1986	100	NULL	0.03
3-RAP006.53	08/19/1986	100	NULL	0.32
3-RAP006.53	09/30/1986	100	NULL	0
3-RAP006.53	10/08/1986	100	NULL	2.53
3-RAP006.53	04/13/1987	100	NULL	0.14
3-RAP006.53	05/11/1987	100	NULL	0.86
3-RAP006.53	06/17/1987	100	NULL	0
3-RAP006.53	08/06/1987	8000	NULL	0.83
3-RAP006.53	09/22/1987	3900	NULL	0.56
3-RAP006.53	10/22/1987	100	NULL	0
3-RAP006.53	11/19/1987	300	NULL	3.52
3-RAP006.53	12/10/1987	100	NULL	4.15
3-RAP006.53	01/25/1988	100	NULL	0.02
3-RAP006.53	02/25/1988	100	NULL	0.43
3-RAP006.53	04/14/1988	100	NULL	0.07
3-RAP006.53	10/06/1988	100	NULL	0.84
3-RAP006.53	11/03/1988	200	NULL	1.45
3-RAP006.53	12/07/1988	100	NULL	0.19

Table A.19. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	01/10/1989	100	NULL	8.57
3-RAP006.53	02/07/1989	200	NULL	0.39
3-RAP006.53	03/23/1989	200	NULL	2.64
3-RAP006.53	02/27/1991	280	NULL	1.25
3-RAP006.53	04/29/1991	78	NULL	1.01
3-RAP006.53	05/21/1991	170	NULL	0.87
3-RAP006.53	06/20/1991	920	NULL	1.91
3-RAP006.53	08/21/1991	45	NULL	0.16
3-RAP006.53	10/21/1991	100	NULL	1.82
3-RAP006.53	12/17/1991	1700	NULL	0
3-RAP006.53	02/18/1992	220	NULL	0.3
3-RAP006.53	03/18/1992	78	NULL	0.1
3-RAP006.53	04/15/1992	18	NULL	2.43
3-RAP006.53	05/14/1992	100	NULL	0
3-RAP006.53	07/28/1992	4700	NULL	1.5
3-RAP006.53	08/25/1992	100	NULL	0.54
3-RAP006.53	09/29/1992	8000	NULL	1.97
3-RAP006.53	10/28/1992	100	NULL	0
3-RAP006.53	11/24/1992	4200	NULL	0.04
3-RAP006.53	12/29/1992	1500	NULL	4.53
3-RAP006.53	01/25/1993	400	NULL	0.34
3-RAP006.53	03/25/1993	4100	NULL	0.8
3-RAP006.53	04/22/1993	600	NULL	2.45
3-RAP006.53	05/27/1993	100	NULL	0.42
3-RAP006.53	06/24/1993	100	NULL	0.06
3-RAP006.53	07/29/1993	700	NULL	2.3
3-RAP006.53	08/30/1993	100	NULL	0.3
3-RAP006.53	09/30/1993	100	NULL	1.15

Table A.20. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	10/21/1993	100	NULL	0.48
3-RAP006.53	11/23/1993	100	NULL	1.49
3-RAP006.53	02/22/1994	200	NULL	0.12
3-RAP006.53	03/24/1994	100	NULL	0.85
3-RAP006.53	04/21/1994	100	NULL	0
3-RAP006.53	05/26/1994	100	NULL	0.11
3-RAP006.53	06/23/1994	100	NULL	3.26
3-RAP006.53	07/21/1994	400	NULL	2.65
3-RAP006.53	08/22/1994	200	NULL	4.7
3-RAP006.53	09/19/1994	100	NULL	0.05
3-RAP006.53	10/26/1994	100	NULL	0.32
3-RAP006.53	11/08/1994	100	NULL	0.05
3-RAP006.53	12/20/1994	100	NULL	1.76
3-RAP006.53	01/25/1995	200	NULL	4.06
3-RAP006.53	02/14/1995	100	NULL	2.72
3-RAP006.53	03/23/1995	100	NULL	0.32
3-RAP006.53	05/24/1995	100	NULL	1.55
3-RAP006.53	06/21/1995	200	NULL	0.71
3-RAP006.53	07/20/1995	100	NULL	0
3-RAP006.53	08/23/1995	300	NULL	0.37
3-RAP006.53	11/08/1995	100	NULL	1.03
3-RAP006.53	01/24/1996	400	NULL	0.99
3-RAP006.53	02/22/1996	2000	NULL	0.41
3-RAP006.53	03/21/1996	4800	NULL	0.25
3-RAP006.53	04/15/1996	100	NULL	3.44
3-RAP006.53	05/21/1996	100	NULL	0.16
3-RAP006.53	06/27/1996	500	NULL	0.65
3-RAP006.53	07/24/1996	600	NULL	1.12

Table A.21. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	08/27/1996	200	NULL	0.01
3-RAP006.53	11/20/1996	200	NULL	0
3-RAP006.53	01/29/1997	400	NULL	1.29
3-RAP006.53	02/20/1997	100	NULL	0.03
3-RAP006.53	03/26/1997	100	NULL	0.66
3-RAP006.53	04/23/1997	100	NULL	#N/A
3-RAP006.53	05/22/1997	100	NULL	0.56
3-RAP006.53	06/26/1997	100	NULL	0.01
3-RAP006.53	07/24/1997	8000	NULL	0.79
3-RAP006.53	08/28/1997	100	NULL	0.25
3-RAP006.53	09/10/1997	100	NULL	3.15
3-RAP006.53	10/08/1997	100	NULL	0.27
3-RAP006.53	11/18/1997	300	NULL	1.42
3-RAP006.53	12/17/1997	100	NULL	0.02
3-RAP006.53	01/21/1998	100	NULL	0.04
3-RAP006.53	02/26/1998	100	NULL	0.85
3-RAP006.53	03/18/1998	100	NULL	0.45
3-RAP006.53	04/09/1998	100	NULL	0
3-RAP006.53	05/12/1998	600	NULL	0.04
3-RAP006.53	06/25/1998	900	NULL	0.05
3-RAP006.53	08/19/1998	300	NULL	1.59
3-RAP006.53	09/16/1998	100	NULL	2.2
3-RAP006.53	11/18/1998	100	NULL	0.29
3-RAP006.53	12/16/1998	1300	NULL	1.71
3-RAP006.53	01/13/1999	700	NULL	0
3-RAP006.53	03/16/1999	3100	NULL	2.37
3-RAP006.53	04/14/1999	100	NULL	0
3-RAP006.53	05/13/1999	100	NULL	0.29

Table A.22. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	06/22/1999	100	NULL	0.2
3-RAP006.53	07/20/1999	100	NULL	0.3
3-RAP006.53	08/17/1999	100	NULL	0.97
3-RAP006.53	09/08/1999	1000	NULL	0.1
3-RAP006.53	10/06/1999	1600	NULL	0
3-RAP006.53	12/13/1999	2400	NULL	0.14
3-RAP006.53	01/12/2000	3300	NULL	0
3-RAP006.53	02/10/2000	200	NULL	0.55
3-RAP006.53	03/23/2000	600	NULL	0
3-RAP006.53	05/04/2000	400	NULL	0.21
3-RAP006.53	06/13/2000	7000	NULL	1.73
3-RAP006.53	07/12/2000	100	NULL	1.6
3-RAP006.53	08/08/2000	300	NULL	1.03
3-RAP006.53	09/13/2000	100	NULL	1.15
3-RAP006.53	10/03/2000	300	NULL	0.17
3-RAP006.53	11/01/2000	100	NULL	1.37
3-RAP006.53	01/18/2001	100	NULL	0
3-RAP006.53	02/06/2001	100	NULL	0.19
3-RAP006.53	03/06/2001	100	NULL	0.2
3-RAP006.53	04/03/2001	200	NULL	0.8
3-RAP006.53	05/01/2001	100	NULL	0.8
3-RAP006.53	06/06/2001	8000	NULL	0.41
3-RAP006.53	02/28/2002	100	NULL	0.79
3-RAP006.53	12/19/2002	120	60	0.53
3-RAP006.53	02/25/2003	280	360	0.06
3-RAP006.53	04/07/2003	125	130	2.63
3-RAP006.53	06/05/2003	500	440	0.75
3-RAP006.53	07/08/2003	NULL	1000	4.28

Table A.23. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 3-RAP006.53 in Rapidan River (VAN-E18R-01) watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed <i>E. coli</i> Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
3-RAP006.53	09/22/2003	280	75	2.6
3-RAP006.53	11/20/2003	2000	2000	0.12
3-RAP006.53	03/11/2004	25	25	0.3
3-RAP006.53	05/20/2004	1200	1000	1.26
3-RAP006.53	07/08/2004	620	680	3.78
3-RAP006.53	09/20/2004	2000	980	2.46
3-RAP006.53	11/03/2004	25	25	0.08
3-RAP006.53	01/20/2005	320	200	0.01
3-RAP006.53	02/08/2005	25	25	0.18
3-RAP006.53	04/20/2005	25	25	0
3-RAP006.53	06/23/2005	25	25	0
3-RAP006.53	07/12/2005	70	NULL	1.75
3-RAP006.53	08/03/2005	20	30	0.06
3-RAP006.53	08/23/2005	25	25	0.58
3-RAP006.53	09/07/2005	50	28	0
3-RAP006.53	10/19/2005	NULL	56	0
3-RAP006.53	10/26/2005	1300	2000	1.66
3-RAP006.53	11/16/2005	NULL	60	0
3-RAP006.53	12/28/2005	480	300	0.64

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-BLU000.80, 3-RAP045.08, 3-CED000.59, and 3-RAP006.53.

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 URR-1.

Month	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	Loafing Lot
Jan.	4	4,070	1,033	251	801	569	0
Fe.	3	4,333	1,098	268	730	518	0
Mar.	4	4,892	1,239	303	673	569	0
Apr.	4	4,866	1,232	301	651	551	0
May.	4	5,163	1,307	320	673	569	0
Jun.	4	5,123	1,296	317	651	551	0
Jul.	4	5,431	1,374	336	673	569	0
Aug.	4	5,568	1,408	345	673	569	0
Sep.	4	5,527	1,397	342	775	551	0
Oct.	4	3,555	904	219	801	569	0
Nov.	4	3,606	916	222	775	551	0
Dec.	4	3,899	990	240	801	569	0
Total	45	56,032	14,193	3,464	8,675	6,703	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.2. Monthly nonpoint fecal coliform loadings in sub-watershed URR-2.

Month	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	Loafing Lot
Jan.	11	20,616	5,231	1,272	270	446	0
Fe.	10	21,953	5,560	1,357	246	407	0
Mar.	11	24,781	6,274	1,533	220	446	0
Apr.	11	24,650	6,239	1,525	213	432	0
May.	11	26,158	6,619	1,619	220	446	0
Jun.	11	25,955	6,566	1,607	213	432	0
Jul.	11	27,513	6,958	1,704	220	446	0
Aug.	11	28,207	7,132	1,747	220	446	0
Sep.	11	28,002	7,078	1,735	261	432	0
Oct.	11	18,006	4,577	1,108	270	446	0
Nov.	11	18,268	4,641	1,125	261	432	0
Dec.	11	19,748	5,013	1,217	270	446	0
Total	131	283,858	71,888	17,549	2,884	5,258	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.3. Monthly nonpoint fecal coliform loadings in sub-watershed URR-3.

Month	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	20	42,550	10,798	2,624	826	1,313	0
Fe.	18	45,306	11,476	2,800	753	1,197	0
Mar.	20	51,141	12,950	3,162	677	1,313	0
Apr.	19	50,870	12,877	3,146	655	1,271	0
May.	20	53,982	13,661	3,340	677	1,313	0
Jun.	19	53,561	13,551	3,315	655	1,271	0
Jul.	20	56,777	14,361	3,515	677	1,313	0
Aug.	20	58,208	14,720	3,604	677	1,313	0
Sep.	19	57,785	14,609	3,579	799	1,271	0
Oct.	20	37,165	9,450	2,287	826	1,313	0
Nov.	19	37,705	9,580	2,322	799	1,271	0
Dec.	20	40,759	10,350	2,512	826	1,313	0
Total	237	585,809	148,384	36,206	8,846	15,475	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.4. Monthly nonpoint fecal coliform loadings in sub-watershed URR-4.

Month	Fecal Coliform loadings ($\times 10^{10}$ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	31	31,551	7,951	1,977	1,300	2,480	0
Fe.	28	33,692	8,482	2,111	1,185	2,260	0
Mar.	31	38,050	9,578	2,384	1,090	2,480	0
Apr.	30	37,866	9,530	2,373	1,055	2,400	0
May.	31	40,200	10,116	2,519	1,090	2,480	0
Jun.	30	39,902	10,040	2,500	1,055	2,400	0
Jul.	31	42,314	10,646	2,651	1,090	2,480	0
Aug.	31	43,396	10,917	2,719	1,090	2,480	0
Sep.	30	43,097	10,841	2,700	1,258	2,400	0
Oct.	31	27,477	6,930	1,722	1,300	2,480	0
Nov.	30	27,906	7,036	1,749	1,258	2,400	0
Dec.	31	30,196	7,611	1,892	1,300	2,480	0
Total	362	435,649	109,680	27,297	14,070	29,220	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.5. Monthly nonpoint fecal coliform loadings in sub-watershed URR-5.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	64	162,472	40,916	10,189	1,608	6,929	0
Fe.	58	172,986	43,529	10,846	1,466	6,315	0
Mar.	64	196,505	49,439	12,320	1,272	6,929	0
Apr.	62	195,771	49,248	12,273	1,231	6,706	0
May.	64	207,702	52,243	13,021	1,272	6,929	0
Jun.	62	206,037	51,819	12,916	1,231	6,706	0
Jul.	64	218,365	54,914	13,688	1,272	6,929	0
Aug.	64	223,825	56,281	14,030	1,272	6,929	0
Sep.	62	222,165	55,858	13,926	1,556	6,706	0
Oct.	64	143,505	36,166	9,001	1,608	6,929	0
Nov.	62	145,172	36,576	9,105	1,556	6,706	0
Dec.	64	155,633	39,203	9,761	1,608	6,929	0
Total	756	2,250,137	566,193	141,075	16,950	81,642	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.6. Monthly nonpoint fecal coliform loadings in sub-watershed URR-6.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	26	76,207	19,132	4,792	393	3,400	0
Fe.	23	77,495	19,450	4,871	358	3,098	0
Mar.	26	95,774	24,032	6,017	308	3,400	0
Apr.	25	96,862	24,303	6,085	298	3,290	0
May.	26	101,825	25,548	6,396	308	3,400	0
Jun.	25	100,124	25,120	6,289	298	3,290	0
Jul.	26	105,224	26,399	6,609	308	3,400	0
Aug.	26	106,987	26,840	6,720	308	3,400	0
Sep.	25	105,374	26,435	6,618	381	3,290	0
Oct.	26	81,107	20,359	5,099	393	3,400	0
Nov.	25	78,156	19,619	4,914	381	3,290	0
Dec.	26	73,999	18,579	4,654	393	3,400	0
Total	304	1,099,135	275,816	69,065	4,127	40,060	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.7. Monthly nonpoint fecal coliform loadings in sub-watershed URR-7.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	3	10,966	2,756	694	291	1,306	0
Fe.	3	11,725	2,945	741	265	1,190	0
Mar.	3	13,244	3,326	836	237	1,306	0
Apr.	3	13,182	3,311	832	229	1,264	0
May.	3	13,997	3,515	884	237	1,306	0
Jun.	3	13,896	3,489	877	229	1,264	0
Jul.	3	14,739	3,701	930	237	1,306	0
Aug.	3	15,118	3,796	954	237	1,306	0
Sep.	3	15,016	3,770	947	281	1,264	0
Oct.	3	9,537	2,398	604	291	1,306	0
Nov.	3	9,691	2,436	614	281	1,264	0
Dec.	3	10,490	2,637	664	291	1,306	0
Total	40	151,602	38,079	9,576	3,107	15,388	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.8. Monthly nonpoint fecal coliform loadings in sub-watershed URR-8.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	6	24,376	6,130	1,545	393	1,508	0
Fe.	5	26,061	6,550	1,649	358	1,374	0
Mar.	6	29,437	7,398	1,862	324	1,508	0
Apr.	5	29,300	7,363	1,853	314	1,459	0
May.	6	31,111	7,817	1,967	324	1,508	0
Jun.	5	30,885	7,760	1,952	314	1,459	0
Jul.	6	32,758	8,229	2,070	324	1,508	0
Aug.	6	33,600	8,441	2,123	324	1,508	0
Sep.	5	33,374	8,383	2,108	381	1,459	0
Oct.	6	21,203	5,336	1,347	393	1,508	0
Nov.	5	21,544	5,420	1,368	381	1,459	0
Dec.	6	23,321	5,866	1,479	393	1,508	0
Total	66	336,969	84,693	21,325	4,225	17,762	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.9. Monthly nonpoint fecal coliform loadings in sub-watershed URR-9.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	37	147,410	37,107	9,183	482	2,265	0
Fe.	34	145,193	36,535	9,049	439	2,064	0
Mar.	37	189,251	47,586	11,803	370	2,265	0
Apr.	36	193,044	48,530	12,042	358	2,192	0
May.	37	201,798	50,728	12,589	370	2,265	0
Jun.	36	197,349	49,608	12,312	358	2,192	0
Jul.	37	206,306	51,857	12,871	370	2,265	0
Aug.	37	208,685	52,453	13,020	370	2,265	0
Sep.	36	204,509	51,401	12,760	466	2,192	0
Oct.	37	173,866	43,733	10,840	482	2,265	0
Nov.	36	163,544	41,142	10,195	466	2,192	0
Dec.	37	144,431	36,361	8,997	482	2,265	0
Total	440	2,175,385	547,040	135,659	5,016	26,687	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.10. Monthly nonpoint fecal coliform loadings in sub-watershed URR-10.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	14	57,691	14,550	3,590	178	1,128	0
Fe.	13	59,046	14,880	3,677	162	1,028	0
Mar.	14	71,883	18,104	4,479	126	1,128	0
Apr.	13	72,498	18,254	4,518	122	1,091	0
May.	14	76,311	19,213	4,756	126	1,128	0
Jun.	13	75,130	18,914	4,683	122	1,091	0
Jul.	14	79,052	19,899	4,928	126	1,128	0
Aug.	14	80,470	20,254	5,017	126	1,128	0
Sep.	13	79,345	19,969	4,947	172	1,091	0
Oct.	14	59,647	15,039	3,713	178	1,128	0
Nov.	13	57,880	14,594	3,603	172	1,091	0
Dec.	14	55,915	14,105	3,479	178	1,128	0
Total	163	824,870	207,775	51,390	1,784	13,286	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.11. Monthly nonpoint fecal coliform loadings in sub-watershed URR-11.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	6	31,052	7,886	1,928	432	1,502	0
Fe.	6	33,067	8,381	2,056	394	1,369	0
Mar.	6	37,327	9,457	2,321	345	1,502	0
Apr.	6	37,130	9,404	2,309	333	1,454	0
May.	6	39,402	9,977	2,451	345	1,502	0
Jun.	6	39,096	9,897	2,432	333	1,454	0
Jul.	6	41,444	10,488	2,579	345	1,502	0
Aug.	6	42,488	10,750	2,644	345	1,502	0
Sep.	6	42,180	10,669	2,626	418	1,454	0
Oct.	6	27,118	6,901	1,682	432	1,502	0
Nov.	6	27,513	6,996	1,707	418	1,454	0
Dec.	6	29,743	7,558	1,846	432	1,502	0
Total	73	427,560	108,364	26,582	4,571	17,703	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.12. Monthly nonpoint fecal coliform loadings in sub-watershed URR-12.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	4	37,497	9,428	2,375	272	988	0
Fe.	4	40,090	10,074	2,535	248	900	0
Mar.	4	45,285	11,378	2,863	209	988	0
Apr.	4	45,074	11,324	2,849	202	956	0
May.	4	47,861	12,023	3,024	209	988	0
Jun.	4	47,514	11,935	3,002	202	956	0
Jul.	4	50,394	12,657	3,183	209	988	0
Aug.	4	51,691	12,982	3,264	209	988	0
Sep.	4	51,342	12,894	3,241	263	956	0
Oct.	4	32,615	8,205	2,070	272	988	0
Nov.	4	33,139	8,335	2,102	263	956	0
Dec.	4	35,873	9,021	2,274	272	988	0
Total	48	518,377	130,255	32,781	2,827	11,637	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.13. Monthly nonpoint fecal coliform loadings in sub-watershed URR-13.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	11	32,626	8,199	2,064	177	870	0
Fe.	10	34,884	8,762	2,203	162	793	0
Mar.	11	39,405	9,897	2,488	133	870	0
Apr.	11	39,222	9,850	2,476	129	842	0
May.	11	41,647	10,458	2,629	133	870	0
Jun.	11	41,346	10,382	2,609	129	842	0
Jul.	11	43,853	11,010	2,767	133	870	0
Aug.	11	44,981	11,293	2,837	133	870	0
Sep.	11	44,678	11,216	2,818	172	842	0
Oct.	11	28,376	7,134	1,798	177	870	0
Nov.	11	28,833	7,248	1,826	172	842	0
Dec.	11	31,212	7,845	1,975	177	870	0
Total	129	451,062	113,294	28,489	1,826	10,250	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.14. Monthly nonpoint fecal coliform loadings in sub-watershed URR-14.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	9	21,388	5,397	1,369	223	1,477	0
Fe.	8	22,855	5,760	1,458	204	1,346	0
Mar.	9	25,814	6,505	1,646	179	1,477	0
Apr.	9	25,692	6,473	1,638	173	1,429	0
May.	9	27,278	6,872	1,738	179	1,477	0
Jun.	9	27,079	6,820	1,725	173	1,429	0
Jul.	9	28,718	7,232	1,828	179	1,477	0
Aug.	9	29,455	7,417	1,874	179	1,477	0
Sep.	9	29,255	7,365	1,861	216	1,429	0
Oct.	9	18,614	4,702	1,196	223	1,477	0
Nov.	9	18,909	4,774	1,213	216	1,429	0
Dec.	9	20,465	5,165	1,311	223	1,477	0
Total	109	295,523	74,483	18,858	2,367	17,401	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.15. Monthly nonpoint fecal coliform loadings in sub-watershed URR-15.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	62	193,252	48,838	12,004	1,119	5,992	0
Fe.	57	202,895	51,214	12,616	1,020	5,460	0
Mar.	62	235,717	59,473	14,662	857	5,992	0
Apr.	60	235,764	59,470	14,668	829	5,798	0
May.	62	249,423	62,905	15,520	857	5,992	0
Jun.	60	246,758	62,224	15,357	829	5,798	0
Jul.	62	260,851	65,767	16,236	857	5,992	0
Aug.	62	266,719	67,237	16,603	857	5,992	0
Sep.	60	264,119	66,572	16,444	1,083	5,798	0
Oct.	62	180,445	45,630	11,202	1,119	5,992	0
Nov.	60	179,763	45,445	11,162	1,083	5,798	0
Dec.	62	185,904	46,998	11,544	1,119	5,992	0
Total	735	2,701,609	681,773	168,018	11,629	70,595	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.16. Monthly nonpoint fecal coliform loadings in sub-watershed URR-16.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	20	30,723	7,753	1,912	122	825	0
Fe.	18	31,632	7,976	1,970	112	752	0
Mar.	20	38,084	9,597	2,373	91	825	0
Apr.	19	38,335	9,658	2,389	88	798	0
May.	20	40,398	10,176	2,518	91	825	0
Jun.	19	39,817	10,029	2,482	88	798	0
Jul.	20	41,940	10,562	2,614	91	825	0
Aug.	20	42,736	10,762	2,664	91	825	0
Sep.	19	42,180	10,621	2,630	118	798	0
Oct.	20	31,042	7,833	1,932	122	825	0
Nov.	19	30,296	7,644	1,886	118	798	0
Dec.	20	29,726	7,504	1,850	122	825	0
Total	232	436,910	110,114	27,218	1,254	9,719	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.17. Monthly nonpoint fecal coliform loadings in sub-watershed URR-17.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	5	9,466	2,390	593	49	292	0
Fe.	4	10,102	2,547	633	45	266	0
Mar.	5	11,408	2,876	715	38	292	0
Apr.	4	11,352	2,861	711	37	282	0
May.	5	12,050	3,037	755	38	292	0
Jun.	4	11,960	3,014	749	37	282	0
Jul.	5	12,682	3,195	794	38	292	0
Aug.	5	13,006	3,276	815	38	292	0
Sep.	4	12,915	3,253	809	47	282	0
Oct.	5	8,248	2,085	517	49	292	0
Nov.	4	8,375	2,116	525	47	282	0
Dec.	5	9,061	2,288	568	49	292	0
Total	54	130,626	32,939	8,183	510	3,439	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.18. Monthly nonpoint fecal coliform loadings in sub-watershed URR-18.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	1	11,786	2,965	748	80	489	0
Fe.	1	12,600	3,167	798	73	446	0
Mar.	1	14,232	3,577	901	59	489	0
Apr.	1	14,166	3,560	896	58	473	0
May.	1	15,041	3,780	952	59	489	0
Jun.	1	14,932	3,752	944	58	473	0
Jul.	1	15,837	3,979	1,001	59	489	0
Aug.	1	16,245	4,081	1,027	59	489	0
Sep.	1	16,135	4,053	1,020	77	473	0
Oct.	1	10,252	2,581	652	80	489	0
Nov.	1	10,417	2,621	662	77	473	0
Dec.	1	11,276	2,837	716	80	489	0
Total	8	162,918	40,955	10,316	820	5,763	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.19. Monthly nonpoint fecal coliform loadings in sub-watershed URR-19.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	4	18,471	4,661	1,155	116	584	0
Fe.	4	19,714	4,969	1,233	105	532	0
Mar.	4	22,263	5,610	1,392	91	584	0
Apr.	4	22,153	5,582	1,385	88	565	0
May.	4	23,516	5,924	1,471	91	584	0
Jun.	4	23,341	5,879	1,460	88	565	0
Jul.	4	24,750	6,233	1,548	91	584	0
Aug.	4	25,381	6,391	1,587	91	584	0
Sep.	4	25,204	6,346	1,576	112	565	0
Oct.	4	16,095	4,066	1,006	116	584	0
Nov.	4	16,343	4,127	1,022	112	565	0
Dec.	4	17,681	4,463	1,105	116	584	0
Total	50	254,912	64,253	15,941	1,218	6,876	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.20. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-1.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	35	110,938	27,984	6,984	920	3,431	0
Fe.	32	118,458	29,849	7,452	839	3,127	0
Mar.	35	133,779	33,704	8,414	706	3,431	0
Apr.	34	133,129	33,535	8,373	684	3,321	0
May.	35	141,332	35,595	8,887	706	3,431	0
Jun.	34	140,284	35,327	8,821	684	3,321	0
Jul.	35	148,763	37,456	9,353	706	3,431	0
Aug.	35	152,566	38,409	9,591	706	3,431	0
Sep.	34	151,513	38,139	9,524	891	3,321	0
Oct.	35	96,620	24,398	6,088	920	3,431	0
Nov.	34	98,126	24,769	6,181	891	3,321	0
Dec.	35	106,176	26,791	6,686	920	3,431	0
Total	415	1,531,687	385,955	96,353	9,574	40,427	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.21. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-2.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	1	2,667	676	166	13	78	0
Fe.	1	2,842	719	177	12	71	0
Mar.	1	3,209	812	200	11	78	0
Apr.	1	3,192	807	199	11	75	0
May.	1	3,388	857	211	11	78	0
Jun.	1	3,362	850	210	11	75	0
Jul.	1	3,564	901	222	11	78	0
Aug.	1	3,655	923	228	11	78	0
Sep.	1	3,628	917	226	12	75	0
Oct.	1	2,328	591	145	13	78	0
Nov.	1	2,362	600	147	12	75	0
Dec.	1	2,554	648	159	13	78	0
Total	7	36,753	9,301	2,291	140	917	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.22. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-3.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	40	84,453	21,230	5,333	449	2,265	0
Fe.	37	83,917	21,089	5,296	409	2,064	0
Mar.	40	107,949	27,114	6,804	338	2,265	0
Apr.	39	109,895	27,599	6,925	327	2,192	0
May.	40	115,048	28,892	7,249	338	2,265	0
Jun.	39	112,672	28,295	7,099	327	2,192	0
Jul.	40	117,952	29,619	7,431	338	2,265	0
Aug.	40	119,476	30,001	7,526	338	2,265	0
Sep.	39	117,242	29,439	7,385	435	2,192	0
Oct.	40	97,152	24,410	6,128	449	2,265	0
Nov.	39	91,911	23,095	5,799	435	2,192	0
Dec.	40	82,545	20,752	5,214	449	2,265	0
Total	477	1,240,214	311,535	78,188	4,630	26,684	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.23. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-4.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	11	40,769	10,364	2,528	329	1,603	0
Fe.	10	43,398	11,009	2,695	300	1,461	0
Mar.	11	48,986	12,422	3,043	243	1,603	0
Apr.	11	48,725	12,351	3,027	235	1,551	0
May.	11	51,703	13,102	3,213	243	1,603	0
Jun.	11	51,299	12,996	3,188	235	1,551	0
Jul.	11	54,377	13,772	3,380	243	1,603	0
Aug.	11	55,745	14,115	3,466	243	1,603	0
Sep.	11	55,339	14,008	3,441	318	1,551	0
Oct.	11	35,617	9,074	2,206	329	1,603	0
Nov.	11	36,132	9,198	2,239	318	1,551	0
Dec.	11	39,055	9,935	2,421	329	1,603	0
Total	132	561,144	142,345	34,847	3,367	18,888	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.24. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-5.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	2	3,571	904	224	104	378	0
Fe.	2	3,807	963	239	95	344	0
Mar.	2	4,299	1,087	270	85	378	0
Apr.	2	4,277	1,081	268	82	366	0
May.	2	4,540	1,147	285	85	378	0
Jun.	2	4,505	1,138	283	82	366	0
Jul.	2	4,777	1,206	300	85	378	0
Aug.	2	4,898	1,237	307	85	378	0
Sep.	2	4,863	1,228	305	100	366	0
Oct.	2	3,114	790	196	104	378	0
Nov.	2	3,161	801	198	100	366	0
Dec.	2	3,419	866	215	104	378	0
Total	27	49,231	12,448	3,089	1,111	4,452	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.25. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-6.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	Loafing Lot
Jan.	0	326	87	17	25	43	0
Fe.	0	340	90	18	23	39	0
Mar.	0	382	101	21	24	43	0
Apr.	0	379	100	21	23	42	0
May.	0	401	105	22	24	43	0
Jun.	0	396	104	22	23	42	0
Jul.	0	419	110	23	24	43	0
Aug.	0	428	112	24	24	43	0
Sep.	0	424	111	23	25	42	0
Oct.	0	291	78	15	25	43	0
Nov.	0	293	78	15	25	42	0
Dec.	0	314	84	16	25	43	0
Total	0	4,393	1,160	237	289	510	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.26. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-7.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	Loafing Lot
Jan.	7	9,000	2,285	552	125	337	0
Fe.	7	9,578	2,427	589	114	308	0
Mar.	7	10,811	2,739	666	103	337	0
Apr.	7	10,753	2,723	662	99	327	0
May.	7	11,410	2,889	703	103	337	0
Jun.	7	11,321	2,866	698	99	327	0
Jul.	7	12,000	3,037	740	103	337	0
Aug.	7	12,301	3,112	759	103	337	0
Sep.	7	12,211	3,089	754	121	327	0
Oct.	7	7,864	2,001	481	125	337	0
Nov.	7	7,977	2,028	488	121	327	0
Dec.	7	8,622	2,191	528	125	337	0
Total	88	123,849	31,387	7,621	1,338	3,976	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.27. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-8.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	104	196,401	49,692	12,215	1,559	3,916	0
Fe.	95	200,924	50,780	12,506	1,421	3,568	0
Mar.	104	244,365	61,704	15,218	1,211	3,916	0
Apr.	101	246,386	62,194	15,347	1,172	3,789	0
May.	104	259,334	65,453	16,155	1,211	3,916	0
Jun.	101	255,312	64,430	15,906	1,172	3,789	0
Jul.	104	268,630	67,781	16,737	1,211	3,916	0
Aug.	104	273,437	68,985	17,038	1,211	3,916	0
Sep.	101	269,601	68,008	16,801	1,509	3,789	0
Oct.	104	202,838	51,304	12,618	1,559	3,916	0
Nov.	101	196,869	49,793	12,247	1,509	3,789	0
Dec.	104	190,380	48,185	11,838	1,559	3,916	0
Total	1,229	2,804,479	708,310	174,628	16,304	46,137	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.28. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-9.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	36	143,307	36,295	8,843	1,074	3,909	0
Fe.	32	150,397	38,034	9,299	979	3,563	0
Mar.	36	174,520	44,112	10,797	836	3,909	0
Apr.	35	174,496	44,092	10,800	809	3,783	0
May.	36	184,600	46,636	11,429	836	3,909	0
Jun.	35	182,625	46,128	11,309	809	3,783	0
Jul.	36	193,050	48,752	11,958	836	3,909	0
Aug.	36	197,388	49,839	12,229	836	3,909	0
Sep.	35	195,458	49,342	12,113	1,040	3,783	0
Oct.	36	133,607	33,865	8,236	1,074	3,909	0
Nov.	35	133,146	33,737	8,211	1,040	3,783	0
Dec.	36	137,875	34,934	8,503	1,074	3,909	0
Total	420	2,000,469	505,768	123,727	11,246	46,062	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.29. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-10.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	11	90,552	22,972	5,548	1,361	4,660	0
Fe.	10	94,330	23,892	5,795	1,240	4,246	0
Mar.	11	110,734	28,026	6,811	1,087	4,660	0
Apr.	11	110,938	28,068	6,828	1,052	4,509	0
May.	11	117,191	29,643	7,216	1,087	4,660	0
Jun.	11	115,776	29,279	7,131	1,052	4,509	0
Jul.	11	122,223	30,903	7,531	1,087	4,660	0
Aug.	11	124,810	31,551	7,693	1,087	4,660	0
Sep.	11	123,438	31,198	7,611	1,317	4,509	0
Oct.	11	86,780	22,027	5,312	1,361	4,660	0
Nov.	11	85,844	21,783	5,257	1,317	4,509	0
Dec.	11	87,312	22,160	5,345	1,361	4,660	0
Total	132	1,269,926	321,502	78,075	14,410	54,903	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.30. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-11.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	18	56,600	14,319	3,526	1,543	6,084	0
Fe.	16	60,351	15,246	3,763	1,406	5,544	0
Mar.	18	68,141	17,210	4,249	1,247	6,084	0
Apr.	17	67,796	17,118	4,228	1,207	5,888	0
May.	18	71,958	18,165	4,488	1,247	6,084	0
Jun.	17	71,411	18,024	4,454	1,207	5,888	0
Jul.	18	75,713	19,106	4,723	1,247	6,084	0
Aug.	18	77,635	19,587	4,843	1,247	6,084	0
Sep.	17	77,085	19,445	4,809	1,493	5,888	0
Oct.	18	49,365	12,507	3,073	1,543	6,084	0
Nov.	17	50,108	12,689	3,120	1,493	5,888	0
Dec.	18	54,193	13,716	3,376	1,543	6,084	0
Total	212	780,356	197,133	48,653	16,425	71,685	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.31. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-12.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	12	51,995	13,053	3,279	688	5,904	0
Fe.	11	50,661	12,716	3,193	627	5,380	0
Mar.	12	67,454	16,924	4,247	567	5,904	0
Apr.	11	69,047	17,322	4,346	549	5,713	0
May.	12	72,045	18,074	4,534	567	5,904	0
Jun.	11	70,329	17,643	4,426	549	5,713	0
Jul.	12	73,392	18,411	4,618	567	5,904	0
Aug.	12	74,110	18,591	4,663	567	5,904	0
Sep.	11	72,505	18,188	4,562	666	5,713	0
Oct.	12	63,614	15,963	4,006	688	5,904	0
Nov.	11	59,359	14,896	3,739	666	5,713	0
Dec.	12	51,095	12,827	3,222	688	5,904	0
Total	139	775,605	194,608	48,836	7,389	69,561	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.32. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-13.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	0	2,364	605	143	138	292	0
Fe.	0	2,509	640	153	126	266	0
Mar.	0	2,831	722	173	116	292	0
Apr.	0	2,814	717	172	112	283	0
May.	0	2,985	760	182	116	292	0
Jun.	0	2,961	754	181	112	283	0
Jul.	0	3,137	798	192	116	292	0
Aug.	0	3,215	818	197	116	292	0
Sep.	0	3,190	811	195	134	283	0
Oct.	0	2,071	531	125	138	292	0
Nov.	0	2,099	538	127	134	283	0
Dec.	0	2,267	580	137	138	292	0
Total	4	32,443	8,274	1,978	1,493	3,441	0

¹Includes Farmstead, Low Density Residential, and High Density Residential Loads

Table C.33. Monthly nonpoint fecal coliform loadings in sub-watershed LRR-14.

Month	Fecal Coliform loadings (x10 ¹⁰ cfu/month)						Loafing Lot
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential ¹	
Jan.	1	3,991	1,016	248	187	846	0
Fe.	1	4,247	1,079	264	170	771	0
Mar.	1	4,794	1,217	298	155	846	0
Apr.	1	4,768	1,210	297	150	819	0
May.	1	5,060	1,283	315	155	846	0
Jun.	1	5,020	1,273	313	150	819	0
Jul.	1	5,321	1,349	331	155	846	0
Aug.	1	5,455	1,382	340	155	846	0
Sep.	1	5,415	1,372	337	181	819	0
Oct.	1	3,488	890	217	187	846	0
Nov.	1	3,538	902	220	181	819	0
Dec.	1	3,824	974	238	187	846	0
Total	12	54,920	13,947	3,418	2,012	9,968	0

¹Includes 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 URR-07 of Marsh Run (VAN-E13R-03).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	3,997	0%	80	98%
Pasture	19,925,723	91%	398,514	98%
Loafing Lots	0	0%	0	98%
Forest	310,651	1%	310,651	0%
Residential	1,538,798	7%	30,776	98%
Total	21,779,170	100%	740,021	97%

Table D.2. Required annual reductions in direct nonpoint sources in sub-watershed URR-07 of Marsh Run (VAN-E13R-03) .

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	20,752	15%	415	98%
Wildlife in Streams	42,193	30%	42,193	0%
Straight Pipes	77,433	55%	0	100%
Total	140,378	100%	42,608	70%

Table D.3. Required annual reductions in nonpoint sources in sub-watershed URR-08 of Marsh Run (VAN-E13R-03).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	6,571	0%	131	98%
Pasture	44,298,763	95%	885,974	98%
Loafing Lots	0	0%	0	98%
Forest	422,500	0.9%	422,500	0%
Residential	1,776,211	4%	35,524	98%
Total	46,504,044	100%	1,344,130	97%

Table D.4. Required annual reductions in direct nonpoint sources in sub-watershed URR-08 of Marsh Run (VAN-E13R-03).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	46,097	19%	922	98%
Wildlife in Streams	63,265	26%	63,265	0%
Straight Pipes	130,394	54%	0	100%
Total	239,757	100%	64,187	73%

Table D.5. Required annual reductions in nonpoint sources in sub-watershed URR-11 of Blue Run (VAN-E13R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	7,330	0%	73	99%
Pasture	56,250,520	96%	562,505	99%
Loafing Lots	0	0%	0	99%
Forest	457,114	0.8%	457,114	0%
Residential	1,770,257	3%	17,703	99%
Total	58,485,221	100%	1,037,395	98%

Table D.6. Required annual reductions in direct nonpoint sources in sub-watershed URR-11 of Blue Run (VAN-E13R-01) .

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	57,154	8%	572	99%
Wildlife in Streams	96,886	14%	67,821	30%
Straight Pipes	528,590	77%	0	100%
Total	682,630	100%	68,392	90%

Table D.7. Required annual reductions in nonpoint sources in sub-watershed URR-12 of Blue Run (VAN-E13R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	4,750	0%	48	99%
Pasture	68,141,251	98%	681,412	99%
Loafing Lots	0	0%	0	99%
Forest	282,703	0.4%	282,703	0%
Residential	1,163,687	2%	11,637	99%
Total	69,592,391	100%	975,799	99%

Table D.8. Required annual reductions in direct nonpoint sources in sub-watershed URR-12 of Blue Run (VAN-E13R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	70,932	32%	709	99%
Wildlife in Streams	56,522	26%	39,566	30%
Straight Pipes	92,481	42%	0	100%
Total	219,936	100%	40,275	82%

Table D.9. Required annual reductions in nonpoint sources in sub-watershed URR-13 of Blue Run (VAN-E13R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	12,881	0%	129	99%
Pasture	59,284,491	98%	592,844	99%
Loafing Lots	0	0%	0	99%
Forest	182,565	0.3%	182,565	0%
Residential	1,024,965	2%	10,250	99%
Total	60,504,902	100%	785,788	99%

Table D.10. Required annual reductions in direct nonpoint sources in sub-watershed URR-13 of Blue Run (VAN-E13R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	61,747	36%	617	99%
Wildlife in Streams	41,337	24%	28,936	30%
Straight Pipes	66,622	39%	0	100%
Total	169,705	100%	29,553	83%

Table D.11. Required annual reductions in nonpoint sources in sub-watershed URR-14 of Blue Run (VAN-E13R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	10,912	0%	109	99%
Pasture	38,886,341	95%	388,863	99%
Loafing Lots	0	0%	0	99%
Forest	236,707	0.6%	236,707	0%
Residential	1,740,051	4%	17,400	99%
Total	40,874,012	100%	643,080	98%

Table D.12. Required annual reductions in direct nonpoint sources in sub-watershed URR-14 of Blue Run (VAN-E13R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	40,314	27%	403	99%
Wildlife in Streams	91,986	61%	64,390	30%
Straight Pipes	19,139	13%	0	100%
Total	151,439	100%	64,793	57%

Table D.13. Required annual reductions in nonpoint sources in sub-watershed URR-18 of UT to Rapidan River.

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	815	0%	8	99%
Pasture	21,418,885	97%	214,189	99%
Loafing Lots	0	0%	0	99%
Forest	82,026	0.4%	82,026	0%
Residential	576,255	3%	5,763	99%
Total	22,077,980	100%	301,985	99%

Table D.14. Required annual reductions in direct nonpoint sources in sub-watershed URR-18 of UT to Rapidan River.

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	22,283	19%	223	99%
Wildlife in Streams	20,326	18%	12,602	38%
Straight Pipes	72,173	63%	0	100%
Total	114,783	100%	12,825	89%

Table D.15. Required annual reductions in nonpoint sources in sub-watershed URR-01 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	4,457	0.1%	89	98%
Pasture	7,368,914	83%	147,378	98%
Loafing Lots	0	0%	0	98%
Forest	867,479	10%	867,479	0%
Residential	670,270	8%	13,405	98%
Total	8,911,120	100%	1,028,351	88%

Table D.16. Required annual reductions in direct nonpoint sources in sub-watershed URR-01 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	7,484	3%	150	98%
Wildlife in Streams	88,530	39%	88,530	0%
Straight Pipes	130,906	58%	0	100%
Total	226,920	100%	88,679	61%

Table D.17. Required annual reductions in nonpoint sources in sub-watershed URR-02 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	13,134	0%	263	98%
Pasture	37,329,470	98%	746,589	98%
Loafing Lots	0	0%	0	98%
Forest	288,386	0.8%	288,386	0%
Residential	525,777	1%	10,516	98%
Total	38,156,768	100%	1,045,753	97%

Table D.18. Required annual reductions in direct nonpoint sources in sub-watershed URR-02 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	37,932	23%	759	98%
Wildlife in Streams	46,023	28%	46,023	0%
Straight Pipes	81,816	49%	0	100%
Total	165,771	100%	46,781	72%

Table D.19. Required annual reductions in nonpoint sources in sub-watershed URR-03 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	23,721	0%	474	98%
Pasture	77,039,871	97%	1,540,796	98%
Loafing Lots	0	0%	0	98%
Forest	884,621	1%	884,621	0%
Residential	1,547,491	2%	30,950	98%
Total	79,495,704	100%	2,456,841	97%

Table D.20. Required annual reductions in direct nonpoint sources in sub-watershed URR-03 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	78,246	14%	1,565	98%
Wildlife in Streams	123,953	22%	123,953	0%
Straight Pipes	358,383	64%	0	100%
Total	560,582	100%	125,518	78%

Table D.21. Required annual reductions in nonpoint sources in sub-watershed URR-04 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	36,238	0.1%	725	98%
Pasture	57,262,576	93%	1,145,250	98%
Loafing Lots	0	0%	0	98%
Forest	1,407,020	2%	1,407,020	0%
Residential	2,922,000	5%	58,440	98%
Total	61,627,834	100%	2,611,435	96%

Table D.22. Required annual reductions in direct nonpoint sources in sub-watershed URR-04 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	59,195	13%	1,184	98%
Wildlife in Streams	160,357	34%	160,357	0%
Straight Pipes	247,640	53%	0	100%
Total	467,192	100%	161,541	65%

Table D.23. Required annual reductions in nonpoint sources in sub-watershed URR-05 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	75,627	0%	1,513	98%
Pasture	295,346,173	97%	5,906,918	98%
Loafing Lots	0	0%	0	98%
Forest	1,695,027	0.6%	1,695,027	0%
Residential	8,164,214	3%	163,284	98%
Total	305,281,042	100%	7,766,742	97%

Table D.24. Required annual reductions in direct nonpoint sources in sub-watershed URR-05 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	305,912	39%	6,118	98%
Wildlife in Streams	289,818	37%	289,818	0%
Straight Pipes	181,456	23%	0	100%
Total	777,187	100%	295,937	62%

Table D.25. Required annual reductions in nonpoint sources in sub-watershed URR-06 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	30,368	0%	607	98%
Pasture	141,535,629	97%	2,830,710	98%
Loafing Lots	0	0%	0	98%
Forest	412,694	0.3%	412,694	0%
Residential	4,005,952	3%	80,119	98%
Total	145,984,643	100%	3,324,130	98%

Table D.26. Required annual reductions in direct nonpoint sources in sub-watershed URR-06 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	148,821	50%	2,976	98%
Wildlife in Streams	79,933	27%	79,933	0%
Straight Pipes	66,402	22%	0	100%
Total	295,157	100%	82,909	72%

Table D.27. Required annual reductions in nonpoint sources in sub-watershed URR-09 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	44,026	0%	881	98%
Pasture	277,026,503	99%	5,540,525	98%
Loafing Lots	0	0%	0	98%
Forest	501,623	0.2%	501,623	0%
Residential	2,668,699	1.0%	53,374	98%
Total	280,240,852	100%	6,096,403	98%

Table D.28. Required annual reductions in direct nonpoint sources in sub-watershed URR-09 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	290,733	45%	5,815	98%
Wildlife in Streams	105,867	16%	105,867	0%
Straight Pipes	245,448	38%	0	100%
Total	642,048	100%	111,681	83%

Table D.29. Required annual reductions in nonpoint sources in sub-watershed URR-10 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	16,342	0%	327	98%
Pasture	106,589,230	99%	2,131,783	98%
Loafing Lots	0	0%	0	98%
Forest	178,380	0.2%	178,380	0%
Residential	1,328,560	1%	26,571	98%
Total	108,112,513	100%	2,337,061	98%

Table D.30. Required annual reductions in direct nonpoint sources in sub-watershed URR-10 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	110,699	56%	2,214	98%
Wildlife in Streams	49,153	25%	49,153	0%
Straight Pipes	39,593	20%	0	100%
Total	199,445	100%	51,367	74%

Table D.31. Required annual reductions in nonpoint sources in sub-watershed URR-15 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	73,477	0%	1,470	98%
Pasture	352,839,316	98%	7,056,780	98%
Loafing Lots	0	0%	0	98%
Forest	1,162,946	0.3%	1,162,946	0%
Residential	7,059,479	2%	141,189	98%
Total	361,135,218	100%	8,362,385	98%

Table D.32. Required annual reductions in direct nonpoint sources in sub-watershed URR-15 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	363,070	27%	7,261	98%
Wildlife in Streams	191,561	14%	191,561	0%
Straight Pipes	782,804	59%	0	100%
Total	1,337,435	100%	198,822	85%

Table D.33. Required annual reductions in nonpoint sources in sub-watershed URR-16 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	23,170	0%	463	98%
Pasture	56,595,989	98%	1,131,919	98%
Loafing Lots	0	0%	0	98%
Forest	125,397	0.2%	125,397	0%
Residential	971,930	2%	19,439	98%
Total	57,716,486	100%	1,277,218	98%

Table D.34. Required annual reductions in direct nonpoint sources in sub-watershed URR-16 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	58,640	47%	1,173	98%
Wildlife in Streams	25,648	21%	25,648	0%
Straight Pipes	40,324	32%	0	100%
Total	124,612	100%	26,821	78%

Table D.35. Required annual reductions in nonpoint sources in sub-watershed URR-17 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	5,370	0%	107	98%
Pasture	17,174,725	98%	343,494	98%
Loafing Lots	0	0%	0	98%
Forest	51,010	0.3%	51,010	0%
Residential	343,883	2%	6,878	98%
Total	17,574,988	100%	401,489	98%

Table D.36. Required annual reductions in direct nonpoint sources in sub-watershed URR-17 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	17,690	34%	354	98%
Wildlife in Streams	14,327	28%	14,327	0%
Straight Pipes	19,431	38%	0	100%
Total	51,449	100%	14,681	71%

Table D.37. Required annual reductions in nonpoint sources in sub-watershed URR-19 of Rapidan River (VAN-E13R-02).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	5,004	0%	100	98%
Pasture	33,510,605	98%	670,211	98%
Loafing Lots	0	0%	0	98%
Forest	121,846	0.4%	121,846	0%
Residential	687,583	2%	13,752	98%
Total	34,325,038	100%	805,909	98%

Table D.38. Required annual reductions in direct nonpoint sources in sub-watershed URR-19 of Rapidan River (VAN-E13R-02).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	34,530	64%	691	98%
Wildlife in Streams	19,553	36%	19,553	0%
Straight Pipes	0	0%	0	100%
Total	54,084	100%	20,244	63%

Table D.39. Required annual reductions in nonpoint sources in sub-watershed LRR-03 of Cedar Run (VAN-E16R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	47,674	0%	953	98%
Pasture	158,418,615	98%	3,168,369	98%
Loafing Lots	0	0%	0	98%
Forest	463,049	0.3%	463,049	0%
Residential	2,668,405	2%	53,368	98%
Total	161,597,742	100%	3,685,740	98%

Table D.40. Required annual reductions in direct nonpoint sources in sub-watershed LRR-03 of Cedar Run (VAN-E16R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	166,991	48%	3,340	98%
Wildlife in Streams	103,444	30%	103,444	0%
Straight Pipes	78,811	23%	0	100%
Total	349,245	100%	106,783	69%

Table D.41. Required annual reductions in nonpoint sources in sub-watershed LRR-04 of Cedar Run (VAN-E16R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	13,190	0%	264	98%
Pasture	73,833,704	97%	1,476,673	98%
Loafing Lots	0	0%	0	98%
Forest	336,690	0.4%	336,690	0%
Residential	1,888,787	2%	37,776	98%
Total	76,072,371	100%	1,851,402	98%

Table D.42. Required annual reductions in direct nonpoint sources in sub-watershed LRR-04 of Cedar Run (VAN-E16R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	74,844	25%	1,497	98%
Wildlife in Streams	75,609	25%	75,609	0%
Straight Pipes	153,072	50%	0	100%
Total	303,525	100%	77,106	75%

Table D.43. Required annual reductions in nonpoint sources in sub-watershed LRR-05 of Cedar Run (VAN-E16R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	2,664	0%	53	98%
Pasture	6,476,712	92%	129,534	98%
Loafing Lots	0	0%	0	98%
Forest	111,148	2%	111,148	0%
Residential	445,152	6%	8,903	98%
Total	7,035,676	100%	249,638	96%

Table D.44. Required annual reductions in direct nonpoint sources in sub-watershed LRR-05 of Cedar Run (VAN-E16R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	6,634	30%	133	98%
Wildlife in Streams	15,224	70%	15,224	0%
Straight Pipes	0	0%	0	100%
Total	21,857	100%	15,356	30%

Table D.45. Required annual reductions in nonpoint sources in sub-watershed LRR-06 of Cedar Run (VAN-E16R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	39	0%	1	98%
Pasture	579,030	88%	11,581	98%
Loafing Lots	0	0%	0	98%
Forest	28,919	4%	28,919	0%
Residential	50,985	8%	1,020	98%
Total	658,973	100%	41,520	94%

Table D.46. Required annual reductions in direct nonpoint sources in sub-watershed LRR-06 of Cedar Run (VAN-E16R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	510	12%	10	98%
Wildlife in Streams	3,795	88%	3,795	0%
Straight Pipes	0	0%	0	100%
Total	4,305	100%	3,805	12%

Table D.47. Required annual reductions in nonpoint sources in sub-watershed LRR-01 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	41,497	0%	1,660	96%
Pasture	201,399,500	98%	8,055,984	96%
Loafing Lots	0	0%	0	96%
Forest	957,391	0.5%	957,391	0%
Residential	4,042,740	2%	161,710	96%
Total	206,441,128	100%	9,176,745	96%

Table D.48. Required annual reductions in direct nonpoint sources in sub-watershed LRR-01 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	208,033	34%	8,321	96%
Wildlife in Streams	190,658	31%	190,658	0%
Straight Pipes	214,995	35%	0	100%
Total	613,687	100%	198,980	68%

Table D.49. Required annual reductions in nonpoint sources in sub-watershed LRR-02 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	744	0%	30	96%
Pasture	4,834,581	98%	193,383	96%
Loafing Lots	0	0%	0	96%
Forest	13,997	0.3%	13,997	0%
Residential	91,656	2%	3,666	96%
Total	4,940,978	100%	211,076	96%

Table D.50. Required annual reductions in direct nonpoint sources in sub-watershed LRR-02 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	4,933	53%	197	96%
Wildlife in Streams	4,385	47%	4,385	0%
Straight Pipes	0	0%	0	100%
Total	9,318	100%	4,582	51%

Table D.51. Required annual reductions in nonpoint sources in sub-watershed LRR-07 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	8,806	0.1%	352	96%
Pasture	16,285,718	97%	651,429	96%
Loafing Lots	0	0%	0	96%
Forest	133,832	0.8%	133,832	0%
Residential	397,578	2%	15,903	96%
Total	16,825,933	100%	801,516	95%

Table D.52. Required annual reductions in direct nonpoint sources in sub-watershed LRR-07 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	16,500	19%	660	96%
Wildlife in Streams	22,491	26%	22,491	0%
Straight Pipes	45,950	54%	0	100%
Total	84,941	100%	23,151	73%

Table D.53. Required annual reductions in nonpoint sources in sub-watershed LRR-08 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	122,888	0%	4,916	96%
Pasture	362,654,855	98%	14,506,202	96%
Loafing Lots	0	0%	0	96%
Forest	1,630,432	0.4%	1,630,432	0%
Residential	4,613,689	1%	184,548	96%
Total	369,021,863	100%	16,326,097	96%

Table D.54. Required annual reductions in direct nonpoint sources in sub-watershed LRR-08 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	374,276	40%	14,971	96%
Wildlife in Streams	308,716	33%	308,716	0%
Straight Pipes	242,798	26%	0	100%
Total	925,790	100%	323,687	65%

Table D.55. Required annual reductions in nonpoint sources in sub-watershed LRR-09 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	42,013	0%	1,681	96%
Pasture	261,353,060	98%	10,454,128	96%
Loafing Lots	0	0%	0	96%
Forest	1,124,586	0.4%	1,124,586	0%
Residential	4,606,231	2%	184,249	96%
Total	267,125,890	100%	11,764,644	96%

Table D.56. Required annual reductions in direct nonpoint sources in sub-watershed LRR-09 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	267,355	44%	10,694	96%
Wildlife in Streams	209,569	34%	209,569	0%
Straight Pipes	134,629	22%	0	100%
Total	611,553	100%	220,263	64%

Table D.57. Required annual reductions in nonpoint sources in sub-watershed LRR-10 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	13,233	0%	529	96%
Pasture	165,464,810	96%	6,618,596	96%
Loafing Lots	0	0%	0	96%
Forest	1,441,024	0.8%	1,441,024	0%
Residential	5,490,297	3%	219,612	96%
Total	172,409,365	100%	8,279,761	95%

Table D.58. Required annual reductions in direct nonpoint sources in sub-watershed LRR-10 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	168,644	32%	6,746	96%
Wildlife in Streams	216,824	41%	216,824	0%
Straight Pipes	137,638	26%	0	100%
Total	523,105	100%	223,569	57%

Table D.59. Required annual reductions in nonpoint sources in sub-watershed LRR-11 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	21,205	0%	848	96%
Pasture	102,614,157	92%	4,104,568	96%
Loafing Lots	0	0%	0	96%
Forest	1,642,492	1%	1,642,492	0%
Residential	7,168,532	6%	286,741	96%
Total	111,446,386	100%	6,034,650	95%

Table D.60. Required annual reductions in direct nonpoint sources in sub-watershed LRR-11 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	105,122	21%	4,205	96%
Wildlife in Streams	226,151	45%	226,151	0%
Straight Pipes	170,124	34%	0	100%
Total	501,398	100%	230,356	54%

Table D.61. Required annual reductions in nonpoint sources in sub-watershed LRR-12 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	13,934	0%	557	96%
Pasture	98,355,277	93%	3,934,213	96%
Loafing Lots	0	0%	0	96%
Forest	738,934	0.7%	738,934	0%
Residential	6,956,121	7%	278,245	96%
Total	106,064,266	100%	4,951,950	95%

Table D.62. Required annual reductions in direct nonpoint sources in sub-watershed LRR-12 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	104,232	52%	4,169	96%
Wildlife in Streams	96,991	48%	96,991	0%
Straight Pipes	0	0%	0	100%
Total	201,223	100%	101,160	50%

Table D.63. Required annual reductions in nonpoint sources in sub-watershed LRR-13 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	404	0%	16	96%
Pasture	4,269,508	90%	170,780	96%
Loafing Lots	0	0%	0	96%
Forest	149,332	3%	149,332	0%
Residential	344,132	7%	13,765	96%
Total	4,763,376	100%	333,894	93%

Table D.64. Required annual reductions in direct nonpoint sources in sub-watershed LRR-13 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	4,253	18%	170	96%
Wildlife in Streams	19,753	82%	19,753	0%
Straight Pipes	0	0%	0	100%
Total	24,006	100%	19,923	17%

Table D.65. Required annual reductions in nonpoint sources in sub-watershed LRR-14 of Rapidan River (VAN-E18R-01).

Land Use	Current conditions load (x 10⁸ cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cropland	1,205	0%	48	96%
Pasture	7,228,511	86%	289,141	96%
Loafing Lots	0	0%	0	96%
Forest	201,167	2%	201,167	0%
Residential	996,782	12%	39,871	96%
Total	8,427,664	100%	530,227	94%

Table D.66. Required annual reductions in direct nonpoint sources in sub-watershed LRR-14 of Rapidan River (VAN-E18R-01).

Source	Current Conditions load (x 10⁸ cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10⁸ cfu/year)	Percent Reduction
Cattle in Streams	7,314	11%	293	96%
Wildlife in Streams	23,715	37%	23,715	0%
Straight Pipes	32,884	51%	0	100%
Total	63,914	100%	24,008	62%